



DERIVATION OF RESPONSE MODIFICATION FACTOR (R) FOR REINFORCED
CONCRETE BUILDINGS IN PALESTINE

BY

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**DERIVATION OF RESPONSE MODIFICATION FACTOR (R) FOR REINFORCED
CONCRETE BUILDINGS IN PALESTINE**

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DEDICATION

To my parents, sister-Rawan, brothers- Mohanad, Qusai, the rest of the family, friends and who have stood behind me. To my people in Palestine, I dedicate this work....

ABSTRACT

The response modification factor (R) is an essential seismic design parameter and also a performance level indicator. It is a force reduction factor that considers the inelastic deformations formed in buildings due to a seismic action that affects the design forces of the structures. The R factors provided in the US and the EU standards give inaccurate representation of the local Palestinian structural systems, which may lead to significant variability and inconsistency in the seismic forces, design of the structures, and consequently, a change in both behavior and performance buildings. This occurs due to traditional construction practices that enforce other components such as infill walls to contribute to the lateral resisting system. Therefore, there is a dire need to investigate the realistic R factor for different structural systems in Palestine. This research assesses the non-linear seismic behavior of different building systems by evaluating the R factor for each building model using non-linear analytical tools such as the OpenSees program. Line framing combinations are used in this study (2D-analysis) as each line frame type is analyzed alone to identify the controlled line framing with minimum R -factor. A set of twelve two-dimensional building models are developed and analyzed using a non-linear static pushover procedure to compute the R factor. Moreover, the coefficient method (CM) estimates the performance level at a particular seismic demand. It was found that the R factor recommended by the ASCE/SEI 7-16, Euro code (EC8), and the Egyptian code (ECP-201) were unconservative and overestimated the R factor for most of the prototype frame models that consider the current construction practices. Structural deficiencies and the height of structure were found to affect the performance of buildings, and decrease the R factor as well. Building structures with stone-concrete or masonry-concrete infills increased the strength and stiffness of the frame system. However, it reduced the frame system's ductility and its plastic strain energy. Consequently, the R factor was affected. Furthermore, the research proved that most frame models were inadequate and failed to meet the required performance level by the conventional standards, which was the life safety performance level under the local seismic demands. Recommendations are presented in this study to enhance the performance and behavior of building structures in Palestine. Lastly, this thesis paves the way for further research on evaluating R -factor and performing seismic assessment of structural buildings in Palestine, considering the limitations that have been faced in this study.

Keywords: Reinforce concrete structures, Moment-resisting frames, Response modification factor, Pushover analysis, OpenSees, Seismic performance assessment.

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CHAPTER 1: INTRODUCTION

1.1 Research Motivation:

Earthquakes are one of the most destructive natural hazards that can cause significant damage to the structures and infrastructure components, which impacts the country's economic and social aspects. Therefore, earthquake engineering is an established interdisciplinary branch of engineering that aims to estimate the seismic impacts on structures in terms of damage and loss in life and property. In the past decades, the seismic design philosophy for buildings developed many procedures to model and determine the seismic loads. Determining seismic loads is an essential step for a proper seismic design of structures. Force-based design procedures are among the most common procedures used in the conventional seismic design codes as SEI/ASCE7-16.

The Equivalent Lateral Force Method (ELF) is the main static analysis procedure, and the Response Spectrum Method (MRS) is the more common dynamic analysis procedure. Both methods are found in seismic codes and guidelines and are popular for their simplicity compared with non-linear time history analysis. These procedures are within the linear analysis, so the inelastic behavior (non-linearity) of the structures under a seismic action is accounted for by response modification factor. The response modification factor considers the inelastic deformations formed in buildings due to a seismic action that affects the design forces of the structures. The response modification factor represents the system's capability of dissipating energy through inelastic deformations, and it depends on the type of building's structural system, regularity, and construction material. Moreover, this factor is used to reduce the elastic seismic forces into their respective inelastic forces that must be resisted by the structures, which is extremely important to evaluate the lateral capacity of the structural systems.

The response modification factor (R) is found for example, in US standards, such as in Uniform Building Code UBC-1997, and SEI/ASCE7-16, and in European Code (Eurocode 8) as the behavior factor (q). The values of this factor are based on the designed lateral resisting system (skeleton structure) and vary among these codes and standards. This indicates that this factor is determined by investigating the performance of the local building stocks during past earthquakes.

However, countries that do not have seismic codes or standards also use R-factors from other standards.

In Palestine, a developing country, buildings are designed according to the R-factors from the US and the EU codes and standards, and this may lead to significant variability in the seismic forces, design of the structures, and consequently, a change in both behavior and performance of buildings due to the fact that the construction technology in Palestine is insufficient to build based on any seismic guidelines. The traditional construction practice of buildings also enforces other components such as infills to contribute to the lateral resisting system. In addition, the region is within a low to moderate seismic zone. On average, one major earthquake happens every century, and one hundred earthquakes occur almost every year due to the movement of the tectonic plate along the Dead Sea fault. Higher seismicity is expected along the fault that gets lower as one moves away from the fault. The seismicity and strong motion records of Palestine are different from the ones in the US and EU. Therefore, local earthquakes may cause different structural damage, and consequently, the behavior needs further investigation.

Based on the reasons mentioned above, there is a need to examine the overall performance of the buildings in Palestine by evaluating the response modification factor (R) for the building systems.

1.2 Research Objectives:

This research aims to assess the non-linear seismic behavior of different building systems in Palestine by evaluating the response modification factor (R) for each building frame model using non-linear analytical tools. The non-linear static pushover analysis procedure is utilized in this research to find the response modification factor R. Moreover, the Response modification factor R is taken as a performance indicator of structures to determine if the system has an acceptable performance level under the current construction technology using performance and damage assessments for specific performance objectives. Lastly, a comparison between the calculated response modification factor and the values from the seismic codes of practice is performed.

1.3 Framework of Thesis:

The following chapters are discussed in this thesis:

Chapter 2: Seismicity in Palestine and Surrounding Countries

This chapter discusses the nature of tectonic plates in Palestine, historical records of earthquakes in Palestine, the different seismic hazards and their effect, the adapted Seismic Codes in Palestine, and seismic hazard maps used in Palestine and in the Region.

Chapter 3: Response Modification Factor and Analysis Methods

An Introduction to the response modification factor (R) concept is presented. An intensive Literature review on the response modification factor R is performed, and the methods for evaluating the response modification factor R are also discussed. Recommended values of the R factor from the adopted seismic codes are presented. Moreover, the definition of the coefficient method (CM) is introduced.

Chapter 4: Type of Building Systems and their Deficiencies

Various types of building systems in Palestine are described in this chapter. Shortcomings in Construction Practices are also discussed. Furthermore, a brief literature review on the effect of structural deficiencies on the R-value. Furthermore, the modeling of infill walls is presented and discussed.

Chapter 5: Selection of Structural Building Models

A description of reinforced concrete moment resisting frame structures in Palestine is introduced. The selection of prototype frame models and their structural detailing is also presented. An overview of material properties and loads used in construction practices is presented.

Chapter 6: Numerical Modeling and Analysis

A detailed description of the 2-D analytical models using OpenSees software is discussed in this chapter. The constitutive material model parameters and beam-column joint input parameters are also defined. The geometrical and structural data used for system modeling, modeling criteria, and model verification are discussed. Furthermore, validation of the behavior of the infills model is presented.

Chapter 7: Evaluation of R Factors of Prototype Frame Systems

The analysis results from the non-linear static pushover method for each reinforced concrete moment-resisting frame (RC-MRF) Prototype are presented in this chapter. The calculated R factors for each prototype frame model are discussed and compared with the recommended values from SEI/ASCE 7-16, Euro code (EC8), and the Egyptian code (ECP-201).

Chapter 8: Performance Assessment for Structural Buildings

This chapter presents an introduction to performance-based seismic assessment, then discusses performance point determination based on the coefficient method (CM). Performance and damage evaluation for each prototype frame model under local seismic demand is also investigated and discussed.

CHAPTER 2: SEISMICITY IN PALESTINE AND SURROUNDING COUNTRIES

2.1 The Nature of Tectonic Plates in Palestine and Countries around:

The seismic activity in the Eastern Mediterranean Region, especially Palestine, is directly affected and controlled by the geodynamic processes along the Dead Sea Transform (DST). The Dead Sea Transform is a fault between the Arabian and the Sinai tectonic plates. The relative motion of the two plates causes a left lateral displacement, which creates a collision zone from the Red Sea to the Taurus-Zagros shown in Fig 2-1. The Dead Sea Transform started to form in the mid-Miocene, accommodating approximately 105 km northwards displacement of the Arabian Plate (Fruend, 1968).

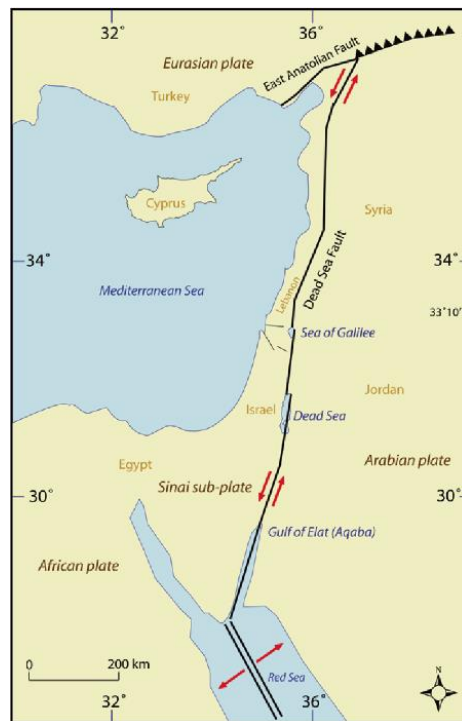


Fig 2-1: The Dead Sea Transform Fault (Garfunkel et al., 2014).

2.2 Seismic Hazard in the Region:

Palestine has a long history with earthquakes, mainly because of the Dead Sea fault along the two plates in the Eastern Mediterranean Region. The historical records show that major earthquakes have caused severe damage in buildings and losses in human lives, and these destructive earthquakes happened in the Jordan-Dead Sea region (Al-Tarazi, 1999). According to Shapira

(Shapira, 1983) and Abou Karaki (Abou Karaki, 1987), most of the recorded earthquakes have a magnitude ranging between 1.0 to 6.5 on the local magnitude scale (ML). Most historical earthquakes are concentrated along the central Dead Sea fault, as shown in Fig 2-2. According to Al-Dabbeek (Al-Dabbeek, 2010), the region is expected to have a major earthquake of magnitude more than six at any time in the near future, and this earthquake will have an epicenter in the north of the dead sea. This is based on the data of an earthquake that occurred in 1927 (6.25 magnitude with an epicenter some 15 km north of the Dead Sea). However, the author states that some other studies in the region predict that a possible earthquake could have an epicenter in the southern part of the dead sea.

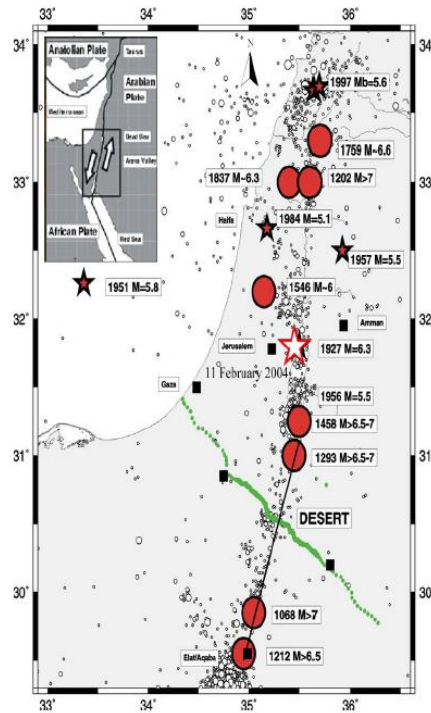


Fig 2-2: Seismicity Map of the Dead Sea Transform Region for the Period 1000-2007 (Ambraseys et al., 1994; Al Dabbeek, 2010).

2.3 Adopted Seismic Codes in Palestine:

As part of the conducted interviews discussed in detail in Chapter 4, an investigation of the most common and adopted design codes in Palestine was conducted. Consequently, most of the design offices adopt the ACI-314 code for structural design of buildings, while others use the Jordanian

code. However, when it comes to the seismic design of structures in Palestine, the seismic forces induced by an earthquake are estimated using Equivalent Static Force Procedure which determines the total design base shear in a given direction. In contrast, the Response Spectrum Method estimating the seismic forces using design response spectrum is not well understood and is randomly used. These seismic forces are calculated according to either UBC 97 (the Uniform Building code, last edition issued in 1997) or SEI/ASCE7-16 (American Society of Civil Engineers). The following sections explain the procedures in UBC-97 and SEI/ASCE7-16.

2.3.1 UBC 1997:

The data required to estimate the seismic loads in the Unified Building Code are shown in Table 2-1.

The procedure for determining the base shear based on UBC 97 is as follows:

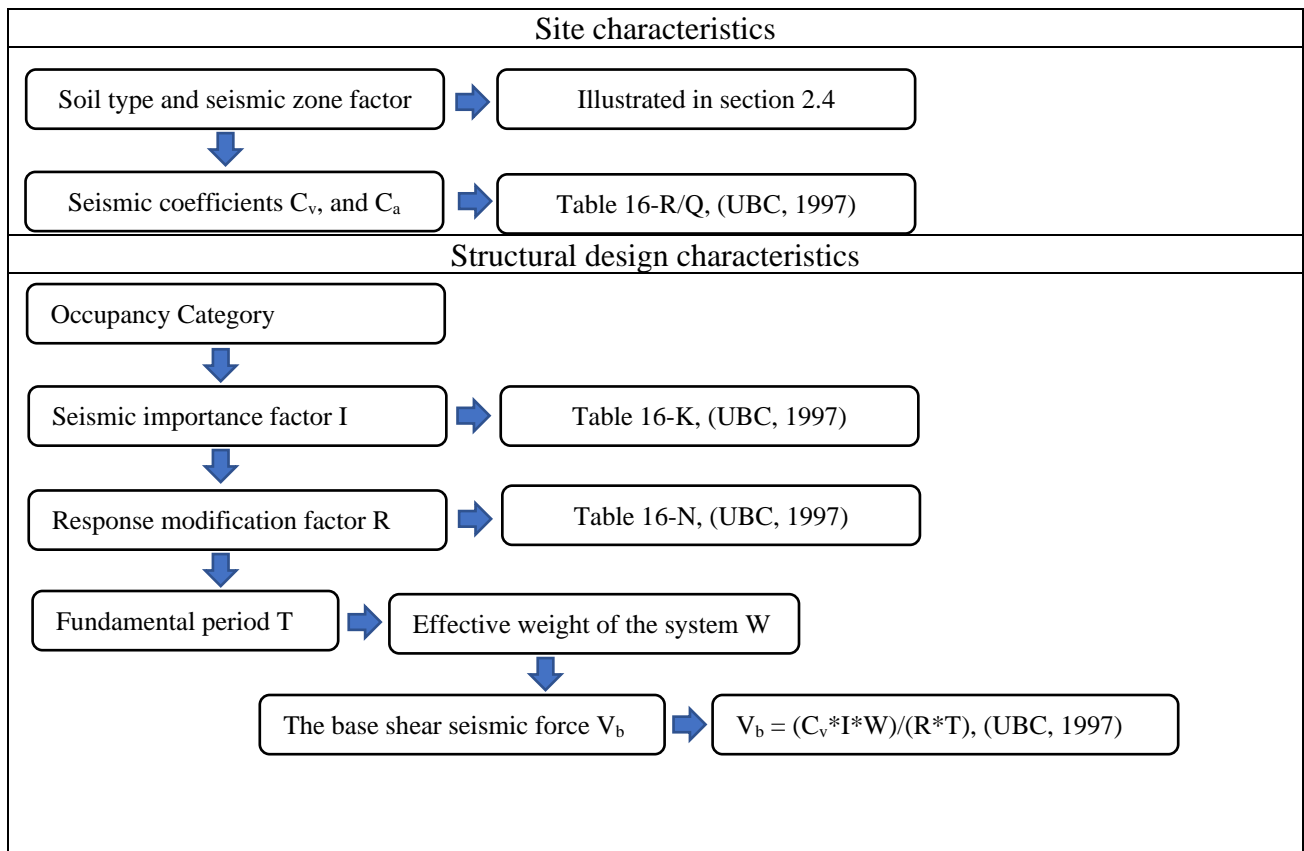


Table 2-1: Data required to estimate the seismic loads in UBC 1997.

Parameter	Abbreviation
Seismic importance factor	I
Soil profile type	S
Seismic zone factor	Z
Seismic coefficient	C_v
Seismic coefficient	C_a
Response modification factor	R
Fundamental period	T
Effective weight of the system	W
The base shear seismic force	V_b

However, the design response spectrum can be constructed according to UBC (UBC, 1997) using the parameters shown in Fig 2-3, which describes the relationship between acceleration spectrum versus time (periods).

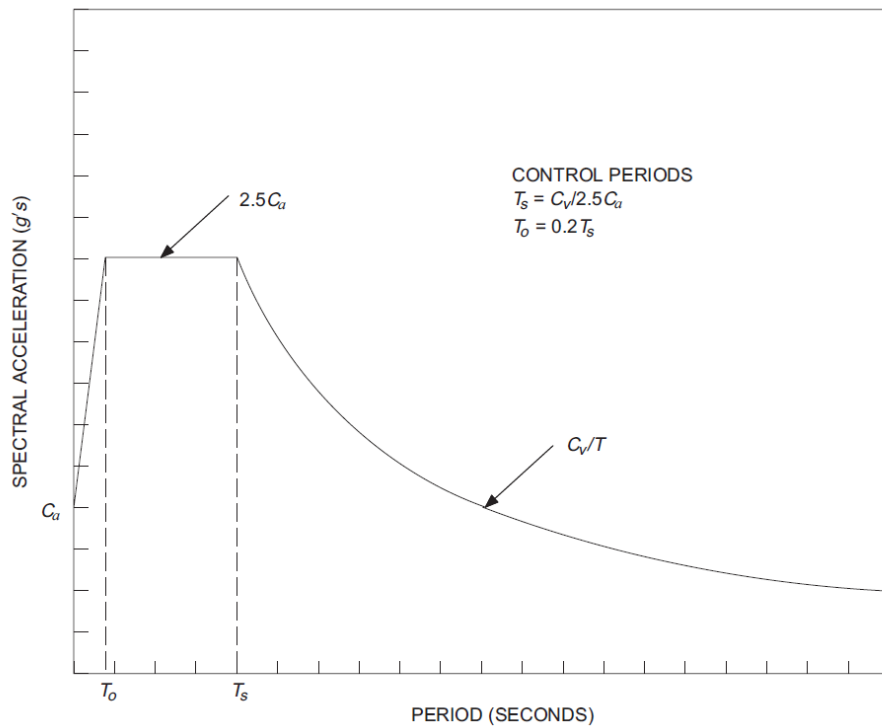


Fig 2-3: Design Response Spectra (UBC, 1997).

2.3.2 SEI/ASCE7-16:

The data required to estimate the seismic loads in the American Society of Civil Engineers Standard are shown in Table 2-2.

The procedure for determining the base shear based on SEI/ASCE7-16 is as follows:

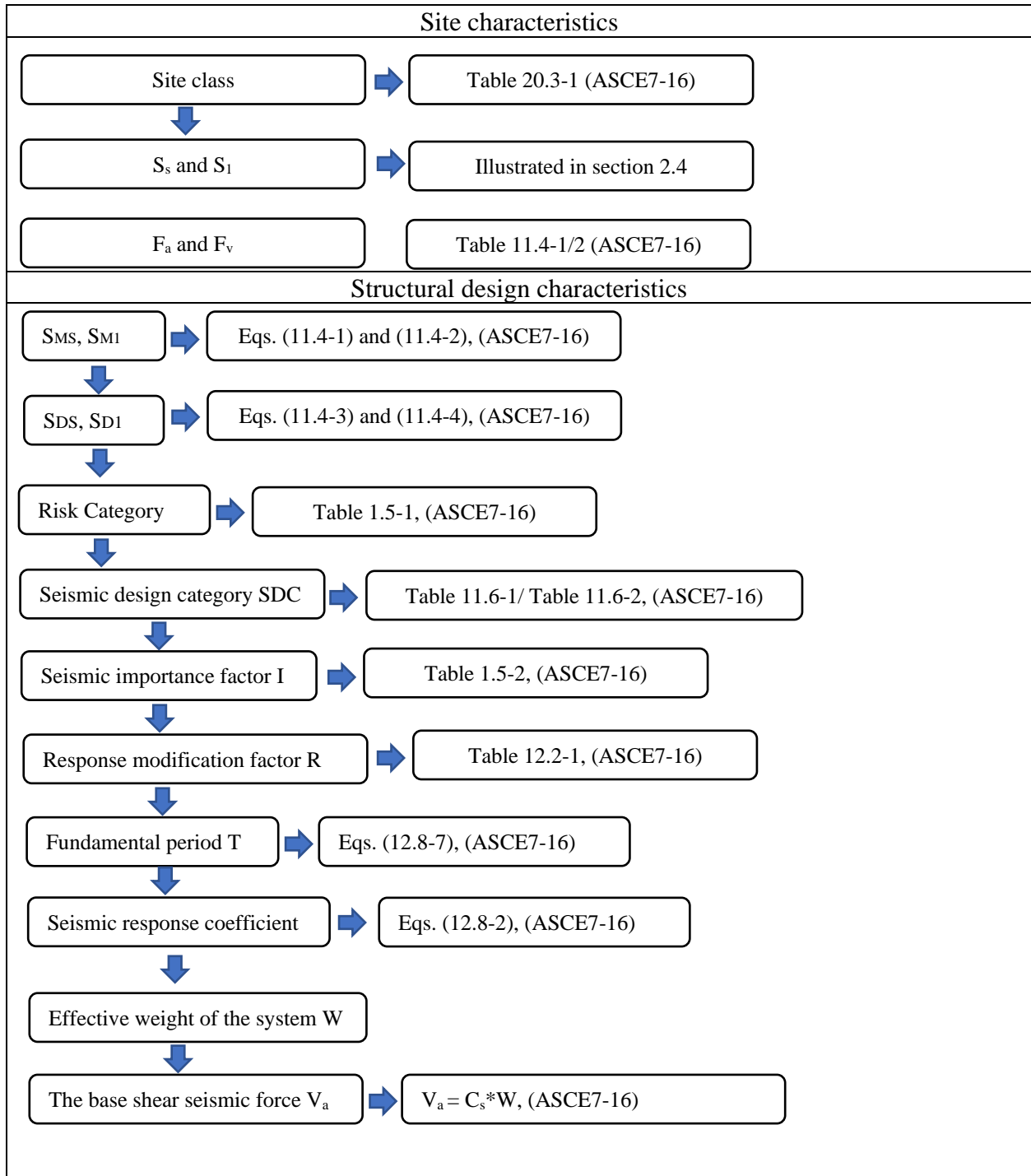


Table 2-2: Data required to estimate the seismic loads in SEI/ASCE7-16.

Parameter	Abbreviation
Seismic importance factor	I
Spectral accelerations for short periods and 1 second periods	S_s, S_1
Site coefficient	F_a
Site coefficient	F_v
Maximum spectral accelerations at short periods and 1 second period	S_{MS}, S_{M1}
Design spectral accelerations at short periods and 1 second period	S_{DS}, S_{D1}
Response modification factor	R
Seismic response coefficient	C_s
Effective weight of the system	W
The base shear seismic force	V_a

Moreover, the design response spectrum can be constructed according to SEI/ASCE7-16 using the parameters shown in Fig 2-4.

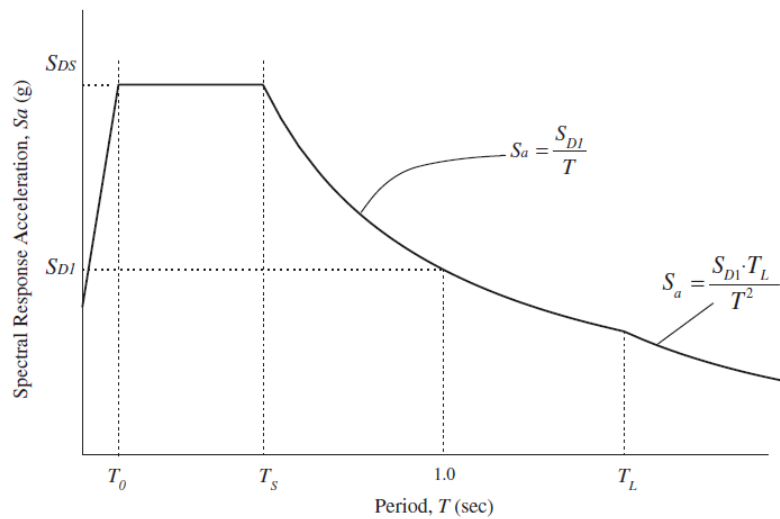


Fig 2-4: Design Response Spectra (SEI/ASCE7-16).

These procedures are adopted in the design offices in Palestine. However, the response modification factor R in both standards is similar. Therefore, the procedure according to SEI/ASCE7-16 is used to evaluate and assess the performance of the chosen models, which represent the existing buildings in Palestine.

2.4 Seismic Hazard Maps used in Palestine and in the Region:

The UBC 97 code procedure to estimate the seismic base shear uses the seismic zone factor for Palestine to represent the seismic hazard for the area, as described in section 2.3.1. This factor divides the area into four different seismic zones (1, 2A, 2B, 3); each seismic zone has a peak horizontal ground acceleration value, as shown in Fig 2-5. In contrast, the seismic hazard map in Fig 2-6 is implemented to estimate the base shear according to SEI/ASCE7-16 procedure.

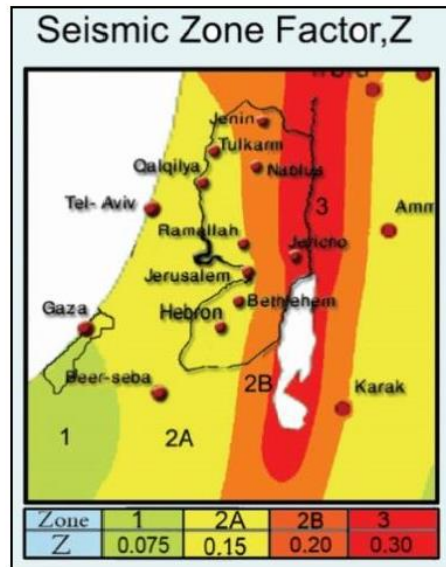


Fig 2-5: Seismic zone factor for Palestine (Source An-Najah National University, Boore et al., 1997).

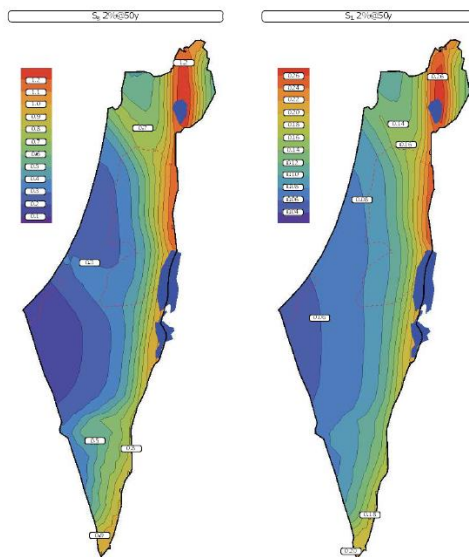


Fig 2-6: Seismic Hazard Map for Historical Palestine (IL Standard SI 413).

CHAPTER 3: RESPONSE MODIFICATION FACTOR AND ANALYSIS METHODS

3.1 Introduction to the Concept of Response Modification Factor:

The definition of the response modification factor (R) for the seismic design of structures was carried out first through (Wu et al., 1989; Hanson et al., 1993). The authors focused on designing energy dissipation systems by looking at the displacement response. The results were implemented in Uniform Building Code (UBC, 1994). Then, the proposals from (Newmark and Hall, 1982) were implemented in the (UBC, 1997) and (FEMA-273, 1997). According to the IBC (IBC, 2000), the value of R should be used to reduce the seismic forces of structures, and it was established based on the performance of different structural systems in previous strong earthquakes. In contrast, the National Earthquake Hazards Reduction Program (NEHRP, 2000) proposed the R coefficient to explain the ductility, over strength, and energy dissipation in the soil-foundation system.

3.2 Literature Review on the Response Modification Factor:

Many studies have been investigating response modification factors (R) for the seismic design of structures. (Miranda, 1994) investigated the response modification factor R coefficients, described as a strength reduction factor (R_μ). Miranda (Miranda, 1994) found that the R factor is primarily a function of displacement ductility (μ) and the structure's natural period (T). (Daza, 2010) defined the relationship between the R factor and the minimum strength of the building using the pushover analysis method. Furthermore, (Mitchell D and Paultre P, 1994) and (Izadinia M, 2012) summarized that non-linear static (conventional pushover or adaptive pushover analysis methods), pseudo-static, or dynamic analysis methods can be used to evaluate the value of the response modification factor.

Moreover, the literature included multiple research work on the numerical derivation of response modification factor R for reinforced concrete structures. (Adeel, 2010) evaluated the response modification factor R for the reinforced concrete moment resisting frames in Pakistan. It was found that the US seismic codes' recommended values of the response modification factors are unconservative and overestimate R values for a selection of ground motion records. (Apurba et al., 2013) investigated the actual values of response modification factors for realistic reinforced

concrete buildings designed and detailed according to Indian standards. These calculated factors were compared with the values suggested in the national design code. The authors concluded that the recommended values of R in the Indian standards are higher than the actual values of R , which is considered unsafe.

In contrast, (Manar et al., 2021) studied the response modification factor for reinforced concrete frames with non-uniform spans and heights. The authors then compared the calculated values with the recommended values in the Egyptian code (ECP-201) of practice. It was found that the recommended values of R in the code are conservative and consequently not economical. Furthermore, the non-uniformity in span lengths significantly affects the R factor.

(Sharifi et al., 2018) derived the response modification factor R for both ordinary and special-moment resisting RC-frame structures designed based on the limit state design. The study results indicated that the response modification factor R is significantly affected by the number of stories, bays number, and the maximum imposed lateral displacement during a pushover analysis. Moreover, (Sharifi et al., 2018) compared the values of the obtained R -factor with the corresponding values prescribed in current seismic design codes. The authors concluded that the design R -factors of both ordinary and special-moment resisting RC-frame structures should be taken as 3 and 7, respectively, to achieve a conservative and safe design. (Brahmavathan et al., 2016) evaluated the response modification factor R for irregular ordinary and special-moment resisting RC-frame structure. The study revealed that the actual value of R was found to be decreasing while the number of stories of frame structures increased. Furthermore, the actual value of R was less than the value assumed in the design process. Following the authors, a certain percentage of reduction for the response modification factor R has to be considered in irregular frame structures.

(Louzai et al., 2015) assessed the value of seismic behavior factors for reinforced concrete frame structures using a comparative analysis between non-linear pushover and incremental dynamic analysis. The structural models were designed according to the reinforced concrete code BAEL 91 and Algerian seismic code RPA 99/Version 2003. The study showed that the adopted value of the seismic behavior factor from the seismic design code RPA 99/Version 2003 was overestimated. Moreover, the value of the seismic behavior factor tended to decrease for larger number of stories and when non-linear static pushover analysis is performed. However, non-linear incremental

dynamic analysis increased the value of the seismic behavior factor for a higher number of stories. This may indicate that the value of the seismic behavior factor does not depend on the structure's height. (Patel et al., 2017) determined the response modification factor R for both ordinary and special-moment resisting RC-frame structures through a non-linear pushover analysis. According to Patel et al. (Patel et al., 2017), the response modification factor R for both ordinary and special-moment resisting RC-frame structures is affected by the seismic zone. Furthermore, the authors concluded that the recommended value of response modification factor in the Indian seismic code (IS-1893, 2002) is on the conservative side.

(Abdi et al., 2017) studied the effect of implementing viscous damper devices in RC structures on the value of response modification factor R . Non-linear pushover analysis was performed to evaluate R -factor. The study results show that the value of R -factor is higher in the case of reinforced concrete structures with damper devices. Furthermore, it was found that the response modification factor is highly affected by the number of dampers and the height of the buildings. (Wang, 2014) investigated the influence of high mode effects on the ductility reduction factor in the case of MDOF shear-type structures. It was found that the modification factor is mainly affected by the fundamental period and ductility.

(Jinkoo et al., 2005) evaluated the response modification factor for both special and ordinary-concentric braced frames by performing a non-linear pushover analysis on the model with different stories and span lengths. It was found that response modification factors are smaller than the recommended ones by design codes except for the low-rise special concentric braced frames. (Mwafy, 2002) assessed and calibrated the force reduction factors adopted in current seismic codes. The author concluded that the force reduction factors adopted by the Eurocode (EC8) design code are over-conservative and can be increased in the case of regular frame structures that are subjected to low ground acceleration. (Junaid et al., 2020) studied the behavior of low-rise reinforced concrete frames retrofitted with steel haunches. The results showed that the response modification factor could be used in a force-based design and assessing haunch-retrofitted reinforced-concrete frame structures. (Borzi et al., 2000) illustrated that there is no influence of the earthquakes data set (magnitude, distance, and site characterization) on values of force reduction factors and found that the force reduction factor is only influenced by the shape of the hysteretic model, and it showed low sensitivity to strong-motion characteristics.

(Chaulagain et al., 2014) investigated the actual response modification factor R for irregular RC buildings in Kathmandu valley, Nepal, through a non-linear static pushover analysis. The authors concluded that geometrical configuration and material strength influence the actual R factor. Furthermore, it was found that the computed R -factor is less than the recommended value in the (IS 1893. 2002). (Ma'moun, 2020) evaluated the response modification factor R for reinforced concrete structures with shear walls. The results of the study showed that the openings in the 2D RC frames with shear walls affect the value of the response modification factor. Likewise, (Badrashi, 2016) computed the response modification factor for special-moment resisting frame buildings in Pakistan using both experimental and numerical work. It was found that the response modification factor for RC special moment resisting frames is 8.5. In comparison, the response modification factor value ranged from 4.0 to 6.1 in the case of special-moment resisting frames with construction deficiencies. Moreover, the span length and building height affect the response modification factor.

(Pandit et al., 2020) studied the effect of using masonry infilled walls on the response modification factor of existing RC-buildings. The authors evaluated the structural response in terms of natural period, base shear, strength, ductility, stiffness, and response modification factor R . and it was found that the inclusion of infills decreased the time period of the structure by 40-60%. The presence of infills increased the base shear of the structure from 1.2 to 2.2 and reduced the displacement ductility factor by 35-45%. In most cases, the response modification factor R values of existing masonry infilled RC buildings were lower than the bare RC buildings. The results confirmed that buildings with infill walls significantly influence the R -factor of structures. In contrast, (Patel and Vasanwala, 2019) assessed the response modification factor of un-reinforced masonry infilled RC buildings. The study results showed that including infill walls decreased the ductility factor, while the overstrength factor was found to be increased. Furthermore, the authors concluded that the overall response modification factor R increased due to the substantial increase in the values of overstrength factor.

(Shendkar et al., 2018) investigated the effect of semi-interlocked masonry (SIM) and unreinforced masonry (URM) infill walls on the response modification factor of RC frame structures. The authors revealed that the base shear of the SIM infilled frame is higher than the base shear in the case of URM infilled walls. The ductility factor is less in both SIM and URM infilled RC frame

structures compared with bare RC frames. However, the over-strength factor increases in the case of SIM and URM infilled panels. In addition. The R-factor is sensitive to material and geometric configuration. (Ko et al., 2008) examined the seismic behavior of a low-rise RC moment-resisting frame with masonry infill walls. The study results indicated that the inclusion of the masonry infill walls increases the structure's global stiffness and decreases the natural periods. The structure may also be subjected to significant damages if there is no consideration of the infill walls in the design.

As noticed from the above research works, there is an active debate regarding the derivation of R values and their influence on seismic design and behavior. Most research works agree that the R-factor is affected by the structure's height, irregularity, damping of frame system, and the existing openings in the structure. Moreover, the inclusion of infill walls decreases the structure's period and ductility and increases the frame systems' base shear. Therefore, in this research, the response modification factor (R) for each building frame model is evaluated to assess the non-linear seismic behavior of different building systems in Palestine, and it is expected to have similar outcomes to the literature mentioned above review with a value of response modification factor around 3.

3.3 Evaluation of the Response Modification Factor:

The response modification factor R is necessary to design earthquake load-resisting elements. The R factor was discussed in (ATC-3-06, 1978) for the first time. It was evaluated based on the performance observed of buildings during past earthquakes. Moreover, according to (ATC-19, 1995), the R accounts for over strength, ductility, and redundancy. Response modification factor R can be calculated by the product of three parameters that influence the response of structures during earthquakes (ATC-19):

$$R = R_0 R_\mu R_r$$

Where:

$R_0 =$ *Over strength factor*

$R_\mu =$ *Ductility factor*

$R_r =$ *Redundancy factor*

Evaluation of these factors is based on running a non-linear static pushover analysis and developing each building category's capacity curve, as shown in Fig 3-1. The capacity curve is the

relationship between base shear and roof displacement and can be obtained from a non-linear static analysis (pushover analysis). This type of analysis depends on incremental lateral load applied to the building until the building collapses or reaches the top target displacement, representing the structure's top displacement under an earthquake. Based on the results of pushover analysis, response modification factor R can be calculated and evaluated.

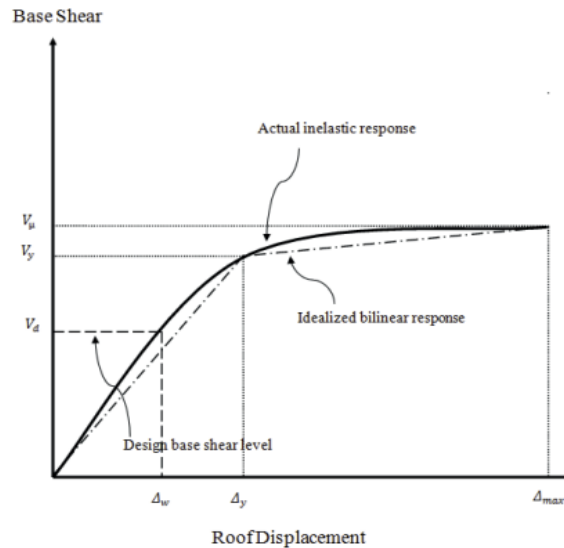


Fig 3-1: Ideal and the Actual Inelastic Response (Capacity Curve).

3.3.1 Ductility Factor (R_μ):

According to Abdi et al. (Abdi et al., 2018), the Ductility ratio (μ) can be calculated at the element, story, and system levels. The terms curvature, strain, and rotational ductility ratio are expressed at the element level. However, the term displacement ductility ratio is used at the story level. The ductility factor (R_μ) is calculated based on the displacement ductility ratio (μ). (Newmark and Hall, 1982) studied the response modification factor R resulting from ductility and found that $R\mu$ is sensitive to the natural period of structures. The authors developed a chart with five periods range to estimate the ductility factor (R_μ), as shown in Fig 3-2. Moreover, Equations (1)-(5) estimate the ductility ratio for different structures' natural periods.

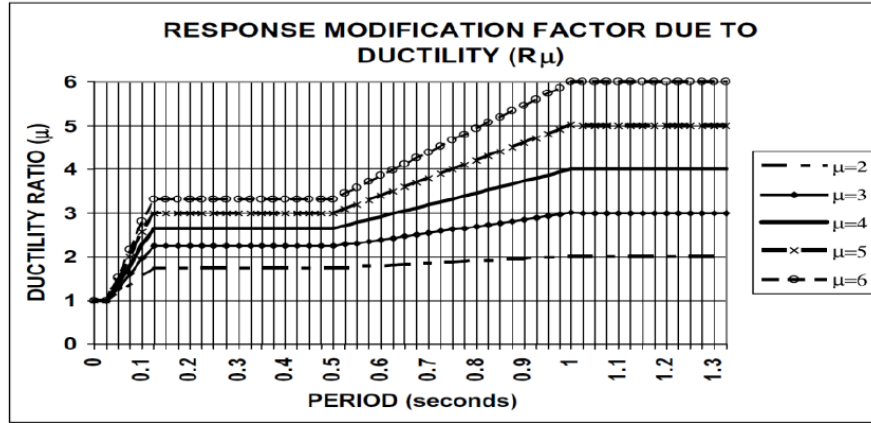


Fig 3-2: $R_{\mu} - T - \mu$ charts (Newmark & Hall, 1982).

Periods ≤ 0.03 sec:

$$R_u = 1.0 \quad (1)$$

Periods $0.03 < t < 0.12$ sec:

$$R_u = 1 + \frac{(T - 0.03) * ((2 * U - 1)^{0.5} - 1)}{0.09} \quad (2)$$

Periods $0.12 \leq T \leq 0.5$ sec:

$$R_u = (2 * u - 1)^{0.5} \quad (3)$$

Periods $0.5 < T < 1.0$ sec:

$$R_u = (2 * u - 1)^{0.5} + 2 * (T - 0.5) * (u - (2 * u - 1)^{0.5}) \quad (4)$$

Periods $T \geq 1.0$ sec:

$$R_u = u \quad (5)$$

3.3.2 Over Strength Factor (R_0):

The actual strength of the structures generally exceeds the design strength due to the overall design simplifications, actual construction practices, and the differences between the real and nominal material strength. Therefore, an overstrength factor should be included to avoid any local and global behavior change. Based on the capacity curves developed from the non-linear static analysis, the maximum base shear (V_0) and the designed base shear (V_d) can be found. Then, the overstrength factor (R_0) can be calculated using Equation (6).

$$R_s = \frac{V_0}{V_d} \quad (6)$$

3.3.3 Redundancy Factor (R_r):

(ATC-19, 1995) defines redundancy as “beyond what is essential or naturally excessive” in the perspective of structural engineering. Redundancy is to take into consideration the reliability of the seismic frame systems that use multiple vertical framing lines in each main direction of the structure. A redundant seismic framing system is built of multiple vertical lines of framing that are designed and detailed to transfer seismic-induced inertial forces to the foundation. This kind of redundancy in the system is active redundancy. However, standby redundancy is when members stay inactive in the typical cases and become active when one of the active components fails. The *redundancy factor* (R_r) can be taken from Table 3-1 (ATC-19, 1995).

Table 3-1: *Redundancy factor* (R_r), (ATC-19 (1995)).

Line of Vertical Seismic Framing	Redundancy Factor R_r
2	0.71
3	0.86
4	1.00

3.4 The R Factor in the Adoptive Seismic Codes and Neighboring Country Codes

The concept of response modification factor has been introduced in many seismic codes and standards of countries with seismic hazards, indicating its significance in seismic analysis and design. The following section presents an overview of the response modification factor and its recommended values in the seismic codes of the U.S (SEI/ASCE7-16, and UBC 1997), Europe (Euro code 8), and Egypt (Egyptian code ECP-201).

3.4.1 U. S (SEI/ASCE7-16, UBC 1997)

In the U.S codes and standards, the response modification factor is defined for reinforced concrete moment resisting frames based on the level of ductility. For instance, an ordinary moment-resisting frame relates to a low ductility. On the other hand, a special moment-resisting frame indicates a high ductility. The recommended values of the response modification factor R in the Uniform Building Code (UBC, 1997) and SEI/ASCE7-16 are shown in Table 3-2.

Table 3-2: Recommended Values of R-Factor in both SEI/ASCE7-16 and UBC-1997.

Building System	R-Factor	
	SEI/ASCE7-16	UBC-1997
Special reinforced concrete moment frames	8	8.5
Intermediate reinforced concrete moment frames	5	5.5
Ordinary reinforced concrete moment frames	3	3.5
Special reinforced concrete shear walls	6	5.5
Ordinary reinforced concrete shear walls	5	4.5

3.4.2 Europe (Euro Code 8)

The concept of response modification factor in the Euro code (EC8) is based on reducing the elastic spectral demand into their corresponding strength design level. This factor is called the behavior factor “q”, which depends on the level of ductility, stiffness regularity, and building strength. The recommended values of the behavior factor q for different structural systems are shown in Table 3-3.

Table 3-3: Recommended Values of Behavior Factor (q) in Euro Code (EC8).

Building System	Behavior Factor (q)
Frame System	5
Wall system with coupled walls	5
Wall system with uncoupled walls	4

3.4.3 Egypt (Egyptian Code ECP-201)

The response modification factor for reinforced concrete structures in the Egyptian Code (ECP-201) is also based on the ductility level. However, high ductility is indicated as sufficient ductility, and low ductility is defined as non-sufficient ductility. The recommended values of the response modification factor R for the RC moment-resisting frame system are shown in Table 3-4.

Table 3-4: Recommended Values of Response Modification Factor R in Egyptian Code (ECP-201).

Building System	R-Factor
Reinforced concrete moment frames with sufficient ductility	7
Reinforced concrete moment frames with non-sufficient ductility	5

It can be seen from the above mentioned that there is variability in the values of response modification factor R for each structural system, which indicates that this factor is determined by investigating the performance of the local behavior of structures during past earthquakes. Therefore, to avoid inconsistency and significant variability in the seismic performance of structures in Palestine, the R-factor should be evaluated based on local conditions and structural parameters.

3.5 Analysis Methods:

The non-linear static pushover analysis is opted to derive and conduct each frame system's capacity curve. This method can provide much characteristic information that cannot be acquired from the elastic static or dynamic analysis, namely; realistic force and deformation demands for each inelastic deformed element, the effect of the deterioration of element's strength on the overall structural stability, identification of the member's yielding and hinge formation which helps in damage assessment of the structural system, and monitor the progress of the capacity curve of the structure. Consequently, this method is adopted because the previously mentioned information is crucial to accomplishing the goals of this research (M. Seifi. et al., 2008).

The capacity curve derived from the non-linear static pushover analysis is a relationship between the base shear and roof displacement. This type of analysis depends on incremental lateral load applied to the building until the building collapses or reaches the top target displacement, representing the structure's maximum displacement under an earthquake, as shown in Fig 3-1. The selection of the lateral load pattern is more critical in the case of performance assessment due to the fact that the load pattern should deform the structure the same way an earthquake does. According to Krawinkler et al. (Krawinkler et al., 1998), the inverted triangular is the conventional

pattern shown in Fig 3-3. The adaptive load shape pattern is more essential when a single mode shape does not control the structure's response.

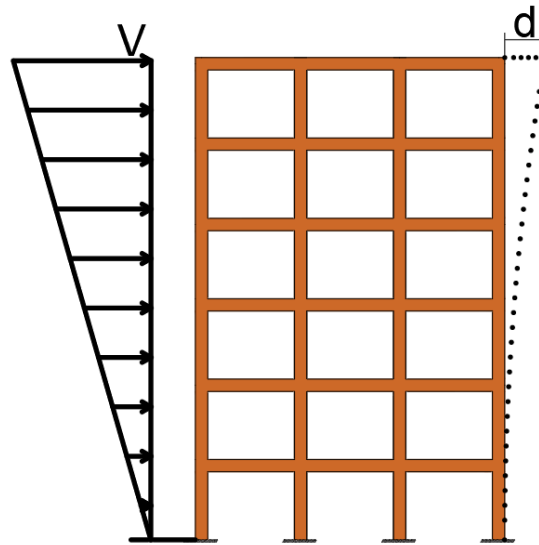


Fig 3-3: Conventional Lateral Load Distribution.

3.6 Determination of the Performance Point: Coefficient Method.

The behavior of the structural systems is further examined by carrying out a performance-based evaluation of buildings. The performance-based method is a relationship between a seismic event and a structural ability to resist that event. The assessment is done by determining the performance of a frame system and comparing it with the required performance objectives. Furthermore, the structure's response should meet the selected acceptance criteria adopted by SEI/ASCE 41-17. According to the SEI/ASCE 41-17 standard, the seismic performance-based method (Coefficient method) principles can be applied to determine the performance point for each frame system.

The displacement coefficient method (CM) is a widely used procedure to estimate the target displacement in a non-linear static pushover procedure (NSP). This method is defined in the FEMA-356 and adopted in the SEI/ASCE 41-17 standard. The coefficient method (CM) utilizes a displacement modification procedure to calculate the target displacement for a linearly elastic single degree of freedom system (SDOFs) using several coefficients. Moreover, the original

structural and equivalent SDOF systems have the same period and damping. The target displacement in SEI/ASCE 41-17 (CM) is computed from Equation (7).

$$\delta_t = C_0 C_1 C_2 S_a \frac{T_e^2}{4\pi^2} g \quad (7)$$

Where S_a relates to the response spectrum acceleration at the fundamental period and 5% damping ratio. It is computed using Equations (8) and (9), as illustrated in Fig 3-4. The coefficient C_0 refers to the spectral displacement of an equivalent SDOF system to the elastic displacement of a multi-degree-of-freedom system at the roof control node.

$$S_{x1} = F_v S_1 \quad (8)$$

$$B_1 = 4/[5.6 - \ln(100 * \text{damping ratio})] \quad (9)$$

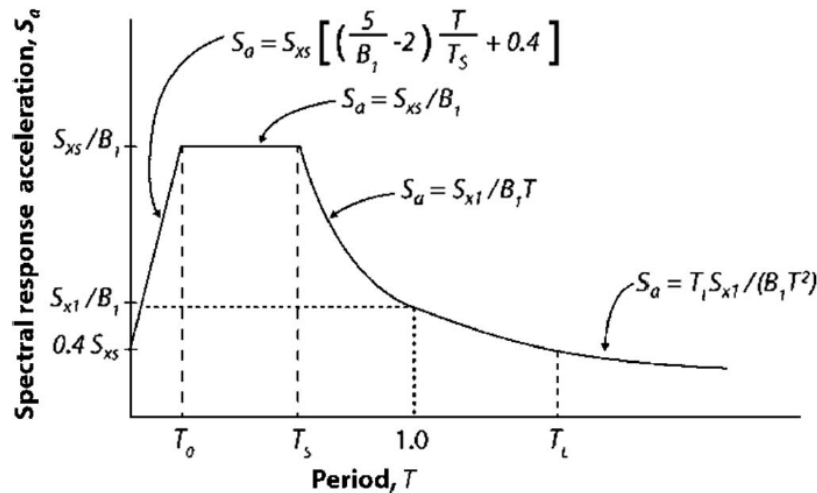


Fig 3-4: General Horizontal Response Spectrum (SEI/ASCE 41-17)

The coefficient C_1 represents the expected maximum inelastic displacements to the linear elastic displacements, given by Equation (10). In contrast, coefficient C_2 takes into account the effect of stiffness degradation and strength deterioration on the maximum displacement. For periods less than 0.7s, C_2 is calculated based on Equation (11). The effective fundamental period (T_e) is evaluated based on the idealized force-displacement curve shown in Fig 3-5. Equation (12) defines the effective fundamental period.

$$C_1 = 1.0; \quad T_e > 1.0s, \quad (10)$$

$$1.0 + \frac{\mu_{strength} - 1}{\alpha T_e^2} \quad T_e < 1.0s,$$

$$C_2 = 1.0 + \frac{1}{800} \left(\frac{\mu_{strength} - 1}{T_e} \right)^2 \quad (11)$$

$$T_e = T_i \left(\frac{K_i}{K_e} \right)^{0.5} \quad (12)$$

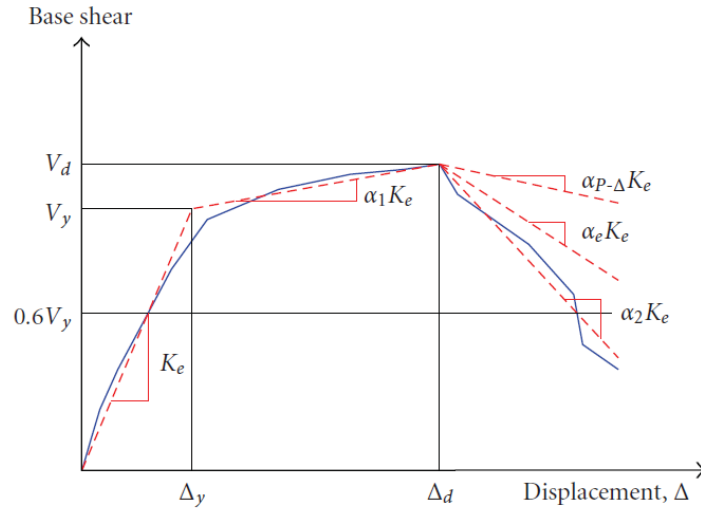


Fig 3-5: Idealized force-deformation curve in SEI/ASCE 41-17 (Goel, 2011)

Furthermore, the target displacement should satisfy the selected performance level. And referring to the FEMA 356, there are three performance levels described in Table 3-5. The chosen performance level is based on the conducted interviews (see section 4.1), and it shows that most of the Palestinian buildings are commercial-residential buildings. This means that buildings are occupied mainly by people. Therefore, the target performance level is set to be Life Safety (LS) to protect and save human lives. The life safety performance level is defined in the SEI/ASCE 41-17 as 0.75 times the deformation at point E shown in Fig 3-6.

Table 3-5: Structural Performance levels (FEMA, 356).

Performance Levels	Description
Immediate Occupancy IO	The structure retains most pre-earthquake strength and stiffness, and the system remains safe to occupy.
Life Safety LS	Significant damage happens to the structural components. However, the elements can resist partial or total collapse, and injuries may occur, but the possibility of life-threatening injuries is low.
Collapse Prevention CP	Substantial damage to the structural components and significant degradation in the stiffness and strength of structural elements occurs. Due to the structural element's damage, life-threatening injuries may occur.

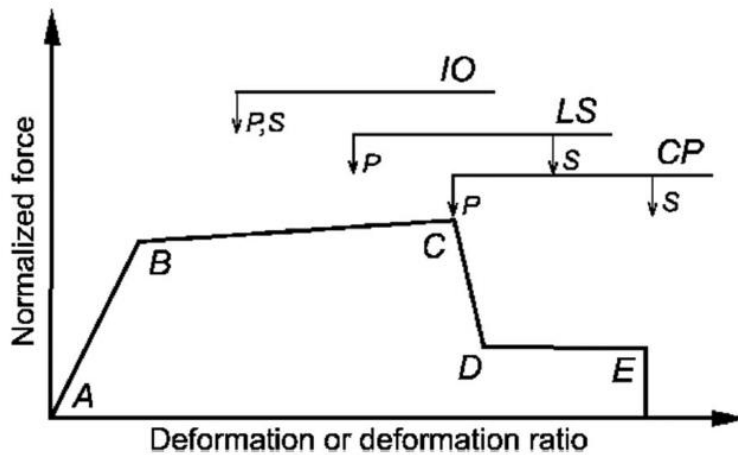


Fig 3-6: Acceptance Criterion Illustration (SEI/ASCE 41-17)

Therefore, on the condition that the performance point is below the life safety performance level, the model performance satisfies the acceptance criteria. The shorter the distance between the performance point and the life safety condition indicates a more efficient design. This procedure is applied to each analyzed frame system.

CHAPTER 4: TYPE OF BUILDING SYSTEMS AND THEIR DEFICIENCIES

4.1 Types of Building Systems:

The data regarding the building categories and their representation percentages are discussed in this chapter. The data were collected through semi-structured interviews. The interviews were personal interviews held with highly skilled/active engineers, contractors, and construction managers. A copy of the interview form and the questions that have been discussed is presented in Appendix 1. Based on these interviews, it was found that reinforced concrete frame buildings are the most common building category in Palestine. Reinforced concrete shear-walls are often used around the stairwells and elevator cases, their poor positioning does not support the frame system effectively for the building to be a shear-wall system or dual system. A study done by (Antonella et al., 2016) agreed with this classification, and it was used to guide and verify the data collection. According to Antonella et al. (Antonella et al., 2016), there are three main types of structures in Nablus city which can be as the following: masonry-concrete wall buildings, RC frame buildings, and RC shear wall buildings. The collected data was compatible with the data from (Antonella et al., 2016). Therefore, it was used for further work in this research.

The interviews were used to determine the current construction practice to build an accurate prototype for each building category. The results of the interviews showed that the majority of buildings have a number of floors ranging from 4 to 6 and from 6 to 9 floors. The inter-storey height in most buildings is 3.0 meters, and the ground floor is 6 meters in the case of commercial-residential buildings (the ground floor is commercial, and the rest are residential). The number of bays ranges from 3 to 6 with a typical span width of 4 meters. Building structures are commonly in regular shape in both horizontal and vertical planes. However, geometric irregularities exist and are presented in building structures due to the region's lack of urban land-use regulations.

Furthermore, most RC buildings have external stone-concrete infill walls with thicknesses ranging from 25 to 35cm, and this type of infill wall consists of stone, plain concrete, insulation boards, and concrete masonry, as shown in Fig 4-1. The Interviewees confirmed that some RC buildings can have concrete masonry infill walls with 20cm concrete masonry and plastering. This type of infill wall can reach 25cm in thickness. These infills are constructed based on the method illustrated by (Halahla, 2019). The author stated that the construction of infill walls precedes the

construction of the flooring system and is the oldest method and most popular in many residential and commercial buildings. This method can affect the interaction between the infills and other structural components. Generally, these infill walls provide a cheap thermal and noise insulation solution. On the other hand, the infills used may add to the lateral stiffness of the frame line, and this may cause an increase in the global stiffness and strength of the frame system. In contrast, the loss in ductility is enormous, and according to Adeel. (Adeel, 2010), this behavior may result in the failure of the infills and creates severe problems in the whole structure.

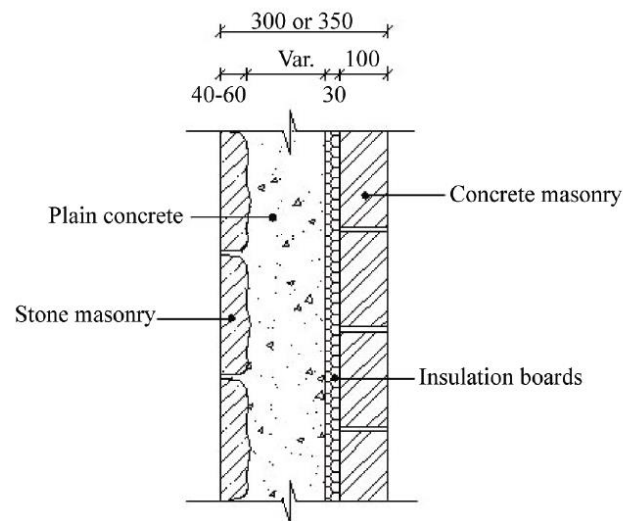


Fig 4-1: Typical Cross-Section of the Stone-Concrete Infill Panel, Dimension in mm (Al-Nimry et al., 2015).

4.2 Deficiencies in Construction Practices:

Based on the interviews, most engineers agreed that most buildings have a structural deficiency in the beam-column joint area, as no transverse reinforcement exists. Furthermore, inadequate development length in beams, columns, and beam-column joints was recognized as a deficiency in the current construction practice. The interviewed engineers also commented on the shear reinforcement and the spacing of the stirrups being in some cases inadequate for new and existing buildings.

4.3 Structural Deficiencies effect on R-value:

The ductility of the frame system mainly depends on the ductility of the beams, columns, and beam-column joints. Any deficiencies in these elements will affect the performance of the entire system. One of the significant deficiencies is the lack of transverse reinforcement in the beam-column joints. The beam-column joint behavior is affected by the inadequate shear capacity and reinforcing bars-concrete bond-slip. The absence of shear reinforcement leads to significant shear deformation in the joint area, restricting the flexural capacities for the beams and columns joining together (Pampanin et al., 2002).

Therefore, many researchers investigated the behavior of the beam-column joint to determine its effect on the lateral response of structures. (Park, 2002) summarized the results of simulated seismic load tests on RC beam-column joints. It was found that the seismic performance of an interior beam-column joint in RC moment resisting frames is poor, especially without transverse reinforcement in the joint cores. This refers to the diagonal tension cracking and bond-slip. Furthermore, the behavior of exterior beam-column joints is influenced mainly by the direction of the beam bar hooks in which way they are bent and anchored in the confined core. The test results showed that the nominal horizontal joint shear stress is less in case bar hooks are bent out of the joint core, which indicates that the seismic performance is more vulnerable. (Pampanin et al., 2002) also studied the seismic behavior of RC beam-column joints designed for gravity loads only. The experimental tests on the beam-column joints with typical structural deficiencies in the Italian construction practice between the '50s and '70s showed a significant vulnerability of the joint area under simulated seismic loads.

Furthermore, the behavior of beam-column joints has been investigated analytically. Many researchers have proposed joint models for use in simulating lateral response in the case of earthquake loadings. (Youssef and Ghobarah, 2001) proposed a joint model which consists of two diagonal translational springs linked to the opposite corners of the joint area, with 12 translational springs located at the interface of the joint area to cover all the modes of inelastic behavior such as bond-slip and concrete crushing. This model demands a large number of translational springs, and each one needs a separate constitutive model. (Lowes and Altoontash, 2003) proposed a joint model with four nodes and 12 degrees of freedom (DOF), representing three types of inelastic mechanisms of beam-column joints under cyclic loading. According to the authors, the bonding-

slip response of beam-column longitudinal reinforcement is modeled as eight zero-length translational springs. Moreover, a zero-length rotational spring is used to represent the joint's shear deformations, and four zero-length shear springs are used to simulate the interface-shear deformations.

(Shin and LaFave, 2004) proposed the joint model as rigid elements located along the edges of the joint area with rotational springs linking the rigid elements and two rotational springs located at the interface of the beam joint to take into account the bond-slip behavior of the beam longitudinal reinforcement. The constitutive parameters for bond-slip deformation were determined. According to the authors, the proposed joint model incorporates the behavior of RC beam-column joints of ductile moment-resisting frames designed and detailed based on current codes. (Mitra et al., 2007) modified the joint model of (Lowe and Altoontash, 2003) to improve the overall joint response mechanisms and anchorage zone response. The study showed that the modified model represented well the stiffness and strength parameters for joints.

Based on these models, many studies were published showing the effect of the beam-column joints' behavior on the global performance of structures subjected to cyclic loads. (Shafaei et al., 2014) investigated the effect of joint flexibility on the lateral response of RC frames. The study showed that the analytical results of a modified joint element accurately predict the behavior of beam-column joints by taking into account the detailing of reinforcement in the joint region, the slip of the beam longitudinal reinforcement in the joint, and shear deformation of the joint area. Moreover, RC structures with deficient beam-column joints are vulnerable, especially under severe earthquakes. (Rajeev et al., 2020) investigated the behavior of RC external beam-column joints subjected to dynamic loads using analytical models and experimental tests. The authors concluded that any additional transverse reinforcement decreases the development of shear cracks in the joint area. (Park et al., 2013) proposed a multi-linear backbone curve for beam-column joint, which was used to assess the seismic performance of non-ductile RC buildings. OpenSees program was utilized to perform the non-linear dynamic analysis based on the proposed backbone curve. The study showed the importance of joint flexibility in assessing the seismic performance of non-ductile reinforced concrete buildings. Furthermore, the derived backbone curve reflected the actual behavior of unreinforced beam-column joints compared with the rigid joints.

(Ahmad et al., 2021) performed a non-linear dynamic analysis on reinforced concrete moment resisting frames with/without beam-column joint detailing to evaluate the significance of joint detailing on the performance of the building under dynamic loads. It was found that the frames with shear reinforcement in beam-column joints have a collapse margin ratio (CMR) equal to 11% higher than the acceptable. However, frames without shear reinforcement in beam-column joints have a CMR equal to 29% less than the other frames with proper joint detailing. Thus, the beam-column joint detailing dramatically affects the dynamic behavior of RC moment-resisting frames.

(K. Ramanjaneyulu et al., 2013) compared the seismic performance of an exterior reinforced concrete beam-column joint according to Eurocode (EC8) and Indian Standard (IS) codes. The study showed that structures designed for gravity loads only are vulnerable to medium earthquake intensities. Moreover, structures designed according to ductile detailing provisions in the Indian Standard (IS) have a better performance than the structures designed based on the ductile detailing provisions in the Eurocode (EC8). Therefore, the authors concluded that the ductile detailing provisions influence the seismic performance of reinforced concrete structures in different standards. (Abdelwahed, 2019) also investigated the behavior of RC beam-column joints in the case of seismic loading. OpenSees program was utilized to perform the analysis. The joint models were selected from the OpenSees library to account for the expected shear deformation and the bar slip. The results showed that the lack of shear reinforcement in beam-column joints reduces the ultimate joint capacity.

Another significant deficiency is the length of longitudinal bars in both members and beam-column joints. This deficiency can affect the bond-slip failure criteria between reinforced bars and concrete. Many researchers highlight the importance of incorporating the bond-slip between longitudinal bars and concrete. (Calvi et al., 2002) experimentally assessed the damage and collapse of the beam-column joints in RC frames. It was concluded that the inadequacy of beam-column joint detailing, such as the lack of end-hook anchorage in beams and smooth bars, may cause strength degradation leading to a brittle failure mechanism. (Goksu et al., 2014) investigated the effect of the lap splices on the lateral behavior of reinforced concrete members. The study showed that the presence of the hooks in lap splices decreased the negative effect of poorly lap splices on RC member performance. (Eshghi et al., 2008) investigated the cyclic behavior of a slender reinforced concrete column with lap splices through experimental work. The data were

verified using the plastic hinge method. The study confirms that the absence of well lap splices in the plastic hinge region significantly affects the member's ductility. Moreover, the bond-slip effect in the splice region on the lateral deformation is substantial and should not be ignored in the analysis.

Many researchers proposed analytical models to include the bond-slippage effect on the response of reinforced concrete elements. In addition to the studies mentioned above, (Ning et al., 2016) proposed a model for beam-column joints under dynamic loading. The bond-slip mechanism of longitudinal reinforcement and the shear deformation mechanism in the joint concrete core were modeled as eight springs and a one-panel zone. The model was calibrated using experimental data for non-seismically detailed joints. (D'Amato et al., 2012) developed a modified steel bar model taking the bond-slip of longitudinal bars into account. According to the authors, the model can predict axial slip deformations with accurate results. (Mergos et al., 2012) built a beam-column model for the seismic analysis of reinforced concrete structures. The model components are two gradual spread inelasticity elements to encounter inelastic flexure and shear response. The model also includes two rotational springs at the end of the member to represent the anchorage slip effect. The study showed that the model could capture the hysteretic response and the type of failure in the member.

(Wei-Chih Lin, 2013) studied the effects of insufficient lap splices in deficient reinforced concrete frames on the system performance. Both experimental and analytical approaches were used to find the response of structures. The authors concluded that in the case of laboratory tests, the presence of a 25% deficient lap splices length does not affect the structures' overall response. However, the analytical models using Opensees program results were not sufficient to catch local deformations such as end rotations.

Furthermore, it can be observed that the inclusion of structural deficiencies (insufficient beam and column shear reinforcement, short anchorage length in longitudinal beam bars, and inadequate beam-column joint shear reinforcement) in the analysis of frame structures influences the seismic performance of reinforced concrete structures by reducing the ultimate system capacity and ductility. Therefore, structural deficiencies shall be considered in modeling and analysis stages to accurately predict the performance of building structures and, consequently, the response modification factor.

CHAPTER 5: SELECTION OF STRUCTURAL BUILDING MODELS

5.1 Description of the Case Study Buildings:

In this study, in order to represent structural building systems in Palestine, semi-structured interviews were conducted and illustrated in section 4.1. The common characteristics of the buildings are identified. The geometrical data selected for RC-frames are also summarized in Table 5-1. Based on the research argument, the performance of the structural buildings is controlled by the line framing with a minimum R-factor (less ductile line frame system) (ASCE 41-17). line framing combinations are used in this study (2D-analysis) as each line frame type is analyzed alone. The external line framing is considered in the analysis due to the high stiffness of infills. Therefore, twelve 2D RC-moment resisting frames (MRFs) were chosen as typical RC-frames in Palestine. Two prototype RC-MRFs are three bay-six storey (3B6S) as bare frame and bare frame with structural deficiencies. Four prototypes RC-MRFs three bay-six storey (3B6S) are used to investigate the effect of the infill walls (stone-concrete and concrete masonry) on the global response, as shown in Fig 5-1. In contrast, two prototype RC-MRFs are three bay-nine storey (3B9S)) as bare frame and bare frame with structural deficiencies. The other four 3B9S frames are to consider the effect of infill walls on the structural performance, as shown in Fig 5-2.

Table 5-1: Selection of Model Characteristics.

Category	Common characteristics	Selected characteristics
Construction material	Reinforced concrete	Reinforced concrete
Structural system	MRFs	MRFs
Number of stories	4-6, 6-9	6 and 9
Number of bays	3-6	3
Plan regularity	Regular	Regular
Plan symmetry	Symmetrical	Symmetrical
Elevation regularity	Regular	Regular
Occupancy	Residential and commercial	Residential and commercial
Floor area (m²)	100-500	100-500

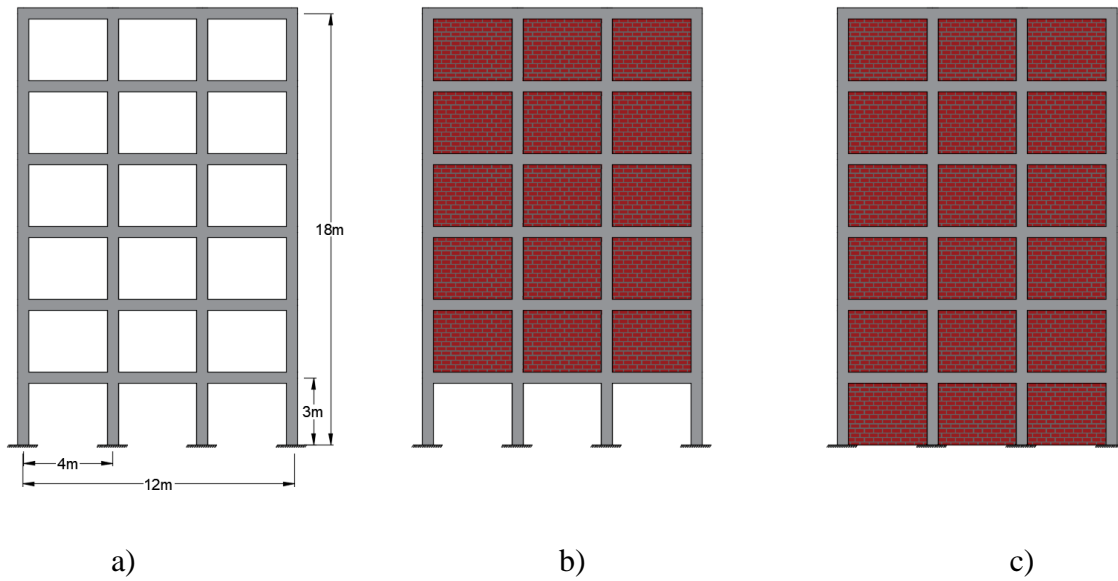


Fig 5-1: Elevation of three bay-six storey (3B6S), a) bare frame/with deficiencies b) infilled frame without ground infills (stone-concrete/concrete masonry) c) infilled frame (stone-concrete/concrete masonry)

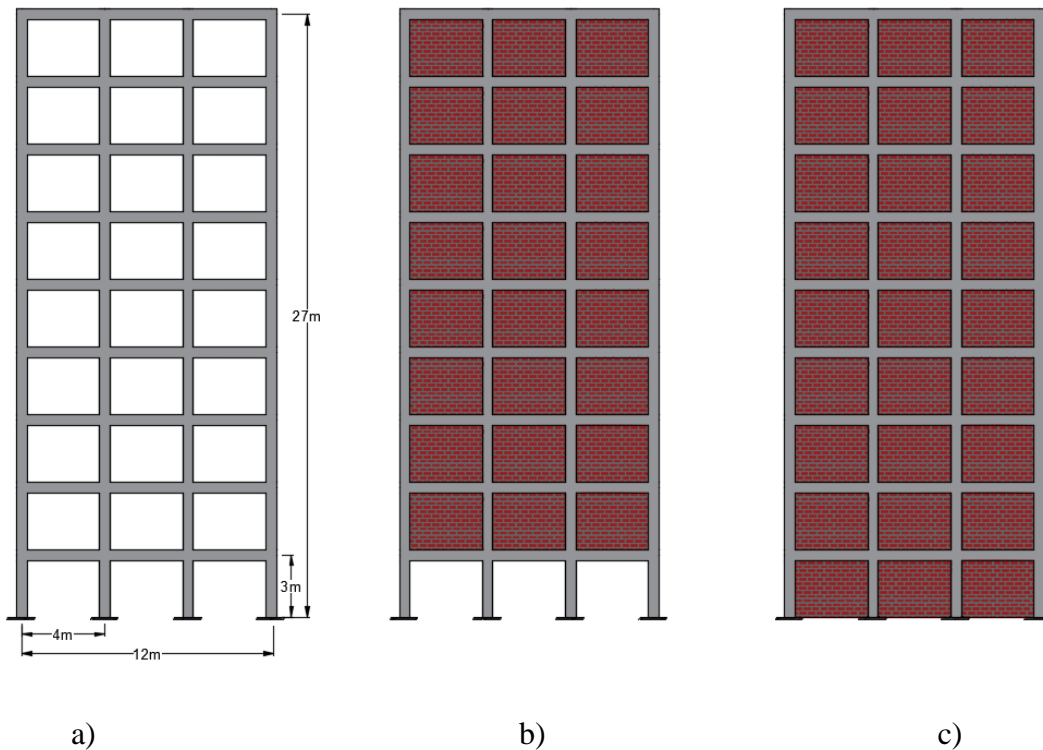


Fig 5-2: Elevation of three bay-nine storey (3B9S), a) bare frame/with deficiencies b) infilled frame without ground infills (stone-concrete/concrete masonry) c) infilled frame (stone-concrete/concrete masonry)

Moreover, these prototype RC-MRFs are based on typical existing buildings constructed in Palestine and are assumed to be designed according to SEI/ASCE7-16 and ACI 314 as intermediate moment-resisting frames. The plan of typical buildings in Fig 5-3 shows multiple line framing of three bay-six and nine stories. Two typical line framing were chosen to represent the three bay-six storey (3B6S) and the three bay-nine storey (3B9S). It can be seen from the figure mentioned earlier that most of the structure's slabs are ribbed slabs with hidden beams or flat slabs. The absence of drop-beams pressing to include the column strip to represent the beams in the modeling and analysis. Fig 5-4 shows cross-sections and reinforcement detailing of typical beams and columns. Full structural detailing for 3B6S and 3B9S ductile and non-ductile frame systems is shown in Appendix 16.

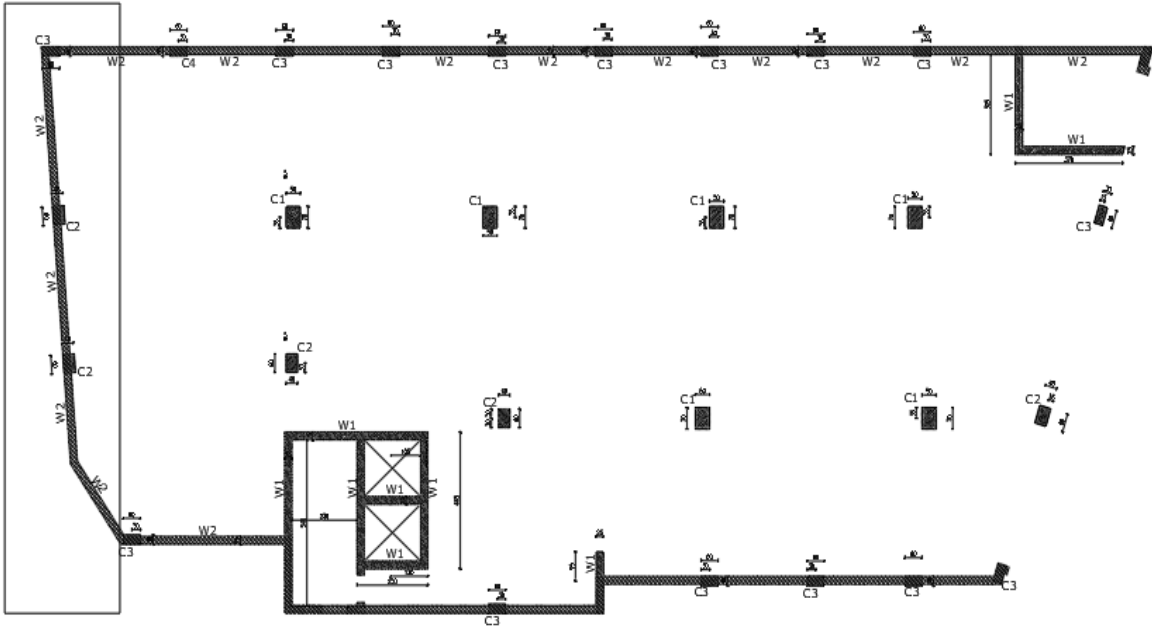
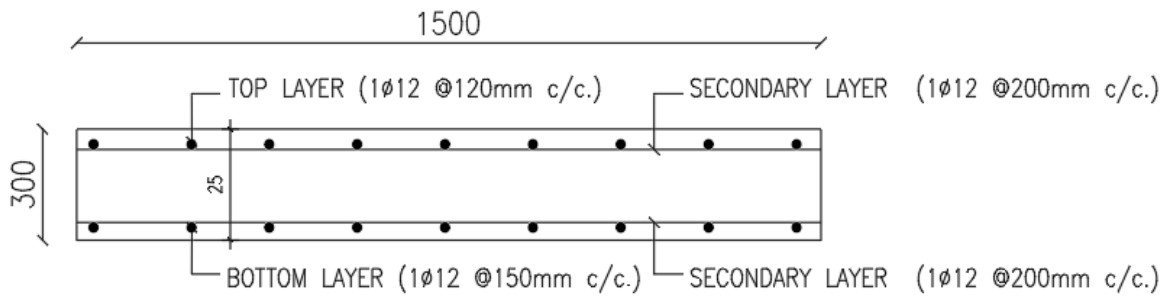
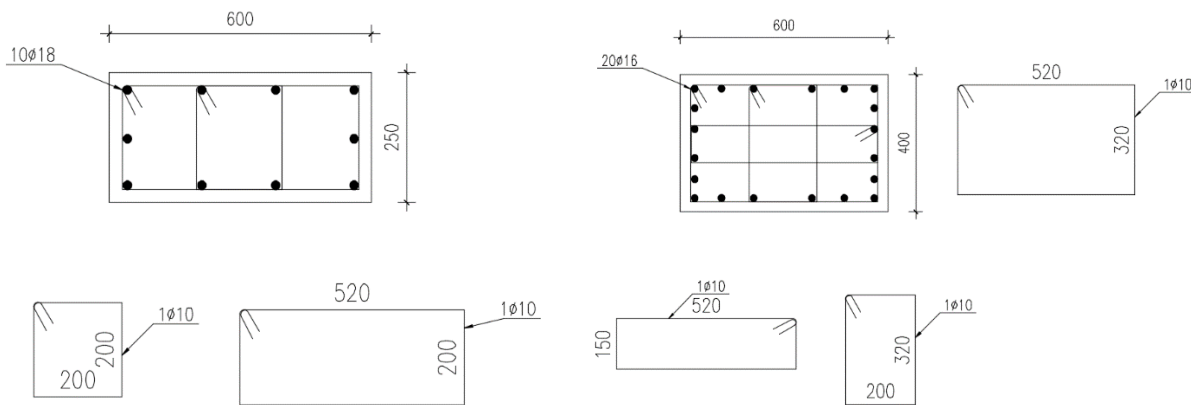


Fig 5-3: Floor plan of an existing prototype three-bay-six and nine-storey structure.



Cross-section and reinforcement detailing (B1)



Cross-section of columns (C1 and C2)

Fig 5-4: Cross-section of the beam (B1) and column (C1) for three bay-six storey. Beam (B1) and Column(C2) are for three bay-nine storey structures.

5.2 Material Properties:

Concrete and steel materials are the main materials used in building structures in Palestine. Based on the interviews (see section 4.1), the concrete has a wide range of design cylinder compressive strength that is used in designing reinforced concrete moment-resisting frames. A typical concrete cylinder compressive strength of 28 MPa is taken for the purpose of this research. In contrast, the steel reinforcement used in reinforced concrete moment resisting frames usually has a yield strength of 420 MPa. Modulus of elasticity in most cases is taken as 200000 MPa. The reinforcement of beam and column bars ranges from 12 mm diameter to 25 mm diameter.

5.3 Gravity Loads used in Construction Practice:

Most of the reinforced concrete moment resisting frames in Palestine are designed for dead and live loads (gravity loads) according to both SEI/ASCE7-16 and UBC 1997 standards. In this research, each prototype model is assigned to a superimposed dead load of 4.5 kN/m^2 and a live load of 3 kN/m^2 . The weight of infill walls is added as a line load along the beam's length, which equals 20 kN/m . The self-weight of beams and columns based on tributary area is considered with a concrete density equal to 24 kN/m^3 . All the assigned loads are converted to concentrated loads and placed at the nodes where the lump masses of the floors exist to avoid convergence problems that may occur in the program.

CHAPTER 6: NUMERICAL MODELING AND ANALYSIS

6.1 Modeling Criteria:

Numerical models for the examined structural systems are developed using an open-source finite element program to investigate the performance of the buildings considering the identified deficiencies. OpenSees is used for this purpose; it is a program designed especially for non-linear seismic analysis. It is utilized to perform a non-linear static pushover analysis for different models based on the collected data. The software has a library with an extensive number of material and element model definitions that capture the non-linear behavior of sections under bending, shear, axial forces and their interactions. The models are created in detail to represent the structural elements and their deficiencies. This level of detailing will provide adequate accuracy for the analysis results to better understand the overall behavior of the building. The structural elements beams, columns, and shear walls are defined as non-linear elements with fiber sections to model the frame elements. These elements are discretized to model longitudinal bars and concrete fiber sections see Fig 6-1.

Furthermore, uniaxial material models predefined in OpenSees are utilized to define the constitutive behavior of concrete and steel materials. According to Mazzoni et al. (Mazzoni et al. 2006), the section's force–deformation relationship is evaluated through numerical integration of the non-linear uniaxial material constitutive behavior of the fibers. The force-displacement behavior of the element is obtained by numerical integration of the section force–deformation behavior along the length of the element. The constitutive material model defined as concrete 02 is used to model confined and unconfined concrete, see Fig 6-2a. This model considers both compression and tensile strength of the concrete material (Yassin, 1994). Steel 02 is taken as a constitutive material model for steel reinforcement see Fig 6-2b, (Filippou, 1983). The distributed plasticity model is used to model the nonlinearities along the beam and column elements.

Moreover, non-structural elements such as infills (masonry walls and concrete stone walls) are modeled using simplified macro-models such the equivalent strut model to include the effect of the infills on the in-plane behavior of the structures. The beam-column joint is modeled according to Lowes and Altoontash (Lowes and Altoontash, 2003). The authors proposed a joint model with four nodes and 12 degrees of freedom (DOF), representing three types of inelastic mechanisms of

beam-column joints under cyclic loading. According to the authors, the bonding-slip response of beam-column longitudinal reinforcement is modeled as eight zero-length translational springs. Furthermore, a zero-length rotational spring is used to represent the joint's shear deformations, and four zero-length shear springs are used to simulate the interface-shear deformations see Fig 6-3.

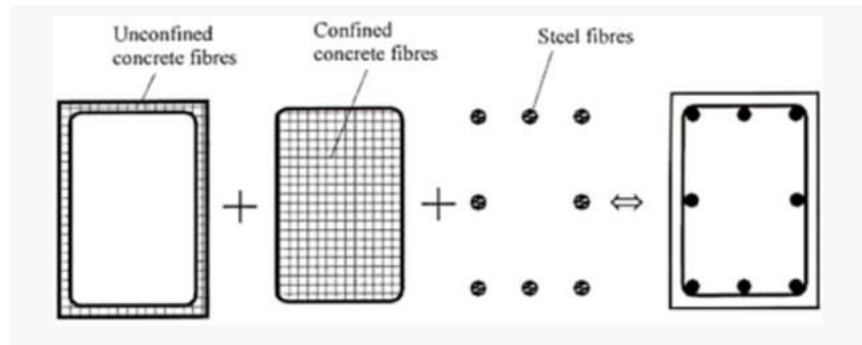


Fig 6-1: Modeling Technique Utilized in OpenSees; Fiber-Section Discretization Approach (Pahlavan et al., 2015).

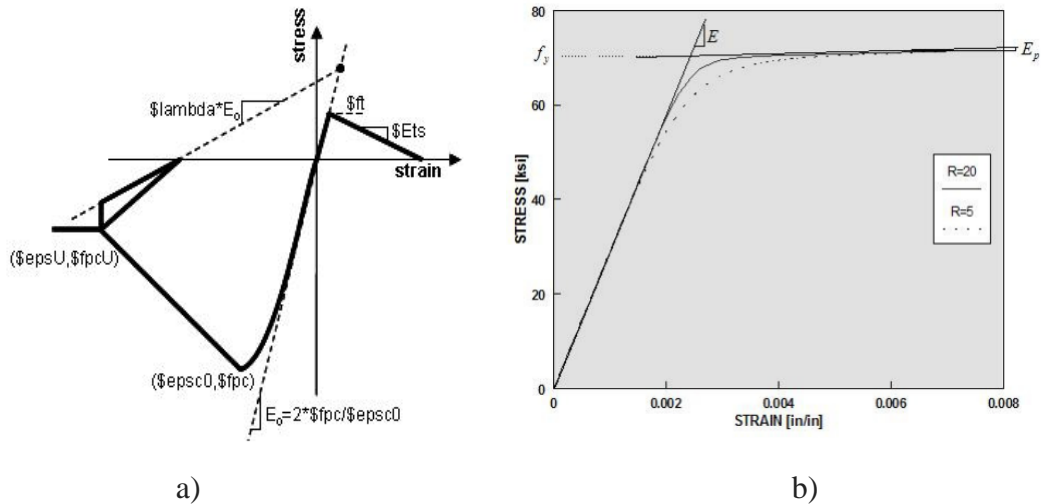


Fig 6-2: a) Stress-Strain Relationship Assumed for the Concrete Material; Confined Concrete, and Unconfined Concrete (Mazzoni, 2006). b) Stress-Strain Relationship Assumed for the Steel Reinforcement (Mazzoni, 2006).

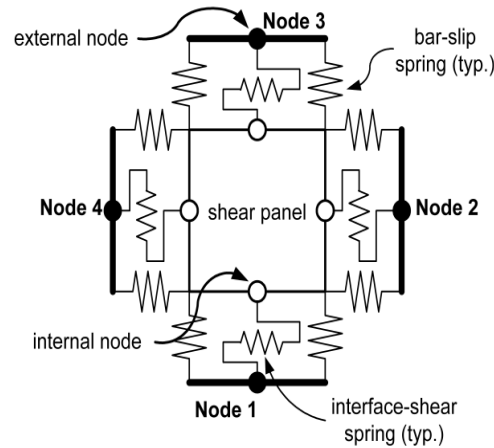


Fig 6-3: Beam-Column Joint Model (Mazzoni, 2006).

6.2 Constitutive Material Model Parameters:

6.2.1 Concrete:

Unconfined and confined concrete are modeled using the Concrete02 constitutive model, which considers the linear tension softening of concrete. The parameters required to define Concrete02 are compressive strength (f_{pc}), strain at compressive strength (ep_{sc0}), ultimate strength (f_{pcu}), strain at ultimate strength (ep_{su}), tensile strength (f_t), tension softening stiffness (E_{ts}), the ratio between unloading slope at (ep_{scu}) and the initial slope (E_o). The initial gradient (E_o) is automatically computed as $2*f_{pc}/ep_{sc0}$.

In the case of unconfined concrete, the compressive strength is the same as the design value, while the strain at maximum strength (ϵ'_c) is assumed to be 0.002. The strain at the ultimate stress equals $2(\epsilon'_c)$, and the residual stress is assumed as 20% of the compressive stress.

Furthermore, the parameters of the confined concrete are determined based on a study by (Mander et al., 1988) to take into account the confinement due to transverse reinforcement. The derived equations in the study are based on a balanced energy approach. The lateral confining pressure (f_l) is determined with the assumption that the transverse reinforcement has yielded. Moreover, Equations (13) and (14) define the lateral confining pressure, which is reduced by (K_e) to exclude the concrete cover from the lateral pressure. Fig 6-4 shows the effective confined core by rectangular hoop reinforcement.

$$f'_l = k_e \quad (13)$$

$$k_e = A_e / (A_c * (1 - p_{cc})) \quad (14)$$

Where f'_l is the effective lateral confining pressure, k_e is the confinement effectiveness ratio, A_e is the effective confined concrete area, A_c is the entire core area, and p_{cc} is the ratio of the area of longitudinal reinforcement to the area of the core section.

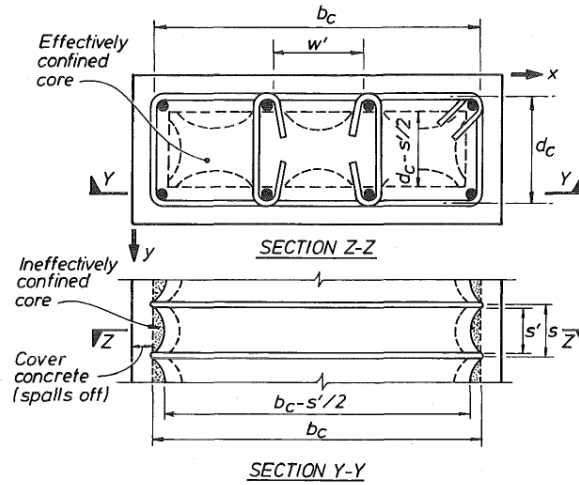


Fig 6-4: The Effective Confined Core for Rectangular Hoop Reinforcement (Mander et al., 1988).

The lateral confining pressure is calculated on both sides of the rectangular section using Equations (15) and (16), and these values are used to calculate the confined strength ratio f'_{cc}/f'_{co} based on the chart provided by (Mander et al., 1988), as shown in Fig 6-5.

$$f'_{lx} = \frac{A_{sx}}{s * d_c} * k_e * f_{yh} \quad (15)$$

$$f'_{ly} = \frac{A_{sy}}{s * b_c} * k_e * f_{yh} \quad (16)$$

Where A_{sx} and A_{sy} are the total area of transverse bars running in each direction, s is the spacing between hoops, d_c and b_c are the dimensions of the effective confined core, and f_{yh} is the yielding stress of transverse reinforcement.

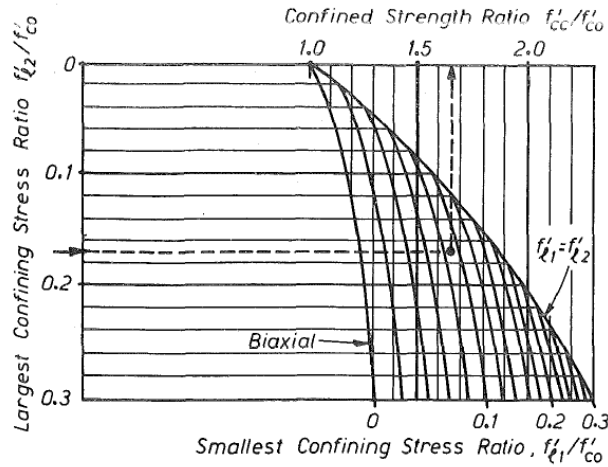


Fig 6-5: Confined Strength Determination from Lateral Confining Pressure for Rectangular Sections (Mander et al., 1988).

After the calculation of the confined strength ratio f'_{cc}/f'_{co} , the compressive strength of confined concrete f'_{cc} can be found. The strain corresponding to the maximum stress can be found using Equation (17). In order to calculate the ultimate strain, (Mander et al., 1988) assumed that failure state is when first hoop reaches fracture. Using the energy balance approach, the energy stored in the transverse reinforcement increase the available ductility of the confined concrete members. The stress-strain curves for unconfined and confined concrete in Fig 6-6 were used by (Mander et al., 1988) to evaluate the ultimate strain. Equation (18) can be used to calculate the ultimate strain for confined concrete. The equations mentioned above that determine the variables of the constitutive models for concrete are used in the current study.

$$\epsilon'_{cc} = \epsilon'_{co} * \left(1 + 5 * \left(\frac{f'_{cc}}{f'_c} - 1 \right) \right) \quad (17)$$

$$110ps = \int_0^{\epsilon'_{cu}} f_c d\epsilon_c + \int_0^{\epsilon'_{cu}} f_{sl} d\epsilon_c - 0.017 * (f'_{co})^{0.5} \quad (18)$$

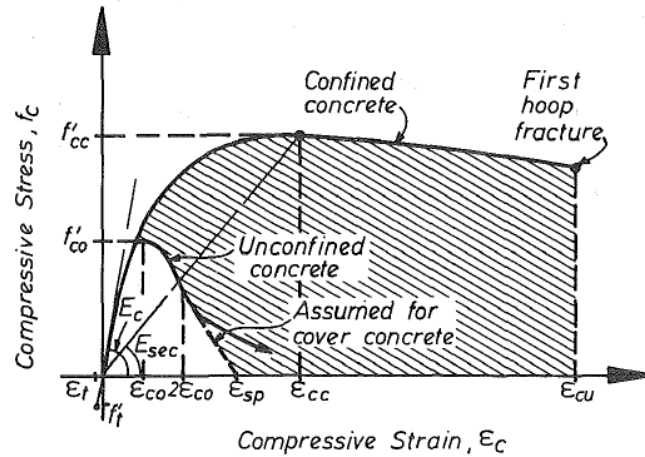


Fig 6-6: Stress-Strain Model Proposed for Monotonic Loading of Confined and Unconfined Concrete (Mander et al., 1988).

6.2.2 Steel:

Steel reinforcement is modeled using the Steel02 constitutive model. The input parameters required to define Steel02 model are yield strength (F_y), initial elastic tangent (E), strain hardening ratio (b), which is defined as ratio between post-yield tangent and initial elastic tangent, and three constants (R_0 , cR_1 , cR_2) in order to control transition from elastic to plastic range. Fig 6-2b shows the material law with the main input variables.

6.3 Beam-Column Joint Input Parameters:

The beam-column joint is modeled according to Lowes and Altoontash (Lowes and Altoontash, 2003). The bonding-slip response of beam-column longitudinal reinforcement is modeled as eight zero-length translational springs. Uniaxial Material Bar slip constitutive model is used to define the bonding-slip response, which was calibrated by (Lowes and Altoontash, 2003) as shown in Fig 6-7. The input parameters that define the Bar slip constitutive model are compressive strength of the concrete (f_c), (yield strength (f_y), modulus of elasticity (E_s), ultimate strength (f_u), hardening modulus (E_h), development length (l_d), and diameter (d_b) of the reinforcing steel bars, number of anchored bars (n_b), dimension of the member (beam or column) perpendicular to the dimension of the plane (depth), dimension perpendicular to the direction in which the reinforcing steel is placed (height), the bond strength of anchored bars (b_{sflag}), (strong or weak), and position of reinforcement, (beam's top, beam's bottom, or column).

The four zero-length shear springs simulate the interface-shear deformations and are defined as uniaxial Material Elastic. Furthermore, the zero-length rotational spring represents the joint's shear deformations. Uniaxial material pinching is used to determine the pinched load-deformation response. The input parameter of pinching material is the envelope stresses and strains, which define the backbone curve for the shear panel, as shown in Fig 6-8. The envelope points of the backbone curve can be determined for joints with shear reinforcements based on the equations from (Kim and LaFave, 2009).

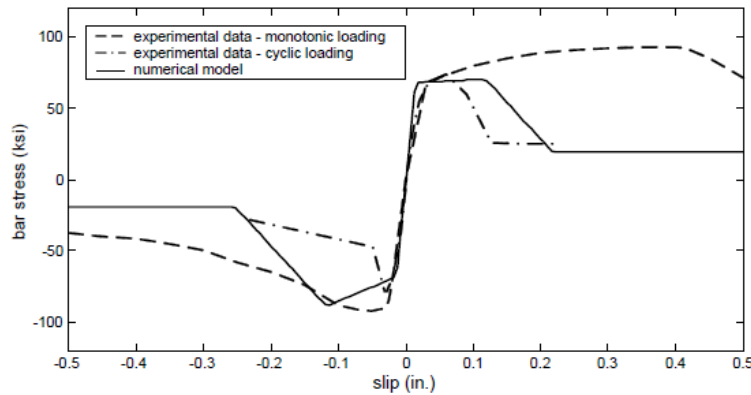


Fig 6-7: Envelope for Hysteretic Bar Slip Versus Slip Response (Lowe and Altoontash, 2003; Viwathanatepa et al. 1979).

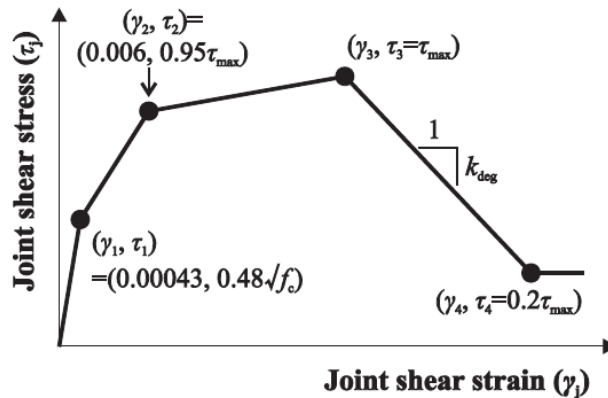


Fig 6-8: Envelope of Joint Shear Stress-Strain Relationship (Jeon et al., 2015).

The first two points of the backbone curve are taken from (Anderson et al. 2008), which was developed for beam-column joints without transverse reinforcement. The third point is determined based on Equations (19) and (20) from (Kim and LaFave, 2009), shown below. The fourth point

represents the residual strength which is equal to 20% of the maximum shear strength. In the case of beam-column joints without transverse reinforcement, the first two points are the same. The maximum shear strength at the third point is calculated by extrapolating the second point and third point, knowing the strain at the maximum shear strength (third point) and the slope of the segment (e2-e3). Fig 6-9 shows the backbone curve for joints without transverse reinforcement.

$$v_i \text{ (MPa)} = 1.07\alpha_1 * \beta_1 * \eta_1 * (JI)^{0.15} * (BI)^{0.3} * (f'_c)^{0.75} \quad (19)$$

$$\gamma \text{ (rad)} = \alpha_{\gamma 1} * \beta_{\gamma 1} * \eta_{\gamma 1} * (JI)^{0.10} * BI * \left(\frac{v_i'}{f_c}\right)^{1.75} \quad (20)$$

where α_1 is a parameter that describes the in-plane geometry 1.0 for interior connections, 0.7 for exterior connections, and 0.4 for knee connections; β_1 a parameter describing the out-of-plane geometry, 1.0 for subassemblies with zero or one transverse beam, and 1.18 if there are two transverse beams; η_1 describes the joint eccentricity; JI is the joint transverse reinforcement index, which equals the volumetric joint transverse reinforcement ratio multiplied by the ratio of the yield stress of joint transverse reinforcement to the compressive strength of concrete. BI is the beam reinforcement index that equals the beam reinforcement ratio multiplied by the ratio of the yield stress of beam reinforcement to the compressive strength of concrete.

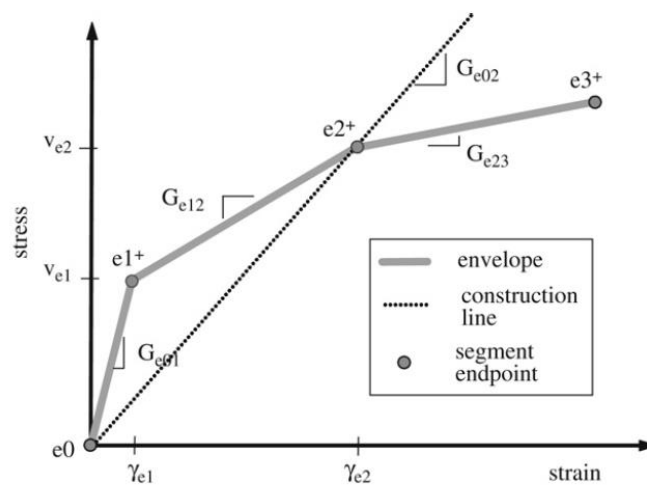


Fig 6-9: The Backbone Curve for Joints without Transverse Reinforcement (Anderson et al. 2008).

The joint model described previously and the relations required to define its constitutive models are used in the current study.

6.4 Infill Walls Modeling:

6.4.1 Infill Walls Modeling Methods:

In the literature, there are many different modeling techniques to simulate the infill walls' behavior, which can be divided into two main categories, namely the micro and macro models. In the micro model, the infill panel is discretized into numerous elements, which consider the local effect of each component in the infill walls, such as mortar, bricks, and the interface element. This type of model is suitable for local analysis and not for global analysis due to the large number of parameters that should be calibrated. In contrast, the macro model is the most common technique utilized to model the infill walls because of its simplicity.

Furthermore, many researchers proposed simplified macro-models for infill walls, such as (Polyakov, 1960), who suggested that infills can be modeled as equivalent one-diagonal struts. (Holmes, 1961) modeled the infills as equivalent pin-joint diagonal struts having the same material and thickness as the infill walls. (Mainstone, 1974) proposed different methods for evaluating the effective width of equivalent diagonal strut based on experimental tests. However, (Zarnic and Tomazevic, 1988) developed a macro-model that takes into account the strength and stiffness of the infill walls, and (Saneinejad and Hobbs, 1995) predicted the stiffness and strength degradation of (Zarnic and Tomazevic, 1988) macro-model using a numerical model. (Dolsek and Fajfar, 2002) proposed a single strut model with a tri-linear response with elastic hardening.

In general, presenting infill walls as one single strut model was found to be insufficient to model the whole behavior of infill walls subjected to seismic actions. (Schmidt, 1989) proposed a double diagonal strut that takes into account the strength, stiffness of the infill wall, and frame-infill interaction. (El-Dakhakhni et al., 2003) modeled infill walls as three non-parallel struts to include the interaction between infill and RC-frame, which also captures the corner crushing failure mechanism. (Rodrigues et al., 2005) proposed a macro-model that simulates the non-linear behavior of infill walls subjected to cyclic loads. Each infill wall is represented by an equivalent bi-diagonal compression strut model with four strut elements (rigid behavior) and one central strut (non-linear behavior).

6.4.2 Infill Walls Modeling Criteria:

To perform an accurate analysis of the RC frame structures with infilled walls, the non-linear behavior of these structural elements should be taken into account. In this study, infill walls are modeled according to Rodrigues (Rodrigues, 2010), which uses an equivalent bi-diagonal-strut model. This model accurately represents the global response and energy dissipation of structures with infill walls. The typical bi-diagonal strut model represents the infill panels as four support strut elements with rigid behavior. The central strut element considers the non-linear behavior of the infill wall, as shown in Fig 6-10. Using OpenSees program, the four diagonal elements are modeled as elastic beam-column and non-linear beam-column for the central elements. The idealization of the central element nonlinear monotonic behavior is modeled as pinching material. The input parameters for infill walls constitutive models are discussed in the following subsections.

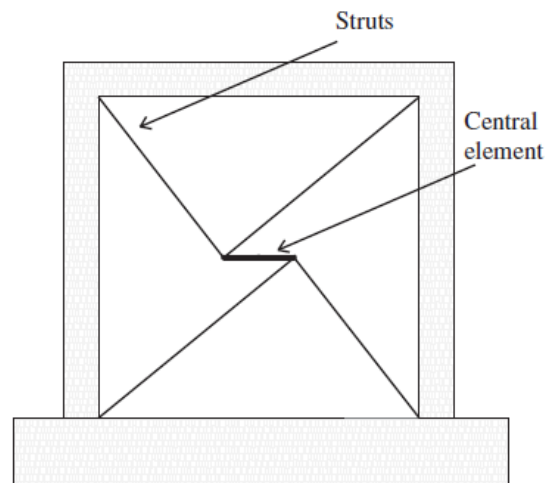


Fig 6-10: Macro-model for the simulation of an infill panel (Rodrigues. 2010).

6.4.2.1 Concrete Masonry Infill Walls Constitutive Model:

The parameters required to define the constitutive model can be obtained following different authors and international code recommendations. According to Mainstone (Mainstone, 1971), the thickness of the strut model (t_w) is the same as the infill wall, the width of the strut model can be evaluated using Equations (21) and (22), and the initial lateral stiffness K_{in} is based on Equation (23). Fig 6-11 shows the equivalent diagonal strut representation.

$$W_{eff} = 0.175(\lambda_h * H)^{-0.4} * (H^2 + L^2)^{0.5} \quad (21)$$

$$\lambda_h = \left(\frac{E_w * t_w * \sin(2 * \theta)}{4 * E_c * I_c * H_{in}} \right)^{0.25} \quad (22)$$

Where E_w and E_c are the modulus of elasticity of the infill wall and the concrete of the frame system, $\theta = \arctan\left(\frac{H}{L}\right)$ is the diagonal strut angle, H and L are the center-to-center height and width of the infill panel, H_{in} is the clear height of the infill panel, and I_c is the moment of inertia of the column of the frame system. The strut element carries only compression, and its constitutive model force-deformation envelope curve, as shown in Fig 6-12, is developed based on the equations and the recommended model values from (Mainstone, 1971; Matjaž and Peter, 2002). The maximum strength of infill walls is determined using the simplified Equation (24) (Žarnić and Gostič, 1997).

$$K_{in} = \left(E_w * W_{eff} * \frac{t_w}{(L^2 + H^2)^{0.5}} \right) * (\cos \theta)^2 \quad (23)$$

$$F_{max} = F_u = 0.818 * \frac{L_{in} * t_w * f_{tp}}{C_1} * (1 + (C_1^2 + 1)^{0.5}), C_1 = 1.925 * \left(\frac{L_{in}}{H_{in}} \right) \quad (24)$$

Where $f_{tp}(F_c)$ is the cracking strength of the infill wall, and L_{in} is the clear width of the infill wall. The recommended values for these parameters are obtained from (Matjaž and Peter, 2002). The modulus of elasticity of the infill wall varied between 6.5 and 8.2 GPa, the modulus of elasticity of concrete is the same as designed value, the value of cracking strength of infill varied between 0.28 and 0.40 MPa, the displacement in the horizontal direction at maximum strength (u_u) ranges between 0.5 to 0.6% of the story height, and the softening segment has a stiffness equal to 5% of the initial stiffness. Moreover, according to FEMA-307. (FEMA-307, 1999), the diagonal cracking (u_c) tends to occur at 0.2 to 0.4% of the inter-story drift.

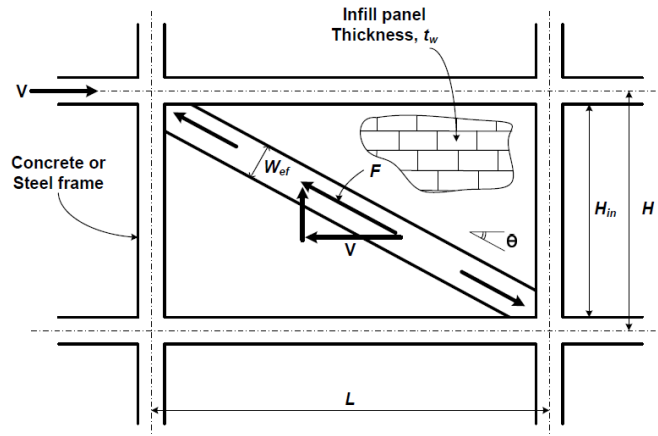


Fig 6-11: Equivalent Diagonal Strut Model (Ko et al. 2008).

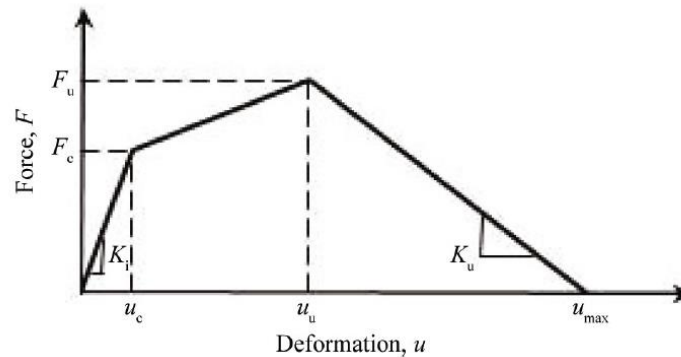


Fig 6-12: Force-Deformation Relationship for Masonry Infill Walls (Al-Nimry et al. 2015).

In this study, and based on the conducted interviews explained in section 4.1, the exterior concrete masonry walls are considered to have a 20cm thickness. And according to Al-Nimry et al. (Al-Nimry et al., 2015), the typical concrete masonry infills in Jordan have a unit compressive strength equal to 3.0MPa. The experimental data and the recommended input parameters for masonry published in (Al-Nimry et al., 2015) are used to represent the infill walls in Palestine. This is accepted as the construction practice in Jordan and Palestine is similar.

6.4.2.2 Stone-Concrete Infill Walls Constitutive Model:

(Al-Nimry, 2010, 2012, 2014) investigated the lateral response of RC frames with stone-concrete infill walls as shown in Fig 4-1 using quasi-static experimentations. The author concluded that the stone-concrete infill panels can be modeled using two non-linear link elements. Each element is

assigned a multi-linear plastic property with only non-linear behavior in the axial direction. The constitutive model of the stone-concrete infill panel is shown in Fig 6-13, and the recommended envelope points for force-deformation definition are shown in Table 6-1. According to the author, the initial axial stiffness is estimated based on the equation from (Fajfar et al., 2001) as given in Equation (25), the modulus of elasticity of the infill panel (E_p) is assumed to be 14.0 GPa, and the effective width of the equivalent strut can be taken as one-tenth the length of the equivalent strut.

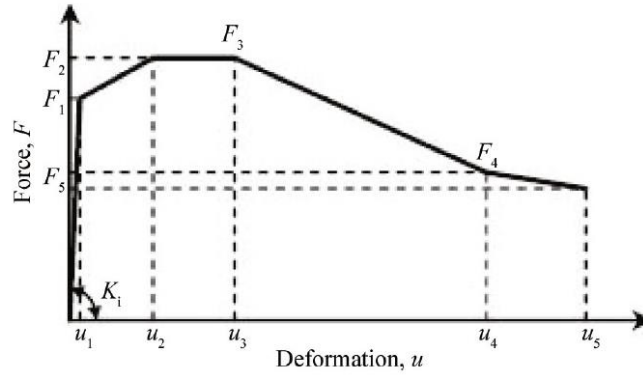


Fig 6-13: Force-Deformation Relationship for Stone-Concrete Infill Walls (Al-Nimry et al., 2015).

Table 6-1: Multi-linear force-displacement definition for the non-linear link element (Al-Nimry et al., 2015).

Point	Axial Deformation (mm)	Axial Force (kN)
(F1, U1)	1.290	540
(F2, U2)	10.50	639
(F3, U3)	20.79	639
(F4, U4)	52.50	360
(F5, U5)	65.00	350

$$K_{in} = \left(E_w * W_{eff} * \frac{t_w}{r} \right) \quad (25)$$

The stone-concrete infill panel model described previously and the relations required to define its constitutive models are used in this study as the typical cross-section of the stone-concrete infill panel presented by (Al-Nimry et al., 2015). The recommended values are checked by calculating the initial stiffness of the diagonal strut using Equation (25) and comparing it with the initial stiffness from Table 6-1. The initial stiffness calculated from Equation 25 using $H = 3m$, $L = 4m$, and $t_w = 0.3m$ equals 420000 kN/m, and the initial stiffness from the table using (F1, U1) equals 418604.7 kN/m.

6.5 Model Verification:

6.5.1 Data Collection:

In this research, a non-linear static pushover analysis is performed for RC frames. The numerical models for RC Frames are developed as explained in the previously explained sections. The numerical analysis results are validated using experimental data retrieved from the open literature. The data available on nonlinear analysis of RC-frame performed by (Vecchio and Emara, 1992) is utilized to verify the developed model. The followings are the structural and geometrical data of the RC frame (Vecchio and Emara, 1992).

- 1) The frame spans 3500mm c/c, the first story height is 2200mm c/c, and the second is 2000mm c/c.
- 2) The reinforcement detailing is shown in Fig 6-14. Beams and columns are 400mm in depth and 300mm wide.
- 3) Material properties:
 - The compressive strength of concrete is 30MPa
 - Steel properties: yield strength is 418MPa, ultimate tensile stress is 596MPa, modulus of elasticity is 192500MPa, and stain hardening modulus is 3100MPa.
 - The shear reinforcement has a yield strength of 454MPa and ultimate stress 640MPa.
- 4) 700kN axial load was applied to each column from the top end to activate the p-delta effect.

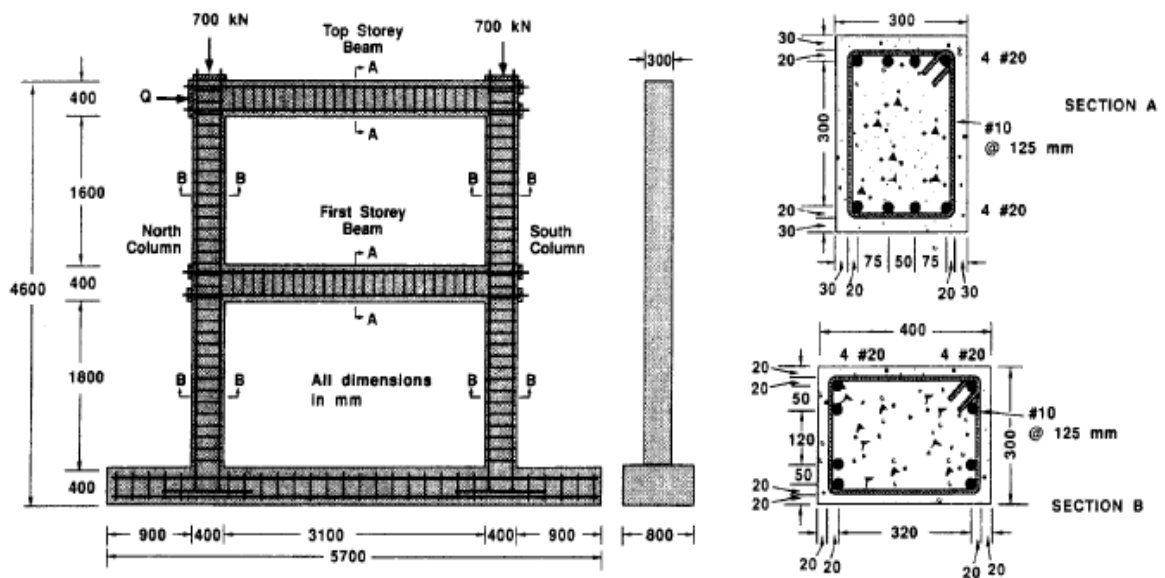


Fig 6-14: Details of the Frame (Vecchio and Emara, 1992).

6.5.2 Modelling Criteria and Results of Non-Linear Static Pushover Analysis:

The frame system was first modeled using beam and column elements without the beam-column joint model. Both beams and columns were modeled as force beam-column. The beam-column joint was added later to the model to investigate the effect of its modeling. The bar-slip spring stiffness was defined based on the existing material. The shear panel constitutive model was built based on section 5.3. The results of both models were compared to the capacity curve provided by (Vecchio and Emara, 1992), as shown in Fig 6-15.

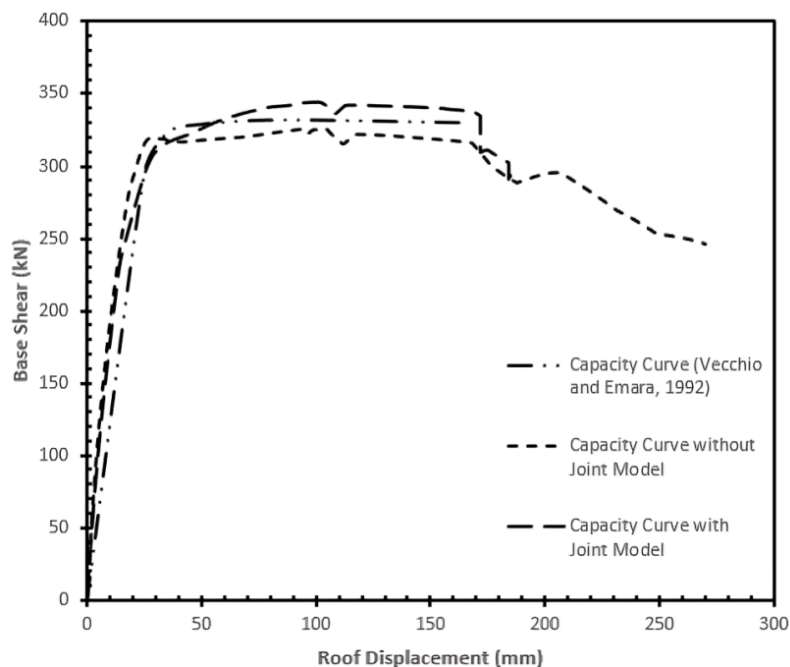


Fig 6-15: Verification of Pushover Analysis Model.

As seen in this figure, there is a good correlation between the pushover analysis results of tested frame and the analysis results of the developed numerical model. In the case of the capacity curve with the joint model, the base shear of the frame system is higher than the reference by 4.2%. However, it anticipates failure earlier than the numerical model without the joint model.

Furthermore, the model was used to examine the significance of the structural deficiencies in the construction practices on the capacity curve of the frame system. Inadequate stirrup spacing for both beams and columns, inadequate joint detailing, and short anchorage of longitudinal bars in the joint were considered. The analysis results are shown in Fig 6-16.

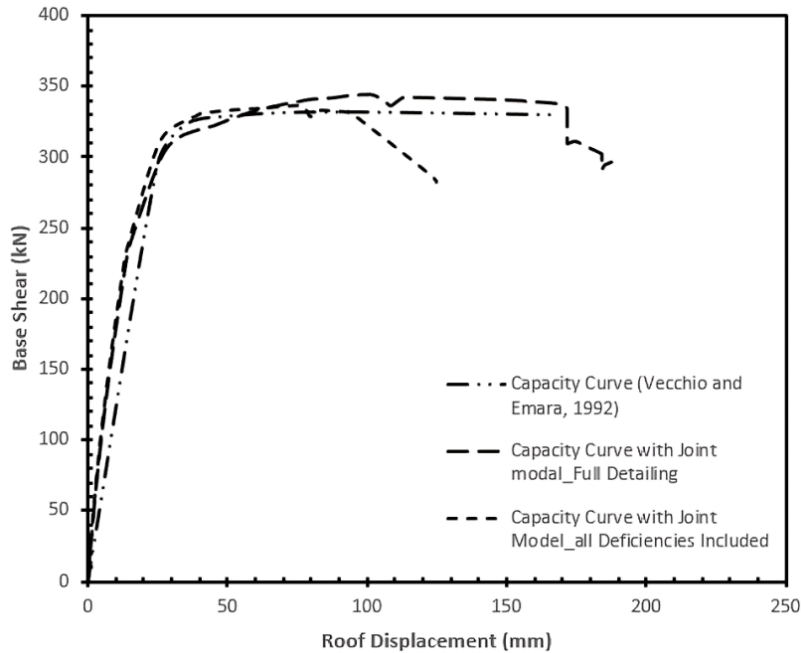


Fig 6-16: Capacity Curve Including the Deficiencies in the Model.

It can be seen that including the deficiencies keeps the base shear at almost the same level; however, it dramatically decreases the frame system's ductility. The response modification factor indicates the ductility of the frame system. Therefore, its value is affected by such deficiencies.

6.5.3 Response Modification Factor for Both Models:

Based on the capacity curves in Fig 6-15 and Fig 6-16 and the procedure explained in chapter three for evaluating the response modification factor R, the R factor was calculated for both models as the following:

➤ Model 1 (joint model with full detailing)

1) Ductility Factor (R_u):

- $T = 0.1997s, u = \frac{\Delta_{max}}{\Delta_y} = \frac{172mm}{27mm} = 6.37$
- $R_u = (2 * 6.37 - 1)^{0.5} = 3.426$

2) Over Strength Factor (R_0):

The maximum base shear (V_0) is found from the capacity curve. The designed base shear (V_d) is evaluated using Equivalent Lateral Force ELF in SEI/ASCE7-16 since the designed base shear (V_d) is not documented by the authors in the study (Vecchio and Emar, 1992).

- $R_s = \frac{V_0}{V_d} = \frac{344kN}{199.4kN} = 1.725$

3) Redundancy Factor (R_r):

- $R_r = 0.71$, since it has one vertical seismic framing

$$R = 3.426 * 1.725 * 0.71 = 4.196,$$

which is less than the recommended by ASCE 7 – 16

The value recommended by SEI/ASCE 7-16 for the ductile moment-resisting frame is 5, considered unconservative compared to the calculated value.

- Model 2 (joint model including all considered deficiencies such as insufficient beam and column shear reinforcement, short anchorage length in longitudinal beam bars, and inadequate beam-column joint shear reinforcement)

1) Ductility Factor (R_u):

- $T = 0.1997s, u = \frac{\Delta_{max}}{\Delta_y} = \frac{96mm}{27mm} = 3.56$
- $R_u = (2 * 2.89 - 1)^{0.5} = 2.47$

2) Over Strength Factor (R_0):

- $R_s = \frac{V_0}{V_d} = \frac{334kN}{199.4kN} = 1.675$

3) Redundancy Factor (R_r):

- $R_r = 0.71$, since it has one vertical seismic framing

$$R = 2.47 * 1.675 * 0.71 = 2.94$$

It can be seen that there is a reduction in the R-factor, which indicates that including the structural deficiencies of construction practice in the models affect the R-factor.

6.6 Infill Walls Modeling Verification:

6.6.1 Data Collection:

In the current study, infill walls are modeled according to Rodrigues (Rodrigues, 2010), which uses an equivalent bi-diagonal-strut model (see section 6.4). The numerical model with reinforced concrete frames is validated using experimental data retrieved from the open literature due to the significance of infill wall modeling and how that could affect the analysis results. The data available on the nonlinear analysis of the RC-frame performed by two authors are utilized to verify the developed model. The followings are the structural and geometrical data of the RC frame (Rodrigues et al., 2010) & (Cavaleri et al., 2004).

❖ The data available from (Rodrigues et al., 2010)

- 1) The frame spans 4350mm c/c, and the story height is 1825mm c/c.
- 2) The reinforcement detailing is shown in Fig 6-17. Beams are 200mm in depth and 150mm wide. Columns are 150mm in depth and 150mm wide
- 3) Material properties:
 - The compressive strength of concrete is 25.3MPa
 - Steel properties: yield strength is 434Mpa, and modulus of elasticity is 190000Mpa.
- 4) Material properties of infills:
 - The compressive strength of infill is 2.2MPa
 - Elasticity modulus E_m 3119MPa
 - Diagonal compression strength f_m 1.1MPa

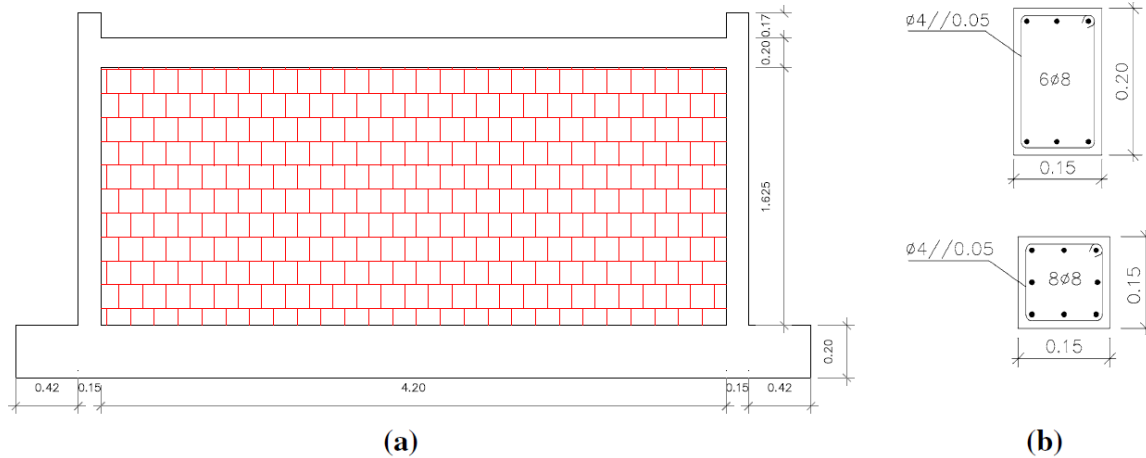


Fig 6-17: a) Single-story single-bay infilled masonry RC frame. b) Cross-section dimensions and detailing of RC beam and column (Vecchio and Emara, 1992).

❖ **The data available from (Cavaleri et al., 2004)**

- 1) The frame spans 1800mm c/c, and the story height is 1800mm c/c.
- 2) The reinforcement detailing is shown in Fig 6-18. Beams are 400mm in depth and 200mm wide. Columns are 200mm in depth and 200mm wide
- 3) Material properties:
 - The compressive strength of concrete is 30Mpa
 - Steel properties: yield strength is 434Mpa, and modulus of elasticity is 190000Mpa.
- 3) 200kN axial load was applied to each column from the top end.
- 5) Material properties of infills:
 - The compressive strength of infill is 3MPa
 - Elasticity modulus E_m 7350MPa

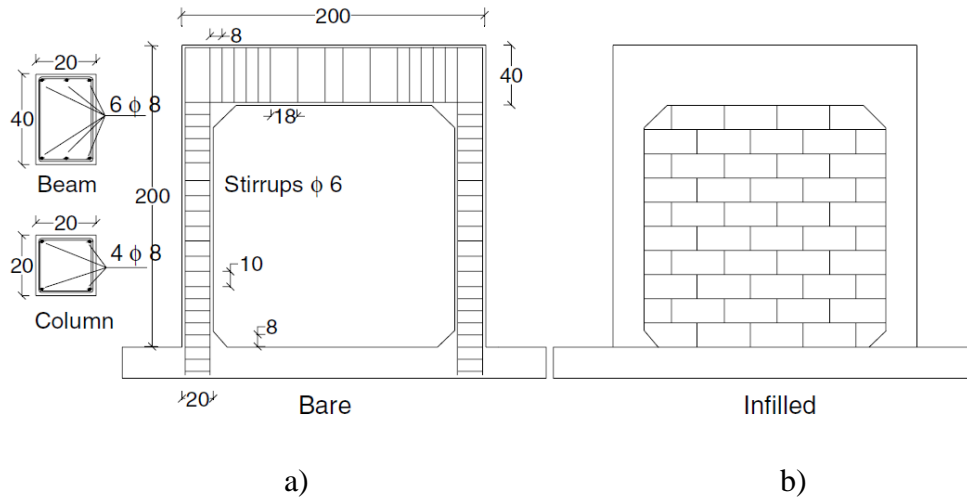


Fig 6-18: a) Single-story single-bay RC frame. Cross-section and detailing of RC elements. b) Single-story single-bay infilled masonry RC frame. (Cavaleri et al., 2004).

6.6.2 Modelling Criteria and Results:

The two frame systems were modeled using beam and column elements without the beam-column joint model. Both beams and columns were modeled as force beam-column elements. The infills were modeled according to Rodrigues. (2010) with the corresponding behavior of the masonry infill wall. The results of both models were compared to the capacity curves provided by both authors (Rodrigues et al., 2010; Cavaleri et al., 2004), as shown in Fig 6-19 and 6-20, respectively.

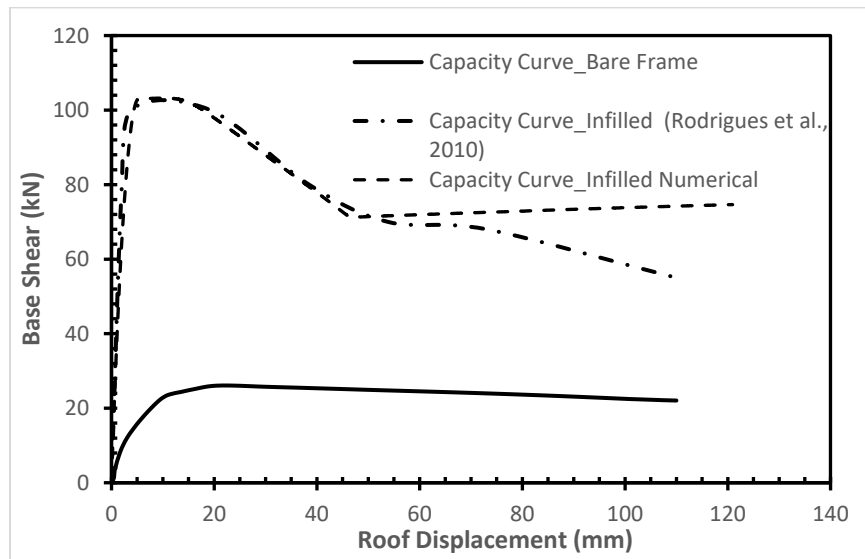


Fig 6-19: Verification of Pushover Analysis Model.

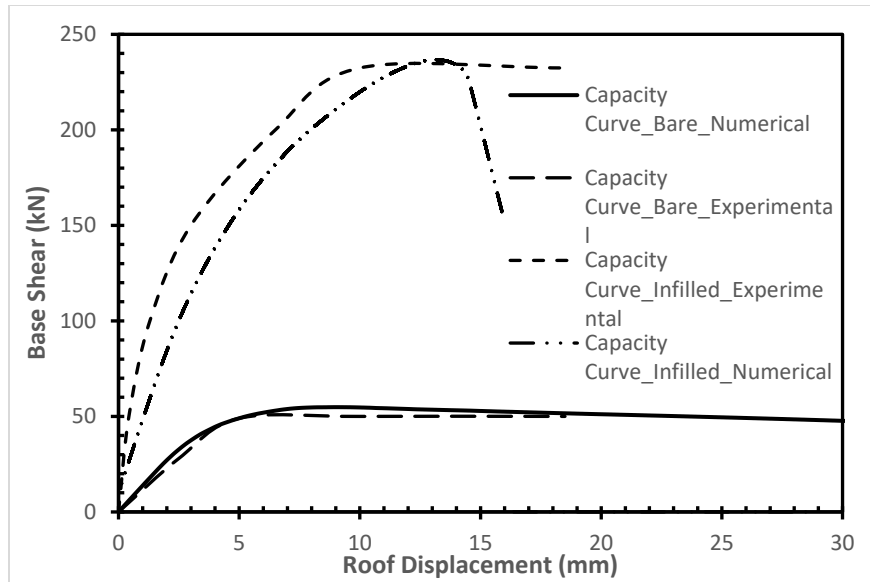


Fig 6-20: Verification of Pushover Analysis Model.

As seen in Fig 6-19 and Fig 6-20, there is a good correlation between the pushover analysis results of tested frames and the analysis results of the developed numerical models. Therefore, the model of infill walls and their corresponding material properties can be used in this research.

CHAPTER 7: EVALUATION OF R FACTORS OF PROTOTYPE FRAME SYSTEMS

7.1 RC MRF Prototypes and their Analysis:

This section discusses the non-linear analysis results of 2D reinforced concrete frames with and without infill walls. Twelve 2D RC-moment resisting frames (MRFs) were selected for the analysis to show the effect of structural deficiencies, infill walls (stone-concrete and masonry-concrete), and soft story mechanism (ground level without infills) on the value of response modification factor R , which is an indicator on the performance of the buildings, plastic energy capacity and ductility. The prototype models have the same height and length of bays which are 3 meters and 4 meters, respectively. The steel reinforcement bars have a yielding strength equal to 420 MPa, while the concrete compressive strength is considered as 28 MPa in this study. Fig 7-1 shows a typical prototype model for 3B6S and 3B9S.

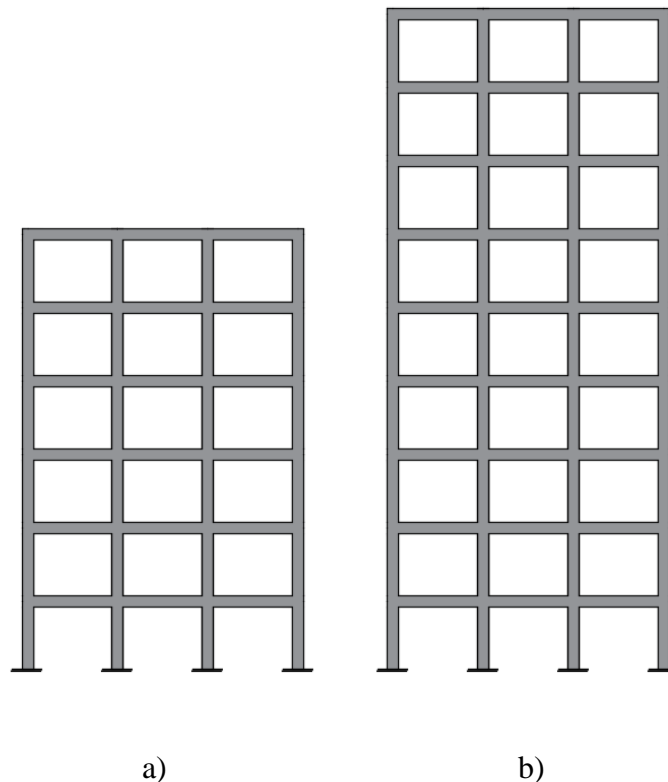


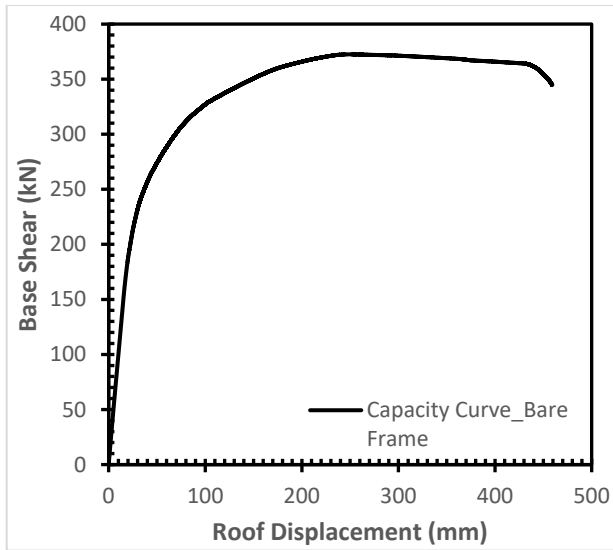
Fig 7-1: a) Elevation of three bay-six storey (3B6S) b) Elevation of three bay-nine storey (3B9S).

In order to perform non-linear analysis, modal analysis was conducted first on each prototype model to determine the fundamental elastic period of vibration. This parameter can be utilized to predict the accuracy of the analytical model before starting the non-linear analysis. Results from modal analysis for each prototype model are summarized in Table 7-1.

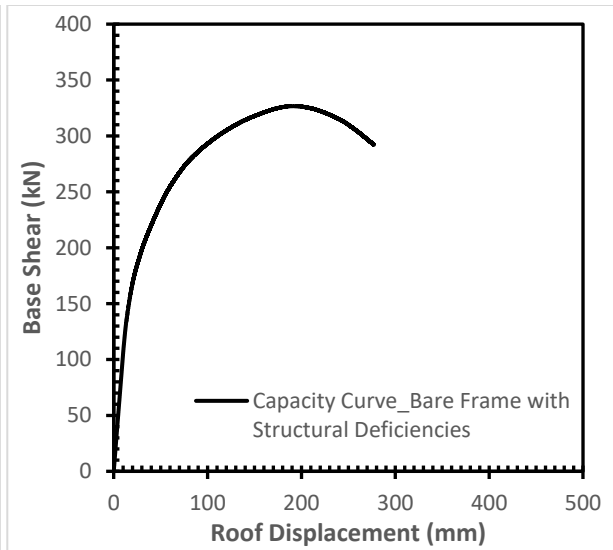
Table 7-1: Fundamental period for each prototype model.

Building System		Fundamental Period T_i (s)
1)	3B6S MRFs-Bare Frame	0.78
2)	3B6S MRFs-Bare Frame with Structural Deficiencies	0.75
3)	3B6S MRFs-Stone-Concrete Infilled Frame	0.49
4)	3B6S MRFs-Stone-Concrete Infilled Frame without ground infills	0.49
5)	3B6S MRFs-Masonry-Concrete Infilled Frame	0.45
6)	3B6S MRFs-Masonry-Concrete Infilled Frame without ground infills	0.45
7)	3B9S MRFs-Bare Frame	1.065
8)	3B9S MRFs-Bare Frame with Structural Deficiencies	1.01
9)	3B9S MRFs-Stone-Concrete Infilled Frame	0.70
10)	3B9S MRFs-Stone-Concrete Infilled Frame without ground infills	0.70
11)	3B9S MRFs-Masonry-Concrete Infilled Frame	0.67
12)	3B9S MRFs-Masonry-Concrete Infilled Frame without ground infills	0.67

Furthermore, the non-linear static pushover analysis was performed for each prototype model using an inverted triangular load pattern. Each model was set to be pushed to a 10% drift to let the structure reach the maximum displacement in the pushover curve (capacity curve). The analysis procedure is utilized to assess the structural capacity and then evaluate the response modification factor R. The analysis results show a total of 12 pushover curves for the selected models. Fig 7-2a to Fig 7-7b present the pushover curves for each prototype model.

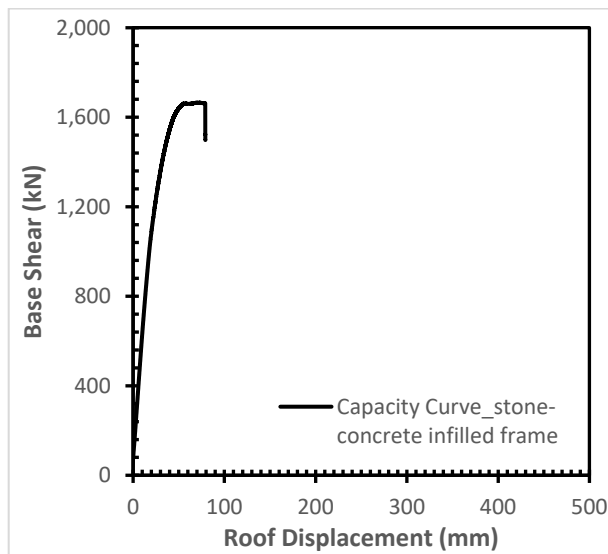


a)

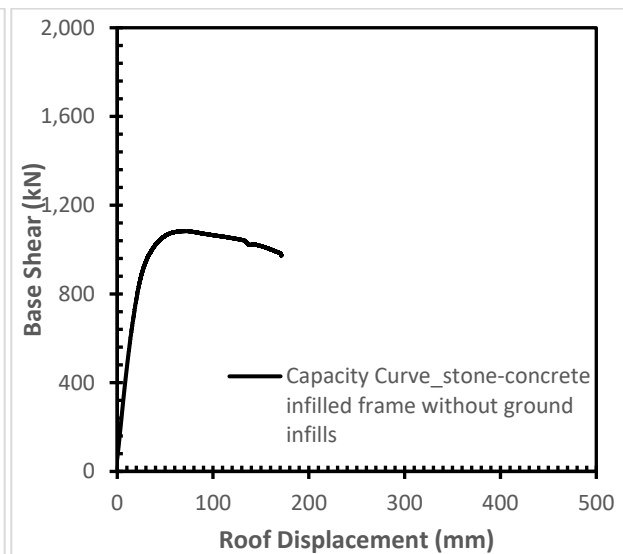


b)

Fig 7-2: a) Pushover curve of 3B6S MRFs-bare frame. b) Pushover curve of 3B6S MRFs-bare frame with structural deficiencies

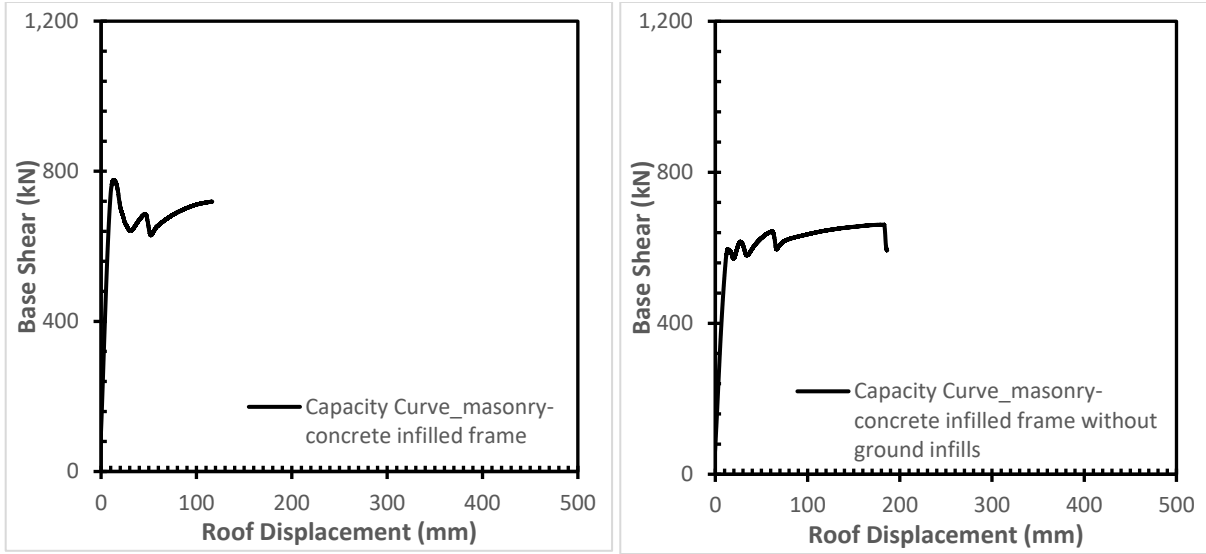


a)



b)

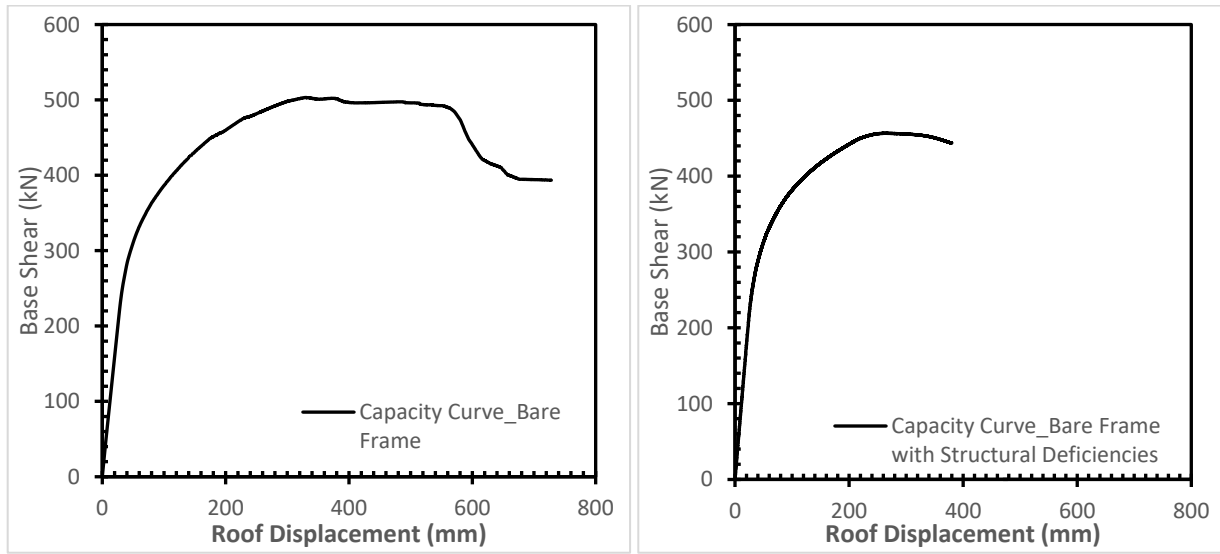
Fig 7-3: a) Pushover curve of 3B6S MRFs- stone-concrete infilled frame. b) Pushover curve of 3B6S MRFs- stone-concrete infilled frame without ground infills



a)

b)

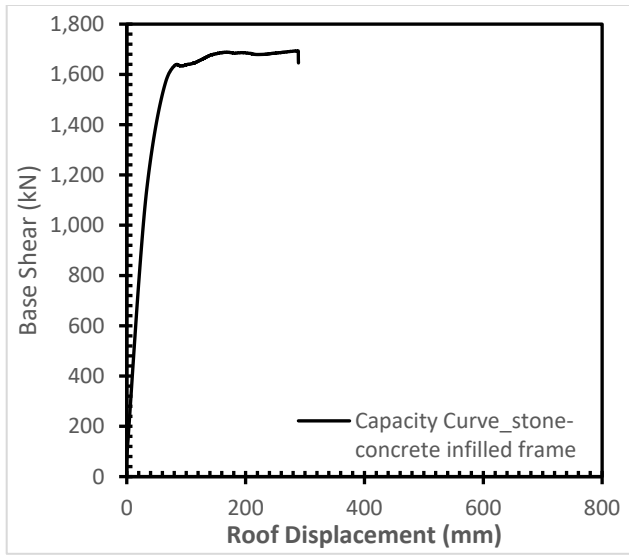
Fig 7-4: a) Pushover curve of 3B6S MRFs- masonry-concrete infilled frame. b) Pushover curve of 3B6S MRFs- masonry-concrete infilled frame without ground infills



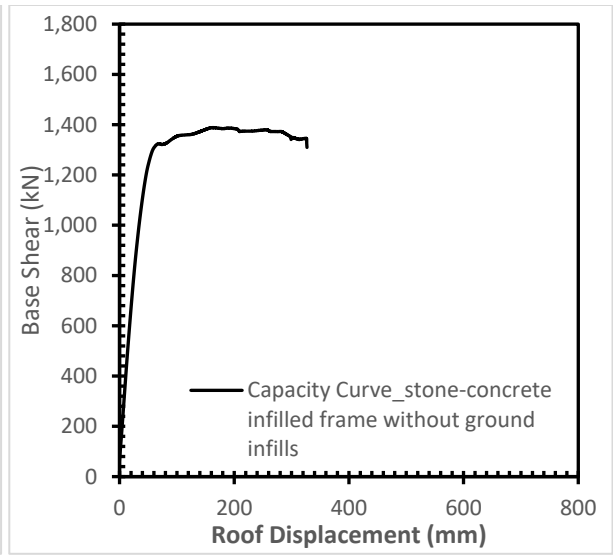
b)

b)

Fig 7-5: a) Pushover curve of 3B9S MRFs-bare frame. b) Pushover curve of 3B9S MRFs-bare frame with structural deficiencies

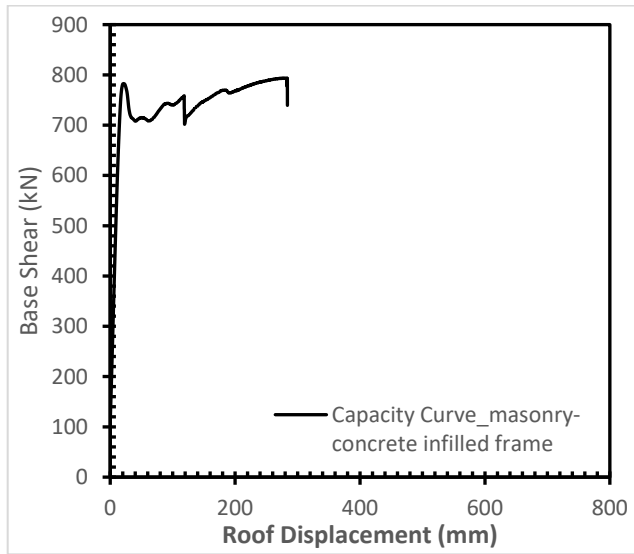


b)

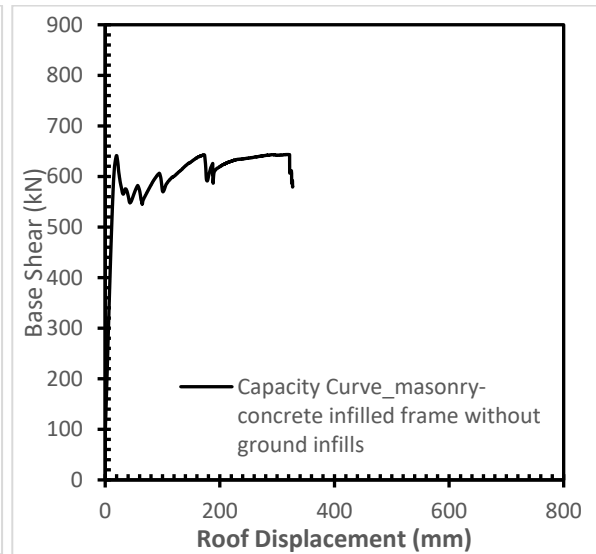


b)

Fig 7-6: a) Pushover curve of 3B9S MRFs- stone-concrete infilled frame. b) Pushover curve of 3B9S MRFs- stone-concrete infilled frame without ground infills



b)



b)

Fig 7-7: a) Pushover curve of 3B9S MRFs- masonry-concrete infilled frame. b) Pushover curve of 3B9S MRFs- masonry-concrete infilled frame without ground infills

7.2 Evaluation of R factor:

The R factor for each prototype model is computed based on the procedure explained previously in chapter three. The record of the calculation of R is presented in Table 7-2, while the full record of the calculation of R-factor can be found in Appendix 2. It was assumed that the redundancy factor (R_r) is 0.86 for all prototype models to present the critical case (three-line framing). Furthermore, the value of the calculated R factor for each frame model, the recommended R values from SEI/ASCE 7-16, Euro code (EC8), and the Egyptian code (ECP-201), and the used R-factor in the analysis are summarized in Table 7-3.

Table 7-2: The record of the calculation of the R-Factor.

	Building System	Ductility Factor (R_μ)	Over Strength Factor (R_0)	Redundancy Factor (R_r)
1)	3B6S MRFs-Bare Frame	4.026	1.81	0.86
2)	3B6S MRFs-Bare Frame with Structural Deficiencies	2.47	1.6	0.86
3)	3B6S MRFs-Stone-Concrete Infilled Frame	1.87	.....	.....
4)	3B6S MRFs-Stone-Concrete Infilled Frame without ground infills	3.2	.....	.....
5)	3B6S MRFs-Masonry-Concrete Infilled Frame	3.26	.....	.....
6)	3B6S MRFs-Masonry-Concrete Infilled Frame without ground infills	4.17	.....	.....
7)	3B9S MRFs-Bare Frame	4.75	1.509	0.86
8)	3B9S MRFs-Bare Frame with Structural Deficiencies	2.98	1.37	0.86
9)	3B9S MRFs-Stone-Concrete Infilled Frame	2.93	.....	.....
10)	3B9S MRFs-Stone-Concrete Infilled Frame without ground infills	3.67	.....	.....
11)	3B9S MRFs-Masonry-Concrete Infilled Frame	5.2	.....	.....
12)	3B9S MRFs-Masonry-Concrete Infilled Frame without ground infills	5.44	.....	.....

Table 7-3: Comparison between the calculated R and recommended R factors from the adopted seismic codes and standards, and the used R-factor in the analysis.

	Building System	R Calculated	R (Used in the Analysis)	R (ASCE 7-16)	R (Europe, EC8)	R (Egyptian, ECP-201)
1)	3B6S MRFs-Bare Frame	6.26	5	8	5	7
2)	3B6S MRFs-Bare Frame with Structural Deficiencies	3.38				
3)	3B6S MRFs-Stone-Concrete Infilled Frame	1.87				
4)	3B6S MRFs-Stone-Concrete Infilled Frame without ground	3.20				
5)	3B6S MRFs-Masonry-Concrete Infilled Frame	3.26				
6)	3B6S MRFs-Masonry-Concrete Infilled Frame	4.17				
7)	3B9S MRFs-Bare Frame	6.17				
8)	3B9S MRFs-Bare Frame with Structural Deficiencies	3.51				
9)	3B9S MRFs-Stone-Concrete Infilled Frame	2.93				
10)	3B9S MRFs-Stone-Concrete Infilled Frame without ground	3.67				
11)	3B9S MRFs-Masonry-Concrete Infilled Frame	5.20				
12)	3B9S MRFs-Masonry-Concrete Infilled Frame	5.44				

Table 7-3 shows that the calculated R factors are highly affected by the type of structural frame system and the ductility of the building system. It was found that the R factors for the bare frames (high ductile frame system) 3B6S and 3B9S are around 6.2, which is less than the suggested R values from the SEI/ASCE 7-16 and the Egyptian code (ECP-201). Moreover, including structural deficiencies (non-ductile frame system) reduces the R factor from 6.2 to 3.45. This reduction is

significant, and the value is far from the recommended values in the SEI/ASCE 7-16, Euro code (EC8), and the Egyptian code (ECP-201). Therefore, the R factors for the bare frame are unconservative by approximately 22.5%, 11.4% for the SEI/ASCE 7-16, and the Egyptian code (ECP-201), respectively. In the case of R factors for bare frames with structural deficiencies, the values are unsafe compared with the recommended values in the above-mentioned codes and standards used in the current practice in Palestine.

Furthermore, it was also noted that using the procedure for calculating the R factor based on the ATC-19 for a frame system with infill walls gives an unrepresentative and unrealistic R factor. As the R factor represents the design force reduction on the condition that the system meets the ductility demand ratio and dissipates the kinetic energy through its plastic-energy capacity without exceeding a life-safety performance objective. Therefore, defining the R factor is corrected with the ductility ratio. In the case of frame systems with infill walls, R values are relatively high. However, it does not indicate ductile behavior, and in most cases, a soft-storey mechanism is activated. To investigate this more, performance and damage assessment are discussed in the next chapter.

It is also worth noting that the R factor computed from the analysis may still need further reduction to take into account structural irregularity and discrepancies in construction. In order to be valid in Palestine.

CHAPTER 8: PERFORMANCE ASSESSMENT FOR STRUCTURAL BUILDINGS

8.1 Introduction to the Performance-Based Seismic Assessment:

The concept of performance-based seismic assessment has been initiated due to the major developments in structures' seismic analysis and design over the years. Traditionally, seismic design codes provide enforceable criteria that can achieve a minimum level of safety and acceptable performance of buildings during an earthquake by specifying a minimum requirement for strength, stiffness and ductility, determining the proper materials, and elements detailing and configuration. Based on this, a minimum level of performance is implied by the requirements of seismic design codes. However, the performance of building structures that are not designed or explicitly constructed according to the seismic design codes. Existing buildings with poor seismic behavior and design are often not identified by conventional standards and need to be assessed. Therefore, Performance-based seismic assessment was introduced for such assessment, and it is now extended for applications for existing and new buildings.

Performance-based seismic assessment is a consistent framework that has been developed particularly in the past 20 years. It accurately predicts building performance under earthquakes through quantitative tools that characterize seismic hazard, non-linear response of structures, elements behavior, damage, and expected losses. However, the assessment outcomes can be affected by the type of analysis, numerical modeling procedure, and how engineers understand seismic behavior (Kam et al., 2017). Moreover, the framework of seismic performance assessment of structures depends mainly on the available structural system capacity and seismic demand produced by earthquake load. Relating the structural capacity with the demand determines whether the performance meets the defined requirements.

Many methods were developed to evaluate the seismic performance of building structures. Some estimate the structural capacity using linear analysis procedures, while others utilize non-linear analysis procedures such as non-linear static pushover and non-linear dynamic analysis. In FEMA-356, and SEI/ASCE41-17, nonlinear analysis techniques are adopted, and definitions of multiple structural performance levels are presented, as shown in Fig 8-1. Furthermore, the acceptance criteria are defined for various structural elements. This chapter discusses the adopted performance assessment procedure and the acceptance criteria in the following sections.

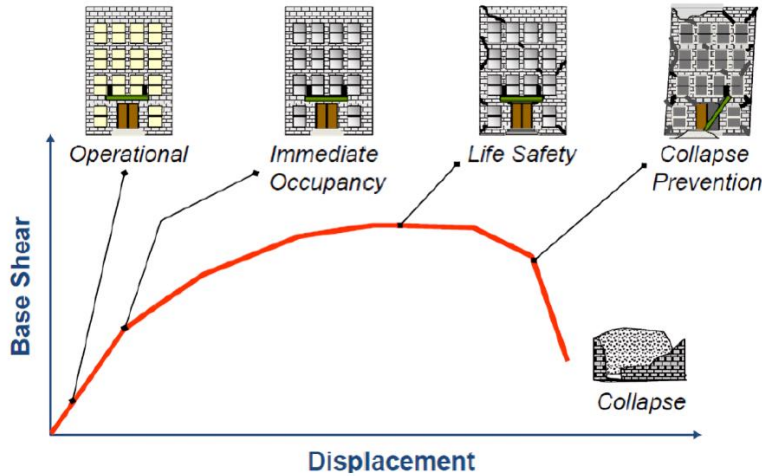


Fig 8-1: Various performance levels according to the SEI/ASCE41-17 (Kam et al., 2017).

8.2 Performance Point and Element Performance Level:

As described in section 3.6, the performance point is evaluated for each prototype frame model under an earthquake event. According to the SEI/ASCE 41-17, in order to satisfy the life safety performance level, a seismic event with a probability of exceedance equal to 10%/50 years should be considered in the analysis. The target displacement is calculated based on a seismic event 10%/50 years probability of exceedance. The life safety objective limit is 0.75 times the maximum displacement in the pushover curve for each prototype model. Table 8-1 shows the target and limit displacement at the life safety performance level.

However, to determine the performance level for each structural element, force-deformation relationship is defined for each model element through the frame hinges assigned to reflect the nonlinear behavior of the model. In the case of the beam and beam-column joint elements, a moment-rotation relationship was chosen to identify the performance of beam and beam-column joint elements, as shown in Fig 8-2a. The x-axis is set to be the rotation (Θ), and the y-axis is the moment stress (M). The performance levels are located in segments B-C and D-E. In contrast, infill models are presented by axial stress-strain relationship, as shown in Fig 8-2a. The x-axis is set to be the strain (mm/mm), and the y-axis is the axial stress. The performance levels are located on segments B-C and D-E as well.

Furthermore, the design interaction diagram (P-M) was utilized to evaluate the seismic performance of columns at the hinges near the supports, as shown in Fig 8-2b. The x-axis is set to be the moment stress (M), and the y-axis is the axial force (P). It was also considered that the collapse prevention performance level is located on the P-M interaction curve, and the life safety performance level is set to be 0.75 times any value on the P-M interaction curve (SEI/ASCE41-17).

Looking at the element level, the element model's target performance (Θ , ϵ , or M) is depicted at the time step where the target displacement is achieved. The limits for different performance objectives for each force-deformation relationship are determined according to SEI/ASCE 41-17. The yielding point is at point B in Fig 8-2a, and intermediate occupancy (IO) occurs where the deformation equals 0.67 times the deformation limit for life safety (LS). Life safety (LS) is estimated where the deformation is at 0.75 times the deformation at point C. Lastly, collapse prevention (CP) is at 1.0 times the deformation at point C on the curve.

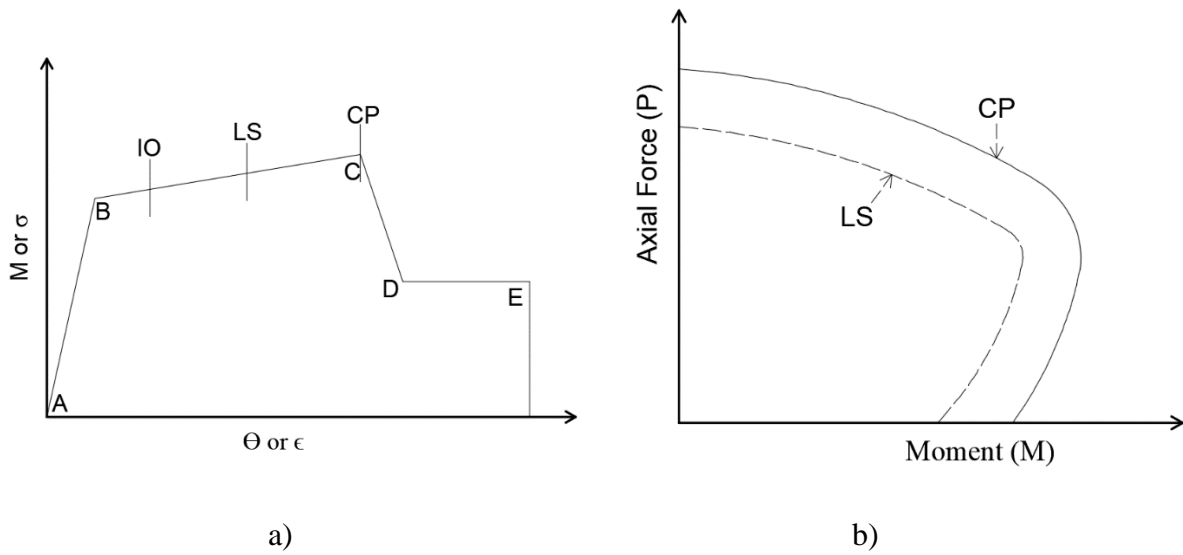


Fig 8-2: a) Force-deformation relationship for beam, beam-column joint, and infill model. b) Force-deformation relationship for column.

Table 8-1: Target displacement and life safety performance level limits.

Building System		Target Displacement (mm)	Limit for LS performance level (mm)
1)	3B6S MRFs-Bare Frame	144.5	345.0
2)	3B6S MRFs-Bare Frame with Structural Deficiencies	144.8	207.8
3)	3B6S MRFs-Stone-Concrete Infilled Frame	90.5	59.2
4)	3B6S MRFs-Stone-Concrete Infilled Frame without ground infills	90.9	128.3
5)	3B6S MRFs-Masonry-Concrete Infilled Frame	91.4	87.3
6)	3B6S MRFs-Masonry-Concrete Infilled Frame without ground infills	91.8	137.5
7)	3B9S MRFs-Bare Frame	190.9	435.0
8)	3B9S MRFs-Bare Frame with Structural Deficiencies	190.9	285.0
9)	3B9S MRFs-Stone-Concrete Infilled Frame	126.6	216.6
10)	3B9S MRFs-Stone-Concrete Infilled Frame without ground infills	126.7	244.9
11)	3B9S MRFs-Masonry-Concrete Infilled Frame	127.2	212.5
12)	3B9S MRFs-Masonry-Concrete Infilled Frame without ground infills	127.5	240.6

It was noted from Table 8-1 that (3B6S, 3B9S) MRFs-bare frames and (3B6S, 3B9S) MRFs-bare frames with structural deficiencies pass the acceptance criteria of life safety performance level with a high margin between maximum displacement and target displacement. On the other hand, 3B6S MRFs-stone-concrete and 3B6S MRFs-masonry-concrete infilled frames did not satisfy the acceptance criteria of life safety performance level. This refers to the high rigidity and brittle behavior of infilled frames at ground level. The 3B6S and 3B9S infilled frames without ground infills fulfilled the acceptance criteria according to the SEI/ASCE 41-17. However, the observations during the analysis showed that the inter-story drift for the first floor, in general, was much larger than the inter-story drifts for the rest of the floors. This concludes that a soft-story mechanism might have occurred. Further investigation on this problem is discussed in section 8.3.

8.3 Performance and Damage-Based Seismic Assessment:

After completing the modeling stage, the analysis was performed using the non-linear static pushover method on each prototype frame model. Evaluation of performance points using the coefficient method (CM) was explained in section 3.6 and performed in section 8.2. In this section, each prototype model's performance and damage assessment was performed. The seismic event 10%/50-year probability of exceedance is considered since the majority of building structures are analyzed and designed to a 10% probability of exceedance seismic event. The damage was monitored at a time step where the target displacement was achieved.

1) 3B6S MRFs- Ductile and Non-Ductile Bare Frame

The analysis was performed on 3B6S MRFs- ductile and non-ductile (with structural deficiencies) bare frames, and the results are summarized in Fig 8-3 to Fig 8-4b. It can be concluded that the performance of both models at target displacement step is within the life safety objective; in other words, none of the hinges exceeded the life safety (LS) performance level, as shown in Fig 8-5a and Fig 8-5b. For the case of 3B6S MRFs- ductile bare frame, it can also be seen that the hinges in beams and beam-column joint hinges are distributed on all floors and reached intermediate occupancy IO performance level. Column hinges formed at lower levels and within the LS performance level. This indicates a ductile frame behavior.

In contrast, the 3B6S MRFs- non-ductile bare frame analysis showed that more hinges in beam and beam-column joint elements reached LS performance level. Column hinges formed at lower levels and within the LS performance level. Comparing it with the performance 3B6S MRFs- ductile bare frame, it can be noted that more damage occurred to the structural elements. The code was generated using OpenSees to perform a complete non-linear static pushover analysis for both 3B6S MRFs- ductile and non-ductile bare frame shown in Appendix 3 and 4.

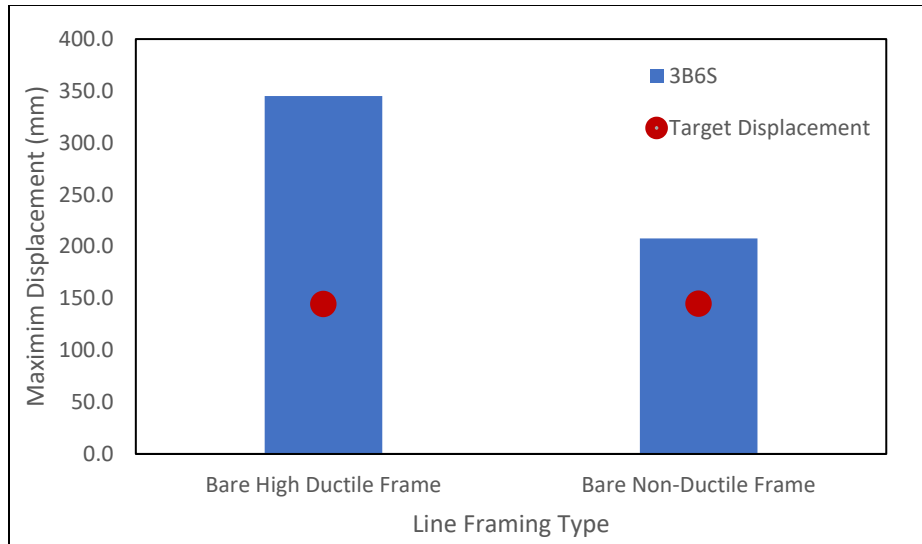


Fig 8-3: Determination of performance level for 3B6S MRFs- ductile and non-ductile bare frame under seismic event (10%/50 years)

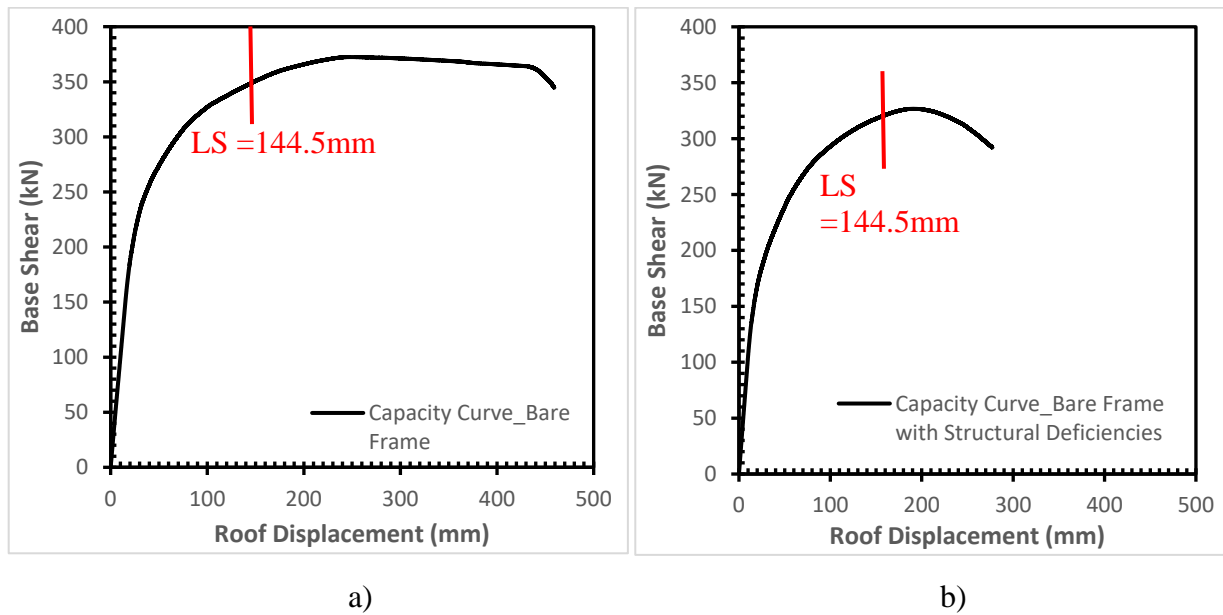


Fig 8-4: a) Performance point for 3B6S MRFs- ductile bare frame. b) Performance point for 3B6S MRFs- non-ductile bare frame.

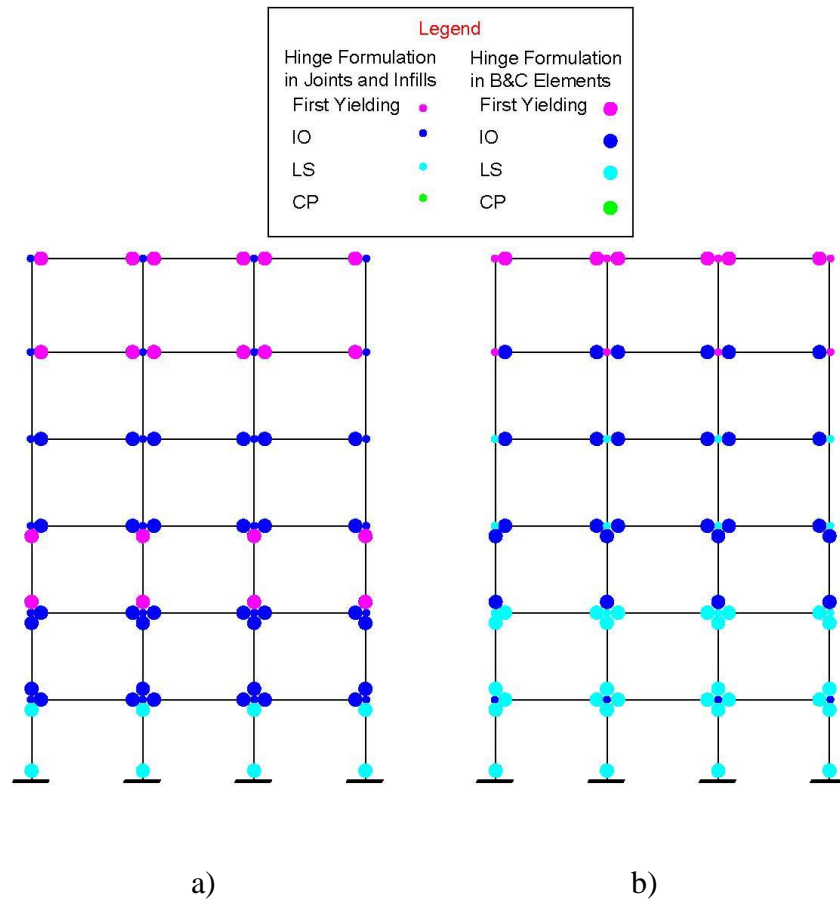


Fig 8-5: a) Hinge formation at the assigned elements in 3B6S MRFs-bare frame. b) Hinge formation at the assigned elements in 3B6S MRFs- non-ductile bare frame.

2) 3B6S MRFs-Ductile Bare Frame, Masonry-Concrete Infilled Frame, and Masonry-Concrete Infilled Frame without ground infills

In this sub-section, a comparison of performance and seismic behavior of 3B6S MRFs-ductile bare frame and masonry-concrete infilled frame with and without ground infills is made. The analysis results of performance level determination are summarized in Fig 8-6, and it can be seen that there is a high reduction in performance in both masonry-concrete infilled frames with and without ground infills compared with a ductile bare frame. In the case of the masonry-concrete infilled frame, the performance at the target displacement step is almost at the life safety objective, as shown in Fig 8-7a, while the masonry-concrete infilled frame without ground infills achieved the target displacement, as shown in Fig 8-7b.

The type of hinges created in each model element, beam, beam-column joint, and infill hinges in the masonry-concrete infilled frame are within the life safety (LS) performance level. Column hinges are concentrated on the first floor and reached intermediate occupancy (IO) performance level, as shown in Fig 8-8a. It also can be noted that all hinges are clustered on lower and middle floors, and the upper floors do not contribute to the frame structural system performance. The poor distribution of hinges indicates bad performance.

On the other hand, the analysis results of the masonry-concrete infilled frame without ground infills shown in Fig 8-8b show that beam and beam-column joint hinges are within the life safety (LS) performance level and concentrated on lower floors. Column hinges were developed on the first floor and failed before achieving the target displacement. The masonry-concrete infilled frame's overall behavior without ground infills satisfies the target displacement. However, looking closely at its performance, collapse prevention (CP) for first-floor columns occurred, which indicates a soft-story mechanism. The code was generated using OpenSees to perform full non-linear static pushover analysis for both 3B6S MRFs- masonry-concrete infilled frames with and without ground infills shown in Appendix 5 and 6, respectively.

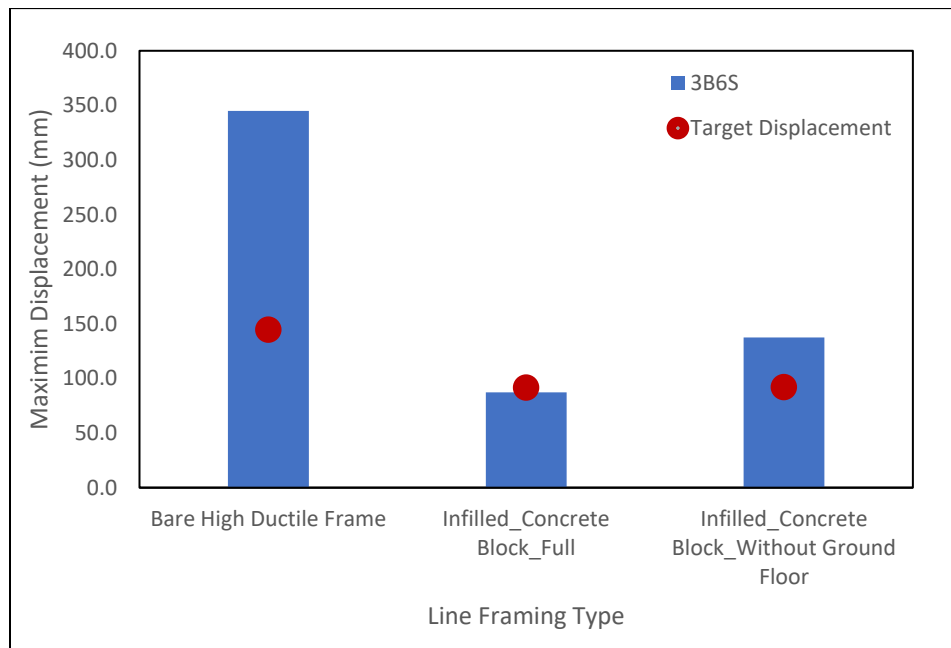
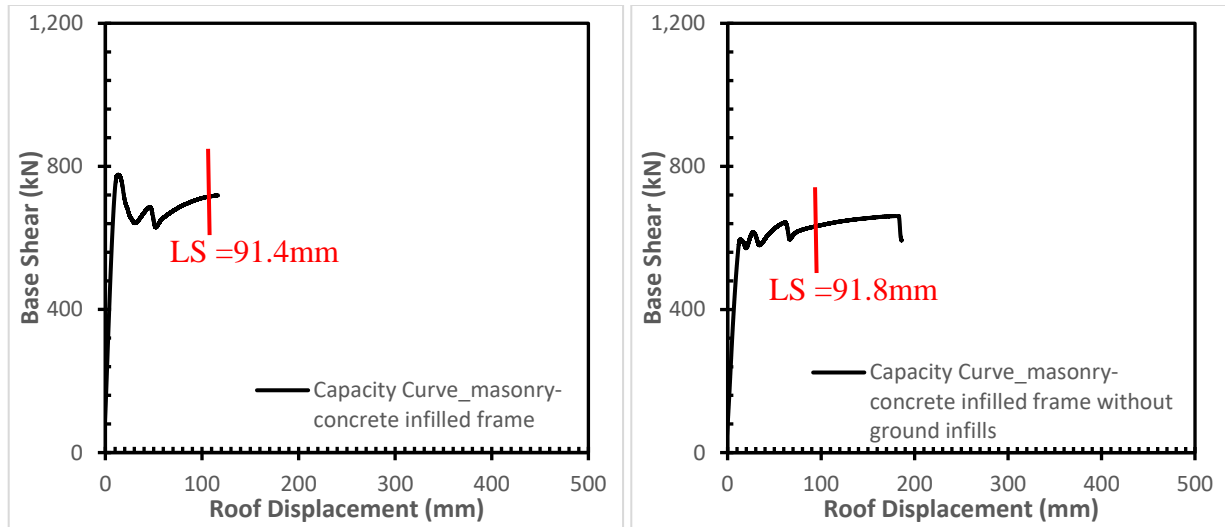


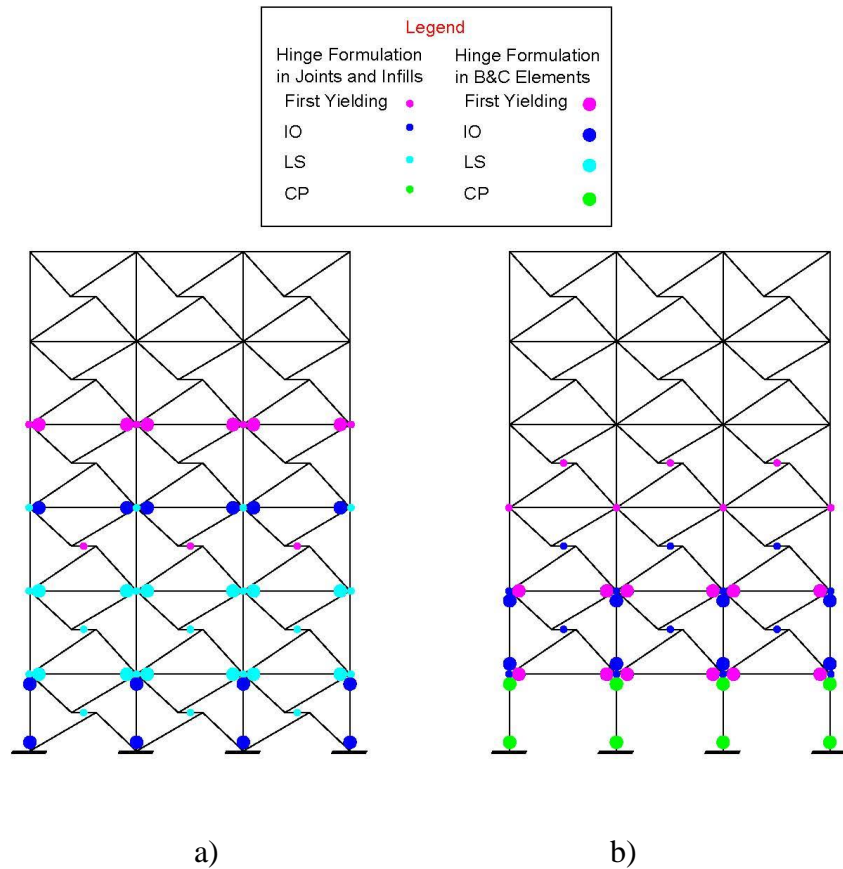
Fig 8-6: Determination of performance level for 3B6S MRFs-ductile bare frame and masonry-concrete infilled frame with and without ground infills under seismic event (10%/50 years).



a)

b)

Fig 8-7: a) Performance point for 3B6S MRFs- masonry-concrete infilled frame. b) Performance point for 3B6S MRFs- masonry-concrete infilled frame without ground infills.



a)

b)

Fig 8-8: a) Hinge formation at the assigned elements in 3B6S MRFs- masonry-concrete infilled frame. b) Hinge formation at the assigned elements in 3B6S MRFs- masonry-concrete infilled frame without ground infills.

3) 3B9S MRFs- Ductile and Non-Ductile Bare Frame

Similar behavior to 3B6S MRFs- ductile and non-ductile bare frame was observed during the analysis of 3B9S MRFs- ductile and non-ductile (with structural deficiencies) bare frame. Both models at the target displacement step are within the life safety objective, as summarized in Fig 8-9 to Fig 8-10b. Moreover, none of the hinges exceeded the life safety (LS) performance level, as shown in Fig 8-11a and Fig 8-11b. Beam and beam-column joint hinges in 3B9S MRFs- ductile bare frames are distributed on almost all floors and reached a maximum performance level of intermediate occupancy (IO). However, Column hinges are created at lower and middle levels and within the LS performance level. In comparison with the 3B9S MRFs- non-ductile bare frame, beams, columns, and beam-column joints formed hinges with LS performance levels. In addition, comparing both models with the performance of 3B6S MRFs- ductile and non-ductile bare frames, it can be concluded that frame systems with a higher elevation, columns tend to form plastic hinges at the upper levels, which gives an indication of lower performance. The code was generated using OpenSees to perform full non-linear static pushover analysis for both 3B9S MRFs- ductile and non-ductile bare frames shown in Appendix 7 and 8.

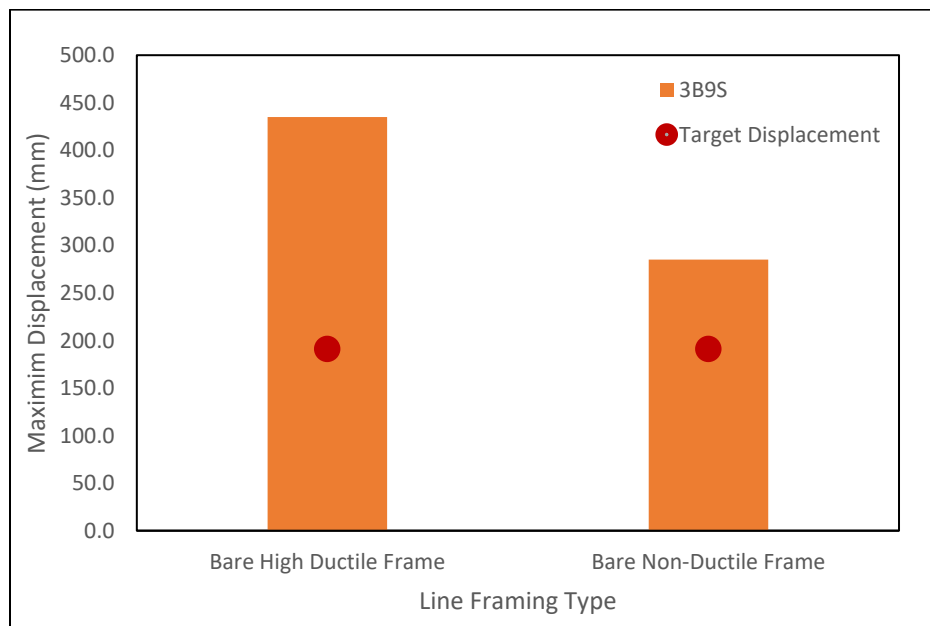
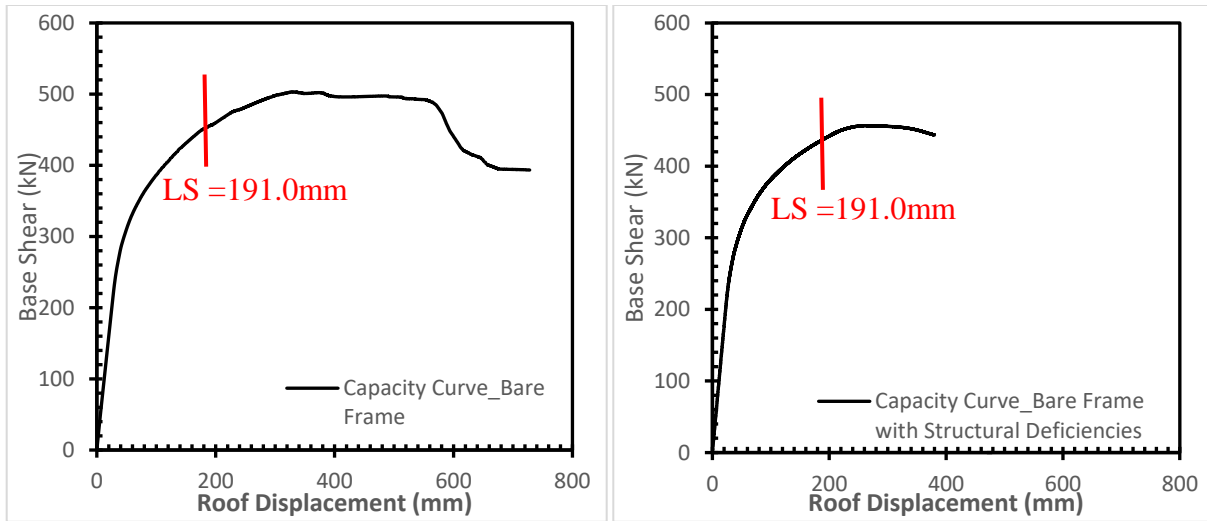


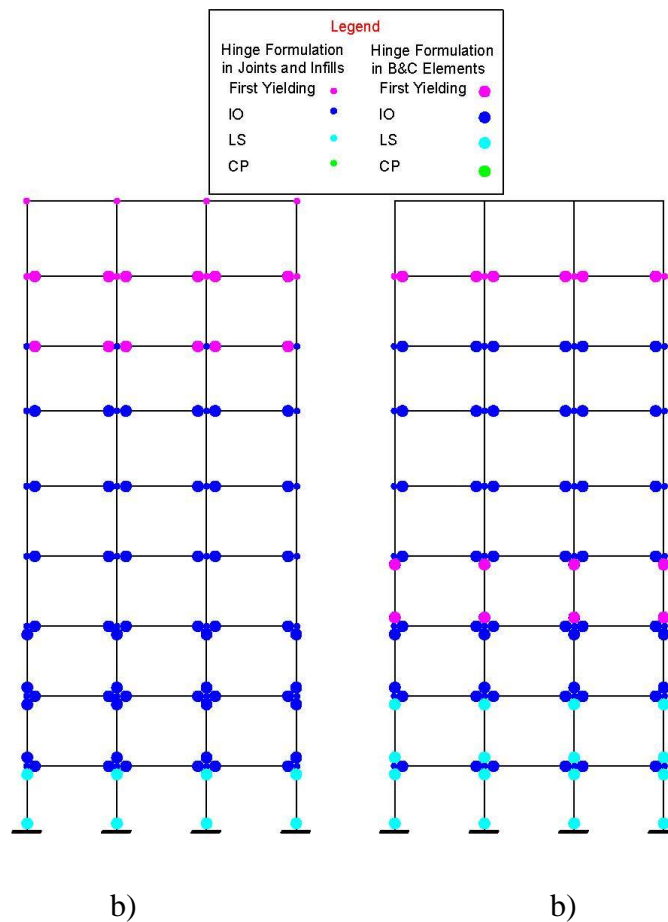
Fig 8-9: Determination of performance level for 3B9S MRFs- ductile and non-ductile bare frame under seismic event (10%/50 years)



b)

b)

Fig 8-10: a) Performance point for 3B9S MRFs- ductile bare frame. b) Performance point for 3B9S MRFs- non-ductile bare frame.



b)

b)

Fig 8-11: a) Hinge formation at the assigned elements in 3B9S MRFs-bare frame. b) Hinge formation at the assigned elements in 3B9S MRFs- non-ductile bare frame.

4) 3B9S MRFs-Ductile Bare Frame, Masonry-Concrete Infilled Frame, and Masonry-Concrete Infilled Frame without ground infills

Fig 8-12 summarizes the results of performance level analysis on 3B9S MRFs-masonry-concrete infilled frame with and without ground infills. It shows a considerable performance loss due to the existence of infills compared with a ductile bare frame. The performance of 3B9S MRFs-masonry-concrete infilled frame models at the target displacement step did not exceed the life safety objective, as shown in Fig 8-13a and Fig 8-13b. From Fig 8-14a, it can be noted that the 3B9S MRFs-masonry-concrete infilled frame formed plastic hinges in beams, columns, and infills with LS performance level. The beam-column joint hinges reached the yielding point. All model element hinges were concentrated at lower and middle floor levels. In contrast, 3B9S MRFs-masonry-concrete infilled frames without ground infills formed hinges with IO performance levels in beams and beam-column joint elements. The Column hinges at first story reached collapse prevention performance level exceeding the LS performance level. This indicates that the soft-story mechanism is activated. In the same way, a comparison with 3B6S MRFs-masonry-concrete infilled frame with and without ground infills show that as the elevation of the frame system increases, the effect of soft-story increases. The code was generated using OpenSees to perform full non-linear static pushover analysis for both 3B9S MRFs- masonry-concrete infilled frames with and without ground infills shown in Appendix 9 and 10, respectively.

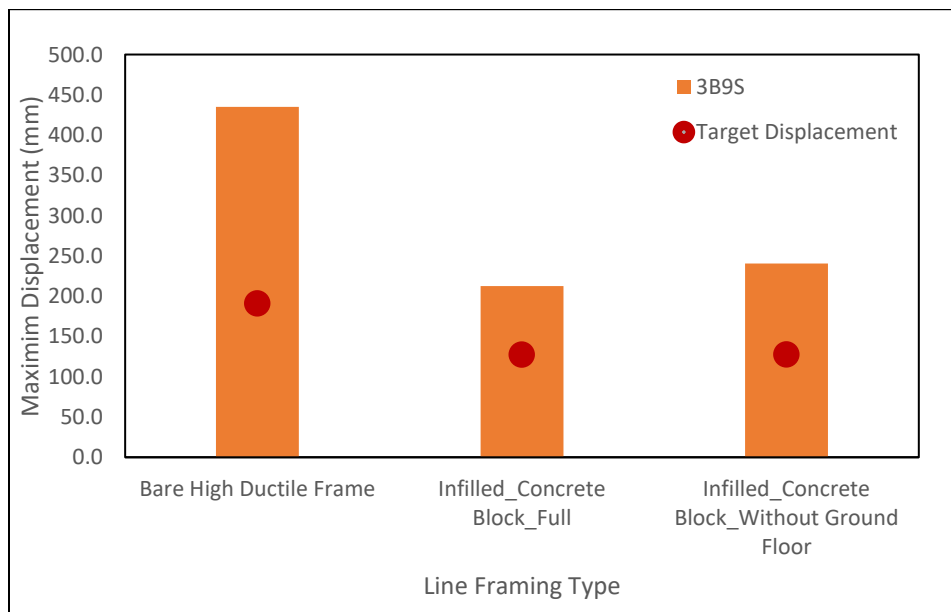
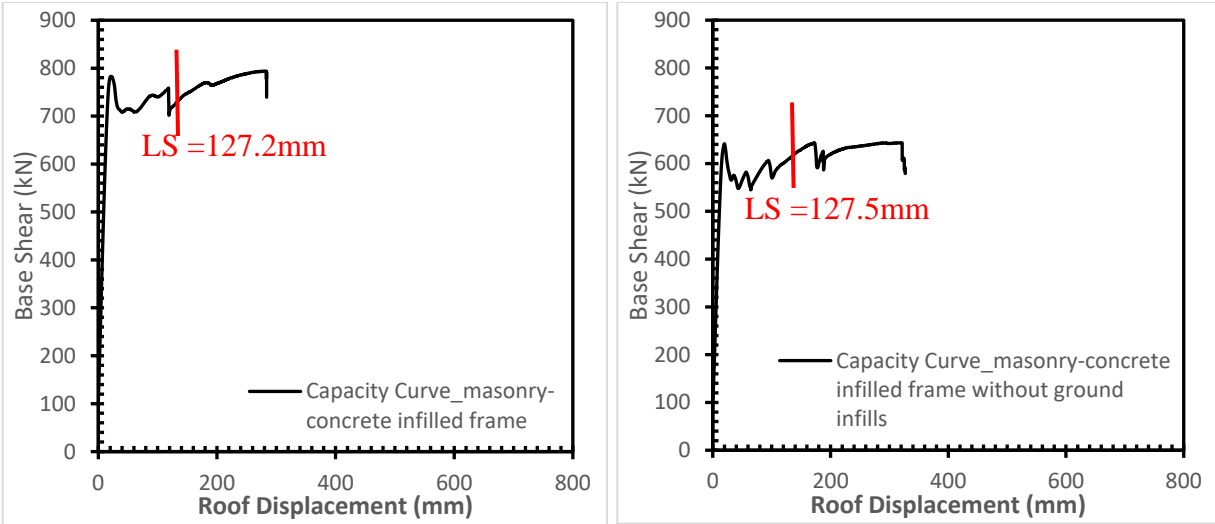


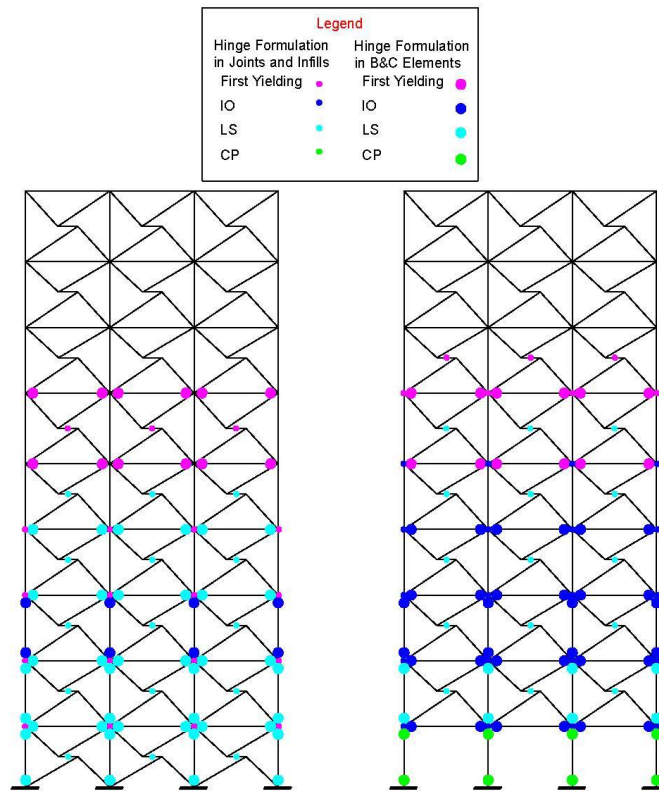
Fig 8-12: Determination of performance level for 3B9S MRFs-ductile bare frame and masonry-concrete infilled frame with and without ground infills under seismic event (10%/50 years).



b)

b)

Fig 8-13: a) 3B9S MRFs- masonry-concrete infilled frame performance point. b) Performance point for 3B9S MRFs- masonry-concrete infilled frame without ground infills.



b)

b)

Fig 8-14: a) Hinge formation at the assigned elements in 3B9S MRFs- masonry-concrete infilled frame. b) Hinge formation at the assigned elements in 3B9S MRFs- masonry-concrete infilled frame without ground infills.

5) 3B6S and 3B9S MRFs-Stone-Concrete Infilled Frame with/without ground infills

The performance and the behavior of 3B6S and 3B9S MRFs-stone-concrete infilled frames with/without ground infills have been observed to be the same as 3B6S, and 3B9S MRFs-masonry-concrete infilled frames with/without ground infills. Therefore, the data analysis regarding each prototype model is shown in Appendix 15. The code generated using the OpenSees program to perform complete non-linear static pushover analysis for 3B6S and 3B9S MRFs-stone-concrete infilled frames with/without ground infills are shown in Appendix 11,12,13 and 14, respectively.

Based on the data analysis performed in sections 8.2 and 8.3, it was found that the inclusion of structural deficiencies in the frame systems increased damage to the structural elements and negatively affected the distribution pattern of the hinges. Consequently, a change in the performance of buildings is anticipated. The existence of infills (stone-concrete or masonry-concrete) clusters the hinge formation on the lower and middle floors of the frame system, leaving the upper floors without any contribution to the performance of the structural frame system. Therefore, bad performance is expected due to the poor distribution of hinges in structural elements. It was also noted that the increase in the building's height increases the rate of the soft-story mechanism formation by the early development of plastic hinges in column elements.

The above analysis of performance assessment supports the need to review the R factors, which describe the seismic behavior of buildings in Palestine. This response modification factor should realistically describe the plastic hinge formation pattern, their ultimate capacity, and expected plastic deformation. Therefore, the use of R factors from the reviewed standards and even calculating them using conventional methods should be reviewed, and consequently, R factors values are reduced.

SUMMARY, CONCLUSIONS, LIMITATIONS AND RECOMMENDATIONS

1. Summary and Conclusions

This research aims to investigate analytically the response modification factor (R factor) of reinforced concrete moment resisting frames (MRFs) in Palestine and compare it with the R factor values recommended by the seismic design codes and standards used in the area. The starting point was to determine a representative model for the analysis, which was done through semi-structured interviews held with highly skilled/active engineers, contractors, and construction managers. Consequently, Numerical models of the examined structural systems were developed using the OpenSees to investigate the performance of the buildings in Palestine. These models were verified using the data available on the non-linear analysis of the RC-frame (Vecchio and Emara, 1992). It was found that the model built in Opensees can accurately show the non-linear behavior of a frame system. Therefore, twelve 2D RC-moment resisting frames (MRFs) are taken as typical RC frames in Palestine. Each frame system is analyzed using a non-linear static pushover analysis to evaluate the response modification factor. Response modification factor R was further examined by performing performance and damage assessment for specific performance objectives. Lastly, a comparison between the calculated response modification factor and the values from the seismic codes of practice is performed.

Based on the modeling and analysis results, the following are the major research findings:

1. It was found that the R factor in the seismic codes and standards adopted in Palestine gives an inaccurate representation of the building structure's response during a seismic event.
2. The R factor recommended in the SEI/ASCE 7-16, Euro code (EC8), and the Egyptian code (ECP-201) is unconservative to be used in Palestine under the current construction technology and thus should be decreased. The current status of calculating the base shear is assuming R-value for the building as a skeleton. However, when considering the infills, the performance and the behavior are affected, and the R factor as well.
3. It was also noted that the inclusion of structural deficiencies (insufficient beam and column shear reinforcement, short anchorage length in longitudinal beam bars, and inadequate beam-column joint shear reinforcement) causes the poor distribution of plastic hinges in

the structural elements. Consequently, a significant loss in ductility of the frame system and a reduction in the R factor was observed.

4. The building's height is an important parameter that affects the performance of structures and highlights the impact of the soft-story mechanism.
5. Using the stone-concrete or masonry-concrete infills increases the strength and stiffness of the frame system. However, it dramatically decreases ductility. Consequently, the R factor is reduced, and severe damage may appear in some elements because of the considerable loss in ductility.
6. Using stone-concrete or masonry-concrete infills in frame systems without ground infills create a soft story mechanism that may cause serious problems such as forming a weak story and the possibility of stone failing. All that could be life-threatening, especially in case of stone or block failing.

2. Limitations

Several restrictions have been faced in this research, and it is summarized in the following points:

- a) The unavailability of experimental data to validate the modeling criteria of structural deficiencies and their effect on the seismic performance of frame structures may affect the analysis results.
- b) The limitations of using pushover analysis are mainly related to the selection of the horizontal load pattern and target displacement at the roof mass center. The load pattern is assumed to be an invariant lateral load pattern, and the system has a constant distribution of inertial forces. In contrast, the top roof displacement represents a single degree of freedom system (SDOFs) target displacement for a multi-degree of freedom system (MDOFs), and that could be a not good indicator of the behavior and performance of the overall structure, especially if the structure is dominated by more than one mode shape.
- c) The assumption of using the same value of redundancy factor for all prototype models (bare frame and infilled frame) may influence the values of the response modification factor.
- d) During non-linear static pushover analysis, the first failure occurrence for the system was not identified, and the failure of the system mainly depended on the degradation of the pushover curve.

- e) The in-plane analysis of infill walls was adopted in this research, and the out-of-plane was not considered, which may count as a limitation.

3. Recommendations

Based on the analysis results and the conclusions mentioned above, the following recommendations are given:

❖ Near future solution:

1. Solve structural deficiencies in the current construction practice by focusing on structural detailing along with seismic analysis and design. Supervision on construction sites is mandatory to ensure that defects such as inadequate joint shear reinforcement, insufficient development length of beam bars, and inadequate stirrup spacing in beams and columns are repealed.
2. The full separation between infills (brittle behavior) and the frame system should be done to let the structure deform without any stresses on the infills. This could be applied using anchored joints and providing a seismic gap between infills and the frame system.
3. In the case of building structures under the current construction technology, a value of response modification factor R in a range of [2-3] should be taken to ensure that minimum performance of structures occurs.

❖ Far future solution:

1. Increasing the relative ductility of infill walls by implementing ductile materials in the infill walls, such as reinforced steel. Further investigation should be done to ensure that the system achieves the acceptance criteria for life safety performance level.
2. Alternatives for the cladding of reinforced concrete buildings in Palestine should be developed. Stone or masonry infills should be replaced with less weight and lower rigidity, such as foam stone or glass panels.

Finally, it is crucial to note that the R factor computed from the analysis may still need further reduction to take into account structural irregularity and discrepancies in construction practice, such as the value of compressive strength of concrete, in order to have a more precise prediction for the R factor.

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**Appendix 1 – A Copy of the Interview Form and the Questions
that have been Discussed**



- This Interview is for research purposes in accordance with student's research regulations by Birzeit University.
 - The aim is to identify building prototypes and shortcomings in construction practice.
 - The collected data is confidential and will be used in the study and analysis for a master's degree thesis.
 - It should last about 30 minutes. With your permission, I will audiotape and take notes during the interview, The recording is to accurately record the information you provide, and will be used for transcription purposes only.
-

Respondent Information

Name of the interviewee.....

Years of experience.....

Contact Details

E-mail..... Telephone.....

Section One: Building Characteristics

- Type of buildings based on construction material (Rank 1-3)

Reinforced Concrete

Steel

Others

- How buildings are constructed? (how many projects done as?)

Floor by floor (stone infills are built simultaneously with RC concretes?)

Skeleton and then cladding stone?

- Type of infill?

○ type of material?

○ thickness?

- What is the building structural system (Trend?)

○ Moment resisting Frames

○ Walls

One direction?

both directions (aside from the stairs shear wall?)

- What is the building occupancy (most buildings you designed or constructed? Can you offer a percentage?)

Residential

Commercial

Others

- Number of stories of Buildings (including basements) (Rank the of building's number of stories following your experience in construction industry)

(1-3) stories	<input type="text"/>	(4-6) stories	<input type="text"/>
(7-9) stories	<input type="text"/>	(10-12) stories	<input type="text"/>
More than 12 stories	<input type="text"/>		

- Rank the typical floor areas following your experience in construction industry.

Less than 100 m ²	<input type="text"/>
(100-500) m ²	<input type="text"/>
More than 500 m ²	<input type="text"/>

Can you offer percentages of buildings that have the following irregularities?

- Plan regularity (Refer to Figure 1)

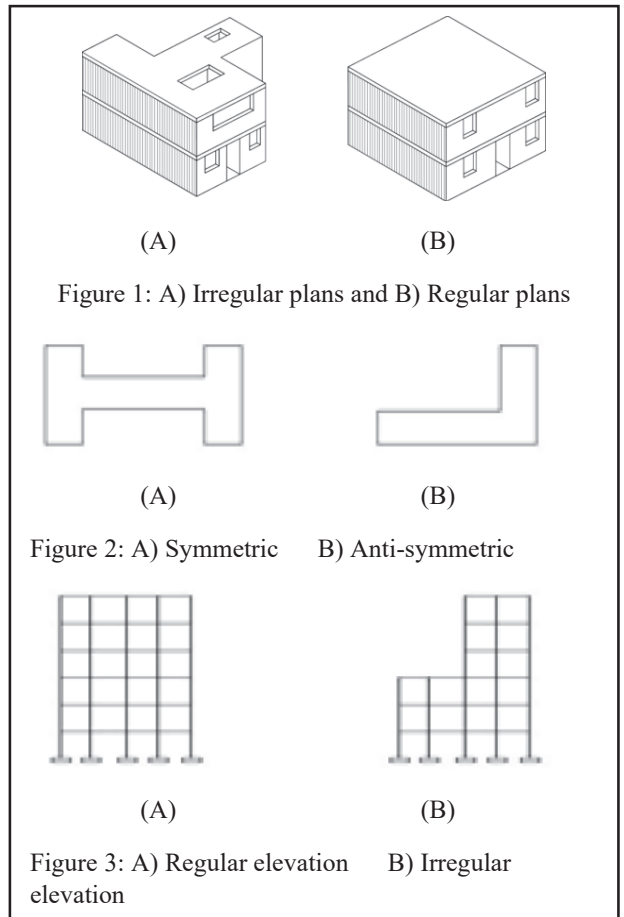
Regular plans	<input type="text"/>
Irregular plans	<input type="text"/>

- Plan symmetry (Refer to Figure 2)

Symmetric plan	<input type="text"/>
Anti-symmetric plan	<input type="text"/>

- Regularity of elevation (Refer to Figure 3)

Regular along elevation	<input type="text"/>
Irregular along elevation	<input type="text"/>



Section Two: Design Current Practice:

- What is the adapted design code in your designs?

- Which provisions you used to design buildings?

- Do you account for earthquake seismic loads in your analysis and design?

Yes

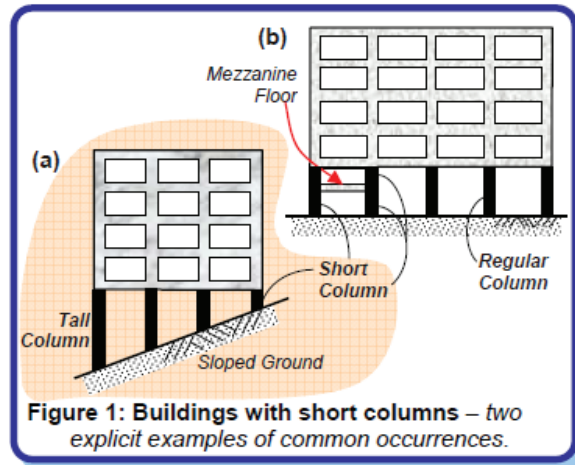
No

If your answer for the previous question is “Yes”, describe briefly how do you take these loads into consideration?

Section Three: Shortcomings and Deficiencies in Design and Construction Current Practice:

- Do the Buildings have soft storey in terms of infills, shear walls?

- Do the Buildings have short columns in buildings? (If they saw such columns in their work experience)
 - The columns stiffened partially along the height by infill or Mezzanine floor



Source: IITK-BMTPC Earthquake, C.V.R. Murty Indian Institute of Technology Kanpur Kanpur, India

- In beams and columns, is transverse reinforcement provided? what is the provided spacing? and how is it calculated?
- Can you describe the joint area in the current construction practice (transverse reinforcement, anchoring of steel bars)?
- What are the used provisions for development length?

- What are the typical concrete covers provided for RC elements?
- Other deficiencies you would like to elaborate or describe in details?

- In scale of 1-10 as shown below, how do you expect the existing structures to withstand severe earthquake load (1 indicates poor, 10 indicates perfect performance)?

Poor (1)	2	3	4	5	6	7	8	9	Perfect (10)
----------	---	---	---	---	---	---	---	---	--------------

Given Rank.....

- In scale of 1-10 as shown below, how do you expect the designed structures to withstand severe earthquake load (1 indicates poor, 10 indicates perfect performance)?

Poor (1)	2	3	4	5	6	7	8	9	Perfect (10)
----------	---	---	---	---	---	---	---	---	--------------

Given Rank.....

End of Interview

Appendix 2 – Full Record of the Calculation of R Factor

❖ Response Modification Factor Calculation for Each Prototype Model:

1) 3B6S MRFs-Bare Frame

Based on the capacity curve in Fig 7-2a, and the procedure explained in chapter three for evaluating the response modification factor R, the R factor was calculated for 3B6S MRFs-bare frame as the following:

1) Ductility Factor (R_μ):

- $T = 0.78, u = \frac{\Delta_{max}}{\Delta_y} = \frac{440mm}{90mm} = 4.88$
- $R_u = (2 * 4.88 - 1)^{0.5} + 2 * (T - 0.5) * (4.88 - (2 * 4.88 - 1)^{0.5}) = 4.026$

2) Over Strength Factor (R_0):

The maximum base shear (V_0) is found from the capacity curve. The designed base shear (V_d) is evaluated using Equivalent Lateral Force ELF in ASCE7-16.

- $V_0 = 372kN$
- V_d , the following equation has been utilized in the base shear calculations:

$$V = C_s W$$

Where:

- V is the base shear (KN)
- C_s is seismic response coefficient, ASCE7-16 section 12.8.1.1
- W is the effective seismic weight as defined in ASCE7-16, section 12.7.2

The given parameters for the frame system are as the following:

- Response modification factor $R = 5$
- Seismic coefficient $C_s = 0.1075$ (12.8.2)

$$V_d = C_s * W = 10.75\% * 1912.6 = 205.6kN$$

$$- R_s = \frac{V_0}{V_d} = \frac{372kN}{205.6kN} = 1.81$$

3) Redundancy Factor (R_r):

- $R_r = 0.86$, since it is assumed to have three vertical seismic framing

$$R = 4.026 * 1.81 * 0.86 = 6.26$$

2) 3B6S MRFs-Bare Frame with Structural Deficiencies

Based on the capacity curve in Fig 7-2b, and the procedure explained in chapter three for evaluating the response modification factor R, the R factor was calculated for 3B6S MRFs-bare frame with structural deficiencies as the following:

1) Ductility Factor (R_μ):

- $T = 0.75, u = \frac{\Delta_{max}}{\Delta_y} = \frac{220mm}{80mm} = 2.75$
- $R_u = (2 * 2.75 - 1)^{0.5} + 2 * (T - 0.5) * (2.75 - (2 * 2.75 - 1)^{0.5}) = 2.47$

2) Over Strength Factor (R_0):

The maximum base shear (V_0) is found from the capacity curve. The designed base shear (V_d) is evaluated using Equivalent Lateral Force ELF in ASCE7-16.

- $V_0 = 327kN$
- $V_d = 205.6kN$
- $R_s = \frac{V_0}{V_d} = \frac{327kN}{205.6kN} = 1.6$

3) Redundancy Factor (R_r):

- $R_r = 0.86$, since it is assumed to have three vertical seismic framing

$$R = 2.47 * 1.6 * 0.86 = 3.38$$

3) 3B6S MRFs-Stone-Concrete Infilled Frame

Based on the capacity curve in Fig 7-3a, the ductility ratio for 3B6S MRFs-stone-concrete infilled frame is calculated as the following:

Ductility Factor (R_μ):

- $u = \frac{\Delta_{max}}{\Delta_y} = \frac{79mm}{35mm} = 2.26$
- $R_u = (2 * u - 1)^{0.5} = 1.87$

4) 3B6S MRFs-Stone-Concrete Infilled Frame without ground infills

Based on the capacity curve in Fig 7-3b, the ductility ratio for 3B6S MRFs-stone-concrete infilled frame without ground infills is calculated as the following:

Ductility Factor (R_μ):

- $u = \frac{\Delta_{max}}{\Delta_y} = \frac{170mm}{30mm} = 5.6$
- $R_u = (2 * u - 1)^{0.5} = 3.2$

5) 3B6S MRFs-Masonry-Concrete Infilled Frame

Based on the capacity curve in Fig 7-4a, the ductility ratio for 3B6S MRFs- masonry-concrete infilled frame is calculated as the following:

Ductility Factor (R_μ):

- $u = \frac{\Delta_{max}}{\Delta_y} = \frac{116mm}{20mm} = 5.8$
- $R_u = (2 * u - 1)^{0.5} = 3.26$

6) 3B6S MRFs-Masonry-Concrete Infilled Frame without ground infills

Based on the capacity curve in Fig 7-4b, the ductility ratio for 3B6S MRFs- masonry-concrete infilled frame without ground infills is calculated as the following:

Ductility Factor (R_μ):

- $u = \frac{\Delta_{max}}{\Delta_y} = \frac{184mm}{20mm} = 9.2$

- $R_u = (2 * u - 1)^{0.5} = 4.17$

7) 3B9S MRFs-Bare Frame

Based on the capacity curve in Fig 7-5a, and the procedure explained in chapter three for evaluating the response modification factor R, the R factor was calculated for 3B9S MRFs-bare frame as the following:

1) Ductility Factor (R_μ):

- $T = 1.06, u = \frac{\Delta_{max}}{\Delta_y} = \frac{550mm}{116mm} = 4.75$
- $R_u = 4.75$

2) Over Strength Factor (R_o):

The maximum base shear (V_0) is found from the capacity curve. The designed base shear (V_d) is evaluated using Equivalent Lateral Force ELF in ASCE7-16.

- $V_0 = 503kN$
- V_d , the following equation has been utilized in the base shear calculations:

$$V = C_s W$$

Where:

- V is the base shear (KN)
- C_s is seismic response coefficient, ASCE7-16 section 12.8.1.1
- W is the effective seismic weight as defined in ASCE7-16, section 12.7.2

The given parameters for the frame system are as the following:

- Response modification factor $R= 5$
- Seismic coefficient $C_s= 0.1075$ (12.8.2)

$$V_d = C_s * W = 10.75\% * 3100.7 = 333.32kN$$

$$- R_s = \frac{V_0}{V_d} = \frac{503kN}{333.32kN} = 1.509$$

3) Redundancy Factor (R_r):

- $R_r = 0.86$, since it is assumed to have three vertical seismic framing

$$R = 4.75 * 1.509 * 0.86 = 6.172$$

8) 3B9S MRFs-Bare Frame with Structural Deficiencies

Based on the capacity curve in Fig 7-5b, and the procedure explained in chapter three for evaluating the response modification factor R, the R factor was calculated for 3B9S MRFs-bare frame with structural deficiencies as the following:

1) Ductility Factor (R_μ):

- $T = 1.01, u = \frac{\Delta_{max}}{\Delta_y} = \frac{305mm}{103mm} = 2.98$
- $R_u = 2.98$

2) Over Strength Factor (R_o):

The maximum base shear (V_0) is found from the capacity curve. The designed base shear (V_d) is evaluated using Equivalent Lateral Force ELF in ASCE7-16.

- $V_0 = 456kN$
- $V_d = 333.32kN$
- $R_s = \frac{V_0}{V_d} = \frac{456kN}{333.32kN} = 1.37$

3) Redundancy Factor (R_r):

- $R_r = 0.86$, since it is assumed to have three vertical seismic framing

$$R = 2.98 * 1.37 * 0.86 = 3.51$$

9) 3B9S MRFs-Stone-Concrete Infilled Frame

Based on the capacity curve in Fig 7-6a, the ductility ratio for 3B9S MRFs-stone-concrete infilled frame is calculated as the following:

Ductility Factor (R_μ):

- $u = \frac{\Delta_{max}}{\Delta_y} = \frac{270mm}{75mm} = 3.6$
- $R_u = (2 * u - 1)^{0.5} + 2 * (T - 0.5) * (u - (2 * u - 1))^{0.5} = 2.93$

10) 3B9S MRFs-Stone-Concrete Infilled Frame without ground infills

Based on the capacity curve in Fig 7-6b, the ductility ratio for 3B9S MRFs- stone-concrete infilled frame without ground infills is calculated as the following:

Ductility Factor (R_μ):

- $u = \frac{\Delta_{max}}{\Delta_y} = \frac{310mm}{62mm} = 5.0$
- $R_u = (2 * u - 1)^{0.5} + 2 * (T - 0.5) * (u - (2 * u - 1))^{0.5} = 3.67$

11) 3B9S MRFs-Masonry-Concrete Infilled Frame

Based on the capacity curve in Fig 7-7a, the ductility ratio for 3B9S MRFs- masonry-concrete infilled frame is calculated as the following:

Ductility Factor (R_μ):

- $u = \frac{\Delta_{max}}{\Delta_y} = \frac{272mm}{33.17mm} = 8.2$
- $R_u = (2 * u - 1)^{0.5} + 2 * (T - 0.5) * (u - (2 * u - 1))^{0.5} = 5.2$

12) 3B9S MRFs-Masonry-Concrete Infilled Frame without ground infills

Based on the capacity curve in Fig 7-4b, the ductility ratio for 3B9S MRFs- masonry-concrete infilled frame without ground infills is calculated as the following:

Ductility Factor (R_μ):

- $u = \frac{\Delta_{max}}{\Delta_y} = \frac{305mm}{34mm} = 8.85$

- $R_u = (2 * u - 1)^{0.5} + 2 * (T - 0.5) * (u - (2 * u - 1)^{0.5}) = 5.44$

**Appendix 3 – The Code Generated Using the OpenSees Program
to Perform Pushover Analysis for 3B6S MRFs-Ductile Bare
Frame**

Appendix 3: 3B6S Bare Frame

```

1
2 1) Complementary files were defined to organize and make the procedure easier:
3
4     1. Library for Units
5
6         # define UNITS-----
7     set m 1.;                # define basic units--output units
8     set kn 1.;              # define basic units--output units
9     set sec 1.;            # define basic units--output units
10
11    set LunitTXT "meter";    # define basic-unit text for output
12    set FunitTXT "kn";       # define basic-unit text for output
13    set TunitTXT "sec";      # define basic-unit text for output
14
15    set cm [expr $m/100.];   # define engineering units
16    set mm [expr $m/1000.];
17    set ton [expr $kn/10.];
18    set pa [expr $kn*0.001/pow($m,2) ];
19    set kpa [expr $pa*1000.];
20    set mpa [expr $kpa*1000.];
21    set gpa [expr $mpa*1000.];
22    set density [expr $kn/pow($m,3)];
23
24    set g [expr 9.81*$m/pow($sec,2)]; # gravitational acceleration
25    set Ubig 1.e10;          # a really large number
26
27     2. Building RC Cross-Section (Fiber Approach)
28
29     proc BuildRCrectSection {id HSec BSec coverH coverB coreID coverID steelID numBarsTop barAreaTop numBarsBot barAreaBot nu
mBarsIntTot barAreaInt nfCoreY nfCoreZ nfCoverY nfCoverZ} {
30         #####
31         # BuildRCrectSection $id $HSec $BSec $coverH $coverB $coreID $coverID $steelID $numBarsTop $barAreaTop $numBarsBot $barAr
eaBot $numBarsIntTot $barAreaInt $nfCoreY $nfCoreZ $nfCoverY $nfCoverZ
32         #####
33         # Build fiber rectangular RC section, 1 steel layer top, 1 bot, 1 skin, confined core
34         # Define a procedure which generates a rectangular reinforced concrete section
35         # with one layer of steel at the top & bottom, skin reinforcement and a
36         # confined core.
37         #     by: Silvia Mazzoni, 2006
38         #     adapted from Michael H. Scott, 2003
39         #
40         # Formal arguments
41         # id - tag for the section that is generated by this procedure
42         # HSec - depth of section, along local-y axis
43         # BSec - width of section, along local-z axis
44         # cH - distance from section boundary to neutral axis of reinforcement
45         # cB - distance from section boundary to side of reinforcement
46         # coreID - material tag for the core patch
47         # coverID - material tag for the cover patches
48         # steelID - material tag for the reinforcing steel
49         # numBarsTop - number of reinforcing bars in the top layer
50         # numBarsBot - number of reinforcing bars in the bottom layer
51         # numBarsIntTot - TOTAL number of reinforcing bars on the intermediate layers, symmetric about z axis and 2 bars per 1
ayer--
needs to be an even integer
52         # barAreaTop - cross-sectional area of each reinforcing bar in top layer
53         # barAreaBot - cross-sectional area of each reinforcing bar in bottom layer
54         # barAreaInt - cross-sectional area of each reinforcing bar in intermediate layer
55         # nfCoreY - number of fibers in the core patch in the y direction
56         # nfCoreZ - number of fibers in the core patch in the z direction
57         # nfCoverY - number of fibers in the cover patches with long sides in the y direction
58         # nfCoverZ - number of fibers in the cover patches with long sides in the z direction
59         #
60         #
61         #
62         #
63         #
64         #
65         #
66         #
67         #
68         #
69         #
70         #
71         #
72         #
73         #
74         #
75         #

```



```

76 #
77 #
78 #
79 #
80 #
81 #
82 #
83 # z <-----|v|
84 #
85 #
86 #
87 #
88 #
89 #
90 #
91 #
92 # Notes
93 # The core concrete ends at the NA of the reinforcement
94 # The center of the section is at (0,0) in the local axis system
95 #
96 set coverY [expr $HSec/2.0]; # The distance from the section z-axis to the edge of the cover concrete -- outer edge o
f cover concrete
97 set coverZ [expr $BSec/2.0]; # The distance from the section y-axis to the edge of the cover concrete -- outer edge o
f cover concrete
98 set coreY [expr $coverY-$coverH]; # The distance from the section z-axis to the edge of the core concrete -- edge o
f the core concrete/inner edge of cover concrete
99 set coreZ [expr $coverZ-$coverB]; # The distance from the section y-axis to the edge of the core concrete -- edge o
f the core concrete/inner edge of cover concrete
100 set numBarsInt [expr $numBarsIntTot/2]; # number of intermediate bars per side
101
102 # Define the fiber section
103 section fiberSec $id {
104 # Define the core patch
105 patch quadr $coreID $nfCoreZ $nfCoreY -$coreY $coreZ -$coreY -$coreZ $coreY -$coreZ $coreY $coreZ
106
107 # Define the four cover patches
108 patch quadr $coverID 2 $nfCoverY -$coverY $coverZ -$coreY $coreZ $coreY $coreZ $coverY $coverZ
109 patch quadr $coverID 2 $nfCoverY -$coreY -$coreZ -$coverY -$coverZ $coverY -$coverZ $coreY -$coreZ
110 patch quadr $coverID $nfCoverZ 2 -$coverY $coverZ -$coreY -$coreZ -$coreY -$coreZ -$coreY $coreZ
111 patch quadr $coverID $nfCoverZ 2 $coreY $coreZ $coreY -$coreZ $coverY -$coverZ $coverY $coverZ
112
113 # define reinforcing layers
114 layer straight $steelID $numBarsInt $barAreaInt -$coreY $coreZ $coreY $coreZ; # intermediate skin reinf. +z
115 layer straight $steelID $numBarsInt $barAreaInt -$coreY -$coreZ $coreY -$coreZ; # intermediate skin reinf. -z
116 layer straight $steelID $numBarsTop $barAreaTop $coreY $coreZ $coreY -$coreZ; # top layer reinforcement
117 layer straight $steelID $numBarsBot $barAreaBot -$coreY $coreZ -$coreY -$coreZ; # bottom layer reinforcement
118
119 }; # end of fibersection definition
120 }; # end of procedure
121
122 3. Display The Model in 2D
123
124 proc DisplayModel2D { {ShapeType nil} {dAmp 5} {xLoc 10} {yLoc 10} {xPixels 512} {yPixels 384} {nEigen 1} } {
125 #####
126 ## DisplayModel2D $ShapeType $dAmp $xLoc $yLoc $xPixels $yPixels $nEigen
127 #####
128 ## display Node Numbers, Deformed or Mode Shape in 2D problem
129 ## Silvia Mazzoni & Frank McKenna, 2006
130 ##
131 ## ShapeType : type of shape to display. # options: ModeShape , NodeNumbers , DeformedShape
132 ## dAmp : relative amplification factor for deformations
133 ## xLoc,yLoc : horizontal & vertical location in pixels of graphical window (0,0=upper left-most corner)
134 ## xPixels,yPixels : width & height of graphical window in pixels
135 ## nEigen : if nEigen not=0, show mode shape for nEigen eigenvalue
136 ##
137 #####
138 global TunitTXT; # load time-unit text
139 global ScreenResolutionX ScreenResolutionY; # read global values for screen resolution
140
141 if { [info exists TunitTXT] != 1 } {set TunitTXT ""}; # set blank if it has not been defined previously.
142
143 if { [info exists ScreenResolutionX] != 1 } {set ScreenResolutionX 1024}; # set default if it has not been defined pr
eviously.
144 if { [info exists ScreenResolutionY] != 1 } {set ScreenResolutionY 768}; # set default if it has not been defined pr
eviously.
145
146 if {$xPixels == 0} {
147 set xPixels [expr int($ScreenResolutionX/2)];
148 set yPixels [expr int($ScreenResolutionY/2)];
149 set xLoc 10

```

```

150     set yLoc 10
151 }
152 if {$ShapeType == "nill"} {
153     puts ""; puts ""; puts "-----"
154     puts "View the Model? (N)odes, (D)eformedShape, anyMode(1),(2),(#). Press enter for NO."
155     gets stdin answer
156     if {[length $answer]>0} {
157         if {$answer != "N" & $answer != "n"} {
158             puts "Modify View Scaling Factor=$dAmp? Type factor, or press enter for NO."
159             gets stdin answerdAmp
160             if {[length $answerdAmp]>0} {
161                 set dAmp $answerdAmp
162             }
163         }
164         if {[string index $answer 0] == "N" || [string index $answer 0] == "n"} {
165             set ShapeType NodeNumbers
166         } elseif {[string index $answer 0] == "D" || [string index $answer 0] == "d"} {
167             set ShapeType DeformedShape
168         } else {
169             set ShapeType ModeShape
170             set nEigen $answer
171         }
172     } else {
173         return
174     }
175 }
176
177 if {$ShapeType == "ModeShape"} {
178     set lambdaN [eigen $nEigen]; # perform eigenvalue analysis for ModeShape
179     set lambda [lindex $lambdaN [expr $nEigen-1]];
180     set omega [expr pow($lambda,0.5)]
181     set PI [expr 2*asin(1.0)]; # define constant
182     set Tperiod [expr 2*$PI/$omega]; # period (sec.)
183     set fmt1 "Mode Shape, Mode=%1.1i Period=%3f %s "
184     set windowTitle [format $fmt1 $nEigen $Tperiod $TunitTXT]
185 } elseif {$ShapeType == "NodeNumbers"} {
186     set windowTitle "Node Numbers"
187 } elseif {$ShapeType == "DeformedShape"} {
188     set windowTitle "Deformed Shape"
189 }
190
191 set viewPlane XY
192 recorder display $windowTitle $xLoc $yLoc $xPixels $yPixels -wipe ; # display recorder
193 DisplayPlane $ShapeType $dAmp $viewPlane $nEigen 0
194 after 3000; #pause for 2 seconds to display
195 }
196
197 4. Display Plane Deformed Shape for 2D Model
198
199 proc DisplayPlane {ShapeType dAmp viewPlane {nEigen 0} {quadrant 0}} {
200     #####
201     ## DisplayPlane $ShapeType $dAmp $viewPlane $nEigen $quadrant
202     #####
203     ## setup display parameters for specified viewPlane and display
204     ##          Silvia Mazzoni & Frank McKenna, 2006
205     ##
206     ## ShapeType : type of shape to display. # options: ModeShape , NodeNumbers , DeformedShape
207     ## dAmp : relative amplification factor for deformations
208     ## viewPlane : set local xy axes in global coordinates (XY,YX,XZ,ZX,YZ,ZY)
209     ## nEigen : if nEigen not=0, show mode shape for nEigen eigenvalue
210     ## quadrant: quadrant where to show this figure (0=full figure)
211     ##
212     #####
213
214     set Xmin [lindex [nodeBounds] 0]; # view bounds in global coords - will add padding on the sides
215     set Ymin [lindex [nodeBounds] 1];
216     set Zmin [lindex [nodeBounds] 2];
217     set Xmax [lindex [nodeBounds] 3];
218     set Ymax [lindex [nodeBounds] 4];
219     set Zmax [lindex [nodeBounds] 5];
220
221     set Xo 0; # center of local viewing system
222     set Yo 0;
223     set Zo 0;
224
225     set uLocal [string index $viewPlane 0]; # viewPlane local-x axis in global coordinates
226     set vLocal [string index $viewPlane 1]; # viewPlane local-y axis in global coordinates
227
228
229     if {$viewPlane == "3D"} {

```

```

230     set uMin $Zmin+$Xmin
231     set uMax $Zmax+$Xmax
232     set vMin $Ymin
233     set vMax $Ymax
234     set wMin -10000
235     set wMax 10000
236     vup 0 1 0; # dirn defining up direction of view plane
237 } else {
238     set keyAxisMin "X $Xmin Y $Ymin Z $Zmin"
239     set keyAxisMax "X $Xmax Y $Ymax Z $Zmax"
240     set axisU [string index $viewPlane 0];
241     set axisV [string index $viewPlane 1];
242     set uMin [string map $keyAxisMin $axisU]
243     set uMax [string map $keyAxisMax $axisU]
244     set vMin [string map $keyAxisMin $axisV]
245     set vMax [string map $keyAxisMax $axisV]
246     if {$viewPlane == "YZ" || $viewPlane == "ZY" } {
247         set wMin $Xmin
248         set wMax $Xmax
249     } elseif {$viewPlane == "XY" || $viewPlane == "YX" } {
250         set wMin $Zmin
251         set wMax $Zmax
252     } elseif {$viewPlane == "XZ" || $viewPlane == "ZX" } {
253         set wMin $Ymin
254         set wMax $Ymax
255     } else {
256         return -1
257     }
258 }
259
260 set epsilon 1e-3; # make windows width or height not zero when the Max and Min values of a coordinate are the same
261
262 set uWide [expr $uMax - $uMin+$epsilon];
263 set vWide [expr $vMax - $vMin+$epsilon];
264 set uSide [expr 0.25*$uWide];
265 set vSide [expr 0.25*$vWide];
266 set uMin [expr $uMin - $uSide];
267 set uMax [expr $uMax + $uSide];
268 set vMin [expr $vMin - $vSide];
269 set vMax [expr $vMax + 2*$vSide]; # pad a little more on top, because of window title
270 set uWide [expr $uMax - $uMin+$epsilon];
271 set vWide [expr $vMax - $vMin+$epsilon];
272 set uMid [expr ($uMin+$uMax)/2];
273 set vMid [expr ($vMin+$vMax)/2];
274
275 # keep the following general, as change the X and Y and Z for each view plane
276 # next three commmands define viewing system, all values in global coords
277 vrp $Xo $Yo $Zo; # point on the view plane in global coord, center of local viewing system
278 if {$vLocal == "X"} {
279     vup 1 0 0; # dirn defining up direction of view plane
280 } elseif {$vLocal == "Y"} {
281     vup 0 1 0; # dirn defining up direction of view plane
282 } elseif {$vLocal == "Z"} {
283     vup 0 0 1; # dirn defining up direction of view plane
284 }
285 if {$viewPlane == "YZ" } {
286     vpn 1 0 0; # direction of outward normal to view plane
287     prp 10000. $uMid $vMid ; # eye location in local coord sys defined by viewing system
288     plane 10000 -10000; # distance to front and back clipping planes from eye
289 } elseif {$viewPlane == "ZY" } {
290     vpn -1 0 0; # direction of outward normal to view plane
291     prp -10000. $vMid $uMid ; # eye location in local coord sys defined by viewing system
292     plane 10000 -10000; # distance to front and back clipping planes from eye
293 } elseif {$viewPlane == "XY" } {
294     vpn 0 0 1; # direction of outward normal to view plane
295     prp $uMid $vMid 10000; # eye location in local coord sys defined by viewing system
296     plane 10000 -10000; # distance to front and back clipping planes from eye
297 } elseif {$viewPlane == "YX" } {
298     vpn 0 0 -1; # direction of outward normal to view plane
299     prp $uMid $vMid -10000; # eye location in local coord sys defined by viewing system
300     plane 10000 -10000; # distance to front and back clipping planes from eye
301 } elseif {$viewPlane == "XZ" } {
302     vpn 0 -1 0; # direction of outward normal to view plane
303     prp $uMid -10000 $vMid ; # eye location in local coord sys defined by viewing system
304     plane 10000 -10000; # distance to front and back clipping planes from eye
305 } elseif {$viewPlane == "ZX" } {
306     vpn 0 1 0; # direction of outward normal to view plane
307     prp $uMid 10000 $vMid ; # eye location in local coord sys defined by viewing system
308     plane 10000 -10000; # distance to front and back clipping planes from eye
309 } elseif {$viewPlane == "3D" } {

```

```

310     vpn 1 0.25 1.25; # direction of outward normal to view plane
311     prp -100 $vMid 10000; # eye location in local coord sys defined by viewing system
312     plane 10000 -10000; # distance to front and back clipping planes from eye
313 } else {
314     return -1
315 }
316 # next three commands define view, all values in local coord system
317 if {$viewPlane == "3D" } {
318     viewWindow [expr $uMin-$uWide/4] [expr $uMax/2] [expr $vMin-0.25*$vWide] [expr $vMax]
319 } else {
320     viewWindow $uMin $uMax $vMin $vMax
321 }
322 projection 1; # projection mode, 0:perspective, 1: parallel
323 fill 1; # fill mode; needed only for solid elements
324
325 if {$quadrant == 0} {
326     port -1 1 -1 1 # area of window that will be drawn into (uMin,uMax,vMin,vMax);
327 } elseif {$quadrant == 1} {
328     port 0 1 0 1 # area of window that will be drawn into (uMin,uMax,vMin,vMax);
329 } elseif {$quadrant == 2} {
330     port -1 0 0 1 # area of window that will be drawn into (uMin,uMax,vMin,vMax);
331 } elseif {$quadrant == 3} {
332     port -1 0 -1 0 # area of window that will be drawn into (uMin,uMax,vMin,vMax);
333 } elseif {$quadrant == 4} {
334     port 0 1 -1 0 # area of window that will be drawn into (uMin,uMax,vMin,vMax);
335 }
336
337 if {$ShapeType == "ModeShape" } {
338     display -$nEigen 0 [expr 5.*$dAmp]; # display mode shape for mode $nEigen
339 } elseif {$ShapeType == "NodeNumbers" } {
340     display 1 -1 0 ; # display node numbers
341 } elseif {$ShapeType == "DeformedShape" } {
342     display 1 2 $dAmp; # display deformed shape the 2 makes the nodes small
343 }
344 };
345 #
346 #####
347
348 5. Procedure for Defining Uniaxial Pinching Material
349
350 #####
351
352 # #
353
354 # procUniaxialPinching.tcl #
355
356 # procedure for activating the pinching material given its parameters in the form of list #
357
358 # created NM (nmitra@u.washington.edu) dated : Feb 2002 #
359
360 #####
361
362 proc procUniaxialPinching { materialTag pEnvelopeStress nEnvelopeStress pEnvelopeStrain nEnvelopeStrain rDisp rForce uForce
363 gammaK gammaD gammaF gammaE damage} {
364 }
365
366
367 2) 2D Model Definition for 3B6S Bare Frame:
368
369
370 #performing nonlinear static pushover analysis on 3B6S Bare Frame
371 #####
372
373 wipe all;
374 # define model builder
375 # model basic builder -ndm $ndm <-ndf $ndf>
376 model basic builder -ndm 2 -ndf 3
377
378 set dataDir Results; # set up name of data directory
379 file mkdir $dataDir; # create data directory
380 source Libunits.tcl; # define basic system units
381 source DisplayModel2D.tcl; # procedure for displaying a 2D View of model
382 source DisplayPlane.tcl; # procedure for displaying a plane in a model
383
384 #####
385
386 # buiding geometry
387 #####

```

```

387
388 # dimensions
389
390     set span1 4000.0;
391     set span2 4000.0;
392     set span3 4000.0;
393     set storey1 3000.0;
394     set storey2 3000.0;
395     set storey3 3000.0;
396     set storey4 3000.0;
397     set storey5 3000.0;
398     set storey6 3000.0;
399
400 # main grid lines
401     # vertical axis, x
402     set x1 [expr 0];
403     set x2 [expr $x1+$span1];
404     set x3 [expr $x2+$span2];
405     set x4 [expr $x3+$span3];
406
407     # horizontal axis, y
408     set z0 [expr 0];
409     set z1 [expr $z0+$storey1];
410     set z2 [expr $z1+$storey2];
411     set z3 [expr $z2+$storey3];
412     set z4 [expr $z3+$storey4];
413     set z5 [expr $z4+$storey5];
414     set z6 [expr $z5+$storey6];
415
416 # definition of nodes
417
418     #assigning node tages                                # for axes A,B,C, and D.
419     set N_A0      1;
420     set N_B0      2;
421     set N_C0      3;
422     set N_D0      4;
423     set N_A1      5;
424     set N_B1      6;
425     set N_C1      7;
426     set N_D1      8;
427     set N_A2      9;
428     set N_B2     10;
429     set N_C2     11;
430     set N_D2     12;
431     set N_A3     13;
432     set N_B3     14;
433     set N_C3     15;
434     set N_D3     16;
435     set N_A4     17;
436     set N_B4     18;
437     set N_C4     19;
438     set N_D4     20;
439     set N_A5     21;
440     set N_B5     22;
441     set N_C5     23;
442     set N_D5     24;
443     set N_A6     25;
444     set N_B6     26;
445     set N_C6     27;
446     set N_D6     28;
447
448     set N_A10_R  29;                                # N_Aij_R    i: story level.  j: axis number
449     set N_A10_A  30;
450     set N_A10_L  31;
451     set N_A20_R  32;
452     set N_A20_A  33;
453     set N_A20_L  34;
454     set N_A30_R  35;
455     set N_A30_A  36;
456     set N_A30_L  37;
457     set N_A40_R  38;
458     set N_A40_A  39;
459     set N_A40_L  40;
460     set N_A50_R  41;
461     set N_A50_A  42;
462     set N_A50_L  43;
463     set N_A60_R  44;
464     set N_A60_A  45;
465     set N_A60_L  46;

```

```

466
467     set N_B11_R 47;
468     set N_B11_A 48;
469     set N_B11_L 49;
470     set N_B21_R 50;
471     set N_B21_A 51;
472     set N_B21_L 52;
473     set N_B31_R 53;
474     set N_B31_A 54;
475     set N_B31_L 55;
476     set N_B41_R 56;
477     set N_B41_A 57;
478     set N_B41_L 58;
479     set N_B51_R 59;
480     set N_B51_A 60;
481     set N_B51_L 61;
482     set N_B61_R 62;
483     set N_B61_A 63;
484     set N_B61_L 64;
485
486     set N_C12_R 65;
487     set N_C12_A 66;
488     set N_C12_L 67;
489     set N_C22_R 68;
490     set N_C22_A 69;
491     set N_C22_L 70;
492     set N_C32_R 71;
493     set N_C32_A 72;
494     set N_C32_L 73;
495     set N_C42_R 74;
496     set N_C42_A 75;
497     set N_C42_L 76;
498     set N_C52_R 77;
499     set N_C52_A 78;
500     set N_C52_L 79;
501     set N_C62_R 80;
502     set N_C62_A 81;
503     set N_C62_L 82;
504
505     set N_D13_R 83;
506     set N_D13_A 84;
507     set N_D13_L 85;
508     set N_D23_R 86;
509     set N_D23_A 87;
510     set N_D23_L 88;
511     set N_D33_R 89;
512     set N_D33_A 90;
513     set N_D33_L 91;
514     set N_D43_R 92;
515     set N_D43_A 93;
516     set N_D43_L 94;
517     set N_D53_R 95;
518     set N_D53_A 96;
519     set N_D53_L 97;
520     set N_D63_R 98;
521     set N_D63_A 99;
522     set N_D63_L 100;
523
524
525     #node $nodetag (ndm $coords) <-mass (ndf $massvalues)>
526
527     set col_halfdepA [expr 600/2];           # This is used to define the joint dimensions.
528     set col_halfdepB [expr 600/2];
529     set col_halfdepC [expr 600/2];
530     set col_halfdepD [expr 600/2];
531     set beam_halfdep1 [expr 300/2];
532     set beam_halfdep2 [expr 300/2];
533     set beam_halfdep3 [expr 300/2];
534     set beam_halfdep4 [expr 300/2];
535     set beam_halfdep5 [expr 300/2];
536     set beam_halfdep6 [expr 300/2];
537
538     node $N_A0 $x1 $z0;
539     node $N_B0 $x2 $z0;
540     node $N_C0 $x3 $z0;
541     node $N_D0 $x4 $z0;
542     node $N_A1 $x1 [expr $z1-$beam_halfdep1];
543     node $N_B1 $x2 [expr $z1-$beam_halfdep1];
544     node $N_C1 $x3 [expr $z1-$beam_halfdep1];
545     node $N_D1 $x4 [expr $z1-$beam_halfdep1];

```

```

546     node $N_A2      $x1 [expr $z2-$beam_halfdep2];
547     node $N_B2      $x2 [expr $z2-$beam_halfdep2];
548     node $N_C2      $x3 [expr $z2-$beam_halfdep2];
549     node $N_D2      $x4 [expr $z2-$beam_halfdep2];
550     node $N_A3      $x1 [expr $z3-$beam_halfdep3];
551     node $N_B3      $x2 [expr $z3-$beam_halfdep3];
552     node $N_C3      $x3 [expr $z3-$beam_halfdep3];
553     node $N_D3      $x4 [expr $z3-$beam_halfdep3];
554     node $N_A4      $x1 [expr $z4-$beam_halfdep4];
555     node $N_B4      $x2 [expr $z4-$beam_halfdep4];
556     node $N_C4      $x3 [expr $z4-$beam_halfdep4];
557     node $N_D4      $x4 [expr $z4-$beam_halfdep4];
558     node $N_A5      $x1 [expr $z5-$beam_halfdep5];
559     node $N_B5      $x2 [expr $z5-$beam_halfdep5];
560     node $N_C5      $x3 [expr $z5-$beam_halfdep5];
561     node $N_D5      $x4 [expr $z5-$beam_halfdep5];
562     node $N_A6      $x1 [expr $z6-$beam_halfdep6];
563     node $N_B6      $x2 [expr $z6-$beam_halfdep6];
564     node $N_C6      $x3 [expr $z6-$beam_halfdep6];
565     node $N_D6      $x4 [expr $z6-$beam_halfdep6];
566
567
568 ##### add nodes - joints #####
569
570                                     # R: node at the right side of joint
571                                     # A: node above the joint
572                                     # L: node at the left side of the joint
573     node $N_A10_R   [expr $x1+$col_halfdepA] $z1;
574     node $N_A10_A   $x1 [expr $z1+$beam_halfdep1];
575     node $N_A10_L   [expr $x1-$col_halfdepA] $z1;
576     node $N_A20_R   [expr $x1+$col_halfdepA] $z2;
577     node $N_A20_A   $x1 [expr $z2+$beam_halfdep2];
578     node $N_A20_L   [expr $x1-$col_halfdepA] $z2;
579     node $N_A30_R   [expr $x1+$col_halfdepA] $z3;
580     node $N_A30_A   $x1 [expr $z3+$beam_halfdep3];
581     node $N_A30_L   [expr $x1-$col_halfdepA] $z3;
582     node $N_A40_R   [expr $x1+$col_halfdepA] $z4;
583     node $N_A40_A   $x1 [expr $z4+$beam_halfdep4];
584     node $N_A40_L   [expr $x1-$col_halfdepA] $z4;
585     node $N_A50_R   [expr $x1+$col_halfdepA] $z5;
586     node $N_A50_A   $x1 [expr $z5+$beam_halfdep5];
587     node $N_A50_L   [expr $x1-$col_halfdepA] $z5;
588     node $N_A60_R   [expr $x1+$col_halfdepA] $z6;
589     node $N_A60_A   $x1 [expr $z6+$beam_halfdep6];
590     node $N_A60_L   [expr $x1-$col_halfdepA] $z6;
591
592     node $N_B11_R   [expr $x2+$col_halfdepB] $z1;
593     node $N_B11_A   $x2 [expr $z1+$beam_halfdep1];
594     node $N_B11_L   [expr $x2-$col_halfdepB] $z1;
595     node $N_B21_R   [expr $x2+$col_halfdepB] $z2;
596     node $N_B21_A   $x2 [expr $z2+$beam_halfdep2];
597     node $N_B21_L   [expr $x2-$col_halfdepB] $z2;
598     node $N_B31_R   [expr $x2+$col_halfdepB] $z3;
599     node $N_B31_A   $x2 [expr $z3+$beam_halfdep3];
600     node $N_B31_L   [expr $x2-$col_halfdepB] $z3;
601     node $N_B41_R   [expr $x2+$col_halfdepB] $z4;
602     node $N_B41_A   $x2 [expr $z4+$beam_halfdep4];
603     node $N_B41_L   [expr $x2-$col_halfdepB] $z4;
604     node $N_B51_R   [expr $x2+$col_halfdepB] $z5;
605     node $N_B51_A   $x2 [expr $z5+$beam_halfdep5];
606     node $N_B51_L   [expr $x2-$col_halfdepB] $z5;
607     node $N_B61_R   [expr $x2+$col_halfdepB] $z6;
608     node $N_B61_A   $x2 [expr $z6+$beam_halfdep6];
609     node $N_B61_L   [expr $x2-$col_halfdepB] $z6;
610
611     node $N_C12_R   [expr $x3+$col_halfdepC] $z1;
612     node $N_C12_A   $x3 [expr $z1+$beam_halfdep1];
613     node $N_C12_L   [expr $x3-$col_halfdepC] $z1;
614     node $N_C22_R   [expr $x3+$col_halfdepC] $z2;
615     node $N_C22_A   $x3 [expr $z2+$beam_halfdep2];
616     node $N_C22_L   [expr $x3-$col_halfdepC] $z2;
617     node $N_C32_R   [expr $x3+$col_halfdepC] $z3;
618     node $N_C32_A   $x3 [expr $z3+$beam_halfdep3];
619     node $N_C32_L   [expr $x3-$col_halfdepC] $z3;
620     node $N_C42_R   [expr $x3+$col_halfdepC] $z4;
621     node $N_C42_A   $x3 [expr $z4+$beam_halfdep4];
622     node $N_C42_L   [expr $x3-$col_halfdepC] $z4;
623     node $N_C52_R   [expr $x3+$col_halfdepC] $z5;
624     node $N_C52_A   $x3 [expr $z5+$beam_halfdep5];
625     node $N_C52_L   [expr $x3-$col_halfdepC] $z5;

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626     node $N_C62_R [expr $x3+$col_halfdepC] $z6;
627     node $N_C62_A $x3 [expr $z6+$beam_halfdep6];
628     node $N_C62_L [expr $x3-$col_halfdepC] $z6;
629
630     node $N_D13_R [expr $x4+$col_halfdepD] $z1;
631     node $N_D13_A $x4 [expr $z1+$beam_halfdep1];
632     node $N_D13_L [expr $x4-$col_halfdepD] $z1;
633     node $N_D23_R [expr $x4+$col_halfdepD] $z2;
634     node $N_D23_A $x4 [expr $z2+$beam_halfdep2];
635     node $N_D23_L [expr $x4-$col_halfdepD] $z2;
636     node $N_D33_R [expr $x4+$col_halfdepD] $z3;
637     node $N_D33_A $x4 [expr $z3+$beam_halfdep3];
638     node $N_D33_L [expr $x4-$col_halfdepD] $z3;
639     node $N_D43_R [expr $x4+$col_halfdepD] $z4;
640     node $N_D43_A $x4 [expr $z4+$beam_halfdep4];
641     node $N_D43_L [expr $x4-$col_halfdepD] $z4;
642     node $N_D53_R [expr $x4+$col_halfdepD] $z5;
643     node $N_D53_A $x4 [expr $z5+$beam_halfdep5];
644     node $N_D53_L [expr $x4-$col_halfdepD] $z5;
645     node $N_D63_R [expr $x4+$col_halfdepD] $z6;
646     node $N_D63_A $x4 [expr $z6+$beam_halfdep6];
647     node $N_D63_L [expr $x4-$col_halfdepD] $z6;
648
649
650 # restraints
651
652     #basefix $nodetag (ndf $constraints)
653     fix $N_A0 1 1 1;
654     fix $N_B0 1 1 1;
655     fix $N_C0 1 1 1;
656     fix $N_D0 1 1 1;
657
658
659 #####
660 ##
661 # material definitions
662 #####
663 ##
664 # Definition of materials IDs
665
666     #set C_confinedB 1;
667     set C_confined 1;
668     set C_unconfined 2;
669     set R_steel 3;
670
671
672 # basic parameters for materials-con-concrete
673
674 # ConfinedConcrete01 Material
675
676     #tag integer tag identifying material.
677     #secType tag for the transverse reinforcement configuration.
678     #fpc unconfined cylindrical strength of concrete specimen.
679     #Ec initial elastic modulus of unconfined concrete.
680     #<-epscu $epscu> OR <-gamma $gamma> confined concrete ultimate strain.
681     #<-nu $nu> OR <-varub> OR <-varnoub> Poisson's Ratio.
682     #L1 length/diameter of square/circular core section measured respect to the hoop center line.
683     #($L2) additional dimensions when multiple hoops are being used.
684     #phiS hoop diameter. If section arrangement has multiple hoops it refers to the external hoop.
685     #S hoop spacing.
686     #fyh yielding strength of the hoop steel.
687     #Es0 elastic modulus of the hoop steel.
688     #haRatio hardening ratio of the hoop steel.
689     #mu ductility factor of the hoop steel.
690     #phiLon diameter of longitudinal bars.
691
692 # basic parameters for materials-uncon-concrete
693
694     set unconfc -28.0; # compression strength for concrete
695     set unconepsc -0.002; # strain at maximum stress in compression
696     set unconfu [expr $unconfc*0.18]; # ultimate stress for concrete
697     set unconepsu -0.01; # strain at ultimate stress in compression
698     set unconlambda 0.1; # ratio between reloading stiffness and itial stiffness in compression
699     set unconft [expr $unconfc*-0.1]; # maximum stress in tension for concrete
700     set unconEt [expr $unconft/0.002]; # elastic modulus in tension
701     set unconE0 [expr 2*$unconfc/$unconepsc]; #intial elastic tangent
702
703 # basic parameters for material--steel # ReinforcingSteel uniaxial material object. This object is intended to be u

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sed in a reinforced concrete fiber section as the steel reinforcing material.
704
705     set Fy 420.0; # Yield stress in tension
706     set Fu 596.0; # Ultimate stress in tension
707     set Es 200000.0; # Initial elastic tangent
708     set Esh 3100.0; # Tangent at initial strain hardening
709     set esh 0.01; # Strain corresponding to initial strain hardening
710     set eult 0.09; # Strain at peak stress
711
712     #uniaxialMaterial ReinforcingSteel $matTag $fy $fu $Es $Esh $esh $eult Define ReinforcingSteel uniaxial material
713     uniaxialMaterial ReinforcingSteel $R_steel $Fy $Fu $Es $Esh $esh $eult -DMBuck 6 0.8 -CMFatigue 0.2600 0.5000 0.3890 -Iso
Hard 4.3000 0.01
714
715 # definition of ConfinedConcrete01 material
716
717 #uniaxialMaterial ConfinedConcrete01 $tag $secType $fpc $Ec -eps cu $eps cu $nu $L1 $L2 $phis $S $f
yh $Es0 $haRatio $mu $phiLon -stRatio $stRatio
718 #uniaxialMaterial ConfinedConcrete01 $C_confinedB R -28 24870.1 -eps cu -0.04 -varUB 250.0 1450.0 10.0 125.0 4
20.0 200000.0 0.00 3100.0 12.0 -stRatio 0.85
719 #uniaxialMaterial ConfinedConcrete01 $C_confinedC R -28 24870.1 -eps cu -0.04 -varUB 550.0 200.0 10.0 125.0 4
20.0 200000.0 0.00 3100.0 18.0 -stRatio 0.85
720
721
722 # basic parameters for materials-con-concrete
723
724     set confc -32.5; # compression strength for concrete
725     set conepsc -0.003; # strain at maximum stress in compression
726     set confu [expr $confc*0.18]; # ultimate stress for concrete
727     set conepsu -0.04; # strain at ultimate stress in compression
728     set conlambda 0.1; # ratio between reloading stiffness and itial stiffness in compression
729     set conft [expr $confc*-0.1]; # maximum stress in tension for concrete
730     set conEt [expr $confu/0.002]; # elastic modulus in tension
731     set conE0 [expr 2*$confc/$conepsc]; #initial elastic tangent
732
733     # uniaxialMaterial Concrete02 $matTag $fpc $eps cu $fpcu $epsU $lambda $ft $Ets
734     uniaxialMaterial Concrete02 $C_unconfined $unconfc $unconepsc $unconfu $unconepsu $unconlambda $unconfu $unco
nEt;
735     uniaxialMaterial Concrete02 $C_confined $confc $conepsc $confu $conepsu $conlambda $confu $conEt;
736
737 #####
738 # definition of the Sections
739 #####
740
741 # define sections IDs
742
743     set col25x60 1;
744     set beam150x30 2;
745
746 # define section parameters
747
748     set pi 3.141593;
749     set rebar_12 [expr $pi*12.0*12.0/4]; # area rebar 12mm
750     set rebar_18 [expr $pi*18.0*18.0/4];
751     set w_col 250.0; # column width
752     set h_col 600.0; # column hieght
753     set c_col 20.0; # column cover
754     set w_beam 1500.0; # beam width
755     set h_beam 300.0; # beam hieght
756     set c_beam 30.0; # beam cover
757
758 # load procedure for fiber section
759
760 source BuildRCrectSection.tcl;
761
762 # build sections
763
764 #BuildRCrectSection $ColSecTag $HSec $BSec $coverH $coverB $coreID $coverID $steelID $numBarsTop $barAre
aTop $numBarsBot $barAreaBot $numBarsIntTot $barAreaInt $nfCoreY $nfCoreZ $nfCoverY $nfCoverZ
765 BuildRCrectSection $col25x60 $h_col $w_col $c_col $c_col $C_confined $C_unconfined $R_steel 4 $rebar_1
8 4 $rebar_18 2 $rebar_18 8 8 8
766 BuildRCrectSection $beam150x30 $h_beam $w_beam $c_beam $c_beam $C_confined $C_unconfined $R_steel 12 $rebar_1
2 8 $rebar_12 0 $rebar_12 8 8 8
767
768
769 #####
770 # beam column joint definition
771 #####

```

```

##
772
773 # dimensions of the joint respectively
774 set JointWidth [expr $h_col]; set JointHeight [expr $h_beam]; set JointDepth $w_col ;
775 set JointVolume [expr $JointWidth*$JointHeight*$JointDepth];
776
777 ##### details for the material models of bar slip of the beam #####
778
779 set bs_fc 28.0; set bs_fs 420.0; set bs_es 200000; set bs_fsu 596; set bs_dbar 12.0; set bs_esh 3100.0;
780 set bs_wid $w_col; set bs_dep $h_beam;
781 set bsT_nbars 12; set bsB_nbars 8;
782 set bs_ljoint $h_col;
783
784 ##### details for the material models of bar slip of the column #####
785
786 set cs_fc 28.0; set cs_fs 420.0; set cs_es 200000.0; set cs_fsu 596; set cs_dbar 18.0; set cs_esh 3100.0;
787 set cs_wid $w_col; set cs_dep $h_col;
788 set cs_nbars 5;
789 set cs_ljoint $h_beam;
790
791 #####
792 #bar slip definition
793
794 # for beam bottom
795
796 set bsid1 11
797 #uniaxialMaterial BarSlip $matTag $fc $fy $Es $fu $Eh $db $ld $nb $depth $height <$ancLratio> $bsFlag $type <$damage $unit>
798 uniaxialMaterial BarSlip $bsid1 $bs_fc $bs_fs $bs_es $bs_fsu $bs_esh $bs_dbar $bs_ljoint $bsB_nbars $bs_wid $bs_dep strong
beambot
799
800 # for beam top
801
802 set bsid2 21
803 #uniaxialMaterial BarSlip $matTag $fc $fy $Es $fu $Eh $db $ld $nb $depth $height <$ancLratio> $bsFlag $type <$damage $unit>
804 uniaxialMaterial BarSlip $bsid2 $bs_fc $bs_fs $bs_es $bs_fsu $bs_esh $bs_dbar $bs_ljoint $bsT_nbars $bs_wid $bs_dep strong
beamtopy
805
806 # for columns
807 set bsid3 31
808
809 #uniaxialMaterial BarSlip $matTag $fc $fy $Es $fu $Eh $db $ld $nb $depth $height <$ancLratio> $bsFlag $type <$damage $unit>
810 uniaxialMaterial BarSlip $bsid3 $cs_fc $cs_fs $cs_es $cs_fsu $cs_esh $cs_dbar $cs_ljoint $cs_nbars $cs_wid $cs_dep strong c
olumn
811
812
813 ##### material for shear panel #####
814
815 ## Positive/Negative envelope Stress
816
817 set spid1 41;
818 set A 0.78;
819 set p1 [expr 2.539*$A]; set p2 [expr 3.005*$A]; set p3 [expr 3.163*$A]; set p4 [expr 0.6326*$A];
820
821 ## stress1 stress2 stress3 stress4
822 set pEnvStrsp [list [expr $p1*$JointVolume] [expr $p2*$JointVolume] [expr $p3*$JointVolume] [expr $p4*$JointVolume]]
823 set nEnvStrsp [list [expr -$p1*$JointVolume] [expr -$p2*$JointVolume] [expr -$p3*$JointVolume] [expr -$p4*$JointVolume]]
824
825 ## Positive/Negative envelope Strain
826 ## strain1 strain2 strain3 strain4
827
828 set pEnvStnsp [list 0.0008 0.015 0.035 0.04]
829 set nEnvStnsp [list -0.0008 -0.015 -0.035 -0.04]
830
831 ## Ratio of maximum deformation at which reloading begins
832 ## Pos_env. Neg_env.
833 set rDispsp [list 0.2 0.2]
834
835 ## Ratio of envelope force (corresponding to maximum deformation) at which reloading begins
836
837 ### Pos_env. Neg_env.
838 set rForcesp [list 0.2 0.2]
839
840
841 ## Ratio of monotonic strength developed upon unloading
842 ### Pos_env. Neg_env.
843
844 set uForcesp [list 0.0 0.0]

```

```

845
846
847 ## Coefficients for Unloading Stiffness degradation
848
849 ## gammaK1 gammaK2 gammaK3 gammaK4 gammaKLimit
850
851 #set gammaKsp [list 1.13364492409642 0.0 0.10111033064469 0.0 0.91652498468618]
852
853 set gammaKsp [list 0.0 0.0 0.0 0.0 0.0]
854
855 ##### Coefficients for Reloading Stiffness degradation
856 ### gammaD1 gammaD2 gammaD3 gammaD4 gammaDLimit
857
858 #set gammaDsp [list 0.12 0.0 0.23 0.0 0.95]
859
860 set gammaDsp [list 0.0 0.0 0.0 0.0 0.0]
861 ##### Coefficients for Strength degradation
862 ### gammaF1 gammaF2 gammaF3 gammaF4 gammaFLimit
863
864 #set gammaFsp [list 1.11 0.0 0.319 0.0 0.125]
865 set gammaFsp [list 0.0 0.0 0.0 0.0 0.0]
866
867 set gammaEsp 10.0
868
869 uniaxialMaterial Pinching4 $spid1 [lindex $pEnvStrsp 0] [lindex $pEnvStnsp 0] \
870 [lindex $pEnvStrsp 1] [lindex $pEnvStnsp 1] [lindex $pEnvStrsp 2] \
871 [lindex $pEnvStrsp 3] [lindex $pEnvStrsp 3] [lindex $pEnvStnsp 3] \
872 [lindex $nEnvStrsp 0] [lindex $nEnvStnsp 0] \
873 [lindex $nEnvStrsp 1] [lindex $nEnvStnsp 1] [lindex $nEnvStrsp 2] \
874 [lindex $nEnvStrsp 2] [lindex $nEnvStrsp 3] [lindex $nEnvStnsp 3] \
875 [lindex $rDispsp 0] [lindex $rForcesp 0] [lindex $uForcesp 0] \
876 [lindex $rDispsp 1] [lindex $rForcesp 1] [lindex $uForcesp 1] \
877 [lindex $gammaKsp 0] [lindex $gammaKsp 1] [lindex $gammaKsp 2] [lindex $gammaKsp 3] [lindex $gammaKsp 4] \
878 [lindex $gammaDsp 0] [lindex $gammaDsp 1] [lindex $gammaDsp 2] [lindex $gammaDsp 3] [lindex $gammaDsp 4] \
879 [lindex $gammaFsp 0] [lindex $gammaFsp 1] [lindex $gammaFsp 2] [lindex $gammaFsp 3] [lindex $gammaFsp 4] \
880 $gammaEsp energy
881
882 ##### beam column joint #####
883
884 #element BeamColumnJoint tag? iNode? jNode? kNode? lNode? matTag1? matTag2? matTag3? matTag4?
885 # matTag5? matTag6? matTag7? matTag8? matTag9? matTag10? matTag11? matTag12? matTag13?
886 # <element Height factor?> <element Width factor?>
887 # please note: the four nodes are in anticlockwise direction around the element
888 # requires material tags for all 13 different components within the element.
889 # the first 12 being that of spring and the last of the shear panel
890
891 set jointA1 611
892 set jointA2 612
893 set jointA3 613
894 set jointA4 614
895 set jointA5 615
896 set jointA6 616
897
898 set jointB1 621
899 set jointB2 622
900 set jointB3 623
901 set jointB4 624
902 set jointB5 625
903 set jointB6 626
904
905 set jointC1 631
906 set jointC2 632
907 set jointC3 633
908 set jointC4 634
909 set jointC5 635
910 set jointC6 636
911
912 set jointD1 641
913 set jointD2 642
914 set jointD3 643
915 set jointD4 644
916 set jointD5 645
917 set jointD6 646
918
919 # add material Properties - command: uniaxialMaterial matType matTag ...
920 #command: uniaxialMaterial Elastic tag? E?
921
922 uniaxialMaterial Elastic 71 1000000000.0
923
924 element beamColumnJoint $jointA1 $N_A1 $N_A10_R $N_A10_A $N_A10_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1

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```

925 element beamColumnJoint $jointA2 $N_A2 $N_A20_R $N_A20_A $N_A20_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
926 element beamColumnJoint $jointA3 $N_A3 $N_A30_R $N_A30_A $N_A30_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
927 element beamColumnJoint $jointA4 $N_A4 $N_A40_R $N_A40_A $N_A40_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
928 element beamColumnJoint $jointA5 $N_A5 $N_A50_R $N_A50_A $N_A50_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
929 element beamColumnJoint $jointA6 $N_A6 $N_A60_R $N_A60_A $N_A60_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
930
931 element beamColumnJoint $jointB1 $N_B1 $N_B11_R $N_B11_A $N_B11_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
932 element beamColumnJoint $jointB2 $N_B2 $N_B21_R $N_B21_A $N_B21_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
933 element beamColumnJoint $jointB3 $N_B3 $N_B31_R $N_B31_A $N_B31_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
934 element beamColumnJoint $jointB4 $N_B4 $N_B41_R $N_B41_A $N_B41_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
935 element beamColumnJoint $jointB5 $N_B5 $N_B51_R $N_B51_A $N_B51_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
936 element beamColumnJoint $jointB6 $N_B6 $N_B61_R $N_B61_A $N_B61_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
937
938 element beamColumnJoint $jointC1 $N_C1 $N_C12_R $N_C12_A $N_C12_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
939 element beamColumnJoint $jointC2 $N_C2 $N_C22_R $N_C22_A $N_C22_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
940 element beamColumnJoint $jointC3 $N_C3 $N_C32_R $N_C32_A $N_C32_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
941 element beamColumnJoint $jointC4 $N_C4 $N_C42_R $N_C42_A $N_C42_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
942 element beamColumnJoint $jointC5 $N_C5 $N_C52_R $N_C52_A $N_C52_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
943 element beamColumnJoint $jointC6 $N_C6 $N_C62_R $N_C62_A $N_C62_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
944
945 element beamColumnJoint $jointD1 $N_D1 $N_D13_R $N_D13_A $N_D13_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
946 element beamColumnJoint $jointD2 $N_D2 $N_D23_R $N_D23_A $N_D23_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
947 element beamColumnJoint $jointD3 $N_D3 $N_D33_R $N_D33_A $N_D33_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
948 element beamColumnJoint $jointD4 $N_D4 $N_D43_R $N_D43_A $N_D43_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
949 element beamColumnJoint $jointD5 $N_D5 $N_D53_R $N_D53_A $N_D53_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
950 element beamColumnJoint $jointD6 $N_D6 $N_D63_R $N_D63_A $N_D63_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
951
952
953 #####
954 # Elements definitions
955 #####
956
957 # COLUMN definition
958
959 # -----
960 # Define geometric transformation
961 # -----
962 set ColTransfTag 1;          # associate a tag to column transformation
963 geomTransf PDelta $ColTransfTag ; #Columns
964
965 # -----
966 # --- element connectivity "Columns Definition"-----
967 # -----
968 set numIntPoints 4;
969 set integrationC "Lobatto $col25x60 $numIntPoints"
970
971 element forceBeamColumn 710      $N_A0  $N_A1 $ColTransfTag $integrationC
972 element forceBeamColumn 720      $N_A10_A  $N_A2 $ColTransfTag $integrationC
973 element forceBeamColumn 730      $N_A20_A  $N_A3 $ColTransfTag $integrationC
974 element forceBeamColumn 740      $N_A30_A  $N_A4 $ColTransfTag $integrationC
975 element forceBeamColumn 750      $N_A40_A  $N_A5 $ColTransfTag $integrationC
976 element forceBeamColumn 760      $N_A50_A  $N_A6 $ColTransfTag $integrationC
977
978 element forceBeamColumn 711      $N_B0  $N_B1 $ColTransfTag $integrationC
979 element forceBeamColumn 721      $N_B11_A  $N_B2 $ColTransfTag $integrationC
980 element forceBeamColumn 731      $N_B21_A  $N_B3 $ColTransfTag $integrationC

```

```

981 element forceBeamColumn 741 $N_B31_A $N_B4 $ColTransfTag $integrationC
982 element forceBeamColumn 751 $N_B41_A $N_B5 $ColTransfTag $integrationC
983 element forceBeamColumn 761 $N_B51_A $N_B6 $ColTransfTag $integrationC
984
985 element forceBeamColumn 712 $N_C0 $N_C1 $ColTransfTag $integrationC
986 element forceBeamColumn 722 $N_C12_A $N_C2 $ColTransfTag $integrationC
987 element forceBeamColumn 732 $N_C22_A $N_C3 $ColTransfTag $integrationC
988 element forceBeamColumn 742 $N_C32_A $N_C4 $ColTransfTag $integrationC
989 element forceBeamColumn 752 $N_C42_A $N_C5 $ColTransfTag $integrationC
990 element forceBeamColumn 762 $N_C52_A $N_C6 $ColTransfTag $integrationC
991
992 element forceBeamColumn 713 $N_D0 $N_D1 $ColTransfTag $integrationC
993 element forceBeamColumn 723 $N_D13_A $N_D2 $ColTransfTag $integrationC
994 element forceBeamColumn 733 $N_D23_A $N_D3 $ColTransfTag $integrationC
995 element forceBeamColumn 743 $N_D33_A $N_D4 $ColTransfTag $integrationC
996 element forceBeamColumn 753 $N_D43_A $N_D5 $ColTransfTag $integrationC
997 element forceBeamColumn 763 $N_D53_A $N_D6 $ColTransfTag $integrationC
998
999
1000 #####
1001
1002 # BEAMS definition
1003
1004 # -----
1005 # Define geometric transformation
1006 # -----
1007 set BeamTransfTag 2; # associate a tag to beam transformation
1008 geomTransf PDelta $BeamTransfTag ; #Beams
1009
1010 # -----
1011 # --- element connectivity "Beams Definition"-----
1012 # -----
1013 set numIntPoints_beams 5;
1014 set integrationB "Lobatto $beam150x30 $numIntPoints_beams"
1015
1016 element forceBeamColumn 810 $N_A10_R $N_B11_L $BeamTransfTag $integrationB
1017 element forceBeamColumn 820 $N_A20_R $N_B21_L $BeamTransfTag $integrationB
1018 element forceBeamColumn 830 $N_A30_R $N_B31_L $BeamTransfTag $integrationB
1019 element forceBeamColumn 840 $N_A40_R $N_B41_L $BeamTransfTag $integrationB
1020 element forceBeamColumn 850 $N_A50_R $N_B51_L $BeamTransfTag $integrationB
1021 element forceBeamColumn 860 $N_A60_R $N_B61_L $BeamTransfTag $integrationB
1022
1023 element forceBeamColumn 811 $N_B11_R $N_C12_L $BeamTransfTag $integrationB
1024 element forceBeamColumn 821 $N_B21_R $N_C22_L $BeamTransfTag $integrationB
1025 element forceBeamColumn 831 $N_B31_R $N_C32_L $BeamTransfTag $integrationB
1026 element forceBeamColumn 841 $N_B41_R $N_C42_L $BeamTransfTag $integrationB
1027 element forceBeamColumn 851 $N_B51_R $N_C52_L $BeamTransfTag $integrationB
1028 element forceBeamColumn 861 $N_B61_R $N_C62_L $BeamTransfTag $integrationB
1029
1030 element forceBeamColumn 812 $N_C12_R $N_D13_L $BeamTransfTag $integrationB
1031 element forceBeamColumn 822 $N_C22_R $N_D23_L $BeamTransfTag $integrationB
1032 element forceBeamColumn 832 $N_C32_R $N_D33_L $BeamTransfTag $integrationB
1033 element forceBeamColumn 842 $N_C42_R $N_D43_L $BeamTransfTag $integrationB
1034 element forceBeamColumn 852 $N_C52_R $N_D53_L $BeamTransfTag $integrationB
1035 element forceBeamColumn 862 $N_C62_R $N_D63_L $BeamTransfTag $integrationB
1036
1037 #####
1038 # display the model with the node numbers
1039 DisplayModel2D NodeNumbers
1040
1041 #####
1042 # gravity and masses load
1043 #####
1044
1045 # timeSeries "LinearDefault": tsTag cFactor
1046 timeSeries Linear 1 -factor 1;
1047
1048 # distributed loads
1049
1050 #set DL 11000.0; # self weight add as point load (N)
1051 set TLE 64800.0; # TLE: Total Load at the middle columns
1052 set TLM 129600.0; # TLM: Total Load at the middle columns
1053
1054 # pattern PatternType $PatternID TimeSeriesType
1055 pattern Plain 1 1 {
1056 #load $nodeTag (ndf $LoadValues)
1057 load $N_A10_A 0 [expr -$TLE] 0;

```

```

1058     load  $N_A20_A 0 [expr -$TLE] 0;
1059     load  $N_A30_A 0 [expr -$TLE] 0;
1060     load  $N_A40_A 0 [expr -$TLE] 0;
1061     load  $N_A50_A 0 [expr -$TLE] 0;
1062     load  $N_A60_A 0 [expr -$TLE] 0;
1063
1064     load  $N_B11_A 0 [expr -$TLM] 0;
1065     load  $N_B21_A 0 [expr -$TLM] 0;
1066     load  $N_B31_A 0 [expr -$TLM] 0;
1067     load  $N_B41_A 0 [expr -$TLM] 0;
1068     load  $N_B51_A 0 [expr -$TLM] 0;
1069     load  $N_B61_A 0 [expr -$TLM] 0;
1070
1071     load  $N_C12_A 0 [expr -$TLM] 0;
1072     load  $N_C22_A 0 [expr -$TLM] 0;
1073     load  $N_C32_A 0 [expr -$TLM] 0;
1074     load  $N_C42_A 0 [expr -$TLM] 0;
1075     load  $N_C52_A 0 [expr -$TLM] 0;
1076     load  $N_C62_A 0 [expr -$TLM] 0;
1077
1078     load  $N_D13_A 0 [expr -$TLE] 0;
1079     load  $N_D23_A 0 [expr -$TLE] 0;
1080     load  $N_D33_A 0 [expr -$TLE] 0;
1081     load  $N_D43_A 0 [expr -$TLE] 0;
1082     load  $N_D53_A 0 [expr -$TLE] 0;
1083     load  $N_D63_A 0 [expr -$TLE] 0;
1084
1085     #eleLoad -ele $eleTag1 <$eleTag2> -type -beamuniformload $wy
1086     #eleLoad -ele 5 6 -type -beamUniform [expr -$DL];
1087
1088 }
1089
1090
1091 # masses
1092
1093     set mass1 19440;
1094     set mass2 19440;
1095     set mass3 19440;
1096     set mass4 19440;
1097     set mass5 19440;
1098     set mass6 19440;
1099
1100
1101
1102 # assign mass to nodes
1103
1104 #mass $nodetag (ndf $massvalues)
1105 mass $N_A10_L [expr $mass1/2] 0.1 0.1;
1106 mass $N_A20_L [expr $mass1/2] 0.1 0.1;
1107 mass $N_A30_L [expr $mass1/2] 0.1 0.1;
1108 mass $N_A40_L [expr $mass1/2] 0.1 0.1;
1109 mass $N_A50_L [expr $mass1/2] 0.1 0.1;
1110 mass $N_A60_L [expr $mass1/2] 0.1 0.1;
1111
1112 mass $N_B11_L [expr $mass1/2] 0.1 0.1;
1113 mass $N_B21_L [expr $mass1/2] 0.1 0.1;
1114 mass $N_B31_L [expr $mass1/2] 0.1 0.1;
1115 mass $N_B41_L [expr $mass1/2] 0.1 0.1;
1116 mass $N_B51_L [expr $mass1/2] 0.1 0.1;
1117 mass $N_B61_L [expr $mass1/2] 0.1 0.1;
1118
1119 mass $N_C12_L [expr $mass1/2] 0.1 0.1;
1120 mass $N_C22_L [expr $mass1/2] 0.1 0.1;
1121 mass $N_C32_L [expr $mass1/2] 0.1 0.1;
1122 mass $N_C42_L [expr $mass1/2] 0.1 0.1;
1123 mass $N_C52_L [expr $mass1/2] 0.1 0.1;
1124 mass $N_C62_L [expr $mass1/2] 0.1 0.1;
1125
1126 mass $N_D13_L [expr $mass1/2] 0.1 0.1;
1127 mass $N_D23_L [expr $mass1/2] 0.1 0.1;
1128 mass $N_D33_L [expr $mass1/2] 0.1 0.1;
1129 mass $N_D43_L [expr $mass1/2] 0.1 0.1;
1130 mass $N_D53_L [expr $mass1/2] 0.1 0.1;
1131 mass $N_D63_L [expr $mass1/2] 0.1 0.1;
1132
1133
1134
1135 puts "Model Built"
1136
1137

```

```

1138 3) Gravity Analysis Procedure:
1139
1140 #####
1141
1142 # start analysis
1143
1144 initialize
1145
1146 puts "ooo Analysis: Gravity ooo"
1147
1148 #####
1149
1150 # set recorders
1151
1152 # Node Recorder "Reactions": fileName <nodeTag> dof resptype
1153 recorder Node -file $dataDir/RBase.out -time -node $N_A0 $N_B0 $N_C0 $N_D0 -dof 2 reaction;
1154
1155 #####
1156
1157 # analysis options
1158
1159
1160 # Constraint Handler
1161 constraints Plain
1162
1163 # DOF numberer
1164 numberer RCM
1165
1166 # System of Equations
1167 system ProfileSPD
1168
1169 # Convergence Test
1170 test NormDispIncr 1.00000E-006 100 0 2;
1171
1172 # Solution Algorithm
1173 algorithm Newton
1174
1175 # Integrator
1176 #integrator LoadControl $Lambda <$numIter $minLambda $maxLambda>
1177 integrator LoadControl 0.01
1178
1179 # Analysis Type
1180 analysis Static
1181
1182 # Record initial state of model
1183 record
1184
1185 #Analysis model
1186 analyze 100
1187
1188 # Reset for next analysis case
1189 setTime 0.0
1190 loadConst
1191 remove recorders
1192 wipeAnalysis
1193
1194 puts "Gravity analysis completed"
1195
1196
1197 4) Modal Analysis Procedure:
1198
1199 #####
1200
1201 # start analysis
1202
1203 initialize
1204
1205 puts "ooo Analysis: ModalAnalysis ooo"
1206
1207 #####
1208
1209 # set recorders
1210
1211 # Node Recorder "EigenVectors": fileName <nodeTag> dof resptype
1212 recorder Node -file $dataDir/ModalAnalysis_Node_EigenVectors_EigenVec1.out -node $N_A0 $N_A10_A $N_A20_A $N_A30_A $N_A40_A $N_A50_A $N_A60_A -dof 1 eigen1
1213 recorder Node -file $dataDir/ModalAnalysis_Node_EigenVectors_EigenVec2.out -node $N_A0 $N_A10_A $N_A20_A $N_A30_A $N_A40_A $N_A50_A $N_A60_A -dof 1 eigen2
1214
1215 #####

```

```

1216 # analysis options
1217
1218
1219
1220 # Constraint Handler
1221 constraints Transformation
1222
1223 # DOF numberer
1224 numberer Plain
1225
1226 # System of Equations
1227 system BandGeneral
1228
1229 # Convergence Test
1230 test NormDispIncr 1.00000E-5 50 0 2;
1231
1232 # Solution Algorithm
1233 algorithm Newton
1234
1235 # Integrator
1236 integrator Newmark 5.000000E-01 2.500000E-01
1237
1238 # Analysis Type
1239 analysis Transient
1240
1241 # Analysis model (and record response)
1242 set pi [expr 2.0*asin(1.0)]; # Definition of pi
1243 set nEigenI 1; # mode i = 1
1244 set nEigenJ 2; # mode j = 2
1245 set lambdaN [eigen [expr $nEigenJ]]; # eigenvalue analysis for nEigenJ modes
1246 set lambdaI [lindex $lambdaN [expr 0]]; # eigenvalue mode i = 1
1247 set lambdaJ [lindex $lambdaN [expr $nEigenJ-1]]; # eigenvalue mode j = 2
1248 set w1 [expr pow(($lambdaI*1000),0.5)]; # w1 (1st mode circular frequency)
1249 set w2 [expr pow(($lambdaJ*1000),0.5)]; # w2 (2nd mode circular frequency)
1250 set T1 [expr 2.0*$pi/$w1]; # 1st mode period of the structure
1251 set T2 [expr 2.0*$pi/$w2]; # 2nd mode period of the structure
1252
1253 puts "T1 is $T1"
1254 puts "T2 is $T2"
1255 # Record eigenvectors
1256 record
1257
1258
1259 # Reset for next analysis case
1260 setTime 0.0
1261 loadConst
1262 remove recorders
1263 wipeAnalysis
1264
1265 puts "Modal analysis completed"
1266
1267 5) Pushover Analysis Procedure:
1268
1269 #####
1270
1271 # start analysis
1272
1273
1274 puts "ooo Analysis: Pushover ooo"
1275
1276 #####
1277
1278 # set recorders
1279
1280 # Global behaviour
1281
1282 # Node Recorder "Displacements": fileName <nodeTag> dof resptype
1283 recorder Node -file $dataDir/Pushover_Horizontal_Reactions.out -time -node $N_A0 $N_B0 $N_C0 $N_D0 -dof 1 rea
tion
1284 recorder Node -file $dataDir/Pushover_Storey_Displacement.out -time -node $N_A50_L $N_A60_L -dof 1 disp
1285 #recorder Node -file $dataDir/DFree.out -time -node $N_A10_L $N_A20_L -dof 1 2 disp; # displacements of free n
odes
1286 recorder Element -file $dataDir/force10.out -time -ele 710 720 730 740 750 760 711 721 731 741 751 761 localForce
;
1287 recorder Element -file $dataDir/ele1sec1StressStrain.out -time -ele 710 section 1 fiber 0 0 $C_confined stressStrain
1288 #recorder Element -file $dataDir/force10c.out -time -ele 710 section 1 fiber $R_steel 0. $C_unconfined stressS
train;
1289 #recorder Element -file $dataDir/force60Bc.out -time -ele 860 section 1 fiber y z $C_unconfined stressStrain;
1290 recorder Element -file $dataDir/force10B.out -time -ele 810 811 812 820 821 822 830 831 832 840 841 842 850 851 852

```



```

1291      860 861 862 localForce;
recorder Element -file $dataDir/SP1.out -time -ele 611 612 613 614 615 616 621 622 623 624 625 626 shearpanel stressStrain

1292
1293
1294 # analysis options
1295
1296
1297 set tStart [clock clicks -milliseconds]
1298
1299
1300 # display deformed shape:
1301     set ViewScale 5;
1302     DisplayModel2D DeformedShape $ViewScale ; # display deformed shape, the scaling factor needs to be adjusted for each mode
1303
1304 # characteristics of pushover analysis
1305 set Dmax 1800; # maximum displacement of pushover. push to 10% drift.
1306 set Dincr 0.01; # displacement increment for pushover. you want this to be very small, but not too small to slow down the analysis
1307 set Tol 1;
1308 # create load pattern for lateral pushover load
1309 pattern Plain 200 Linear {; # define load pattern -- generalized
1310     load $N_A60_L 6 0 0
1311     load $N_A50_L 5 0 0
1312     load $N_A40_L 4 0 0
1313     load $N_A30_L 3 0 0
1314     load $N_A20_L 2 0 0
1315     load $N_A10_L 1 0 0
1316
1317
1318 }
1319
1320
1321 # ----- set up analysis parameters
1322
1323 # ## CONSTRAINTS handler >> Determines how the constraint equations are enforced in the analysis
1324
1325 # >> Plain Constraints -- Removes constrained degrees of freedom from the system of equations (only for homogeneous equations)
1326 # >> Lagrange Multipliers -- Uses the method of Lagrange multipliers to enforce constraints
1327 # >> Penalty Method -- Uses penalty numbers to enforce constraints --good for static analysis with non-homogeneous eqns (rigidDiaphragm)
1328 # >> Transformation Method -- Performs a condensation of constrained degrees of freedom
1329 variable constraintsTypeStatic Transformation; # default;
1330 constraints $constraintsTypeStatic
1331
1332 # DOF NUMBERER (number the degrees of freedom in the domain):
1333
1334 # Determines the mapping between equation numbers and degrees-of-freedom
1335 # Plain -- Uses the numbering provided by the user
1336 # RCM -- Renumbers the DOF to minimize the matrix band-width using the Reverse Cuthill-McKee algorithm
1337 set numbererTypeStatic RCM
1338 numberer $numbererTypeStatic
1339
1340
1341 # SYSTEM:
1342
1343 # Linear Equation Solvers (how to store and solve the system of equations in the analysis)
1344 # -- provide the solution of the linear system of equations  $Ku = P$ . Each solver is tailored to a specific matrix topology.
1345 # ProfileSPD -- Direct profile solver for symmetric positive definite matrices
1346 # BandGeneral -- Direct solver for banded unsymmetric matrices
1347 # BandSPD -- Direct solver for banded symmetric positive definite matrices
1348 # SparseGeneral -- Direct solver for unsymmetric sparse matrices
1349 # SparseSPD -- Direct solver for symmetric sparse matrices
1350 # UmfPack -- Direct UmfPack solver for unsymmetric matrices
1351 set systemTypeStatic UmfPack; # try UmfPack for large model
1352 system $systemTypeStatic
1353
1354 # TEST: # convergence test to
1355
1356 # -- Accept the current state of the domain as being on the converged solution path
1357 # -- determine if convergence has been achieved at the end of an iteration step
1358 # NormUnbalance -- Specifies a tolerance on the norm of the unbalanced load at the current iteration
1359 # NormDispIncr -- Specifies a tolerance on the norm of the displacement increments at the current iteration
1360 # EnergyIncr-- Specifies a tolerance on the inner product of the unbalanced load and displacement increments at the current iteration
1361 # RelativeNormUnbalance --
1362 # RelativeNormDispIncr --

```

```

1363 #           RelativeEnergyIncr --
1364 variable TolStatic 0.01;                # Convergence Test: tolerance
1365 variable maxNumIterStatic 10000;        # Convergence Test: maximum number of iterations that will be performed befo
re "failure to converge" is returned
1366 variable printFlagStatic 0;            # Convergence Test: flag used to print information on convergence (optional)
# 1: print information on each step;
1367 variable testTypeStatic EnergyIncr ;   # Convergence-test type
1368 test $testTypeStatic $TolStatic $maxNumIterStatic $printFlagStatic;
1369
1370 # Solution ALGORITHM: -- Iterate from the last time step to the current
1371 #     Linear -- Uses the solution at the first iteration and continues
1372 #     Newton -- Uses the tangent at the current iteration to iterate to convergence
1373 #     ModifiedNewton -- Uses the tangent at the first iteration to iterate to convergence
1374 #     NewtonLineSearch --
1375 #     KrylovNewton --
1376 #     BFGS --
1377 #     Broyden --
1378 variable algorithmTypeStatic Newton
1379 algorithm $algorithmTypeStatic;
1380
1381 # Static INTEGRATOR: -- determine the next time step for an analysis
1382
1383 #     LoadControl -- Specifies the incremental load factor to be applied to the loads in the domain
1384 #     DisplacementControl -- Specifies the incremental displacement at a specified DOF in the domain
1385 #     Minimum Unbalanced Displacement Norm -- Specifies the incremental load factor such that the residual displacement
norm in minimized
1386 #     Arc Length -- Specifies the incremental arc-length of the load-displacement path
1387 # Transient INTEGRATOR: -- determine the next time step for an analysis including inertial effects
1388 #     Newmark -- The two parameter time-stepping method developed by Newmark
1389 #     HHT -- The three parameter Hilbert-Hughes-Taylor time-stepping method
1390 #     Central Difference -- Approximates velocity and acceleration by centered finite differences of displacement
1391 integrator DisplacementControl $N_A60_L 1 $Dincr
1392
1393 # ANALYSIS -- defines what type of analysis is to be performed
1394
1395 #     Static Analysis -- solves the KU=R problem, without the mass or damping matrices.
1396 #     Transient Analysis -- solves the time-dependent analysis. The time step in this type of analysis is constant. The
time step in the output is also constant.
1397 #     variableTransient Analysis -- performs the same analysis type as the Transient Analysis object. The time step, ho
wever, is variable. This method is used when
1398 #         there are convergence problems with the Transient Analysis object at a peak or when the time step is too s
mall. The time step in the output is also variable.
1399 set analysisTypeStatic Static
1400 analysis $analysisTypeStatic
1401
1402
1403 # ----- perform Static Pushover Analysis
1404 set Nsteps [expr int($Dmax/$Dincr)];    # number of pushover analysis steps
1405 set ok [analyze $Nsteps];              # this will return zero if no convergence problems were encountered
1406 set fmt1 "%s Pushover analysis: CtrlNode %.24i, dof %.1i, Disp=%.4f %s"; # format for screen/file output of DONE/PROBLEM a
nalysis
1407 if {$ok != 0} {
1408 # if analysis fails, we try some other stuff, performance is slower inside this loop
1409 set Dstep 0.0;
1410 set ok 0
1411 while {$Dstep <= 1.0 && $ok == 0} {
1412 set controlDisp [nodeDisp $N_A60_L 1 ]
1413 set Dstep [expr $controlDisp/$Dmax]
1414 set ok [analyze 1 ]
1415 # if analysis fails, we try some other stuff
1416 # performance is slower inside this loop global maxNumIterStatic; # max no. of iterations performed before "fai
lure to converge" is ret'd
1417 if {$ok != 0} {
1418 puts "Trying Newton with Initial Tangent .."
1419 test NormDispIncr $Tol 3000 0
1420 algorithm Newton -initial
1421 set ok [analyze 1]
1422 test $testTypeStatic $TolStatic $maxNumIterStatic 0
1423 algorithm $algorithmTypeStatic
1424 }
1425 if {$ok != 0} {
1426 puts "Trying Broyden .."
1427 algorithm Broyden 8
1428 set ok [analyze 1 ]
1429 algorithm $algorithmTypeStatic
1430 }
1431 if {$ok != 0} {
1432 puts "Trying NewtonWithLineSearch .."
1433 algorithm NewtonLineSearch 0.8
1434 set ok [analyze 1]

```

```
1435     algorithm $algorithmTypeStatic
1436     }
1437
1438 }; # end while loop
1439 }; # end if ok !0
1440
1441 # -----
1442 if {$ok != 0} {
1443     puts [format $fmt1 "PROBLEM" $N_A60_L 1 [nodeDisp $N_A60_L 1] "mm"]
1444 } else {
1445     puts [format $fmt1 "DONE" $N_A60_L 1 [nodeDisp $N_A60_L 1] "mm"]
1446 }
1447
1448
1449 # Stop timing of this analysis sequence
1450 set tStop [clock clicks -milliseconds]
1451 puts "o Time taken: [expr ($tStop-$tStart)/1000.0] sec"
1452
1453 puts "pushover analysis completed"
1454
1455 # Reset for next analysis sequence
1456 wipe all;
```

**Appendix 4 – The Code Generated Using the OpenSees Program
to Perform Pushover Analysis for 3B6S MRFs- Non-Ductile Bare
Frame**

Appendix 4: 3B6S Bare Frame with Structural Deficiencies

```

1
2 1) Complementary files were defined to organize and make the procedure easier:
3
4     1. Library for Units
5
6     The code generated is the same as Appendix 3
7
8     2. Building RC Cross-Section (Fiber Approach)
9
10    The code generated is the same as Appendix 3
11
12    3. Display The Model in 2D
13
14    The code generated is the same as Appendix 3
15
16    4. Display Plane Deformed Shape for 2D Model
17
18    The code generated is the same as Appendix 3
19
20
21    5. Procedure for Defining Uniaxial Pinching Material
22
23    The code generated is the same as Appendix 3.
24
25
26 2) 2D Model Definition for 3B6S Bare Frame with structural deficiencies:
27
28    The code generated is the same as Appendix 3. However, some changes were applied to represent structural deficiencies
29
30    1. Consider the effect of stirrups spacing
31
32    # basic parameters for materials-con-concrete
33
34    # ConfinedConcrete01 Material
35
36    # $tag          integer tag identifying material.
37    # $secType      tag for the transverse reinforcement configuration.
38    # $fpc          unconfined cylindrical strength of concrete specimen.
39    # $Ec          initial elastic modulus of unconfined concrete.
40    # <-epscu $epscu> OR <-gamma $gamma> confined concrete ultimate strain.
41    # <-nu $nu> OR <-varub> OR <-varnoub> Poisson's Ratio.
42    # $L1          length/diameter of square/circular core section measured respect to the hoop center line.
43    # ($L2)        additional dimensions when multiple hoops are being used.
44    # $phis        hoop diameter. If section arrangement has multiple hoops it refers to the external hoop.
45    # $S           hoop spacing.
46    # $fyh         yielding strength of the hoop steel.
47    # $Es0         elastic modulus of the hoop steel.
48    # $haRatio     hardening ratio of the hoop steel.
49    # $mu          ductility factor of the hoop steel.
50    # $phiLon      diameter of longitudinal bars.
51
52    # basic parameters for materials-uncon-concrete
53
54    set unconfc -28.0; # compression strength for concrete
55    set unconepsc -0.002; # strain at maximum stress in compression
56    set unconfu [expr $unconfc*0.18]; # ultimate stress for concrete
57    set unconepsu -0.01; # strain at ultimate stress in compression
58    set unconlambda 0.1; # ratio between reloading stiffness and initial stiffness in compression
59    set unconft [expr $unconfc*-0.1]; # maximum stress in tension for concrete
60    set unconEt [expr $unconft/0.002]; # elastic modulus in tension
61    set unconE0 [expr 2*$unconfc/$unconepsc]; # initial elastic tangent
62
63    # basic parameters for material--steel # ReinforcingSteel uniaxial material object. This object is intended to be used
64    # in a reinforced concrete fiber section as the steel reinforcing material.
65
66    set Fy 420.0; # Yield stress in tension
67    set Fu 596.0; # Ultimate stress in tension
68    set Es 200000.0; # Initial elastic tangent
69    set Esh 3100.0; # Tangent at initial strain hardening
70    set esh 0.01; # Strain corresponding to initial strain hardening
71    set eult 0.09; # Strain at peak stress
72
73    #uniaxialMaterial ReinforcingSteel $matTag $fy $fu $Es $Esh $esh $eult Define ReinforcingSteel uniaxial material
74    uniaxialMaterial ReinforcingSteel $R_steel $Fy $Fu $Es $Esh $esh $eult -DMBuck 6 0.8 -CMFatigue 0.2600 0.5000 0.3890 -Iso
75    Hard 4.3000 0.01
76
77    # definition of ConfinedConcrete01 material

```

```

77      #uniaxialMaterial ConfinedConcrete01 $tag          $secType $fpc $Ec -eps cu $eps cu $nu $L1 $L2 $phis $S $f
yh $Es0 $haRatio $mu $phiLon -stRatio $stRatio
78      #uniaxialMaterial ConfinedConcrete01 $C_confinedB R -28 24870.1 -eps cu -0.04 -varUB 250.0 1450.0 10.0 125.0 4
20.0 200000.0 0.00 3100.0 12.0 -stRatio 0.85
79      #uniaxialMaterial ConfinedConcrete01 $C_confinedC R -28 24870.1 -eps cu -0.04 -varUB 550.0 200.0 10.0 125.0 4
20.0 200000.0 0.00 3100.0 18.0 -stRatio 0.85
80
81
82      # basic parameters for materials-con-concrete
83
84          set confc -28; # compression strength for concrete
85          set conepsc -0.003; # strain at maximum stress in compression
86          set confu [expr $unconfc*0.18]; # ultimate stress for concrete
87          set conepsc -0.04; # strain at ultimate stress in compression
88          set conlambda 0.1; # ratio between reloading stiffness and initial stiffness in compression
89          set conft [expr $unconfc*-0.1]; # maximum stress in tension for concrete
90          set conEt [expr $unconfc/0.002]; # elastic modulus in tension
91          set conE0 [expr 2*$unconfc/$unconepsc]; # initial elastic tangent
92
93      # uniaxialMaterial Concrete02 $matTag $fpc $eps cu $fpcu $eps U $lambda $ft $Ets
94      uniaxialMaterial Concrete02 $C_unconfined $unconfc $unconepsc $unconfu $unconepsc $unconlambda $unconfc $unco
nEt;
95      uniaxialMaterial Concrete02 $C_confined $confc $conepsc $confu $conepsc $conlambda $conft $conEt;
96
97      2. Consider Development Length
98
99      ##### details for the material models of bar slip of the beam #####
100
101      set bs_fc 28.0; set bs_fs 420.0; set bs_es 200000; set bs_fsu 596; set bs_dbar 12.0; set bs_esh 3100.0;
102      set bs_wid $w_col; set bs_dep $h_beam;
103      set bsT_nbars 12; set bsB_nbars 8;
104      set bs_ljoint 50;
105
106      3. Beam Column Joint Properties
107
108      ##### material for shear panel #####
109
110      ## Positive/Negative envelope Stress
111
112      set spid1 41;
113      set A 0.78;
114      set p1 [expr 1.899*$A]; set p2 [expr 2.466*$A]; set p3 [expr 2.596*$A]; set p4 [expr 0.5192*$A];
115
116      ## stress1 stress2 stress3 stress4
117      set pEnvStrsp [list [expr $p1*$JointVolume] [expr $p2*$JointVolume] [expr $p3*$JointVolume] [expr $p4*$JointVolume]]
118      set nEnvStrsp [list [expr -$p1*$JointVolume] [expr -$p2*$JointVolume] [expr -$p3*$JointVolume] [expr -$p4*$JointVolume]]
119
120      ## Positive/Negative envelope Strain
121      ## strain1 strain2 strain3 strain4
122
123      set pEnvStnsp [list 0.00043 0.006 0.015 0.04]
124      set nEnvStnsp [list -0.00043 -0.006 -0.015 -0.04]
125
126      ## Ratio of maximum deformation at which reloading begins
127      ## Pos_env. Neg_env.
128      set rDispsp [list 0.2 0.2]
129
130      ## Ratio of envelope force (corresponding to maximum deformation) at which reloading begins
131
132      ### Pos_env. Neg_env.
133      set rForcesp [list 0.2 0.2]
134
135
136      ## Ratio of monotonic strength developed upon unloading
137      ### Pos_env. Neg_env.
138
139      set uForcesp [list 0.0 0.0]
140
141
142      ## Coefficients for Unloading Stiffness degradation
143
144      ## gammaK1 gammaK2 gammaK3 gammaK4 gammaKLimit
145
146      #set gammaKsp [list 1.13364492409642 0.0 0.10111033064469 0.0 0.91652498468618]
147
148      set gammaKsp [list 0.0 0.0 0.0 0.0 0.0]
149
150      ##### Coefficients for Reloading Stiffness degradation
151      ### gammaD1 gammaD2 gammaD3 gammaD4 gammaDLimit
152

```

```

153 #set gammaDsp [list 0.12 0.0 0.23 0.0 0.95]
154
155 set gammaDsp [list 0.0 0.0 0.0 0.0 0.0]
156 ##### Coefficients for Strength degradation
157 ### gammaF1 gammaF2 gammaF3 gammaF4 gammaFLimit
158
159 #set gammaFsp [list 1.11 0.0 0.319 0.0 0.125]
160 set gammaFsp [list 0.0 0.0 0.0 0.0 0.0]
161
162 set gammaEsp 10.0
163
164 uniaxialMaterial Pinching4 $spid1 [lindex $pEnvStrsp 0] [lindex $pEnvStnsp 0] \
165 [lindex $pEnvStrsp 1] [lindex $pEnvStnsp 1] [lindex $pEnvStrsp 2] \
166 [lindex $pEnvStrsp 2] [lindex $pEnvStrsp 3] [lindex $pEnvStnsp 3] \
167 [lindex $nEnvStrsp 0] [lindex $nEnvStnsp 0] \
168 [lindex $nEnvStrsp 1] [lindex $nEnvStnsp 1] [lindex $nEnvStrsp 2] \
169 [lindex $nEnvStrsp 2] [lindex $nEnvStrsp 3] [lindex $nEnvStnsp 3] \
170 [lindex $rDispsp 0] [lindex $rForcesp 0] [lindex $uForcesp 0] \
171 [lindex $rDispsp 1] [lindex $rForcesp 1] [lindex $uForcesp 1] \
172 [lindex $gammaKsp 0] [lindex $gammaKsp 1] [lindex $gammaKsp 2] [lindex $gammaKsp 3] [lindex $gammaKsp 4] \
173 [lindex $gammaDsp 0] [lindex $gammaDsp 1] [lindex $gammaDsp 2] [lindex $gammaDsp 3] [lindex $gammaDsp 4] \
174 [lindex $gammaFsp 0] [lindex $gammaFsp 1] [lindex $gammaFsp 2] [lindex $gammaFsp 3] [lindex $gammaFsp 4] \
175 $gammaEsp energy
176
177
178 3) Gravity Analysis Procedure:
179
180 The code generated is the same as Appendix 3
181
182 4) Modal Analysis Procedure:
183
184 The code generated is the same as Appendix 3
185
186 5) Pushover Analysis Procedure:
187
188 #####
189
190 # start analysis
191
192
193 puts "ooo Analysis: Pushover ooo"
194
195 #####
196
197 # set recorders
198
199 # Global behaviour
200
201 # Node Recorder "Displacements": fileName <nodeTag> dof resptype
202 recorder Node -file $dataDir/Pushover_Horizontal_Reactions.out -time -node $N_A0 $N_B0 $N_C0 $N_D0 -dof 1 rea
tion
203 recorder Node -file $dataDir/Pushover_Storey_Displacement.out -time -node $N_A50_L $N_A60_L -dof 1 disp
204 #recorder Node -file $dataDir/DFree.out -time -node $N_A10_L $N_A20_L -dof 1 2 disp; # displacements of free nodes
205
206 #recorder Element -file $dataDir/stressStrain.out -time -ele 5 6 section fiber y z $R_steel stressStrain
207 #recorder Element -file $dataDir/force10.out -time -ele 710 section 1 fiber y z $R_steel stressStrain;
208 #recorder Element -file $dataDir/force60B.out -time -ele 860 section 1 fiber y z $R_steel stressStrain;
209 recorder Element -file $dataDir/force10B.out -time -ele 810 820 830 840 850 860 localForce;
210 recorder Element -file $dataDir/SP1.out -time -ele 611 612 613 614 615 616 621 622 623 624 625 626 shearpanel stressStrain
211
212 recorder Element -file $dataDir/force10.out -time -ele 710 720 730 740 750 760 711 721 731 741 751 761 localForce
213 ;
214 # analysis options
215
216
217 set tStart [clock clicks -milliseconds]
218
219 # display deformed shape:
220 set ViewScale 5;
221 DisplayModel2D DeformedShape $ViewScale ; # display deformed shape, the scaling factor needs to be adjusted for each model
222
223 # characteristics of pushover analysis
224 set Dmax 1800; # maximum displacement of pushover. push to 10% drift.
225 set Dincr 0.01; # displacement increment for pushover. you want this to be very small, but not too small to slow down the
analysis
226 set Tol 1;
227 # create load pattern for lateral pushover load
228 pattern Plain 200 Linear {}; # define load pattern -- generalized

```

```

227     load $N_A60_L 6 0 0
228     load $N_A50_L 5 0 0
229     load $N_A40_L 4 0 0
230     load $N_A30_L 3 0 0
231     load $N_A20_L 2 0 0
232     load $N_A10_L 1 0 0
233
234
235 }
236
237
238 # ----- set up analysis parameters
239
240 # ## CONSTRAINTS handler >> Determines how the constraint equations are enforced in the analysis
241
242 #     >> Plain Constraints -- Removes constrained degrees of freedom from the system of equations (only for homogeneous
    equations)
243 #     >> Lagrange Multipliers -- Uses the method of Lagrange multipliers to enforce constraints
244 #     >> Penalty Method -- Uses penalty numbers to enforce constraints --good for static analysis with non-homogeneous
    eqns (rigidDiaphragm)
245 #     >> Transformation Method -- Performs a condensation of constrained degrees of freedom
246 variable constraintsTypeStatic Transformation; # default;
247 constraints $constraintsTypeStatic
248
249 # DOF NUMBERER (number the degrees of freedom in the domain):
250
251 #     Determines the mapping between equation numbers and degrees-of-freedom
252 #     Plain -- Uses the numbering provided by the user
253 #     RCM -- Renumbers the DOF to minimize the matrix band-width using the Reverse Cuthill-McKee algorithm
254 set numbererTypeStatic RCM
255 numberer $numbererTypeStatic
256
257
258 # SYSTEM:
259
260 # Linear Equation Solvers (how to store and solve the system of equations in the analysis)
261 # -- provide the solution of the linear system of equations  $Ku = P$ . Each solver is tailored to a specific matrix topology.
262
263 # ProfileSPD -- Direct profile solver for symmetric positive definite matrices
264 # BandGeneral -- Direct solver for banded unsymmetric matrices
265 # BandSPD -- Direct solver for banded symmetric positive definite matrices
266 # SparseGeneral -- Direct solver for unsymmetric sparse matrices
267 # SparseSPD -- Direct solver for symmetric sparse matrices
268 # UmfPack -- Direct UmfPack solver for unsymmetric matrices
269 set systemTypeStatic UmfPack; # try UmfPack for large model
270 system $systemTypeStatic
271
272 # TEST: # convergence test to
273
274 # -- Accept the current state of the domain as being on the converged solution path
275 # -- determine if convergence has been achieved at the end of an iteration step
276 # NormUnbalance -- Specifies a tolerance on the norm of the unbalanced load at the current iteration
277 # NormDispIncr -- Specifies a tolerance on the norm of the displacement increments at the current iteration
278 # EnergyIncr -- Specifies a tolerance on the inner product of the unbalanced load and displacement increments at the
    current iteration
279 # RelativeNormUnbalance --
280 # RelativeNormDispIncr --
281 # RelativeEnergyIncr --
282 variable TolStatic 0.01; # Convergence Test: tolerance
283 variable maxNumIterStatic 10000; # Convergence Test: maximum number of iterations that will be performed befo
    re "failure to converge" is returned
284 variable printFlagStatic 0; # Convergence Test: flag used to print information on convergence (optional)
285 # 1: print information on each step;
286 variable testTypeStatic EnergyIncr; # Convergence-test type
287 test $testTypeStatic $TolStatic $maxNumIterStatic $printFlagStatic;
288
289 # Solution ALGORITHM: -- Iterate from the last time step to the current
290 # Linear -- Uses the solution at the first iteration and continues
291 # Newton -- Uses the tangent at the current iteration to iterate to convergence
292 # ModifiedNewton -- Uses the tangent at the first iteration to iterate to convergence
293 # NewtonLineSearch --
294 # KrylovNewton --
295 # BFGS --
296 # Broyden --
297 variable algorithmTypeStatic Newton
298 algorithm $algorithmTypeStatic;
299
300 # Static INTEGRATOR: -- determine the next time step for an analysis
301
302 # LoadControl -- Specifies the incremental load factor to be applied to the loads in the domain

```



```

301 # DisplacementControl -- Specifies the incremental displacement at a specified DOF in the domain
302 # Minimum Unbalanced Displacement Norm -- Specifies the incremental load factor such that the residual displacement
    norm in minimized
303 # Arc Length -- Specifies the incremental arc-length of the load-displacement path
304 # Transient INTEGRATOR: -- determine the next time step for an analysis including inertial effects
305 # Newmark -- The two parameter time-stepping method developed by Newmark
306 # HHT -- The three parameter Hilbert-Hughes-Taylor time-stepping method
307 # Central Difference -- Approximates velocity and acceleration by centered finite differences of displacement
308 integrator DisplacementControl $N_A60_L 1 $Dincr
309
310 # ANALYSIS -- defines what type of analysis is to be performed
311
312 # Static Analysis -- solves the KU=R problem, without the mass or damping matrices.
313 # Transient Analysis -- solves the time-dependent analysis. The time step in this type of analysis is constant. The
    time step in the output is also constant.
314 # variableTransient Analysis -- performs the same analysis type as the Transient Analysis object. The time step, ho
    wever, is variable. This method is used when
315 # there are convergence problems with the Transient Analysis object at a peak or when the time step is too s
    mall. The time step in the output is also variable.
316 set analysisTypeStatic Static
317 analysis $analysisTypeStatic
318
319
320 # ----- perform Static Pushover Analysis
321 set Nsteps [expr int($Dmax/$Dincr)]; # number of pushover analysis steps
322 set ok [analyze $Nsteps]; # this will return zero if no convergence problems were encountered
323 set fmt1 "%s Pushover analysis: CtrlNode %.24i, dof %.1i, Disp=%.4f %s"; # format for screen/file output of DONE/PROBLEM an
    alysis
324 if {$ok != 0} {
325     # if analysis fails, we try some other stuff, performance is slower inside this loop
326     set Dstep 0.0;
327     set ok 0
328     while {$Dstep <= 1.0 && $ok == 0} {
329         set controlDisp [nodeDisp $N_A60_L 1 ]
330         set Dstep [expr $controlDisp/$Dmax]
331         set ok [analyze 1 ]
332         # if analysis fails, we try some other stuff
333         # performance is slower inside this loop global maxNumIterStatic; # max no. of iterations performed before "failur
    e to converge" is ret'd
334         if {$ok != 0} {
335             puts "Trying Newton with Initial Tangent .."
336             test NormDispIncr $Tol 3000 0
337             algorithm Newton -initial
338             set ok [analyze 1]
339             test $testTypeStatic $TolStatic $maxNumIterStatic 0
340             algorithm $algorithmTypeStatic
341         }
342         if {$ok != 0} {
343             puts "Trying Broyden .."
344             algorithm Broyden 8
345             set ok [analyze 1 ]
346             algorithm $algorithmTypeStatic
347         }
348         if {$ok != 0} {
349             puts "Trying NewtonWithLineSearch .."
350             algorithm NewtonLineSearch 0.8
351             set ok [analyze 1]
352             algorithm $algorithmTypeStatic
353         }
354     }
355 }; # end while loop
356 }; # end if ok != 0
357
358 # -----
359 if {$ok != 0} {
360     puts [format $fmt1 "PROBLEM" $N_A60_L 1 [nodeDisp $N_A60_L 1] "mm"]
361 } else {
362     puts [format $fmt1 "DONE" $N_A60_L 1 [nodeDisp $N_A60_L 1] "mm"]
363 }
364
365
366 # Stop timing of this analysis sequence
367 set tStop [clock clicks -milliseconds]
368 puts "o Time taken: [expr ($tStop-$tStart)/1000.0] sec"
369
370 puts "pushover analysis completed"
371
372 # Reset for next analysis sequence
373 wipe all;

```

**Appendix 5 – The Code Generated Using the OpenSees Program
to Perform Pushover Analysis for 3B6S MRFs- Masonry-
Concrete Infilled Frames**

Appendix 5: 3B6S Masonry infilled Frame

```
1
2 1) Complementary files were defined to organize and make the procedure easier:
3
4     1. Library for Units
5
6     The code generated is the same as Appendix 3
7
8     2. Building RC Cross-Section (Fiber Approach)
9
10    The code generated is the same as Appendix 3
11
12    3. Display The Model in 2D
13
14    The code generated is the same as Appendix 3
15
16    4. Display Plane Deformed Shape for 2D Model
17
18    The code generated is the same as Appendix 3
19
20
21    5. Procedure for Defining Uniaxial Pinching Material
22
23    The code generated is the same as Appendix 3.
24
25
26 2) 2D Model Definition for 3B6S MRFs-Masonry-Concrete Infilled Frame :
27
28
29 #performing nonlinear static pushover analysis on 3B6S MRFs-Masonry-Concrete Infilled Frame
30 #####
31
32     wipe all;
33     # define model builder
34     #   model basic builder -ndm $ndm <-ndf $ndf>
35     #   model basic builder -ndm 2 -ndf 3
36
37     set dataDir Results;           # set up name of data directory
38     file mkdir $dataDir;           # create data directory
39     source Libunits.tcl;           # define basic system units
40     source DisplayModel2D.tcl;     # procedure for displaying a 2D View of model
41     source DisplayPlane.tcl;       # procedure for displaying a plane in a model
42
43 #####
44
45 # buiding geometry
46 #####
47
48 # dimensions
49
50     set span1 4000.0;
51     set span2 4000.0;
52     set span3 4000.0;
53     set storey1 3000.0;
54     set storey2 3000.0;
55     set storey3 3000.0;
56     set storey4 3000.0;
57     set storey5 3000.0;
58     set storey6 3000.0;
59
60 # main grid lines
61     # vertical axis, x
62     set x1 [expr 0];
63     set x2 [expr $x1+$span1];
64     set x3 [expr $x2+$span2];
65     set x4 [expr $x3+$span3];
66
67     # hoeizontal axis, y
68     set z0 [expr 0];
69     set z1 [expr $z0+$storey1];
70     set z2 [expr $z1+$storey2];
71     set z3 [expr $z2+$storey3];
72     set z4 [expr $z3+$storey4];
73     set z5 [expr $z4+$storey5];
74     set z6 [expr $z5+$storey6];
75
76 # definition of nodes
```

```

77      #assigning node tages                                # for axes A,B,C, and D.
78      set N_A0      1;
79      set N_B0      2;
80      set N_C0      3;
81      set N_D0      4;
82      set N_A1      5;
83      set N_B1      6;
84      set N_C1      7;
85      set N_D1      8;
86      set N_A2      9;
87      set N_B2     10;
88      set N_C2     11;
89      set N_D2     12;
90      set N_A3     13;
91      set N_B3     14;
92      set N_C3     15;
93      set N_D3     16;
94      set N_A4     17;
95      set N_B4     18;
96      set N_C4     19;
97      set N_D4     20;
98      set N_A5     21;
99      set N_B5     22;
100     set N_C5     23;
101     set N_D5     24;
102     set N_A6     25;
103     set N_B6     26;
104     set N_C6     27;
105     set N_D6     28;
106
107     set N_A10_R   29;                                # N_Aij_R    i: story level.    j: axis number
108     set N_A10_A   30;
109     set N_A10_L   31;
110     set N_A20_R   32;
111     set N_A20_A   33;
112     set N_A20_L   34;
113     set N_A30_R   35;
114     set N_A30_A   36;
115     set N_A30_L   37;
116     set N_A40_R   38;
117     set N_A40_A   39;
118     set N_A40_L   40;
119     set N_A50_R   41;
120     set N_A50_A   42;
121     set N_A50_L   43;
122     set N_A60_R   44;
123     set N_A60_A   45;
124     set N_A60_L   46;
125
126     set N_B11_R   47;
127     set N_B11_A   48;
128     set N_B11_L   49;
129     set N_B21_R   50;
130     set N_B21_A   51;
131     set N_B21_L   52;
132     set N_B31_R   53;
133     set N_B31_A   54;
134     set N_B31_L   55;
135     set N_B41_R   56;
136     set N_B41_A   57;
137     set N_B41_L   58;
138     set N_B51_R   59;
139     set N_B51_A   60;
140     set N_B51_L   61;
141     set N_B61_R   62;
142     set N_B61_A   63;
143     set N_B61_L   64;
144
145     set N_C12_R   65;
146     set N_C12_A   66;
147     set N_C12_L   67;
148     set N_C22_R   68;
149     set N_C22_A   69;
150     set N_C22_L   70;
151     set N_C32_R   71;
152     set N_C32_A   72;
153     set N_C32_L   73;
154     set N_C42_R   74;
155     set N_C42_A   75;
156     set N_C42_L   76;

```

```

157     set N_C52_R 77;
158     set N_C52_A 78;
159     set N_C52_L 79;
160     set N_C62_R 80;
161     set N_C62_A 81;
162     set N_C62_L 82;
163
164     set N_D13_R 83;
165     set N_D13_A 84;
166     set N_D13_L 85;
167     set N_D23_R 86;
168     set N_D23_A 87;
169     set N_D23_L 88;
170     set N_D33_R 89;
171     set N_D33_A 90;
172     set N_D33_L 91;
173     set N_D43_R 92;
174     set N_D43_A 93;
175     set N_D43_L 94;
176     set N_D53_R 95;
177     set N_D53_A 96;
178     set N_D53_L 97;
179     set N_D63_R 98;
180     set N_D63_A 99;
181     set N_D63_L 100;
182
183     #infill wall nodes
184     set N_W1A_L 3001;           # l: means the node at the left side of the panel
185     set N_W1A_R 3002;           # R: means the node at the right side of the panel
186     set N_W2A_L 3003;
187     set N_W2A_R 3004;
188     set N_W3A_L 3005;
189     set N_W3A_R 3006;
190     set N_W4A_L 3007;
191     set N_W4A_R 3008;
192     set N_W5A_L 3009;
193     set N_W5A_R 3010;
194     set N_W6A_L 3011;
195     set N_W6A_R 3012;
196
197     set N_W1B_L 3013;
198     set N_W1B_R 3014;
199     set N_W2B_L 3015;
200     set N_W2B_R 3016;
201     set N_W3B_L 3017;
202     set N_W3B_R 3018;
203     set N_W4B_L 3019;
204     set N_W4B_R 3020;
205     set N_W5B_L 3021;
206     set N_W5B_R 3022;
207     set N_W6B_L 3023;
208     set N_W6B_R 3024;
209
210     set N_W1C_L 3025;
211     set N_W1C_R 3026;
212     set N_W2C_L 3027;
213     set N_W2C_R 3028;
214     set N_W3C_L 3029;
215     set N_W3C_R 3030;
216     set N_W4C_L 3031;
217     set N_W4C_R 3032;
218     set N_W5C_L 3033;
219     set N_W5C_R 3034;
220     set N_W6C_L 3035;
221     set N_W6C_R 3036;
222
223
224     #node $nodetag (ndm $coords) <-mass (ndf $massvalues)>
225
226     set col_halfdepA [expr 600/2];           # This is used to define the joint dimensions.
227     set col_halfdepB [expr 600/2];
228     set col_halfdepC [expr 600/2];
229     set col_halfdepD [expr 600/2];
230     set beam_halfdep1 [expr 300/2];
231     set beam_halfdep2 [expr 300/2];
232     set beam_halfdep3 [expr 300/2];
233     set beam_halfdep4 [expr 300/2];
234     set beam_halfdep5 [expr 300/2];
235     set beam_halfdep6 [expr 300/2];
236

```

```

237     node $N_A0      $x1 $z0;
238     node $N_B0      $x2 $z0;
239     node $N_C0      $x3 $z0;
240     node $N_D0      $x4 $z0;
241     node $N_A1      $x1 [expr $z1-$beam_halfdep1];
242     node $N_B1      $x2 [expr $z1-$beam_halfdep1];
243     node $N_C1      $x3 [expr $z1-$beam_halfdep1];
244     node $N_D1      $x4 [expr $z1-$beam_halfdep1];
245     node $N_A2      $x1 [expr $z2-$beam_halfdep2];
246     node $N_B2      $x2 [expr $z2-$beam_halfdep2];
247     node $N_C2      $x3 [expr $z2-$beam_halfdep2];
248     node $N_D2      $x4 [expr $z2-$beam_halfdep2];
249     node $N_A3      $x1 [expr $z3-$beam_halfdep3];
250     node $N_B3      $x2 [expr $z3-$beam_halfdep3];
251     node $N_C3      $x3 [expr $z3-$beam_halfdep3];
252     node $N_D3      $x4 [expr $z3-$beam_halfdep3];
253     node $N_A4      $x1 [expr $z4-$beam_halfdep4];
254     node $N_B4      $x2 [expr $z4-$beam_halfdep4];
255     node $N_C4      $x3 [expr $z4-$beam_halfdep4];
256     node $N_D4      $x4 [expr $z4-$beam_halfdep4];
257     node $N_A5      $x1 [expr $z5-$beam_halfdep5];
258     node $N_B5      $x2 [expr $z5-$beam_halfdep5];
259     node $N_C5      $x3 [expr $z5-$beam_halfdep5];
260     node $N_D5      $x4 [expr $z5-$beam_halfdep5];
261     node $N_A6      $x1 [expr $z6-$beam_halfdep6];
262     node $N_B6      $x2 [expr $z6-$beam_halfdep6];
263     node $N_C6      $x3 [expr $z6-$beam_halfdep6];
264     node $N_D6      $x4 [expr $z6-$beam_halfdep6];
265
266
267 ##### add nodes - joints #####
268
269                                     # R: node at the right side of joint
270                                     # A: node above the joint
271                                     # L: node at the left side of the joint
272     node $N_A10_R    [expr $x1+$col_halfdepA] $z1;
273     node $N_A10_A    $x1 [expr $z1+$beam_halfdep1];
274     node $N_A10_L    [expr $x1-$col_halfdepA] $z1;
275     node $N_A20_R    [expr $x1+$col_halfdepA] $z2;
276     node $N_A20_A    $x1 [expr $z2+$beam_halfdep2];
277     node $N_A20_L    [expr $x1-$col_halfdepA] $z2;
278     node $N_A30_R    [expr $x1+$col_halfdepA] $z3;
279     node $N_A30_A    $x1 [expr $z3+$beam_halfdep3];
280     node $N_A30_L    [expr $x1-$col_halfdepA] $z3;
281     node $N_A40_R    [expr $x1+$col_halfdepA] $z4;
282     node $N_A40_A    $x1 [expr $z4+$beam_halfdep4];
283     node $N_A40_L    [expr $x1-$col_halfdepA] $z4;
284     node $N_A50_R    [expr $x1+$col_halfdepA] $z5;
285     node $N_A50_A    $x1 [expr $z5+$beam_halfdep5];
286     node $N_A50_L    [expr $x1-$col_halfdepA] $z5;
287     node $N_A60_R    [expr $x1+$col_halfdepA] $z6;
288     node $N_A60_A    $x1 [expr $z6+$beam_halfdep6];
289     node $N_A60_L    [expr $x1-$col_halfdepA] $z6;
290
291     node $N_B11_R    [expr $x2+$col_halfdepB] $z1;
292     node $N_B11_A    $x2 [expr $z1+$beam_halfdep1];
293     node $N_B11_L    [expr $x2-$col_halfdepB] $z1;
294     node $N_B21_R    [expr $x2+$col_halfdepB] $z2;
295     node $N_B21_A    $x2 [expr $z2+$beam_halfdep2];
296     node $N_B21_L    [expr $x2-$col_halfdepB] $z2;
297     node $N_B31_R    [expr $x2+$col_halfdepB] $z3;
298     node $N_B31_A    $x2 [expr $z3+$beam_halfdep3];
299     node $N_B31_L    [expr $x2-$col_halfdepB] $z3;
300     node $N_B41_R    [expr $x2+$col_halfdepB] $z4;
301     node $N_B41_A    $x2 [expr $z4+$beam_halfdep4];
302     node $N_B41_L    [expr $x2-$col_halfdepB] $z4;
303     node $N_B51_R    [expr $x2+$col_halfdepB] $z5;
304     node $N_B51_A    $x2 [expr $z5+$beam_halfdep5];
305     node $N_B51_L    [expr $x2-$col_halfdepB] $z5;
306     node $N_B61_R    [expr $x2+$col_halfdepB] $z6;
307     node $N_B61_A    $x2 [expr $z6+$beam_halfdep6];
308     node $N_B61_L    [expr $x2-$col_halfdepB] $z6;
309
310     node $N_C12_R    [expr $x3+$col_halfdepC] $z1;
311     node $N_C12_A    $x3 [expr $z1+$beam_halfdep1];
312     node $N_C12_L    [expr $x3-$col_halfdepC] $z1;
313     node $N_C22_R    [expr $x3+$col_halfdepC] $z2;
314     node $N_C22_A    $x3 [expr $z2+$beam_halfdep2];
315     node $N_C22_L    [expr $x3-$col_halfdepC] $z2;
316     node $N_C32_R    [expr $x3+$col_halfdepC] $z3;

```

```

317 node $N_C32_A $x3 [expr $z3+$beam_halfdep3];
318 node $N_C32_L [expr $x3-$col_halfdepC] $z3;
319 node $N_C42_R [expr $x3+$col_halfdepC] $z4;
320 node $N_C42_A $x3 [expr $z4+$beam_halfdep4];
321 node $N_C42_L [expr $x3-$col_halfdepC] $z4;
322 node $N_C52_R [expr $x3+$col_halfdepC] $z5;
323 node $N_C52_A $x3 [expr $z5+$beam_halfdep5];
324 node $N_C52_L [expr $x3-$col_halfdepC] $z5;
325 node $N_C62_R [expr $x3+$col_halfdepC] $z6;
326 node $N_C62_A $x3 [expr $z6+$beam_halfdep6];
327 node $N_C62_L [expr $x3-$col_halfdepC] $z6;
328
329 node $N_D13_R [expr $x4+$col_halfdepD] $z1;
330 node $N_D13_A $x4 [expr $z1+$beam_halfdep1];
331 node $N_D13_L [expr $x4-$col_halfdepD] $z1;
332 node $N_D23_R [expr $x4+$col_halfdepD] $z2;
333 node $N_D23_A $x4 [expr $z2+$beam_halfdep2];
334 node $N_D23_L [expr $x4-$col_halfdepD] $z2;
335 node $N_D33_R [expr $x4+$col_halfdepD] $z3;
336 node $N_D33_A $x4 [expr $z3+$beam_halfdep3];
337 node $N_D33_L [expr $x4-$col_halfdepD] $z3;
338 node $N_D43_R [expr $x4+$col_halfdepD] $z4;
339 node $N_D43_A $x4 [expr $z4+$beam_halfdep4];
340 node $N_D43_L [expr $x4-$col_halfdepD] $z4;
341 node $N_D53_R [expr $x4+$col_halfdepD] $z5;
342 node $N_D53_A $x4 [expr $z5+$beam_halfdep5];
343 node $N_D53_L [expr $x4-$col_halfdepD] $z5;
344 node $N_D63_R [expr $x4+$col_halfdepD] $z6;
345 node $N_D63_A $x4 [expr $z6+$beam_halfdep6];
346 node $N_D63_L [expr $x4-$col_halfdepD] $z6;
347
348
349 ##### add nodes - infill walls #####
350
351 node $N_W1A_R [expr $x2*0.54] [expr $z0+($storey1*0.5)];
352 node $N_W1A_L [expr $x2*0.46] [expr $z0+($storey1*0.5)];
353 node $N_W2A_R [expr $x2*0.54] [expr $z1+($storey1*0.5)];
354 node $N_W2A_L [expr $x2*0.46] [expr $z1+($storey1*0.5)];
355 node $N_W3A_R [expr $x2*0.54] [expr $z2+($storey1*0.5)];
356 node $N_W3A_L [expr $x2*0.46] [expr $z2+($storey1*0.5)];
357 node $N_W4A_R [expr $x2*0.54] [expr $z3+($storey1*0.5)];
358 node $N_W4A_L [expr $x2*0.46] [expr $z3+($storey1*0.5)];
359 node $N_W5A_R [expr $x2*0.54] [expr $z4+($storey1*0.5)];
360 node $N_W5A_L [expr $x2*0.46] [expr $z4+($storey1*0.5)];
361 node $N_W6A_R [expr $x2*0.54] [expr $z5+($storey1*0.5)];
362 node $N_W6A_L [expr $x2*0.46] [expr $z5+($storey1*0.5)];
363
364 node $N_W1B_R [expr $x2+($span2*0.54)] [expr $z0+($storey1*0.5)];
365 node $N_W1B_L [expr $x2+($span2*0.46)] [expr $z0+($storey1*0.5)];
366 node $N_W2B_R [expr $x2+($span2*0.54)] [expr $z1+($storey1*0.5)];
367 node $N_W2B_L [expr $x2+($span2*0.46)] [expr $z1+($storey1*0.5)];
368 node $N_W3B_R [expr $x2+($span2*0.54)] [expr $z2+($storey1*0.5)];
369 node $N_W3B_L [expr $x2+($span2*0.46)] [expr $z2+($storey1*0.5)];
370 node $N_W4B_R [expr $x2+($span2*0.54)] [expr $z3+($storey1*0.5)];
371 node $N_W4B_L [expr $x2+($span2*0.46)] [expr $z3+($storey1*0.5)];
372 node $N_W5B_R [expr $x2+($span2*0.54)] [expr $z4+($storey1*0.5)];
373 node $N_W5B_L [expr $x2+($span2*0.46)] [expr $z4+($storey1*0.5)];
374 node $N_W6B_R [expr $x2+($span2*0.54)] [expr $z5+($storey1*0.5)];
375 node $N_W6B_L [expr $x2+($span2*0.46)] [expr $z5+($storey1*0.5)];
376
377 node $N_W1C_R [expr $x3+($span2*0.54)] [expr $z0+($storey1*0.5)];
378 node $N_W1C_L [expr $x3+($span2*0.46)] [expr $z0+($storey1*0.5)];
379 node $N_W2C_R [expr $x3+($span2*0.54)] [expr $z1+($storey1*0.5)];
380 node $N_W2C_L [expr $x3+($span2*0.46)] [expr $z1+($storey1*0.5)];
381 node $N_W3C_R [expr $x3+($span2*0.54)] [expr $z2+($storey1*0.5)];
382 node $N_W3C_L [expr $x3+($span2*0.46)] [expr $z2+($storey1*0.5)];
383 node $N_W4C_R [expr $x3+($span2*0.54)] [expr $z3+($storey1*0.5)];
384 node $N_W4C_L [expr $x3+($span2*0.46)] [expr $z3+($storey1*0.5)];
385 node $N_W5C_R [expr $x3+($span2*0.54)] [expr $z4+($storey1*0.5)];
386 node $N_W5C_L [expr $x3+($span2*0.46)] [expr $z4+($storey1*0.5)];
387 node $N_W6C_R [expr $x3+($span2*0.54)] [expr $z5+($storey1*0.5)];
388 node $N_W6C_L [expr $x3+($span2*0.46)] [expr $z5+($storey1*0.5)];
389
390
391
392 # restraints
393
394 #basefix $nodetag (ndf $constraints)
395 fix $N_A0 1 1 1;
396 fix $N_B0 1 1 1;

```

```

397     fix      $N_C0      1 1 1;
398     fix      $N_D0      1 1 1;
399
400
401 #####
402 ##
403 # material definitions
404 #####
405 ##
406 # Definition of materials IDs
407
408     #set C_confinedB  1;
409     set C_confined  1;
410     set C_unconfined 2;
411     set R_steel     3;
412     set C_unconfinedw 4;
413
414
415 # basic parameters for materials-con-concrete
416
417 # ConfinedConcrete01 Material
418
419     # $tag          integer tag identifying material.
420     # $secType      tag for the transverse reinforcement configuration.
421     # $fpc          unconfined cylindrical strength of concrete specimen.
422     # $Ec           initial elastic modulus of unconfined concrete.
423     # <-epscu $epscu> OR <-gamma $gamma> confined concrete ultimate strain.
424     # <-nu $nu> OR <-varub> OR <-varnoub> Poisson's Ratio.
425     # $L1          length/diameter of square/circular core section measured respect to the hoop center line.
426     # ($L2)        additional dimensions when multiple hoops are being used.
427     # $phis        hoop diameter. If section arrangement has multiple hoops it refers to the external hoop.
428     # $S           hoop spacing.
429     # $fyh         yielding strength of the hoop steel.
430     # $Es0         elastic modulus of the hoop steel.
431     # $haRatio     hardening ratio of the hoop steel.
432     # $mu          ductility factor of the hoop steel.
433     # $phiLon     diameter of longitudinal bars.
434
435 # basic parameters for materials-uncon-concrete
436
437     set unconfc  -28.0;          # compression strength for concrete
438     set unconepsc -0.002;        # strain at maximum stress in compression
439     set unconfu  [expr $unconfc*0.18]; # ultimate stress for concrete
440     set unconepsu -0.01;        # strain at ultimate stress in compression
441     set unconlambda 0.1;        # ratio between reloading stiffness and initial stiffness in compression
442     set unconft  [expr $unconfc*-0.1]; # maximum stress in tension for concrete
443     set unconEt  [expr $unconft/0.002]; # elastic modulus in tension
444     set unconE0  [expr 2*$unconfc/$unconepsc]; # initial elastic tangent
445
446 # basic parameters for material--steel # ReinforcingSteel uniaxial material object. This object is intended to be used in a reinforced concrete fiber section as the steel reinforcing material.
447
448     set Fy 420.0; # Yield stress in tension
449     set Fu 596.0; # Ultimate stress in tension
450     set Es 200000.0; # Initial elastic tangent
451     set Esh 3100.0; # Tangent at initial strain hardening
452     set esh 0.01; # Strain corresponding to initial strain hardening
453     set eult 0.09; # Strain at peak stress
454
455 #uniaxialMaterial ReinforcingSteel $matTag $fy $fu $Es $Esh $esh $eult Define ReinforcingSteel uniaxial material
456 uniaxialMaterial ReinforcingSteel $R_steel $Fy $Fu $Es $Esh $esh $eult -DMBuck 6 0.8 -CMFatigue 0.2600 0.5000 0.3890 -Iso
Hard 4.3000 0.01
457
458 # definition of ConfinedConcrete01 material
459
460 #uniaxialMaterial ConfinedConcrete01 $tag $secType $fpc $Ec -epscu $epscu $nu $L1 $L2 $phis $S $fyh $Es0 $haRatio $mu $phiLon -stRatio $stRatio
461 #uniaxialMaterial ConfinedConcrete01 $C_confinedB R -28 24870.1 -epscu -0.04 -varUB 250.0 1450.0 10.0 125.0 4
20.0 200000.0 0.00 3100.0 12.0 -stRatio 0.85
462 #uniaxialMaterial ConfinedConcrete01 $C_confinedC R -28 24870.1 -epscu -0.04 -varUB 550.0 200.0 10.0 125.0 4
20.0 200000.0 0.00 3100.0 18.0 -stRatio 0.85
463
464 # basic parameters for materials-con-concrete
465
466     set confc  -32.5;          # compression strength for concrete
467     set conepsc -0.003;        # strain at maximum stress in compression
468     set confu  [expr $unconfc*0.18]; # ultimate stress for concrete
469     set conepsu -0.04;        # strain at ultimate stress in compression

```



```

470     set conlambda    0.1;                # ratio between reloading stiffness and itial stiffness in compression
471     set conft    [expr $unconfc*-0.1];    # maximum stress in tension for concrete
472     set conEt    [expr $unconfc/0.002];   # elastic modulus in tension
473     set conE0    [expr 2*$unconfc/$unconepsc]; #intial elastic tangent
474
475     # uniaxialMaterial Concrete02 $matTag    $fpc $eps0 $fpcu $epsU $lambda $ft $Ets
476     uniaxialMaterial Concrete02 $C_unconfined $unconfc $unconepsc $unconfu $unconepsu $unconlambda $unconfc $unco
nEt;
477     uniaxialMaterial Concrete02 $C_confined $confc $conepsc $confu $conepsu $conlambda $confc $conEt;
478
479     #####
480     # definition of the Sections
481     #####
482
483     # define sections IDs
484
485     set col25x60 1;
486     set beam150x30 2;
487
488     # define section parameters
489
490     set pi        3.141593;
491     set rebar_12  [expr $pi*12.0*12.0/4]; # area rebar 12mm
492     set rebar_18  [expr $pi*18.0*18.0/4];
493     set w_col     250.0; # column width
494     set h_col     600.0; # column hieght
495     set c_col     20.0; # column cover
496     set w_beam    1500.0; # beam width
497     set h_beam    300.0; # beam hieght
498     set c_beam    30.0; # beam cover
499
500     # load procedure for fiber section
501
502     source BuildRCrectSection.tcl;
503
504     # build sections
505
506     #BuildRCrectSection $ColSecTag $HSec $BSec $coverH $coverB $coreID $coverID $steelID $numBarsTop $barAre
aTop $numBarsBot $barAreaBot $numBarsIntTot $barAreaInt $nfCoreY $nfCoreZ $nfCoverY $nfCoverZ
507     BuildRCrectSection $col25x60 $h_col $w_col $c_col $c_col $C_confined $C_unconfined $R_steel 4 $rebar_1
8 4 $rebar_18 2 $rebar_18 8 8 8 8
508     BuildRCrectSection $beam150x30 $h_beam $w_beam $c_beam $c_beam $C_confined $C_unconfined $R_steel 12 $rebar_1
2 8 $rebar_12 0 $rebar_12 8 8 8 8
509
510
511     #####
512     # beam column joint definition
513     #####
514
515     # dimensions of the joint respectively
516     set JointWidth [expr $h_col]; set JointHeight [expr $h_beam]; set JointDepth $w_col ;
517     set JointVolume [expr $JointWidth*$JointHeight*$JointDepth];
518
519     ##### details for the material models of bar slip of the beam #####
520
521     set bs_fc 28.0; set bs_fs 420.0; set bs_es 200000; set bs_fsu 596; set bs_dbar 12.0; set bs_esh 3100.0;
522     set bs_wid $w_col; set bs_dep $h_beam;
523     set bsT_nbars 12; set bsB_nbars 8;
524     set bs_ljoint $h_col;
525
526     ##### details for the material models of bar slip of the column #####
527
528     set cs_fc 28.0; set cs_fs 420.0; set cs_es 200000.0; set cs_fsu 596; set cs_dbar 18.0; set cs_esh 3100.0;
529     set cs_wid $w_col; set cs_dep $h_col;
530     set cs_nbars 5;
531     set cs_ljoint $h_beam;
532
533     #####
534     #bar slip definition
535
536     # for beam bottom
537
538     set bsid1 11
539     #uniaxialMaterial BarSlip $matTag $fc $fy $Es $fu $EH $db $ld $nb $depth $height <$anLratio> $bsFlag $stype <$damage $unit>
540     uniaxialMaterial BarSlip $bsid1 $bs_fc $bs_fs $bs_es $bs_fsu $bs_esh $bs_dbar $bs_ljoint $bsB_nbars $bs_wid $bs_dep strong

```

```

beambot
541
542 # for beam top
543
544 set bsid2 21
545 #uniaxialMaterial BarSlip $matTag $fc $fy $Es $fu $Eh $db $ld $nb $depth $height <$anclratio> $bsFlag $type <$damage $unit>
546 uniaxialMaterial BarSlip $bsid2 $bs_fc $bs_fs $bs_es $bs_fsu $bs_esh $bs_dbar $bs_ljoint $bsT_nbars $bs_wid $bs_dep strong
beamtop
547
548 # for columns
549 set bsid3 31
550
551 #uniaxialMaterial BarSlip $matTag $fc $fy $Es $fu $Eh $db $ld $nb $depth $height <$anclratio> $bsFlag $type <$damage $unit>
552 uniaxialMaterial BarSlip $bsid3 $cs_fc $cs_fs $cs_es $cs_fsu $cs_esh $cs_dbar $cs_ljoint $cs_nbars $cs_wid $cs_dep strong c
olumn
553
554
555 ##### material for shear panel #####
556
557 ## Positive/Negative envelope Stress
558
559 set spid1 41;
560 set A 0.78;
561 set p1 [expr 2.539*$A]; set p2 [expr 3.005*$A]; set p3 [expr 3.163*$A]; set p4 [expr 0.6326*$A];
562
563 ## stress1 stress2 stress3 stress4
564 set pEnvStrsp [list [expr $p1*$JointVolume] [expr $p2*$JointVolume] [expr $p3*$JointVolume] [expr $p4*$JointVolume]]
565 set nEnvStrsp [list [expr -$p1*$JointVolume] [expr -$p2*$JointVolume] [expr -$p3*$JointVolume] [expr -$p4*$JointVolume]]
566
567 ## Positive/Negative envelope Strain
568 ## strain1 strain2 strain3 strain4
569
570 set pEnvStnsp [list 0.0008 0.015 0.035 0.04]
571 set nEnvStnsp [list -0.0008 -0.015 -0.035 -0.04]
572
573 ## Ratio of maximum deformation at which reloading begins
574 ## Pos_env. Neg_env.
575 set rDisp [list 0.2 0.2]
576
577 ## Ratio of envelope force (corresponding to maximum deformation) at which reloading begins
578
579 ### Pos_env. Neg_env.
580 set rForcesp [list 0.2 0.2]
581
582
583 ## Ratio of monotonic strength developed upon unloading
584 ### Pos_env. Neg_env.
585
586 set uForcesp [list 0.0 0.0]
587
588
589 ## Coefficients for Unloading Stiffness degradation
590
591 ## gammaK1 gammaK2 gammaK3 gammaK4 gammaKLimit
592
593 #set gammaKsp [list 1.13364492409642 0.0 0.10111033064469 0.0 0.91652498468618]
594
595 set gammaKsp [list 0.0 0.0 0.0 0.0 0.0]
596
597 ##### Coefficients for Reloading Stiffness degradation
598 ## gammaD1 gammaD2 gammaD3 gammaD4 gammaDLimit
599
600 #set gammaDsp [list 0.12 0.0 0.23 0.0 0.95]
601
602 set gammaDsp [list 0.0 0.0 0.0 0.0 0.0]
603
604 ##### Coefficients for Strength degradation
605 ## gammaF1 gammaF2 gammaF3 gammaF4 gammaFLimit
606
607 #set gammaFsp [list 1.11 0.0 0.319 0.0 0.125]
608
609 set gammaFsp [list 0.0 0.0 0.0 0.0 0.0]
610
611 set gammaEsp 10.0
612
613 uniaxialMaterial Pinching4 $spid1 [lindex $pEnvStrsp 0] [lindex $pEnvStnsp 0] \
614 [lindex $pEnvStrsp 1] [lindex $pEnvStnsp 1] [lindex $pEnvStrsp 2] \
615 [lindex $pEnvStrsp 3] [lindex $pEnvStnsp 3] [lindex $pEnvStrsp 4] \
616 [lindex $nEnvStrsp 0] [lindex $nEnvStnsp 0] \
617 [lindex $nEnvStrsp 1] [lindex $nEnvStnsp 1] [lindex $nEnvStrsp 2] \

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616 [lindex $nEnvStnsp 2] [lindex $nEnvStrsp 3] [lindex $nEnvStnsp 3] \
617 [lindex $rDispsp 0] [lindex $rForcesp 0] [lindex $uForcesp 0] \
618 [lindex $rDispsp 1] [lindex $rForcesp 1] [lindex $uForcesp 1] \
619 [lindex $gammaKsp 0] [lindex $gammaKsp 1] [lindex $gammaKsp 2] [lindex $gammaKsp 3] [lindex $gammaKsp 4] \
620 [lindex $gammaDsp 0] [lindex $gammaDsp 1] [lindex $gammaDsp 2] [lindex $gammaDsp 3] [lindex $gammaDsp 4] \
621 [lindex $gammaFsp 0] [lindex $gammaFsp 1] [lindex $gammaFsp 2] [lindex $gammaFsp 3] [lindex $gammaFsp 4] \
622 $gammaEsp energy
623
624 ##### beam column joint #####
625
626 ##element BeamColumnJoint tag? iNode? jNode? kNode? lNode? matTag1? matTag2? matTag3? matTag4?
627 ## matTag5? matTag6? matTag7? matTag8? matTag9? matTag10? matTag11? matTag12? matTag13?
628 ## <element Height factor?> <element Width factor?>
629 ## please note: the four nodes are in anticlockwise direction around the element
630 ## requires material tags for all 13 different components within the element.
631 ## the first 12 being that of spring and the last of the shear panel
632
633 set jointA1 611
634 set jointA2 612
635 set jointA3 613
636 set jointA4 614
637 set jointA5 615
638 set jointA6 616
639
640 set jointB1 621
641 set jointB2 622
642 set jointB3 623
643 set jointB4 624
644 set jointB5 625
645 set jointB6 626
646
647 set jointC1 631
648 set jointC2 632
649 set jointC3 633
650 set jointC4 634
651 set jointC5 635
652 set jointC6 636
653
654 set jointD1 641
655 set jointD2 642
656 set jointD3 643
657 set jointD4 644
658 set jointD5 645
659 set jointD6 646
660
661 # add material Properties - command: uniaxialMaterial matType matTag ...
662 #command: uniaxialMaterial Elastic tag? E?
663
664 uniaxialMaterial Elastic 71 1000000000.0
665
666 element beamColumnJoint $jointA1 $N_A1 $N_A10_R $N_A10_A $N_A10_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
667 $bsid2 71 $spid1
668 element beamColumnJoint $jointA2 $N_A2 $N_A20_R $N_A20_A $N_A20_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
669 $bsid2 71 $spid1
670 element beamColumnJoint $jointA3 $N_A3 $N_A30_R $N_A30_A $N_A30_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
671 $bsid2 71 $spid1
672 element beamColumnJoint $jointA4 $N_A4 $N_A40_R $N_A40_A $N_A40_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
673 $bsid2 71 $spid1
674 element beamColumnJoint $jointA5 $N_A5 $N_A50_R $N_A50_A $N_A50_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
675 $bsid2 71 $spid1
676 element beamColumnJoint $jointA6 $N_A6 $N_A60_R $N_A60_A $N_A60_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
677 $bsid2 71 $spid1
678
679 element beamColumnJoint $jointB1 $N_B1 $N_B11_R $N_B11_A $N_B11_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
680 $bsid2 71 $spid1
681 element beamColumnJoint $jointB2 $N_B2 $N_B21_R $N_B21_A $N_B21_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
682 $bsid2 71 $spid1
683 element beamColumnJoint $jointB3 $N_B3 $N_B31_R $N_B31_A $N_B31_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
684 $bsid2 71 $spid1
685 element beamColumnJoint $jointB4 $N_B4 $N_B41_R $N_B41_A $N_B41_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
686 $bsid2 71 $spid1
687 element beamColumnJoint $jointB5 $N_B5 $N_B51_R $N_B51_A $N_B51_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
688 $bsid2 71 $spid1
689 element beamColumnJoint $jointB6 $N_B6 $N_B61_R $N_B61_A $N_B61_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
690 $bsid2 71 $spid1
691
692 element beamColumnJoint $jointC1 $N_C1 $N_C12_R $N_C12_A $N_C12_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
693 $bsid2 71 $spid1
694 element beamColumnJoint $jointC2 $N_C2 $N_C22_R $N_C22_A $N_C22_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
695 $bsid2 71 $spid1

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682 element beamColumnJoint $jointC3 $N_C3 $N_C32_R $N_C32_A $N_C32_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
683 element beamColumnJoint $jointC4 $N_C4 $N_C42_R $N_C42_A $N_C42_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
684 element beamColumnJoint $jointC5 $N_C5 $N_C52_R $N_C52_A $N_C52_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
685 element beamColumnJoint $jointC6 $N_C6 $N_C62_R $N_C62_A $N_C62_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
686
687 element beamColumnJoint $jointD1 $N_D1 $N_D13_R $N_D13_A $N_D13_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
688 element beamColumnJoint $jointD2 $N_D2 $N_D23_R $N_D23_A $N_D23_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
689 element beamColumnJoint $jointD3 $N_D3 $N_D33_R $N_D33_A $N_D33_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
690 element beamColumnJoint $jointD4 $N_D4 $N_D43_R $N_D43_A $N_D43_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
691 element beamColumnJoint $jointD5 $N_D5 $N_D53_R $N_D53_A $N_D53_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
692 element beamColumnJoint $jointD6 $N_D6 $N_D63_R $N_D63_A $N_D63_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
693
694
695 #####
696 # Elements definitions
697 #####
698
699 # COLUMN definition
700
701 # -----
702 # Define geometric transformation
703 # -----
704 set ColTransfTag 1;          # associate a tag to column transformation
705 geomTransf PDelta $ColTransfTag ; #Columns
706
707 # -----
708 # ---- element connectivity "Columns Definition"-----
709 # -----
710 set numIntPoints 4;
711 set integrationC "Lobatto $col25x60 $numIntPoints"
712
713 element forceBeamColumn 710      $N_A0  $N_A1 $ColTransfTag $integrationC
714 element forceBeamColumn 720      $N_A10_A  $N_A2 $ColTransfTag $integrationC
715 element forceBeamColumn 730      $N_A20_A  $N_A3 $ColTransfTag $integrationC
716 element forceBeamColumn 740      $N_A30_A  $N_A4 $ColTransfTag $integrationC
717 element forceBeamColumn 750      $N_A40_A  $N_A5 $ColTransfTag $integrationC
718 element forceBeamColumn 760      $N_A50_A  $N_A6 $ColTransfTag $integrationC
719
720 element forceBeamColumn 711      $N_B0  $N_B1 $ColTransfTag $integrationC
721 element forceBeamColumn 721      $N_B11_A  $N_B2 $ColTransfTag $integrationC
722 element forceBeamColumn 731      $N_B21_A  $N_B3 $ColTransfTag $integrationC
723 element forceBeamColumn 741      $N_B31_A  $N_B4 $ColTransfTag $integrationC
724 element forceBeamColumn 751      $N_B41_A  $N_B5 $ColTransfTag $integrationC
725 element forceBeamColumn 761      $N_B51_A  $N_B6 $ColTransfTag $integrationC
726
727 element forceBeamColumn 712      $N_C0  $N_C1 $ColTransfTag $integrationC
728 element forceBeamColumn 722      $N_C12_A  $N_C2 $ColTransfTag $integrationC
729 element forceBeamColumn 732      $N_C22_A  $N_C3 $ColTransfTag $integrationC
730 element forceBeamColumn 742      $N_C32_A  $N_C4 $ColTransfTag $integrationC
731 element forceBeamColumn 752      $N_C42_A  $N_C5 $ColTransfTag $integrationC
732 element forceBeamColumn 762      $N_C52_A  $N_C6 $ColTransfTag $integrationC
733
734 element forceBeamColumn 713      $N_D0  $N_D1 $ColTransfTag $integrationC
735 element forceBeamColumn 723      $N_D13_A  $N_D2 $ColTransfTag $integrationC
736 element forceBeamColumn 733      $N_D23_A  $N_D3 $ColTransfTag $integrationC
737 element forceBeamColumn 743      $N_D33_A  $N_D4 $ColTransfTag $integrationC
738 element forceBeamColumn 753      $N_D43_A  $N_D5 $ColTransfTag $integrationC
739 element forceBeamColumn 763      $N_D53_A  $N_D6 $ColTransfTag $integrationC
740
741
742 #####
743
744 # BEAMS definition
745
746 # -----
747 # Define geometric transformation
748 # -----
749 set BeamTransfTag 2;          # associate a tag to beam transformation
750 geomTransf PDelta $BeamTransfTag ; #Beams
751

```

```

752 # -----
753 # ---- element connectivity "Beamss Definition"-----
754 # -----
755 set numIntPoints_beams 5;
756 set integrationB "Lobatto $beam150x30 $numIntPoints_beams"
757
758 element forceBeamColumn 810 $N_A10_R $N_B11_L $BeamTransfTag $integrationB
759 element forceBeamColumn 820 $N_A20_R $N_B21_L $BeamTransfTag $integrationB
760 element forceBeamColumn 830 $N_A30_R $N_B31_L $BeamTransfTag $integrationB
761 element forceBeamColumn 840 $N_A40_R $N_B41_L $BeamTransfTag $integrationB
762 element forceBeamColumn 850 $N_A50_R $N_B51_L $BeamTransfTag $integrationB
763 element forceBeamColumn 860 $N_A60_R $N_B61_L $BeamTransfTag $integrationB
764
765 element forceBeamColumn 811 $N_B11_R $N_C12_L $BeamTransfTag $integrationB
766 element forceBeamColumn 821 $N_B21_R $N_C22_L $BeamTransfTag $integrationB
767 element forceBeamColumn 831 $N_B31_R $N_C32_L $BeamTransfTag $integrationB
768 element forceBeamColumn 841 $N_B41_R $N_C42_L $BeamTransfTag $integrationB
769 element forceBeamColumn 851 $N_B51_R $N_C52_L $BeamTransfTag $integrationB
770 element forceBeamColumn 861 $N_B61_R $N_C62_L $BeamTransfTag $integrationB
771
772 element forceBeamColumn 812 $N_C12_R $N_D13_L $BeamTransfTag $integrationB
773 element forceBeamColumn 822 $N_C22_R $N_D23_L $BeamTransfTag $integrationB
774 element forceBeamColumn 832 $N_C32_R $N_D33_L $BeamTransfTag $integrationB
775 element forceBeamColumn 842 $N_C42_R $N_D43_L $BeamTransfTag $integrationB
776 element forceBeamColumn 852 $N_C52_R $N_D53_L $BeamTransfTag $integrationB
777 element forceBeamColumn 862 $N_C62_R $N_D63_L $BeamTransfTag $integrationB
778
779
780 #####
781 # infill walls definitions
782 #####
783
784 ##### METHOD A #####
785
786 # diagonal members
787
788 set dia1A 101;
789 set dia2A 102;
790 set dia3A 103;
791 set dia4A 104;
792 set dia5A 105;
793 set dia6A 106;
794 set dia7A 107;
795 set dia8A 108;
796 set dia9A 109;
797 set dia10A 1010;
798 set dia11A 1011;
799 set dia12A 1012;
800 set dia13A 1013;
801 set dia14A 1014;
802 set dia15A 1015;
803 set dia16A 1016;
804 set dia17A 1017;
805 set dia18A 1018;
806 set dia19A 1019;
807 set dia20A 1020;
808 set dia21A 1021;
809 set dia22A 1022;
810 set dia23A 1023;
811 set dia24A 1024;
812
813 set dia1B 1025;
814 set dia2B 1026;
815 set dia3B 1027;
816 set dia4B 1028;
817 set dia5B 1029;
818 set dia6B 1030;
819 set dia7B 1031;
820 set dia8B 1032;
821 set dia9B 1033;
822 set dia10B 1034;
823 set dia11B 1035;
824 set dia12B 1036;
825 set dia13B 1037;
826 set dia14B 1038;
827 set dia15B 1039;
828 set dia16B 1040;
829 set dia17B 1041;
830 set dia18B 1042;
831 set dia19B 1043;

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```

832 set dia20B 1044;
833 set dia21B 1045;
834 set dia22B 1046;
835 set dia23B 1047;
836 set dia24B 1048;
837
838 set dia1C 1049;
839 set dia2C 1050;
840 set dia3C 1051;
841 set dia4C 1052;
842 set dia5C 1053;
843 set dia6C 1054;
844 set dia7C 1055;
845 set dia8C 1056;
846 set dia9C 1057;
847 set dia10C 1058;
848 set dia11C 1059;
849 set dia12C 1060;
850 set dia13C 1061;
851 set dia14C 1062;
852 set dia15C 1063;
853 set dia16C 1064;
854 set dia17C 1065;
855 set dia18C 1066;
856 set dia19C 1067;
857 set dia20C 1068;
858 set dia21C 1069;
859 set dia22C 1070;
860 set dia23C 1071;
861 set dia24C 1072;
862
863 set width_wall 665; #using equation 16 in the report, the width of the strut based on H=3m,L=4m, and t=0.3m
864 set t_wall 200;
865 set Aw [expr $width_wall*$t_wall]; #cross-sectional
866 set Ew 10000000000.0; #Young's Modulus
867 set Izw [expr $t_wall*(pow($width_wall,3))/12]; #second moment of area about the local z-axis
868
869 set WtransfTag 81;
870 geomTransf Linear $WtransfTag;
871
872 # -----
873 # ---- element connectivity "diagonal infill walls Definition"-----
874 # -----
875
876 element elasticBeamColumn $dia1A $N_A1 $N_W1A_L $Aw $Ew $Izw $WtransfTag
877 element elasticBeamColumn $dia2A $N_B1 $N_W1A_L $Aw $Ew $Izw $WtransfTag
878 element elasticBeamColumn $dia3A $N_A0 $N_W1A_R $Aw $Ew $Izw $WtransfTag
879 element elasticBeamColumn $dia4A $N_B0 $N_W1A_R $Aw $Ew $Izw $WtransfTag
880 element elasticBeamColumn $dia5A $N_A2 $N_W2A_L $Aw $Ew $Izw $WtransfTag
881 element elasticBeamColumn $dia6A $N_B2 $N_W2A_L $Aw $Ew $Izw $WtransfTag
882 element elasticBeamColumn $dia7A $N_A10_A $N_W2A_R $Aw $Ew $Izw $WtransfTag
883 element elasticBeamColumn $dia8A $N_B11_A $N_W2A_R $Aw $Ew $Izw $WtransfTag
884 element elasticBeamColumn $dia9A $N_A3 $N_W3A_L $Aw $Ew $Izw $WtransfTag
885 element elasticBeamColumn $dia10A $N_B3 $N_W3A_L $Aw $Ew $Izw $WtransfTag
886 element elasticBeamColumn $dia11A $N_A20_A $N_W3A_R $Aw $Ew $Izw $WtransfTag
887 element elasticBeamColumn $dia12A $N_B21_A $N_W3A_R $Aw $Ew $Izw $WtransfTag
888 element elasticBeamColumn $dia13A $N_A4 $N_W4A_L $Aw $Ew $Izw $WtransfTag
889 element elasticBeamColumn $dia14A $N_B4 $N_W4A_L $Aw $Ew $Izw $WtransfTag
890 element elasticBeamColumn $dia15A $N_A30_A $N_W4A_R $Aw $Ew $Izw $WtransfTag
891 element elasticBeamColumn $dia16A $N_B31_A $N_W4A_R $Aw $Ew $Izw $WtransfTag
892 element elasticBeamColumn $dia17A $N_A5 $N_W5A_L $Aw $Ew $Izw $WtransfTag
893 element elasticBeamColumn $dia18A $N_B5 $N_W5A_L $Aw $Ew $Izw $WtransfTag
894 element elasticBeamColumn $dia19A $N_A40_A $N_W5A_R $Aw $Ew $Izw $WtransfTag
895 element elasticBeamColumn $dia20A $N_B41_A $N_W5A_R $Aw $Ew $Izw $WtransfTag
896 element elasticBeamColumn $dia21A $N_A6 $N_W6A_L $Aw $Ew $Izw $WtransfTag
897 element elasticBeamColumn $dia22A $N_B6 $N_W6A_L $Aw $Ew $Izw $WtransfTag
898 element elasticBeamColumn $dia23A $N_A50_A $N_W6A_R $Aw $Ew $Izw $WtransfTag
899 element elasticBeamColumn $dia24A $N_B51_A $N_W6A_R $Aw $Ew $Izw $WtransfTag
900
901 element elasticBeamColumn $dia1B $N_B1 $N_W1B_L $Aw $Ew $Izw $WtransfTag
902 element elasticBeamColumn $dia2B $N_C1 $N_W1B_L $Aw $Ew $Izw $WtransfTag
903 element elasticBeamColumn $dia3B $N_B0 $N_W1B_R $Aw $Ew $Izw $WtransfTag
904 element elasticBeamColumn $dia4B $N_C0 $N_W1B_R $Aw $Ew $Izw $WtransfTag
905 element elasticBeamColumn $dia5B $N_B2 $N_W2B_L $Aw $Ew $Izw $WtransfTag
906 element elasticBeamColumn $dia6B $N_C2 $N_W2B_L $Aw $Ew $Izw $WtransfTag
907 element elasticBeamColumn $dia7B $N_B11_A $N_W2B_R $Aw $Ew $Izw $WtransfTag
908 element elasticBeamColumn $dia8B $N_C12_A $N_W2B_R $Aw $Ew $Izw $WtransfTag
909 element elasticBeamColumn $dia9B $N_B3 $N_W3B_L $Aw $Ew $Izw $WtransfTag
910 element elasticBeamColumn $dia10B $N_C3 $N_W3B_L $Aw $Ew $Izw $WtransfTag
911 element elasticBeamColumn $dia11B $N_B21_A $N_W3B_R $Aw $Ew $Izw $WtransfTag

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912 element elasticBeamColumn $dia12B $N_C22_A $N_W3B_R $Aw $Ew $Izw $WtransfTag
913 element elasticBeamColumn $dia13B $N_B4 $N_W4B_L $Aw $Ew $Izw $WtransfTag
914 element elasticBeamColumn $dia14B $N_C4 $N_W4B_L $Aw $Ew $Izw $WtransfTag
915 element elasticBeamColumn $dia15B $N_B31_A $N_W4B_R $Aw $Ew $Izw $WtransfTag
916 element elasticBeamColumn $dia16B $N_C32_A $N_W4B_R $Aw $Ew $Izw $WtransfTag
917 element elasticBeamColumn $dia17B $N_B5 $N_W5B_L $Aw $Ew $Izw $WtransfTag
918 element elasticBeamColumn $dia18B $N_C5 $N_W5B_L $Aw $Ew $Izw $WtransfTag
919 element elasticBeamColumn $dia19B $N_B41_A $N_W5B_R $Aw $Ew $Izw $WtransfTag
920 element elasticBeamColumn $dia20B $N_C42_A $N_W5B_R $Aw $Ew $Izw $WtransfTag
921 element elasticBeamColumn $dia21B $N_B6 $N_W6B_L $Aw $Ew $Izw $WtransfTag
922 element elasticBeamColumn $dia22B $N_C6 $N_W6B_L $Aw $Ew $Izw $WtransfTag
923 element elasticBeamColumn $dia23B $N_B51_A $N_W6B_R $Aw $Ew $Izw $WtransfTag
924 element elasticBeamColumn $dia24B $N_C52_A $N_W6B_R $Aw $Ew $Izw $WtransfTag
925
926 element elasticBeamColumn $dia1C $N_C1 $N_W1C_L $Aw $Ew $Izw $WtransfTag
927 element elasticBeamColumn $dia2C $N_D1 $N_W1C_L $Aw $Ew $Izw $WtransfTag
928 element elasticBeamColumn $dia3C $N_C0 $N_W1C_R $Aw $Ew $Izw $WtransfTag
929 element elasticBeamColumn $dia4C $N_D0 $N_W1C_R $Aw $Ew $Izw $WtransfTag
930 element elasticBeamColumn $dia5C $N_C2 $N_W2C_L $Aw $Ew $Izw $WtransfTag
931 element elasticBeamColumn $dia6C $N_D2 $N_W2C_L $Aw $Ew $Izw $WtransfTag
932 element elasticBeamColumn $dia7C $N_C12_A $N_W2C_R $Aw $Ew $Izw $WtransfTag
933 element elasticBeamColumn $dia8C $N_D13_A $N_W2C_R $Aw $Ew $Izw $WtransfTag
934 element elasticBeamColumn $dia9C $N_C3 $N_W3C_L $Aw $Ew $Izw $WtransfTag
935 element elasticBeamColumn $dia10C $N_D3 $N_W3C_L $Aw $Ew $Izw $WtransfTag
936 element elasticBeamColumn $dia11C $N_C22_A $N_W3C_R $Aw $Ew $Izw $WtransfTag
937 element elasticBeamColumn $dia12C $N_D23_A $N_W3C_R $Aw $Ew $Izw $WtransfTag
938 element elasticBeamColumn $dia13C $N_C4 $N_W4C_L $Aw $Ew $Izw $WtransfTag
939 element elasticBeamColumn $dia14C $N_D4 $N_W4C_L $Aw $Ew $Izw $WtransfTag
940 element elasticBeamColumn $dia15C $N_C32_A $N_W4C_R $Aw $Ew $Izw $WtransfTag
941 element elasticBeamColumn $dia16C $N_D33_A $N_W4C_R $Aw $Ew $Izw $WtransfTag
942 element elasticBeamColumn $dia17C $N_C5 $N_W5C_L $Aw $Ew $Izw $WtransfTag
943 element elasticBeamColumn $dia18C $N_D5 $N_W5C_L $Aw $Ew $Izw $WtransfTag
944 element elasticBeamColumn $dia19C $N_C42_A $N_W5C_R $Aw $Ew $Izw $WtransfTag
945 element elasticBeamColumn $dia20C $N_D43_A $N_W5C_R $Aw $Ew $Izw $WtransfTag
946 element elasticBeamColumn $dia21C $N_C6 $N_W6C_L $Aw $Ew $Izw $WtransfTag
947 element elasticBeamColumn $dia22C $N_D6 $N_W6C_L $Aw $Ew $Izw $WtransfTag
948 element elasticBeamColumn $dia23C $N_C52_A $N_W6C_R $Aw $Ew $Izw $WtransfTag
949 element elasticBeamColumn $dia24C $N_D53_A $N_W6C_R $Aw $Ew $Izw $WtransfTag
950
951 # Central member
952
953 set cen1A 2001;
954 set cen2A 2002;
955 set cen3A 2003;
956 set cen4A 2004;
957 set cen5A 2005;
958 set cen6A 2006;
959 set cen1B 2007;
960 set cen2B 2008;
961 set cen3B 2009;
962 set cen4B 20010;
963 set cen5B 20011;
964 set cen6B 20012;
965 set cen1C 20013;
966 set cen2C 20014;
967 set cen3C 20015;
968 set cen4C 20016;
969 set cen5C 20017;
970 set cen6C 20018;
971
972 # -----
973 # Define geometric transformation
974 # -----
975 #set wallTransfTag 82; # associate a tag to wall transformation
976 #geomTransf Linear $wallTransfTag ; #walls
977
978 # -----
979 # ---- element connectivity "wall Definition"-----
980 # -----
981 #set numIntPoints_wall 2;
982
983 set wall_sec 91;
984 set wall_mat 92;
985
986
987
988
989
990 ##### material for infill walls #####
991

```

```

992 ## Positive/Negative envelope Stress
993
994 set A 1;
995 set p1 [expr 0.4*$A]; set p2 [expr 1.025*$A]; set p3 [expr 2.05*$A]; set p4 [expr 0.41*$A];
996
997 ## stress1 stress2 stress3 stress4
998 set pEnvStrsp [list [expr $p1] [expr $p2] [expr $p3] [expr $p4]]
999 set nEnvStrsp [list [expr -$p1] [expr -$p2] [expr -$p3] [expr -$p4]]
1000
1001 ## Positive/Negative envelope Strain
1002 ## strain1 strain2 strain3 strain4
1003
1004 set pEnvStnsp [list 0.000065 0.00385 0.00771 0.0120]
1005 set nEnvStnsp [list -0.000065 -0.00385 -0.00771 -0.0120]
1006
1007 ## Ratio of maximum deformation at which reloading begins
1008 ## Pos_env. Neg_env.
1009 set rDispsp [list 0.2 0.2]
1010
1011 ## Ratio of envelope force (corresponding to maximum deformation) at which reloading begins
1012
1013 ### Pos_env. Neg_env.
1014 set rForcesp [list 0.2 0.2]
1015
1016
1017 ## Ratio of monotonic strength developed upon unloading
1018 ### Pos_env. Neg_env.
1019
1020 set uForcesp [list 0.0 0.0]
1021
1022
1023 ## Coefficients for Unloading Stiffness degradation
1024
1025 ## gammaK1 gammaK2 gammaK3 gammaK4 gammaKLimit
1026
1027 #set gammaKsp [list 1.13364492409642 0.0 0.10111033064469 0.0 0.91652498468618]
1028
1029 set gammaKsp [list 0.0 0.0 0.0 0.0 0.0]
1030
1031 ##### Coefficients for Reloading Stiffness degradation
1032 ### gammaD1 gammaD2 gammaD3 gammaD4 gammaDLimit
1033
1034 #set gammaDsp [list 0.12 0.0 0.23 0.0 0.95]
1035
1036 set gammaDsp [list 0.0 0.0 0.0 0.0 0.0]
1037 ##### Coefficients for Strength degradation
1038 ### gammaF1 gammaF2 gammaF3 gammaF4 gammaFLimit
1039
1040 #set gammaFsp [list 1.11 0.0 0.319 0.0 0.125]
1041 set gammaFsp [list 0.0 0.0 0.0 0.0 0.0]
1042
1043 set gammaEsp 10.0
1044
1045 uniaxialMaterial Pinching4 $wall_mat [lindex $pEnvStrsp 0] [lindex $pEnvStnsp 0] \
1046 [lindex $pEnvStrsp 1] [lindex $pEnvStnsp 1] [lindex $pEnvStrsp 2] \
1047 [lindex $pEnvStrsp 3] [lindex $pEnvStnsp 3] [lindex $pEnvStrsp 4] \
1048 [lindex $nEnvStrsp 0] [lindex $nEnvStnsp 0] \
1049 [lindex $nEnvStrsp 1] [lindex $nEnvStnsp 1] [lindex $nEnvStrsp 2] \
1050 [lindex $nEnvStrsp 3] [lindex $nEnvStnsp 3] [lindex $nEnvStrsp 4] \
1051 [lindex $rDispsp 0] [lindex $rForcesp 0] [lindex $uForcesp 0] \
1052 [lindex $rDispsp 1] [lindex $rForcesp 1] [lindex $uForcesp 1] \
1053 [lindex $gammaKsp 0] [lindex $gammaKsp 1] [lindex $gammaKsp 2] [lindex $gammaKsp 3] [lindex $gammaKsp 4] \
1054 [lindex $gammaDsp 0] [lindex $gammaDsp 1] [lindex $gammaDsp 2] [lindex $gammaDsp 3] [lindex $gammaDsp 4] \
1055 [lindex $gammaFsp 0] [lindex $gammaFsp 1] [lindex $gammaFsp 2] [lindex $gammaFsp 3] [lindex $gammaFsp 4] \
1056 $gammaEsp energy
1057
1058 ##### wall section #####
1059 #####
1060 #BuildRCrectSection $ColSecTag $HSec $BSec $coverH $coverB $coreID $coverID $steelID $numBarsTop $barArea
1061 aTop $numBarsBot $barAreaBot $numBarsIntTot $barAreaInt $nfCoreY $nfCoreZ $nfCoverY $nfCoverZ
1062 BuildRCrectSection $wall_sec $width_wall $t_wall 20 20 $wall_mat $wall_mat $wall_mat 0 $reba
1063 r_18 0 $rebar_18 0 $rebar_18 8 8 8 8
1064
1065 set wallTransfTag 3; # associate a tag to column transformation
1066 geomTransf PDelta $wallTransfTag ; #Columns
1067
1068 # -----
1069 # ---- element connectivity "Columns Definition"-----
1070 # -----

```



```

1069 set numIntPoints_wall 4;
1070 set integrationw "Lobatto $wall_sec $numIntPoints_wall"
1071
1072 element forceBeamColumn $cen1A $N_W1A_L $N_W1A_R $wallTransfTag $integrationw
1073 element forceBeamColumn $cen2A $N_W2A_L $N_W2A_R $wallTransfTag $integrationw
1074 element forceBeamColumn $cen3A $N_W3A_L $N_W3A_R $wallTransfTag $integrationw
1075 element forceBeamColumn $cen4A $N_W4A_L $N_W4A_R $wallTransfTag $integrationw
1076 element forceBeamColumn $cen5A $N_W5A_L $N_W5A_R $wallTransfTag $integrationw
1077 element forceBeamColumn $cen6A $N_W6A_L $N_W6A_R $wallTransfTag $integrationw
1078
1079 element forceBeamColumn $cen1B $N_W1B_L $N_W1B_R $wallTransfTag $integrationw
1080 element forceBeamColumn $cen2B $N_W2B_L $N_W2B_R $wallTransfTag $integrationw
1081 element forceBeamColumn $cen3B $N_W3B_L $N_W3B_R $wallTransfTag $integrationw
1082 element forceBeamColumn $cen4B $N_W4B_L $N_W4B_R $wallTransfTag $integrationw
1083 element forceBeamColumn $cen5B $N_W5B_L $N_W5B_R $wallTransfTag $integrationw
1084 element forceBeamColumn $cen6B $N_W6B_L $N_W6B_R $wallTransfTag $integrationw
1085
1086 element forceBeamColumn $cen1C $N_W1C_L $N_W1C_R $wallTransfTag $integrationw
1087 element forceBeamColumn $cen2C $N_W2C_L $N_W2C_R $wallTransfTag $integrationw
1088 element forceBeamColumn $cen3C $N_W3C_L $N_W3C_R $wallTransfTag $integrationw
1089 element forceBeamColumn $cen4C $N_W4C_L $N_W4C_R $wallTransfTag $integrationw
1090 element forceBeamColumn $cen5C $N_W5C_L $N_W5C_R $wallTransfTag $integrationw
1091 element forceBeamColumn $cen6C $N_W6C_L $N_W6C_R $wallTransfTag $integrationw
1092
1093
1094
1095 ##### METHOD B ##### Can be used in case of convergence problem
1096 s (Validated Method Experimentally)
1097
1098 #set width_wall 665; #using equation 16 in the report, the width of the strut based on H=3m,L=4m, and t=0.3m
1099 #set t_wall 200;
1100 #set Aw [expr $width_wall*$t_wall]; #cross-sectional
1101 #set Ew 10000000000.0; #Young's Modulus
1102 #set Izw [expr $t_wall*(pow($width_wall,3))/12]; #second moment of area about the local z-axis
1103
1104 # Central member
1105
1106 #set cenA1 111; #A: means that the diagonal strut start from axis A to B, and the rest in that analogy
1107 .
1108 #set cenA2 112;
1109 #set cenA3 113;
1110 #set cenA4 114;
1111 #set cenA5 115;
1112 #set cenA6 116;
1113
1114 #set cenB1 121;
1115 #set cenB2 122;
1116 #set cenB3 123;
1117 #set cenB4 124;
1118 #set cenB5 125;
1119 #set cenB6 126;
1120
1121 #set cenC1 131;
1122 #set cenC2 132;
1123 #set cenC3 133;
1124 #set cenC4 134;
1125 #set cenC5 135;
1126 #set cenC6 136;
1127
1128 # -----
1129 # ---- element connectivity "wall Definition"-----
1130 # -----
1131
1132 #set wall_sec 91;
1133 #set wall_mat 92;
1134
1135
1136
1137
1138 ##### material for infill walls #####
1139
1140 ## Positive/Negative envelope Stress
1141
1142 # set unconfcw -2.05; # compression strength for concrete
1143 # set unconepscw -0.000352; # strain at maximum stress in compression
1144 # set unconfw [expr $unconfcw*0.4]; # ultimate stress for concrete
1145 # set unconpsuw -0.012; # strain at ultimate stress in compression
1146 # set unconlambdaw 0.1; # ratio between reloading stiffness and itial stiffness in compression

```

```

1147 # set unconftw [expr $unconfcw*-0.0001]; # maximum stress in tension for concrete
1148 # set unconEtw [expr $unconftw/0.2]; # elastic modulus in tension
1149 # set unconE0w 8000; #initial elastic tangent
1150
1151 # uniaxialMaterial Concrete02 $C_unconfinedw $unconfcw $unconepscw $unconfuw $unconepsw $unconlambdaw $unconftw
w $unconEtw;
1152
1153
1154
1155 ##### wall section #####
#####
1156
1157 #BuildRCrectSection $ColSecTag $HSec $BSec $coverH $coverB $coreID $coverID $steelID $numBarsTop $barArea
aTop $numBarsBot $barAreaBot $numBarsIntTot $barAreaInt $nfCoreY $nfCoreZ $nfCoverY $nfCoverZ
1158 #BuildRCrectSection $wall_sec $width_wall $t_wall 20 20 $C_unconfinedw $C_unconfinedw $C_unconfinedw 0
$rebar_18 0 $rebar_18 0 $rebar_18 8 8 8 8
1159
1160 #set wallTransfTag 3; # associate a tag to column transformation
1161 #geomTransf PDelta $wallTransfTag ; #Columns
1162
1163
1164 # -----
1165 # ---- element connectivity "Wall Definition"-----
1166 # -----
1167 #set numIntPoints_wall 4;
1168 #set integrationw "Lobatto $wall_sec $numIntPoints_wall"
1169
1170 #element forceBeamColumn $cenA1 $N_A1 $N_B0 $wallTransfTag $integrationw
1171 #element forceBeamColumn $cenA2 $N_A2 $N_B11_A $wallTransfTag $integrationw
1172 #element forceBeamColumn $cenA3 $N_A3 $N_B21_A $wallTransfTag $integrationw
1173 #element forceBeamColumn $cenA4 $N_A4 $N_B31_A $wallTransfTag $integrationw
1174 #element forceBeamColumn $cenA5 $N_A5 $N_B41_A $wallTransfTag $integrationw
1175 #element forceBeamColumn $cenA6 $N_A6 $N_B51_A $wallTransfTag $integrationw
1176
1177 #element forceBeamColumn $cenB1 $N_B1 $N_C0 $wallTransfTag $integrationw
1178 #element forceBeamColumn $cenB2 $N_B2 $N_C12_A $wallTransfTag $integrationw
1179 #element forceBeamColumn $cenB3 $N_B3 $N_C22_A $wallTransfTag $integrationw
1180 #element forceBeamColumn $cenB4 $N_B4 $N_C32_A $wallTransfTag $integrationw
1181 #element forceBeamColumn $cenB5 $N_B5 $N_C42_A $wallTransfTag $integrationw
1182 #element forceBeamColumn $cenB6 $N_B6 $N_C52_A $wallTransfTag $integrationw
1183
1184 #element forceBeamColumn $cenC1 $N_C1 $N_D0 $wallTransfTag $integrationw
1185 #element forceBeamColumn $cenC2 $N_C2 $N_D13_A $wallTransfTag $integrationw
1186 #element forceBeamColumn $cenC3 $N_C3 $N_D23_A $wallTransfTag $integrationw
1187 #element forceBeamColumn $cenC4 $N_C4 $N_D33_A $wallTransfTag $integrationw
1188 #element forceBeamColumn $cenC5 $N_C5 $N_D43_A $wallTransfTag $integrationw
1189 #element forceBeamColumn $cenC6 $N_C6 $N_D53_A $wallTransfTag $integrationw
1190
1191
1192
1193
1194
1195
1196 #####
#####
1197 # display the model with the node numbers
1198 DisplayModel2D NodeNumbers
1199
1200 #####
#####
1201 # gravity and masses load
1202 #####
#####
1203
1204 # timeSeries "LinearDefault": tsTag cFactor
1205 timeSeries Linear 1 -factor 1;
1206
1207 # distributed loads
1208
1209 #set DL 11000.0; # self weight add as point load (N)
1210 set TLE 64800.0; # TLE: Total Load at the middle columns
1211 set TLM 129600.0; # TLM: Total Load at the middle columns
1212
1213 # pattern PatternType $PatternID TimeSeriesType
1214 pattern Plain 1 1 {
1215 #load $nodeTag (ndf $LoadValues)
1216 load $N_A10_A 0 [expr -$TLE] 0;
1217 load $N_A20_A 0 [expr -$TLE] 0;
1218 load $N_A30_A 0 [expr -$TLE] 0;
1219 load $N_A40_A 0 [expr -$TLE] 0;

```

```

1220     load  $N_A50_A 0 [expr -$TLE] 0;
1221     load  $N_A60_A 0 [expr -$TLE] 0;
1222
1223     load  $N_B11_A 0 [expr -$TLM] 0;
1224     load  $N_B21_A 0 [expr -$TLM] 0;
1225     load  $N_B31_A 0 [expr -$TLM] 0;
1226     load  $N_B41_A 0 [expr -$TLM] 0;
1227     load  $N_B51_A 0 [expr -$TLM] 0;
1228     load  $N_B61_A 0 [expr -$TLM] 0;
1229
1230     load  $N_C12_A 0 [expr -$TLM] 0;
1231     load  $N_C22_A 0 [expr -$TLM] 0;
1232     load  $N_C32_A 0 [expr -$TLM] 0;
1233     load  $N_C42_A 0 [expr -$TLM] 0;
1234     load  $N_C52_A 0 [expr -$TLM] 0;
1235     load  $N_C62_A 0 [expr -$TLM] 0;
1236
1237     load  $N_D13_A 0 [expr -$TLE] 0;
1238     load  $N_D23_A 0 [expr -$TLE] 0;
1239     load  $N_D33_A 0 [expr -$TLE] 0;
1240     load  $N_D43_A 0 [expr -$TLE] 0;
1241     load  $N_D53_A 0 [expr -$TLE] 0;
1242     load  $N_D63_A 0 [expr -$TLE] 0;
1243
1244     #eleLoad -ele $eleTag1 <$eleTag2> -type -beamuniformload $wy
1245     #eleLoad -ele 5 6 -type -beamUniform [expr -$DL];
1246
1247 }
1248
1249 # masses
1250
1251     set mass1 19440;
1252     set mass2 19440;
1253     set mass3 19440;
1254     set mass4 19440;
1255     set mass5 19440;
1256     set mass6 19440;
1257
1258
1259
1260 # assign mass to nodes
1261
1262 #mass $nodetag (ndf $massvalues)
1263 mass $N_A10_L [expr $mass1/2] 0.1 0.1;
1264 mass $N_A20_L [expr $mass1/2] 0.1 0.1;
1265 mass $N_A30_L [expr $mass1/2] 0.1 0.1;
1266 mass $N_A40_L [expr $mass1/2] 0.1 0.1;
1267 mass $N_A50_L [expr $mass1/2] 0.1 0.1;
1268 mass $N_A60_L [expr $mass1/2] 0.1 0.1;
1269
1270 mass $N_B11_L [expr $mass1/2] 0.1 0.1;
1271 mass $N_B21_L [expr $mass1/2] 0.1 0.1;
1272 mass $N_B31_L [expr $mass1/2] 0.1 0.1;
1273 mass $N_B41_L [expr $mass1/2] 0.1 0.1;
1274 mass $N_B51_L [expr $mass1/2] 0.1 0.1;
1275 mass $N_B61_L [expr $mass1/2] 0.1 0.1;
1276
1277 mass $N_C12_L [expr $mass1/2] 0.1 0.1;
1278 mass $N_C22_L [expr $mass1/2] 0.1 0.1;
1279 mass $N_C32_L [expr $mass1/2] 0.1 0.1;
1280 mass $N_C42_L [expr $mass1/2] 0.1 0.1;
1281 mass $N_C52_L [expr $mass1/2] 0.1 0.1;
1282 mass $N_C62_L [expr $mass1/2] 0.1 0.1;
1283
1284 mass $N_D13_L [expr $mass1/2] 0.1 0.1;
1285 mass $N_D23_L [expr $mass1/2] 0.1 0.1;
1286 mass $N_D33_L [expr $mass1/2] 0.1 0.1;
1287 mass $N_D43_L [expr $mass1/2] 0.1 0.1;
1288 mass $N_D53_L [expr $mass1/2] 0.1 0.1;
1289 mass $N_D63_L [expr $mass1/2] 0.1 0.1;
1290
1291
1292
1293 puts "Model Built"
1294
1295
1296
1297 3) Gravity Analysis Procedure:
1298
1299 The code generated is the same as Appendix 3

```

```

1300
1301 4) Modal Analysis Procedure:
1302
1303 The code generated is the same as Appendix 3
1304
1305 5) Pushover Analysis Procedure:
1306
1307 #####
1308 # start analysis
1309
1310
1311 puts "ooo Analysis: Pushover ooo"
1312
1313 #####
1314 # set recorders
1315
1316 # Global behaviour
1317
1318 # Node Recorder "Displacements": fileName <nodeTag> dof resptype
1319 #recorder Node -file $dataDir/Pushover_Horizontal_Reactions.out -time -node $N_A0 $N_B0 $N_C0 $N_D0 -dof 1 re
1320 action
1321 #recorder Node -file $dataDir/Pushover_Storey_Displacement.out -time -node $N_A5 $N_A6 -dof 1 disp
1322 #recorder Node -file $dataDir/DFree.out -time -node $N_A1 $N_A2 -dof 1 2 disp; # displacements of free nodes
1323 #recorder Element -file $dataDir/stressStrain.out -time -ele 5 6 section fiber y z $R_steel stressStrain
1324 #recorder Element -file $dataDir/force10.out -time -ele 710 section 1 fiber y z $R_steel stressStrain;
1325 #recorder Element -file $dataDir/force60B.out -time -ele 860 section 1 fiber y z $R_steel stressStrain;
1326 recorder Element -file $dataDir/force10B.out -time -ele 810 820 830 840 850 860 localForce;
1327 recorder Element -file $dataDir/SP1.out -time -ele 611 612 613 614 615 616 621 622 623 624 625 626 shearpanel stressStrain
1328
1329 recorder Element -file $dataDir/Strut1.out -time -ele 111 112 113 114 115 116 121 122 123 124 125 126 section 1 f
1330 iber y z stressStrain;
1331 recorder Element -file $dataDir/force10.out -time -ele 710 720 730 740 750 760 711 721 731 741 751 761 localForce
1332 ;
1333 # analysis options
1334
1335 set tStart [clock clicks -milliseconds]
1336
1337 # display deformed shape:
1338 set ViewScale 5;
1339 DisplayModel2D DeformedShape $ViewScale ; # display deformed shape, the scaling factor needs to be adjusted for each mode
1340 l
1341 # characteristics of pushover analysis
1342 set Dmax 1800; # maximum displacement of pushover. push to 10% drift.
1343 set Dincr 0.01; # displacement increment for pushover. you want this to be very small, but not too small to slow down t
1344 he analysis
1345 set Tol 1;
1346 # create load pattern for lateral pushover load
1347 pattern Plain 200 Linear {; # define load pattern -- generalized
1348 load $N_A6 6 0 0
1349 load $N_A5 5 0 0
1350 load $N_A4 4 0 0
1351 load $N_A3 3 0 0
1352 load $N_A2 2 0 0
1353 load $N_A1 1 0 0
1354
1355 }
1356
1357 # ----- set up analysis parameters
1358
1359 # ## CONSTRAINTS handler >> Determines how the constraint equations are enforced in the analysis
1360 #
1361 # >> Plain Constraints -- Removes constrained degrees of freedom from the system of equations (only for homogeneous
1362 equations)
1363 # >> Lagrange Multipliers -- Uses the method of Lagrange multipliers to enforce constraints
1364 # >> Penalty Method -- Uses penalty numbers to enforce constraints --good for static analysis with non-homogeneous
1365 eqns (rigidDiaphragm)
1366 # >> Transformation Method -- Performs a condensation of constrained degrees of freedom
1367 variable constraintsTypeStatic Transformation; # default;
1368 constraints $constraintsTypeStatic
1369
1370 # DOF NUMBERER (number the degrees of freedom in the domain):
1371 #
1372 Determines the mapping between equation numbers and degrees-of-freedom

```

```

1372 # Plain -- Uses the numbering provided by the user
1373 # RCM -- Renumbers the DOF to minimize the matrix band-width using the Reverse Cuthill-McKee algorithm
1374 set numbererTypeStatic RCM
1375 numberer $numbererTypeStatic
1376
1377
1378 # SYSTEM:
1379
1380 # Linear Equation Solvers (how to store and solve the system of equations in the analysis)
1381 # -- provide the solution of the linear system of equations  $Ku = P$ . Each solver is tailored to a specific matrix topology.
1382 # ProfileSPD -- Direct profile solver for symmetric positive definite matrices
1383 # BandGeneral -- Direct solver for banded unsymmetric matrices
1384 # BandSPD -- Direct solver for banded symmetric positive definite matrices
1385 # SparseGeneral -- Direct solver for unsymmetric sparse matrices
1386 # SparseSPD -- Direct solver for symmetric sparse matrices
1387 # UmfPack -- Direct UmfPack solver for unsymmetric matrices
1388 set systemTypeStatic UmfPack; # try UmfPack for large model
1389 system $systemTypeStatic
1390
1391 # TEST: # convergence test to
1392
1393 # -- Accept the current state of the domain as being on the converged solution path
1394 # -- determine if convergence has been achieved at the end of an iteration step
1395 # NormUnbalance -- Specifies a tolerance on the norm of the unbalanced load at the current iteration
1396 # NormDispIncr -- Specifies a tolerance on the norm of the displacement increments at the current iteration
1397 # EnergyIncr -- Specifies a tolerance on the inner product of the unbalanced load and displacement increments at the
current iteration
1398 # RelativeNormUnbalance --
1399 # RelativeNormDispIncr --
1400 # RelativeEnergyIncr --
1401 variable TolStatic 0.01; # Convergence Test: tolerance
1402 variable maxNumIterStatic 10000; # Convergence Test: maximum number of iterations that will be performed befo
re "failure to converge" is returned
1403 variable printFlagStatic 0; # Convergence Test: flag used to print information on convergence (optional)
# 1: print information on each step;
1404 variable testTypeStatic EnergyIncr; # Convergence-test type
1405 test $testTypeStatic $TolStatic $maxNumIterStatic $printFlagStatic;
1406
1407 # Solution ALGORITHM: -- Iterate from the last time step to the current
1408 # Linear -- Uses the solution at the first iteration and continues
1409 # Newton -- Uses the tangent at the current iteration to iterate to convergence
1410 # ModifiedNewton -- Uses the tangent at the first iteration to iterate to convergence
1411 # NewtonLineSearch --
1412 # KrylovNewton --
1413 # BFGS --
1414 # Broyden --
1415 variable algorithmTypeStatic Newton
1416 algorithm $algorithmTypeStatic;
1417
1418 # Static INTEGRATOR: -- determine the next time step for an analysis
1419
1420 # LoadControl -- Specifies the incremental load factor to be applied to the loads in the domain
1421 # DisplacementControl -- Specifies the incremental displacement at a specified DOF in the domain
1422 # Minimum Unbalanced Displacement Norm -- Specifies the incremental load factor such that the residual displacement
norm is minimized
1423 # Arc Length -- Specifies the incremental arc-length of the load-displacement path
1424 # Transient INTEGRATOR: -- determine the next time step for an analysis including inertial effects
1425 # Newmark -- The two parameter time-stepping method developed by Newmark
1426 # HHT -- The three parameter Hilbert-Hughes-Taylor time-stepping method
1427 # Central Difference -- Approximates velocity and acceleration by centered finite differences of displacement
1428 integrator DisplacementControl $N_A6 1 $Dincr
1429
1430 # ANALYSIS -- defines what type of analysis is to be performed
1431
1432 # Static Analysis -- solves the  $KU=R$  problem, without the mass or damping matrices.
1433 # Transient Analysis -- solves the time-dependent analysis. The time step in this type of analysis is constant. The
time step
in the output is also constant.
1434 # variableTransient Analysis -- performs the same analysis type as the Transient Analysis object. The time step, ho
wever, is variable. This method is used when
1435 # there are convergence problems with the Transient Analysis object at a peak or when the time step is too s
mall. The time step in the output is also variable.
1436 set analysisTypeStatic
1437 analysis $analysisTypeStatic
1438
1439
1440 # ----- perform Static Pushover Analysis
1441 set Nsteps [expr int($Dmax/$Dincr)]; # number of pushover analysis steps
1442 set ok [analyze $Nsteps]; # this will return zero if no convergence problems were encountered
1443 set fmt1 "%s Pushover analysis: CtrlNode %.24i, dof %.1i, Disp=%.4f %s"; # format for screen/file output of DONE/PROBLEM a

```

```

nalysis
1444 if {$ok != 0} {
1445   # if analysis fails, we try some other stuff, performance is slower inside this loop
1446   set Dstep 0.0;
1447   set ok 0
1448   while {$Dstep <= 1.0 && $ok == 0} {
1449     set controlDisp [nodeDisp $N_A6 1 ]
1450     set Dstep [expr $controlDisp/$Dmax]
1451     set ok [analyze 1 ]
1452     # if analysis fails, we try some other stuff
1453     # performance is slower inside this loop global maxNumIterStatic;      # max no. of iterations performed before "fail
1454     # ure to converge" is ret'd
1455     if {$ok != 0} {
1456       puts "Trying Newton with Initial Tangent .."
1457       test NormDispIncr $Tol 3000 0
1458       algorithm Newton -initial
1459       set ok [analyze 1]
1460       test $testTypeStatic $TolStatic $maxNumIterStatic 0
1461       algorithm $algorithmTypeStatic
1462     }
1463     if {$ok != 0} {
1464       puts "Trying Broyden .."
1465       algorithm Broyden 8
1466       set ok [analyze 1 ]
1467       algorithm $algorithmTypeStatic
1468     }
1469     if {$ok != 0} {
1470       puts "Trying NewtonWithLineSearch .."
1471       algorithm NewtonLineSearch 0.8
1472       set ok [analyze 1]
1473       algorithm $algorithmTypeStatic
1474     }
1475   }; # end while loop
1476 }; # end if ok !0
1477
1478 # -----
1479 if {$ok != 0} {
1480   puts [format $fmt1 "PROBLEM" $N_A6 1 [nodeDisp $N_A6 1] "mm"]
1481 } else {
1482   puts [format $fmt1 "DONE" $N_A6 1 [nodeDisp $N_A6 1] "mm"]
1483 }
1484
1485 # Stop timing of this analysis sequence
1486 set tStop [clock clicks -milliseconds]
1487 puts "o Time taken: [expr ($tStop-$tStart)/1000.0] sec"
1488
1489 puts "pushover analysis completed"
1490
1491 # Reset for next analysis sequence
1492 wipe all;
1493

```

**Appendix 6 – The Code Generated Using the OpenSees Program
to Perform Pushover Analysis for 3B6S MRFs- Masonry-
Concrete Infilled Frames without Ground Infills**

Appendix 6: 3B6S masonry infilled Frame without ground infills

```
1
2 1) Complementary files were defined to organize and make the procedure easier:
3
4     1. Library for Units
5
6     The code generated is the same as Appendix 3
7
8     2. Building RC Cross-Section (Fiber Approach)
9
10    The code generated is the same as Appendix 3
11
12    3. Display The Model in 2D
13
14    The code generated is the same as Appendix 3
15
16    4. Display Plane Deformed Shape for 2D Model
17
18    The code generated is the same as Appendix 3
19
20
21    5. Procedure for Defining Uniaxial Pinching Material
22
23    The code generated is the same as Appendix 3.
24
25
26 2) 2D Model Definition for 3B6S MRFs-Masonry-Concrete Infilled Frame without ground infills:
27
28    The code generated is the same as Appendix 5. However, infill walls at ground level shall be removed as the following:
29
30    -These elements must be removed:
31
32    1. Diagonal members
33
34    element elasticBeamColumn $dia1A $N_A1 $N_W1A_L $Aw $Ew $Izw $WtransfTag
35    element elasticBeamColumn $dia2A $N_B1 $N_W1A_L $Aw $Ew $Izw $WtransfTag
36    element elasticBeamColumn $dia3A $N_A0 $N_W1A_R $Aw $Ew $Izw $WtransfTag
37    element elasticBeamColumn $dia4A $N_B0 $N_W1A_R $Aw $Ew $Izw $WtransfTag
38
39    element elasticBeamColumn $dia1B $N_B1 $N_W1B_L $Aw $Ew $Izw $WtransfTag
40    element elasticBeamColumn $dia2B $N_C1 $N_W1B_L $Aw $Ew $Izw $WtransfTag
41    element elasticBeamColumn $dia3B $N_B0 $N_W1B_R $Aw $Ew $Izw $WtransfTag
42    element elasticBeamColumn $dia4B $N_C0 $N_W1B_R $Aw $Ew $Izw $WtransfTag
43
44    element elasticBeamColumn $dia1C $N_C1 $N_W1C_L $Aw $Ew $Izw $WtransfTag
45    element elasticBeamColumn $dia2C $N_D1 $N_W1C_L $Aw $Ew $Izw $WtransfTag
46    element elasticBeamColumn $dia3C $N_C0 $N_W1C_R $Aw $Ew $Izw $WtransfTag
47    element elasticBeamColumn $dia4C $N_D0 $N_W1C_R $Aw $Ew $Izw $WtransfTag
48
49    2. Central members
50
51    element forceBeamColumn $cen1A $N_W1A_L $N_W1A_R $wallTransfTag $integrationw
52    element forceBeamColumn $cen1B $N_W1B_L $N_W1B_R $wallTransfTag $integrationw
53    element forceBeamColumn $cen1C $N_W1C_L $N_W1C_R $wallTransfTag $integrationw
54
55
56 3) Gravity Analysis Procedure:
57
58    The code generated is the same as Appendix 3
59
60 4) Modal Analysis Procedure:
61
62    The code generated is the same as Appendix 3
63
64 5) Pushover Analysis Procedure:
65
66    #####
67
68    # start analysis
69
70
71    puts "ooo Analysis: Pushover ooo"
72
73    #####
74
75    # set recorders
76
77    # Global behaviour
78
```



```

79 # Node Recorder "Displacements": fileName <nodeTag> dof resptype
80 #recorder Node -file $dataDir/Pushover_Horizontal_Reactions.out -time -node $N_A0 $N_B0 $N_C0 $N_D0 -dof 1 re
action
81 #recorder Node -file $dataDir/Pushover_Storey_Displacement.out -time -node $N_A5 $N_A6 -dof 1 disp
82 #recorder Node -file $dataDir/DFree.out -time -node $N_A1 $N_A2 -dof 1 2 disp; # displacements of free nodes
83 #recorder Element -file $dataDir/stressStrain.out -time -ele 5 6 section fiber y z $R_steel stressStrain
84 #recorder Element -file $dataDir/force10.out -time -ele 710 section 1 fiber y z $R_steel stressStrain;
85 #recorder Element -file $dataDir/force60B.out -time -ele 860 section 1 fiber y z $R_steel stressStrain;
86 recorder Element -file $dataDir/force10B.out -time -ele 810 820 830 840 850 860 localForce;
87 recorder Element -file $dataDir/SP1.out -time -ele 611 612 613 614 615 616 621 622 623 624 625 626 shearpanel stressStrain

88 recorder Element -file $dataDir/Strut1.out -time -ele 112 113 114 115 116 122 123 124 125 126 section 1 fiber y
z stressStrain;
89 recorder Element -file $dataDir/force10.out -time -ele 710 720 730 740 750 760 711 721 731 741 751 761 localForce
;
90 # analysis options
91
92
93 set tStart [clock clicks -milliseconds]
94
95
96 # display deformed shape:
97 set ViewScale 5;
98 DisplayModel2D DeformedShape $ViewScale ; # display deformed shape, the scaling factor needs to be adjusted for each model

99
100 # characteristics of pushover analysis
101 set Dmax 1800; # maximum displacement of pushover. push to 10% drift.
102 set Dincr 0.01; # displacement increment for pushover. you want this to be very small, but not too small to slow down the
analysis
103 set Tol 1;
104 # create load pattern for lateral pushover load
105 pattern Plain 200 Linear {; # define load pattern -- generalized
106 load $N_A6 6 0 0
107 load $N_A5 5 0 0
108 load $N_A4 4 0 0
109 load $N_A3 3 0 0
110 load $N_A2 2 0 0
111 load $N_A1 1 0 0
112
113 }
114
115
116 # ----- set up analysis parameters
117
118 # ## CONSTRAINTS handler >> Determines how the constraint equations are enforced in the analysis
119
120 # >> Plain Constraints -- Removes constrained degrees of freedom from the system of equations (only for homogeneous
equations)
121 # >> Lagrange Multipliers -- Uses the method of Lagrange multipliers to enforce constraints
122 # >> Penalty Method -- Uses penalty numbers to enforce constraints --good for static analysis with non-homogeneous
eqns (rigidDiaphragm)
123 # >> Transformation Method -- Performs a condensation of constrained degrees of freedom
124 #
125 variable constraintsTypeStatic Transformation; # default;
126 constraints $constraintsTypeStatic
127
128 # DOF NUMBERER (number the degrees of freedom in the domain):
129
130 # Determines the mapping between equation numbers and degrees-of-freedom
131 # Plain -- Uses the numbering provided by the user
132 # RCM -- Renumbers the DOF to minimize the matrix band-width using the Reverse Cuthill-McKee algorithm
133 set numbererTypeStatic RCM
134 numberer $numbererTypeStatic
135
136
137 # SYSTEM:
138
139 # Linear Equation Solvers (how to store and solve the system of equations in the analysis)
140 # -- provide the solution of the linear system of equations Ku = P. Each solver is tailored to a specific matrix topology.

141 # ProfileSPD -- Direct profile solver for symmetric positive definite matrices
142 # BandGeneral -- Direct solver for banded unsymmetric matrices
143 # BandSPD -- Direct solver for banded symmetric positive definite matrices
144 # SparseGeneral -- Direct solver for unsymmetric sparse matrices
145 # SparseSPD -- Direct solver for symmetric sparse matrices
146 # UmfPack -- Direct UmfPack solver for unsymmetric matrices
147 set systemTypeStatic UmfPack; # try UmfPack for large model
148 system $systemTypeStatic
149

```

```

150 # TEST: # convergence test to
151
152 # -- Accept the current state of the domain as being on the converged solution path
153 # -- determine if convergence has been achieved at the end of an iteration step
154 # NormUnbalance -- Specifies a tolerance on the norm of the unbalanced load at the current iteration
155 # NormDispIncr -- Specifies a tolerance on the norm of the displacement increments at the current iteration
156 # EnergyIncr-- Specifies a tolerance on the inner product of the unbalanced load and displacement increments at the
    current iteration
157 # RelativeNormUnbalance --
158 # RelativeNormDispIncr --
159 # RelativeEnergyIncr --
160 variable TolStatic 1; # Convergence Test: tolerance
161 variable maxNumIterStatic 10000; # Convergence Test: maximum number of iterations that will be performed befo
re "failure to converge" is returned
162 variable printFlagStatic 0; # Convergence Test: flag used to print information on convergence (optional)
    # 1: print information on each step;
163 variable testTypeStatic EnergyIncr ; # Convergence-test type
164 test $testTypeStatic $TolStatic $maxNumIterStatic $printFlagStatic;
165
166 # Solution ALGORITHM: -- Iterate from the last time step to the current
167 # Linear -- Uses the solution at the first iteration and continues
168 # Newton -- Uses the tangent at the current iteration to iterate to convergence
169 # ModifiedNewton -- Uses the tangent at the first iteration to iterate to convergence
170 # NewtonLineSearch --
171 # KrylovNewton --
172 # BFGS --
173 # Broyden --
174 variable algorithmTypeStatic Newton
175 algorithm $algorithmTypeStatic;
176
177 # Static INTEGRATOR: -- determine the next time step for an analysis
178
179 # LoadControl -- Specifies the incremental load factor to be applied to the loads in the domain
180 # DisplacementControl -- Specifies the incremental displacement at a specified DOF in the domain
181 # Minimum Unbalanced Displacement Norm -- Specifies the incremental load factor such that the residual displacement
    norm in minimized
182 # Arc Length -- Specifies the incremental arc-length of the load-displacement path
183 # Transient INTEGRATOR: -- determine the next time step for an analysis including inertial effects
184 # Newmark -- The two parameter time-stepping method developed by Newmark
185 # HHT -- The three parameter Hilbert-Hughes-Taylor time-stepping method
186 # Central Difference -- Approximates velocity and acceleration by centered finite differences of displacement
187 integrator DisplacementControl $N_A6 1 $Dincr
188
189 # ANALYSIS -- defines what type of analysis is to be performed
190
191 # Static Analysis -- solves the KU=R problem, without the mass or damping matrices.
192 # Transient Analysis -- solves the time-dependent analysis. The time step in this type of analysis is constant. The
    time step in the output is also constant.
193 # variableTransient Analysis -- performs the same analysis type as the Transient Analysis object. The time step, ho
wever, is variable. This method is used when
194 # there are convergence problems with the Transient Analysis object at a peak or when the time step is too s
mall. The time step in the output is also variable.
195 set analysisTypeStatic Static
196 analysis $analysisTypeStatic
197
198
199 # ----- perform Static Pushover Analysis
200 set Nsteps [expr int($Dmax/$Dincr)]; # number of pushover analysis steps
201 set ok [analyze $Nsteps]; # this will return zero if no convergence problems were encountered
202 set fmt1 "%s Pushover analysis: CtrlNode %.24i, dof %.1i, Disp=%.4f %s"; # format for screen/file output of DONE/PROBLEM an
alysis
203 if {$ok != 0} {
204     # if analysis fails, we try some other stuff, performance is slower inside this loop
205     set Dstep 0.0;
206     set ok 0
207     while {$Dstep <= 1.0 && $ok == 0} {
208         set controlDisp [nodeDisp $N_A6 1 ]
209         set Dstep [expr $controlDisp/$Dmax]
210         set ok [analyze 1 ]
211         # if analysis fails, we try some other stuff
212         # performance is slower inside this loop global maxNumIterStatic; # max no. of iterations performed before "failur
e to converge" is ret'd
213         if {$ok != 0} {
214             puts "Trying Newton with Initial Tangent .."
215             test NormDispIncr $Tol 3000 0
216             algorithm Newton -initial
217             set ok [analyze 1]
218             test $testTypeStatic $TolStatic $maxNumIterStatic 0
219             algorithm $algorithmTypeStatic
220         }

```

```

221     if {$ok != 0} {
222         puts "Trying Broyden .."
223         algorithm Broyden 8
224         set ok [analyze 1 ]
225         algorithm $algorithmTypeStatic
226     }
227     if {$ok != 0} {
228         puts "Trying NewtonWithLineSearch .."
229         algorithm NewtonLineSearch 0.8
230         set ok [analyze 1]
231         algorithm $algorithmTypeStatic
232     }
233
234 }; # end while loop
235 }; # end if ok !0
236
237 # -----
238 if {$ok != 0} {
239     puts [format $fmt1 "PROBLEM" $N_A6 1 [nodeDisp $N_A6 1] "mm"]
240 } else {
241     puts [format $fmt1 "DONE" $N_A6 1 [nodeDisp $N_A6 1] "mm"]
242 }
243
244
245 # Stop timing of this analysis sequence
246 set tStop [clock clicks -milliseconds]
247 puts "o Time taken: [expr ($tStop-$tStart)/1000.0] sec"
248
249 puts "pushover analysis completed"
250
251 # Reset for next analysis sequence
252 wipe all;

```

**Appendix 7 – The Code Generated Using the OpenSees Program
to Perform Pushover Analysis for 3B9S MRFs-Ductile Bare
Frame**

Appendix 7: 3B9S Bare Frame

```
1
2 1) Complementary files were defined to organize and make the procedure easier:
3
4     1. Library for Units
5
6     The code generated is the same as Appendix 3
7
8     2. Building RC Cross-Section (Fiber Approach)
9
10    The code generated is the same as Appendix 3
11
12    3. Display The Model in 2D
13
14    The code generated is the same as Appendix 3
15
16    4. Display Plane Deformed Shape for 2D Model
17
18    The code generated is the same as Appendix 3
19
20
21    5. Procedure for Defining Uniaxial Pinching Material
22
23    The code generated is the same as Appendix 3.
24
25
26 2) 2D Model Definition for 3B9S Bare Frame:
27
28
29 #performing nonlinear static pushover analysis on 3B9S Bare Frame
30 #####
31
32     wipe all;
33 # define model builder
34 #     model basic builder -ndm $ndm <-ndf $ndf>
35     model basic builder -ndm 2 -ndf 3
36
37     set dataDir Results;           # set up name of data directory
38     file mkdir $dataDir;          # create data directory
39     source Libunits.tcl;           # define basic system units
40     source DisplayModel2D.tcl;     # procedure for displaying a 2D View of model
41     source DisplayPlane.tcl;       # procedure for displaying a plane in a model
42
43 #####
44 # buiding geometry
45 #####
46
47 # dimensions
48
49     set span1 4000.0;
50     set span2 4000.0;
51     set span3 4000.0;
52     set storey1 3000.0;
53     set storey2 3000.0;
54     set storey3 3000.0;
55     set storey4 3000.0;
56     set storey5 3000.0;
57     set storey6 3000.0;
58     set storey7 3000.0;
59     set storey8 3000.0;
60     set storey9 3000.0;
61
62 # main grid lines
63 # vertical axis, x
64     set x1 [expr 0];
65     set x2 [expr $x1+$span1];
66     set x3 [expr $x2+$span2];
67     set x4 [expr $x3+$span3];
68
69 # hoeizontal axis, y
70     set z0 [expr 0];
71     set z1 [expr $z0+$storey1];
72     set z2 [expr $z1+$storey2];
73     set z3 [expr $z2+$storey3];
74     set z4 [expr $z3+$storey4];
75     set z5 [expr $z4+$storey5];
76     set z6 [expr $z5+$storey6];
```

```

77     set z7 [expr $z6+$storey7];
78     set z8 [expr $z7+$storey8];
79     set z9 [expr $z8+$storey9];
80
81 # definition of nodes
82
83     #assigning node tages                                # for axes A,B,C, and D.
84     set N_A0      1;
85     set N_B0      2;
86     set N_C0      3;
87     set N_D0      4;
88     set N_A1      5;
89     set N_B1      6;
90     set N_C1      7;
91     set N_D1      8;
92     set N_A2      9;
93     set N_B2     10;
94     set N_C2     11;
95     set N_D2     12;
96     set N_A3     13;
97     set N_B3     14;
98     set N_C3     15;
99     set N_D3     16;
100    set N_A4     17;
101    set N_B4     18;
102    set N_C4     19;
103    set N_D4     20;
104    set N_A5     21;
105    set N_B5     22;
106    set N_C5     23;
107    set N_D5     24;
108    set N_A6     25;
109    set N_B6     26;
110    set N_C6     27;
111    set N_D6     28;
112    set N_A7     29;
113    set N_B7     30;
114    set N_C7     31;
115    set N_D7     32;
116    set N_A8     33;
117    set N_B8     34;
118    set N_C8     35;
119    set N_D8     36;
120    set N_A9     37;
121    set N_B9     38;
122    set N_C9     39;
123    set N_D9     40;
124
125    set N_A10_R   41;                                # N_Aij_R   i: story level.   j: axis number
126    set N_A10_A   42;
127    set N_A10_L   43;
128    set N_A20_R   44;
129    set N_A20_A   45;
130    set N_A20_L   46;
131    set N_A30_R   47;
132    set N_A30_A   48;
133    set N_A30_L   49;
134    set N_A40_R   50;
135    set N_A40_A   51;
136    set N_A40_L   52;
137    set N_A50_R   53;
138    set N_A50_A   54;
139    set N_A50_L   55;
140    set N_A60_R   56;
141    set N_A60_A   57;
142    set N_A60_L   58;
143    set N_A70_R   59;
144    set N_A70_A   60;
145    set N_A70_L   61;
146    set N_A80_R   62;
147    set N_A80_A   63;
148    set N_A80_L   64;
149    set N_A90_R   65;
150    set N_A90_A   66;
151    set N_A90_L   67;
152
153    set N_B11_R   68;
154    set N_B11_A   69;
155    set N_B11_L   70;
156    set N_B21_R   71;

```

157 set N_B21_A 72;
158 set N_B21_L 73;
159 set N_B31_R 74;
160 set N_B31_A 75;
161 set N_B31_L 76;
162 set N_B41_R 77;
163 set N_B41_A 78;
164 set N_B41_L 79;
165 set N_B51_R 80;
166 set N_B51_A 81;
167 set N_B51_L 82;
168 set N_B61_R 83;
169 set N_B61_A 84;
170 set N_B61_L 85;
171 set N_B71_R 86;
172 set N_B71_A 87;
173 set N_B71_L 88;
174 set N_B81_R 89;
175 set N_B81_A 90;
176 set N_B81_L 91;
177 set N_B91_R 92;
178 set N_B91_A 93;
179 set N_B91_L 94;
180
181 set N_C12_R 95;
182 set N_C12_A 96;
183 set N_C12_L 97;
184 set N_C22_R 98;
185 set N_C22_A 99;
186 set N_C22_L 100;
187 set N_C32_R 101;
188 set N_C32_A 102;
189 set N_C32_L 103;
190 set N_C42_R 104;
191 set N_C42_A 105;
192 set N_C42_L 106;
193 set N_C52_R 107;
194 set N_C52_A 108;
195 set N_C52_L 109;
196 set N_C62_R 110;
197 set N_C62_A 111;
198 set N_C62_L 112;
199 set N_C72_R 113;
200 set N_C72_A 114;
201 set N_C72_L 115;
202 set N_C82_R 116;
203 set N_C82_A 117;
204 set N_C82_L 118;
205 set N_C92_R 119;
206 set N_C92_A 120;
207 set N_C92_L 121;
208
209 set N_D13_R 122;
210 set N_D13_A 123;
211 set N_D13_L 124;
212 set N_D23_R 125;
213 set N_D23_A 126;
214 set N_D23_L 127;
215 set N_D33_R 128;
216 set N_D33_A 129;
217 set N_D33_L 130;
218 set N_D43_R 131;
219 set N_D43_A 132;
220 set N_D43_L 133;
221 set N_D53_R 134;
222 set N_D53_A 135;
223 set N_D53_L 136;
224 set N_D63_R 137;
225 set N_D63_A 138;
226 set N_D63_L 139;
227 set N_D73_R 140;
228 set N_D73_A 141;
229 set N_D73_L 142;
230 set N_D83_R 143;
231 set N_D83_A 144;
232 set N_D83_L 145;
233 set N_D93_R 146;
234 set N_D93_A 147;
235 set N_D93_L 148;
236

```

237
238 #node $nodetag (ndm $coords) <-mass (ndf $massvalues)>
239
240 set col_halfdepA [expr 600/2]; # This is used to define the joint dimensions.
241 set col_halfdepB [expr 600/2];
242 set col_halfdepC [expr 600/2];
243 set col_halfdepD [expr 600/2];
244 set beam_halfdep1 [expr 300/2];
245 set beam_halfdep2 [expr 300/2];
246 set beam_halfdep3 [expr 300/2];
247 set beam_halfdep4 [expr 300/2];
248 set beam_halfdep5 [expr 300/2];
249 set beam_halfdep6 [expr 300/2];
250 set beam_halfdep7 [expr 300/2];
251 set beam_halfdep8 [expr 300/2];
252 set beam_halfdep9 [expr 300/2];
253
254 node $N_A0 $x1 $z0;
255 node $N_B0 $x2 $z0;
256 node $N_C0 $x3 $z0;
257 node $N_D0 $x4 $z0;
258 node $N_A1 $x1 [expr $z1-$beam_halfdep1];
259 node $N_B1 $x2 [expr $z1-$beam_halfdep1];
260 node $N_C1 $x3 [expr $z1-$beam_halfdep1];
261 node $N_D1 $x4 [expr $z1-$beam_halfdep1];
262 node $N_A2 $x1 [expr $z2-$beam_halfdep2];
263 node $N_B2 $x2 [expr $z2-$beam_halfdep2];
264 node $N_C2 $x3 [expr $z2-$beam_halfdep2];
265 node $N_D2 $x4 [expr $z2-$beam_halfdep2];
266 node $N_A3 $x1 [expr $z3-$beam_halfdep3];
267 node $N_B3 $x2 [expr $z3-$beam_halfdep3];
268 node $N_C3 $x3 [expr $z3-$beam_halfdep3];
269 node $N_D3 $x4 [expr $z3-$beam_halfdep3];
270 node $N_A4 $x1 [expr $z4-$beam_halfdep4];
271 node $N_B4 $x2 [expr $z4-$beam_halfdep4];
272 node $N_C4 $x3 [expr $z4-$beam_halfdep4];
273 node $N_D4 $x4 [expr $z4-$beam_halfdep4];
274 node $N_A5 $x1 [expr $z5-$beam_halfdep5];
275 node $N_B5 $x2 [expr $z5-$beam_halfdep5];
276 node $N_C5 $x3 [expr $z5-$beam_halfdep5];
277 node $N_D5 $x4 [expr $z5-$beam_halfdep5];
278 node $N_A6 $x1 [expr $z6-$beam_halfdep6];
279 node $N_B6 $x2 [expr $z6-$beam_halfdep6];
280 node $N_C6 $x3 [expr $z6-$beam_halfdep6];
281 node $N_D6 $x4 [expr $z6-$beam_halfdep6];
282 node $N_A7 $x1 [expr $z7-$beam_halfdep7];
283 node $N_B7 $x2 [expr $z7-$beam_halfdep7];
284 node $N_C7 $x3 [expr $z7-$beam_halfdep7];
285 node $N_D7 $x4 [expr $z7-$beam_halfdep7];
286 node $N_A8 $x1 [expr $z8-$beam_halfdep8];
287 node $N_B8 $x2 [expr $z8-$beam_halfdep8];
288 node $N_C8 $x3 [expr $z8-$beam_halfdep8];
289 node $N_D8 $x4 [expr $z8-$beam_halfdep8];
290 node $N_A9 $x1 [expr $z9-$beam_halfdep9];
291 node $N_B9 $x2 [expr $z9-$beam_halfdep9];
292 node $N_C9 $x3 [expr $z9-$beam_halfdep9];
293 node $N_D9 $x4 [expr $z9-$beam_halfdep9];
294
295
296
297 ##### add nodes - joints #####
298
299 # R: node at the right side of joint
300 # A: node above the joint
301 # L: node at the left side of the joint
302 node $N_A10_R [expr $x1+$col_halfdepA] $z1;
303 node $N_A10_A $x1 [expr $z1+$beam_halfdep1];
304 node $N_A10_L [expr $x1-$col_halfdepA] $z1;
305 node $N_A20_R [expr $x1+$col_halfdepA] $z2;
306 node $N_A20_A $x1 [expr $z2+$beam_halfdep2];
307 node $N_A20_L [expr $x1-$col_halfdepA] $z2;
308 node $N_A30_R [expr $x1+$col_halfdepA] $z3;
309 node $N_A30_A $x1 [expr $z3+$beam_halfdep3];
310 node $N_A30_L [expr $x1-$col_halfdepA] $z3;
311 node $N_A40_R [expr $x1+$col_halfdepA] $z4;
312 node $N_A40_A $x1 [expr $z4+$beam_halfdep4];
313 node $N_A40_L [expr $x1-$col_halfdepA] $z4;
314 node $N_A50_R [expr $x1+$col_halfdepA] $z5;
315 node $N_A50_A $x1 [expr $z5+$beam_halfdep5];
316 node $N_A50_L [expr $x1-$col_halfdepA] $z5;

```



```

317 node $N_A60_R [expr $x1+$col_halfdepA] $z6;
318 node $N_A60_A $x1 [expr $z6+$beam_halfdep6];
319 node $N_A60_L [expr $x1-$col_halfdepA] $z6;
320 node $N_A70_R [expr $x1+$col_halfdepA] $z7;
321 node $N_A70_A $x1 [expr $z7+$beam_halfdep7];
322 node $N_A70_L [expr $x1-$col_halfdepA] $z7;
323 node $N_A80_R [expr $x1+$col_halfdepA] $z8;
324 node $N_A80_A $x1 [expr $z8+$beam_halfdep8];
325 node $N_A80_L [expr $x1-$col_halfdepA] $z8;
326 node $N_A90_R [expr $x1+$col_halfdepA] $z9;
327 node $N_A90_A $x1 [expr $z9+$beam_halfdep9];
328 node $N_A90_L [expr $x1-$col_halfdepA] $z9;
329
330 node $N_B11_R [expr $x2+$col_halfdepB] $z1;
331 node $N_B11_A $x2 [expr $z1+$beam_halfdep1];
332 node $N_B11_L [expr $x2-$col_halfdepB] $z1;
333 node $N_B21_R [expr $x2+$col_halfdepB] $z2;
334 node $N_B21_A $x2 [expr $z2+$beam_halfdep2];
335 node $N_B21_L [expr $x2-$col_halfdepB] $z2;
336 node $N_B31_R [expr $x2+$col_halfdepB] $z3;
337 node $N_B31_A $x2 [expr $z3+$beam_halfdep3];
338 node $N_B31_L [expr $x2-$col_halfdepB] $z3;
339 node $N_B41_R [expr $x2+$col_halfdepB] $z4;
340 node $N_B41_A $x2 [expr $z4+$beam_halfdep4];
341 node $N_B41_L [expr $x2-$col_halfdepB] $z4;
342 node $N_B51_R [expr $x2+$col_halfdepB] $z5;
343 node $N_B51_A $x2 [expr $z5+$beam_halfdep5];
344 node $N_B51_L [expr $x2-$col_halfdepB] $z5;
345 node $N_B61_R [expr $x2+$col_halfdepB] $z6;
346 node $N_B61_A $x2 [expr $z6+$beam_halfdep6];
347 node $N_B61_L [expr $x2-$col_halfdepB] $z6;
348 node $N_B71_R [expr $x2+$col_halfdepB] $z7;
349 node $N_B71_A $x2 [expr $z7+$beam_halfdep7];
350 node $N_B71_L [expr $x2-$col_halfdepB] $z7;
351 node $N_B81_R [expr $x2+$col_halfdepB] $z8;
352 node $N_B81_A $x2 [expr $z8+$beam_halfdep8];
353 node $N_B81_L [expr $x2-$col_halfdepB] $z8;
354 node $N_B91_R [expr $x2+$col_halfdepB] $z9;
355 node $N_B91_A $x2 [expr $z9+$beam_halfdep9];
356 node $N_B91_L [expr $x2-$col_halfdepB] $z9;
357
358 node $N_C12_R [expr $x3+$col_halfdepC] $z1;
359 node $N_C12_A $x3 [expr $z1+$beam_halfdep1];
360 node $N_C12_L [expr $x3-$col_halfdepC] $z1;
361 node $N_C22_R [expr $x3+$col_halfdepC] $z2;
362 node $N_C22_A $x3 [expr $z2+$beam_halfdep2];
363 node $N_C22_L [expr $x3-$col_halfdepC] $z2;
364 node $N_C32_R [expr $x3+$col_halfdepC] $z3;
365 node $N_C32_A $x3 [expr $z3+$beam_halfdep3];
366 node $N_C32_L [expr $x3-$col_halfdepC] $z3;
367 node $N_C42_R [expr $x3+$col_halfdepC] $z4;
368 node $N_C42_A $x3 [expr $z4+$beam_halfdep4];
369 node $N_C42_L [expr $x3-$col_halfdepC] $z4;
370 node $N_C52_R [expr $x3+$col_halfdepC] $z5;
371 node $N_C52_A $x3 [expr $z5+$beam_halfdep5];
372 node $N_C52_L [expr $x3-$col_halfdepC] $z5;
373 node $N_C62_R [expr $x3+$col_halfdepC] $z6;
374 node $N_C62_A $x3 [expr $z6+$beam_halfdep6];
375 node $N_C62_L [expr $x3-$col_halfdepC] $z6;
376 node $N_C72_R [expr $x3+$col_halfdepC] $z7;
377 node $N_C72_A $x3 [expr $z7+$beam_halfdep7];
378 node $N_C72_L [expr $x3-$col_halfdepC] $z7;
379 node $N_C82_R [expr $x3+$col_halfdepC] $z8;
380 node $N_C82_A $x3 [expr $z8+$beam_halfdep8];
381 node $N_C82_L [expr $x3-$col_halfdepC] $z8;
382 node $N_C92_R [expr $x3+$col_halfdepC] $z9;
383 node $N_C92_A $x3 [expr $z9+$beam_halfdep9];
384 node $N_C92_L [expr $x3-$col_halfdepC] $z9;
385
386 node $N_D13_R [expr $x4+$col_halfdepD] $z1;
387 node $N_D13_A $x4 [expr $z1+$beam_halfdep1];
388 node $N_D13_L [expr $x4-$col_halfdepD] $z1;
389 node $N_D23_R [expr $x4+$col_halfdepD] $z2;
390 node $N_D23_A $x4 [expr $z2+$beam_halfdep2];
391 node $N_D23_L [expr $x4-$col_halfdepD] $z2;
392 node $N_D33_R [expr $x4+$col_halfdepD] $z3;
393 node $N_D33_A $x4 [expr $z3+$beam_halfdep3];
394 node $N_D33_L [expr $x4-$col_halfdepD] $z3;
395 node $N_D43_R [expr $x4+$col_halfdepD] $z4;
396 node $N_D43_A $x4 [expr $z4+$beam_halfdep4];

```

```

397     node $N_D43_L [expr $x4-$col_halfdepD] $z4;
398     node $N_D53_R [expr $x4+$col_halfdepD] $z5;
399     node $N_D53_A $x4 [expr $z5+$beam_halfdep5];
400     node $N_D53_L [expr $x4-$col_halfdepD] $z5;
401     node $N_D63_R [expr $x4+$col_halfdepD] $z6;
402     node $N_D63_A $x4 [expr $z6+$beam_halfdep6];
403     node $N_D63_L [expr $x4-$col_halfdepD] $z6;
404     node $N_D73_R [expr $x4+$col_halfdepD] $z7;
405     node $N_D73_A $x4 [expr $z7+$beam_halfdep7];
406     node $N_D73_L [expr $x4-$col_halfdepD] $z7;
407     node $N_D83_R [expr $x4+$col_halfdepD] $z8;
408     node $N_D83_A $x4 [expr $z8+$beam_halfdep8];
409     node $N_D83_L [expr $x4-$col_halfdepD] $z8;
410     node $N_D93_R [expr $x4+$col_halfdepD] $z9;
411     node $N_D93_A $x4 [expr $z9+$beam_halfdep9];
412     node $N_D93_L [expr $x4-$col_halfdepD] $z9;
413
414
415 # restraints
416
417     #basefix $nodetag (ndf $constraints)
418     fix $N_A0 1 1 1;
419     fix $N_B0 1 1 1;
420     fix $N_C0 1 1 1;
421     fix $N_D0 1 1 1;
422
423
424 #####
425 ##
426 # material definitions
427 #####
428 ## Definition of materials IDs
429
430     #set C_confinedB 1;
431     set C_confined 1;
432     set C_unconfined 2;
433     set R_steel 3;
434
435
436
437 # basic parameters for materials-con-concrete
438
439 # ConfinedConcrete01 Material
440
441     # $tag integer tag identifying material.
442     # $secType tag for the transverse reinforcement configuration.
443     # $fpc unconfined cylindrical strength of concrete specimen.
444     # $Ec initial elastic modulus of unconfined concrete.
445     # <-eps cu $eps cu> OR <-gamma $gamma> confined concrete ultimate strain.
446     # <-nu $nu> OR <-var ub> OR <-var nou b> Poisson's Ratio.
447     # $L1 length/diameter of square/circular core section measured respect to the hoop center line.
448     # ($L2) additional dimensions when multiple hoops are being used.
449     # $phis hoop diameter. If section arrangement has multiple hoops it refers to the external hoop.
450     # $S hoop spacing.
451     # $fyh yielding strength of the hoop steel.
452     # $Es0 elastic modulus of the hoop steel.
453     # $haRatio hardening ratio of the hoop steel.
454     # $mu ductility factor of the hoop steel.
455     # $phiLon diameter of longitudinal bars.
456
457 # basic parameters for materials-uncon-concrete
458
459     set unconfc -28.0; # compression strength for concrete
460     set unconepsc -0.002; # strain at maximum stress in compression
461     set unconfu [expr $unconfc*0.18]; # ultimate stress for concrete
462     set unconepsu -0.01; # strain at ultimate stress in compression
463     set unconlambda 0.1; # ratio between reloading stiffness and initial stiffness in compression
464     set unconft [expr $unconfc*-0.1]; # maximum stress in tension for concrete
465     set unconEt [expr $unconft/0.002]; # elastic modulus in tension
466     set unconE0 [expr 2*$unconfc/$unconepsc]; # initial elastic tangent
467
468 # basic parameters for material--steel # ReinforcingSteel uniaxial material object. This object is intended to be used in a reinforced concrete fiber section as the steel reinforcing material.
469
470     set Fy 420.0; # Yield stress in tension
471     set Fu 596.0; # Ultimate stress in tension
472     set Es 200000.0; # Initial elastic tangent
473     set Esh 3100.0; # Tangent at initial strain hardening

```

```

474     set esh 0.01;          # Strain corresponding to initial strain hardening
475     set eult 0.09;        # Strain at peak stress
476
477     #uniaxialMaterial ReinforcingSteel $matTag $fy $fu $Es $Esh $esh $eult   Define ReinforcingSteel uniaxial material
478     uniaxialMaterial ReinforcingSteel $R_steel $Fy $Fu $Es $Esh $esh $eult -DMBuck 6 0.8 -CMFatigue 0.2600 0.5000 0.3890 -Iso
Hard 4.3000 0.01
479
480 # definition of ConfinedConcrete01 material
481
482     #uniaxialMaterial ConfinedConcrete01 $tag          $secType $fpc $Ec -epscu $epsucu $nu $L1 $L2 $phis $S $f
yh $Es0 $haRatio $mu $phiLon -stRatio $stRatio
483     #uniaxialMaterial ConfinedConcrete01 $C_confinedB R -28 24870.1 -epscu -0.04 -varUB 250.0 1450.0 10.0 125.0 4
20.0 20000.0 0.00 3100.0 12.0 -stRatio 0.85
484     #uniaxialMaterial ConfinedConcrete01 $C_confinedC R -28 24870.1 -epscu -0.04 -varUB 550.0 200.0 10.0 125.0 4
20.0 20000.0 0.00 3100.0 18.0 -stRatio 0.85
485
486
487 # basic parameters for materials-con-concrete
488
489     set confc -32.5;          # compression strength for concrete
490     set conepsc -0.003;      # strain at maximum stress in compression
491     set confu [expr $unconfc*0.18]; # ultimate stress for concrete
492     set conepsu -0.04;      # strain at ultimate stress in compression
493     set conlambda 0.1;      # ratio between reloading stiffness and itial stiffness in compression
494     set conft [expr $unconfc*-0.1]; # maximum stress in tension for concrete
495     set conEt [expr $unconfc/0.002]; # elastic modulus in tension
496     set conE0 [expr 2*$unconfc/$unconepsc]; #intial elastic tangent
497
498     # uniaxialMaterial Concrete02 $matTag $fpc $epsu0 $fpcu $epsU $lambda $ft $Ets
499     uniaxialMaterial Concrete02 $C_unconfined $unconfc $unconepsc $unconfu $unconepsu $unconlambda $unconfc $unco
nEt;
500     uniaxialMaterial Concrete02 $C_confined $confc $conepsc $confu $conepsu $conlambda $conft $conEt;
501
502     #####
503 # definition of the Sections
504     #####
505
506 # define sections IDs
507
508     set col40x60 1;
509     set beam150x30 2;
510
511 # define section parameters
512
513     set pi 3.141593;
514     set rebar_12 [expr $pi*12.0*12.0/4]; # area rebar 12mm
515     set rebar_16 [expr $pi*16.0*16.0/4];
516     set w_col 400.0; # column width
517     set h_col 600.0; # column hieght
518     set c_col 20.0; # column cover
519     set w_beam 1500.0; # beam width
520     set h_beam 300.0; # beam hieght
521     set c_beam 30.0; # beam cover
522
523 # load procedure for fiber section
524
525     source BuildRCrectSection.tcl;
526
527 # build sections
528
529     #BuildRCrectSection $ColSecTag $HSec $BSec $coverH $coverB $coreID $coverID $steelID $numBarsTop $barAre
aTop $numBarsBot $barAreaBot $numBarsIntTot $barAreaInt $nfCoreY $nfCoreZ $nfCoverY $nfCoverZ
530     BuildRCrectSection $col40x60 $h_col $w_col $c_col $c_col $C_confined $C_unconfined $R_steel 9 $rebar_1
6 9 $rebar_16 2 $rebar_16 8 8 8 8
531     BuildRCrectSection $beam150x30 $h_beam $w_beam $c_beam $c_beam $C_confined $C_unconfined $R_steel 12 $rebar_1
2 8 $rebar_12 0 $rebar_12 8 8 8 8
532
533
534     #####
535 # beam column joint definition
536     #####
537
538 # dimensions of the joint respectively
539     set JointWidth [expr $h_col]; set JointHeight [expr $h_beam]; set JointDepth $w_col ;
540     set JointVolume [expr $JointWidth*$JointHeight*$JointDepth];
541

```

```

542 ##### details for the material models of bar slip of the beam #####
543
544 set bs_fc 28.0; set bs_fs 420.0; set bs_es 200000; set bs_fsu 596; set bs_dbar 12.0; set bs_esh 3100.0;
545 set bs_wid $w_col; set bs_dep $h_beam;
546 set bsT_nbars 12; set bsB_nbars 8;
547 set bs_ljoint $h_col;
548
549 ##### details for the material models of bar slip of the column #####
550
551 set cs_fc 28.0; set cs_fs 420.0; set cs_es 200000.0; set cs_fsu 596; set cs_dbar 16.0; set cs_esh 3100.0;
552 set cs_wid $w_col; set cs_dep $h_col;
553 set cs_nbars 9;
554 set cs_ljoint $h_beam;
555
556 #####
557 #bar slip definition
558
559 # for beam bottom
560
561 set bsid1 11
562 #uniaxialMaterial BarSlip $matTag $fc $fy $Es $fu $Eh $db $ld $nb $depth $height <$ancLratio> $bsFlag $type <$damage $unit>
563 uniaxialMaterial BarSlip $bsid1 $bs_fc $bs_fs $bs_es $bs_fsu $bs_esh $bs_dbar $bs_ljoint $bsB_nbars $bs_wid $bs_dep strong
beambot
564
565 # for beam top
566
567 set bsid2 21
568 #uniaxialMaterial BarSlip $matTag $fc $fy $Es $fu $Eh $db $ld $nb $depth $height <$ancLratio> $bsFlag $type <$damage $unit>
569 uniaxialMaterial BarSlip $bsid2 $bs_fc $bs_fs $bs_es $bs_fsu $bs_esh $bs_dbar $bs_ljoint $bsT_nbars $bs_wid $bs_dep strong
beamtopy
570
571 # for columns
572 set bsid3 31
573
574 #uniaxialMaterial BarSlip $matTag $fc $fy $Es $fu $Eh $db $ld $nb $depth $height <$ancLratio> $bsFlag $type <$damage $unit>
575 uniaxialMaterial BarSlip $bsid3 $cs_fc $cs_fs $cs_es $cs_fsu $cs_esh $cs_dbar $cs_ljoint $cs_nbars $cs_wid $cs_dep strong c
olumn
576
577 ##### material for shear panel #####
578
579 ## Positive/Negative envelope Stress
580
581
582 set spid1 41;
583 set A 0.78;
584 set p1 [expr 2.539*$A]; set p2 [expr 3.393*$A]; set p3 [expr 3.57*$A]; set p4 [expr 0.7143*$A];
585
586 ## stress1 stress2 stress3 stress4
587 set pEnvStrsp [list [expr $p1*$JointVolume] [expr $p2*$JointVolume] [expr $p3*$JointVolume] [expr $p4*$JointVolume]]
588 set nEnvStrsp [list [expr -$p1*$JointVolume] [expr -$p2*$JointVolume] [expr -$p3*$JointVolume] [expr -$p4*$JointVolume]]
589
590 ## Positive/Negative envelope Strain
591 ## strain1 strain2 strain3 strain4
592
593 set pEnvStnsp [list 0.0008 0.015 0.035 0.04]
594 set nEnvStnsp [list -0.0008 -0.015 -0.035 -0.04]
595
596 ## Ratio of maximum deformation at which reloading begins
597 ## Pos_env. Neg_env.
598 set rDisp [list 0.2 0.2]
599
600 ## Ratio of envelope force (corresponding to maximum deformation) at which reloading begins
601
602 ### Pos_env. Neg_env.
603 set rForcesp [list 0.2 0.2]
604
605
606 ## Ratio of monotonic strength developed upon unloading
607 ### Pos_env. Neg_env.
608
609 set uForcesp [list 0.0 0.0]
610
611
612 ## Coefficients for Unloading Stiffness degradation
613
614 ## gammaK1 gammaK2 gammaK3 gammaK4 gammaKLimit
615

```

```

616 #set gammaKsp [list 1.13364492409642 0.0 0.10111033064469 0.0 0.91652498468618]
617
618 set gammaKsp [list 0.0 0.0 0.0 0.0 0.0]
619
620 ##### Coefficients for Reloading Stiffness degradation
621 ### gammaD1 gammaD2 gammaD3 gammaD4 gammaDLimit
622
623 #set gammaDsp [list 0.12 0.0 0.23 0.0 0.95]
624
625 set gammaDsp [list 0.0 0.0 0.0 0.0 0.0]
626 ##### Coefficients for Strength degradation
627 ### gammaF1 gammaF2 gammaF3 gammaF4 gammaFLimit
628
629 #set gammaFsp [list 1.11 0.0 0.319 0.0 0.125]
630 set gammaFsp [list 0.0 0.0 0.0 0.0 0.0]
631
632 set gammaEsp 10.0
633
634 uniaxialMaterial Pinching4 $spid1 [lindex $pEnvStrsp 0] [lindex $pEnvStnsp 0] \
635 [lindex $pEnvStrsp 1] [lindex $pEnvStnsp 1] [lindex $pEnvStrsp 2] \
636 [lindex $pEnvStnsp 2] [lindex $pEnvStrsp 3] [lindex $pEnvStnsp 3] \
637 [lindex $nEnvStrsp 0] [lindex $nEnvStnsp 0] \
638 [lindex $nEnvStrsp 1] [lindex $nEnvStnsp 1] [lindex $nEnvStrsp 2] \
639 [lindex $nEnvStnsp 2] [lindex $nEnvStrsp 3] [lindex $nEnvStnsp 3] \
640 [lindex $rDispsp 0] [lindex $rForcesp 0] [lindex $uForcesp 0] \
641 [lindex $rDispsp 1] [lindex $rForcesp 1] [lindex $uForcesp 1] \
642 [lindex $gammaKsp 0] [lindex $gammaKsp 1] [lindex $gammaKsp 2] [lindex $gammaKsp 3] [lindex $gammaKsp 4] \
643 [lindex $gammaDsp 0] [lindex $gammaDsp 1] [lindex $gammaDsp 2] [lindex $gammaDsp 3] [lindex $gammaDsp 4] \
644 [lindex $gammaFsp 0] [lindex $gammaFsp 1] [lindex $gammaFsp 2] [lindex $gammaFsp 3] [lindex $gammaFsp 4] \
645 $gammaEsp energy
646
647 ##### beam column joint #####
648
649 ##element BeamColumnJoint tag? iNode? jNode? kNode? lNode? matTag1? matTag2? matTag3? matTag4?
650 ## matTag5? matTag6? matTag7? matTag8? matTag9? matTag10? matTag11? matTag12? matTag13?
651 ## <element Height factor?> <element Width factor?>
652 ## please note: the four nodes are in anticlockwise direction around the element
653 ## requires material tags for all 13 different components within the element.
654 ## the first 12 being that of spring and the last of the shear panel
655
656 set jointA1 611
657 set jointA2 612
658 set jointA3 613
659 set jointA4 614
660 set jointA5 615
661 set jointA6 616
662 set jointA7 617
663 set jointA8 618
664 set jointA9 619
665
666 set jointB1 621
667 set jointB2 622
668 set jointB3 623
669 set jointB4 624
670 set jointB5 625
671 set jointB6 626
672 set jointB7 627
673 set jointB8 628
674 set jointB9 629
675
676 set jointC1 631
677 set jointC2 632
678 set jointC3 633
679 set jointC4 634
680 set jointC5 635
681 set jointC6 636
682 set jointC7 637
683 set jointC8 638
684 set jointC9 639
685
686 set jointD1 641
687 set jointD2 642
688 set jointD3 643
689 set jointD4 644
690 set jointD5 645
691 set jointD6 646
692 set jointD7 647
693 set jointD8 648
694 set jointD9 649
695

```



```

740
741
742 #####
743 # Elements definitions
744 #####
745
746 # COLUMN definition
747
748 # -----
749 # Define geometric transformation
750 # -----
751 set ColTransfTag 1;          # associate a tag to column transformation
752 geomTransf PDelta $ColTransfTag ; #Columns
753
754 # -----
755 # ---- element connectivity "Columns Definition"-----
756 # -----
757 set numIntPoints 4;
758 set integrationC "Lobatto $col140x60 $numIntPoints"
759
760 element forceBeamColumn 710      $N_A0  $N_A1 $ColTransfTag $integrationC
761 element forceBeamColumn 720      $N_A10_A $N_A2 $ColTransfTag $integrationC
762 element forceBeamColumn 730      $N_A20_A $N_A3 $ColTransfTag $integrationC
763 element forceBeamColumn 740      $N_A30_A $N_A4 $ColTransfTag $integrationC
764 element forceBeamColumn 750      $N_A40_A $N_A5 $ColTransfTag $integrationC
765 element forceBeamColumn 760      $N_A50_A $N_A6 $ColTransfTag $integrationC
766 element forceBeamColumn 770      $N_A60_A $N_A7 $ColTransfTag $integrationC
767 element forceBeamColumn 780      $N_A70_A $N_A8 $ColTransfTag $integrationC
768 element forceBeamColumn 790      $N_A80_A $N_A9 $ColTransfTag $integrationC
769
770 element forceBeamColumn 711      $N_B0  $N_B1 $ColTransfTag $integrationC
771 element forceBeamColumn 721      $N_B11_A $N_B2 $ColTransfTag $integrationC
772 element forceBeamColumn 731      $N_B21_A $N_B3 $ColTransfTag $integrationC
773 element forceBeamColumn 741      $N_B31_A $N_B4 $ColTransfTag $integrationC
774 element forceBeamColumn 751      $N_B41_A $N_B5 $ColTransfTag $integrationC
775 element forceBeamColumn 761      $N_B51_A $N_B6 $ColTransfTag $integrationC
776 element forceBeamColumn 771      $N_B61_A $N_B7 $ColTransfTag $integrationC
777 element forceBeamColumn 781      $N_B71_A $N_B8 $ColTransfTag $integrationC
778 element forceBeamColumn 791      $N_B81_A $N_B9 $ColTransfTag $integrationC
779
780 element forceBeamColumn 712      $N_C0  $N_C1 $ColTransfTag $integrationC
781 element forceBeamColumn 722      $N_C12_A $N_C2 $ColTransfTag $integrationC
782 element forceBeamColumn 732      $N_C22_A $N_C3 $ColTransfTag $integrationC
783 element forceBeamColumn 742      $N_C32_A $N_C4 $ColTransfTag $integrationC
784 element forceBeamColumn 752      $N_C42_A $N_C5 $ColTransfTag $integrationC
785 element forceBeamColumn 762      $N_C52_A $N_C6 $ColTransfTag $integrationC
786 element forceBeamColumn 772      $N_C62_A $N_C7 $ColTransfTag $integrationC
787 element forceBeamColumn 782      $N_C72_A $N_C8 $ColTransfTag $integrationC
788 element forceBeamColumn 792      $N_C82_A $N_C9 $ColTransfTag $integrationC
789
790 element forceBeamColumn 713      $N_D0  $N_D1 $ColTransfTag $integrationC
791 element forceBeamColumn 723      $N_D13_A $N_D2 $ColTransfTag $integrationC
792 element forceBeamColumn 733      $N_D23_A $N_D3 $ColTransfTag $integrationC
793 element forceBeamColumn 743      $N_D33_A $N_D4 $ColTransfTag $integrationC
794 element forceBeamColumn 753      $N_D43_A $N_D5 $ColTransfTag $integrationC
795 element forceBeamColumn 763      $N_D53_A $N_D6 $ColTransfTag $integrationC
796 element forceBeamColumn 773      $N_D63_A $N_D7 $ColTransfTag $integrationC
797 element forceBeamColumn 783      $N_D73_A $N_D8 $ColTransfTag $integrationC
798 element forceBeamColumn 793      $N_D83_A $N_D9 $ColTransfTag $integrationC
799
800
801 #####
802
803 # BEAMS definition
804
805 # -----
806 # Define geometric transformation
807 # -----
808 set BeamTransfTag 2;          # associate a tag to beam transformation
809 geomTransf PDelta $BeamTransfTag ; #Beams
810
811 # -----
812 # ---- element connectivity "Beams Definition"-----
813 # -----
814 set numIntPoints_beams 5;
815 set integrationB "Lobatto $beam150x30 $numIntPoints_beams"
816
817 element forceBeamColumn 810      $N_A10_R $N_B11_L $BeamTransfTag $integrationB
818 element forceBeamColumn 820      $N_A20_R $N_B21_L $BeamTransfTag $integrationB
819 element forceBeamColumn 830      $N_A30_R $N_B31_L $BeamTransfTag $integrationB

```

```

820 element forceBeamColumn 840 $N_A40_R $N_B41_L $BeamTransfTag $integrationB
821 element forceBeamColumn 850 $N_A50_R $N_B51_L $BeamTransfTag $integrationB
822 element forceBeamColumn 860 $N_A60_R $N_B61_L $BeamTransfTag $integrationB
823 element forceBeamColumn 870 $N_A70_R $N_B71_L $BeamTransfTag $integrationB
824 element forceBeamColumn 880 $N_A80_R $N_B81_L $BeamTransfTag $integrationB
825 element forceBeamColumn 890 $N_A90_R $N_B91_L $BeamTransfTag $integrationB
826
827 element forceBeamColumn 811 $N_B11_R $N_C12_L $BeamTransfTag $integrationB
828 element forceBeamColumn 821 $N_B21_R $N_C22_L $BeamTransfTag $integrationB
829 element forceBeamColumn 831 $N_B31_R $N_C32_L $BeamTransfTag $integrationB
830 element forceBeamColumn 841 $N_B41_R $N_C42_L $BeamTransfTag $integrationB
831 element forceBeamColumn 851 $N_B51_R $N_C52_L $BeamTransfTag $integrationB
832 element forceBeamColumn 861 $N_B61_R $N_C62_L $BeamTransfTag $integrationB
833 element forceBeamColumn 871 $N_B71_R $N_C72_L $BeamTransfTag $integrationB
834 element forceBeamColumn 881 $N_B81_R $N_C82_L $BeamTransfTag $integrationB
835 element forceBeamColumn 891 $N_B91_R $N_C92_L $BeamTransfTag $integrationB
836
837 element forceBeamColumn 812 $N_C12_R $N_D13_L $BeamTransfTag $integrationB
838 element forceBeamColumn 822 $N_C22_R $N_D23_L $BeamTransfTag $integrationB
839 element forceBeamColumn 832 $N_C32_R $N_D33_L $BeamTransfTag $integrationB
840 element forceBeamColumn 842 $N_C42_R $N_D43_L $BeamTransfTag $integrationB
841 element forceBeamColumn 852 $N_C52_R $N_D53_L $BeamTransfTag $integrationB
842 element forceBeamColumn 862 $N_C62_R $N_D63_L $BeamTransfTag $integrationB
843 element forceBeamColumn 872 $N_C72_R $N_D73_L $BeamTransfTag $integrationB
844 element forceBeamColumn 882 $N_C82_R $N_D83_L $BeamTransfTag $integrationB
845 element forceBeamColumn 892 $N_C92_R $N_D93_L $BeamTransfTag $integrationB
846
847 #####
#####
848 # display the model with the node numbers
849 DisplayModel2D NodeNumbers
850
851 #####
#####
852 # gravity and masses load
853 #####
#####
854
855 # timeSeries "LinearDefault": tsTag cFactor
856 timeSeries Linear 1 -factor 1;
857
858 # distributed loads
859
860 #set DL 11000.0; # self weight add as point load (N)
861 set TLE 68100.0; # TLE: Total Load at the middle columns
862 set TLM 136100.0; # TLM: Total Load at the middle columns
863
864 # pattern PatternType $PatternID TimeSeriesType
865 pattern Plain 1 1 {
866 #load $nodeTag (ndf $LoadValues)
867 load $N_A10_A 0 [expr -$TLE] 0;
868 load $N_A20_A 0 [expr -$TLE] 0;
869 load $N_A30_A 0 [expr -$TLE] 0;
870 load $N_A40_A 0 [expr -$TLE] 0;
871 load $N_A50_A 0 [expr -$TLE] 0;
872 load $N_A60_A 0 [expr -$TLE] 0;
873 load $N_A70_A 0 [expr -$TLE] 0;
874 load $N_A80_A 0 [expr -$TLE] 0;
875 load $N_A90_A 0 [expr -$TLE] 0;
876
877 load $N_B11_A 0 [expr -$TLM] 0;
878 load $N_B21_A 0 [expr -$TLM] 0;
879 load $N_B31_A 0 [expr -$TLM] 0;
880 load $N_B41_A 0 [expr -$TLM] 0;
881 load $N_B51_A 0 [expr -$TLM] 0;
882 load $N_B61_A 0 [expr -$TLM] 0;
883 load $N_B71_A 0 [expr -$TLM] 0;
884 load $N_B81_A 0 [expr -$TLM] 0;
885 load $N_B91_A 0 [expr -$TLM] 0;
886
887 load $N_C12_A 0 [expr -$TLM] 0;
888 load $N_C22_A 0 [expr -$TLM] 0;
889 load $N_C32_A 0 [expr -$TLM] 0;
890 load $N_C42_A 0 [expr -$TLM] 0;
891 load $N_C52_A 0 [expr -$TLM] 0;
892 load $N_C62_A 0 [expr -$TLM] 0;
893 load $N_C72_A 0 [expr -$TLM] 0;
894 load $N_C82_A 0 [expr -$TLM] 0;
895 load $N_C92_A 0 [expr -$TLM] 0;
896

```



```

897     load  $N_D13_A 0 [expr -$TLE] 0;
898     load  $N_D23_A 0 [expr -$TLE] 0;
899     load  $N_D33_A 0 [expr -$TLE] 0;
900     load  $N_D43_A 0 [expr -$TLE] 0;
901     load  $N_D53_A 0 [expr -$TLE] 0;
902     load  $N_D63_A 0 [expr -$TLE] 0;
903     load  $N_D73_A 0 [expr -$TLE] 0;
904     load  $N_D83_A 0 [expr -$TLE] 0;
905     load  $N_D93_A 0 [expr -$TLE] 0;
906
907     #eleLoad -ele $eleTag1 <$eleTag2> -type -beamuniformload $wy
908     #eleLoad -ele 5 6 -type -beamUniform [expr -$DL];
909
910 }
911
912 # masses
913
914     set mass1 20420;
915     set mass2 20420;
916     set mass3 20420;
917     set mass4 20420;
918     set mass5 20420;
919     set mass6 20420;
920     set mass7 20420;
921     set mass8 20420;
922     set mass9 20420;
923
924
925 # assign mass to nodes
926
927 #mass $nodetag (ndf $massvalues)
928
929     mass $N_A10_L [expr $mass1/2] 0.1 0.1;
930     mass $N_A20_L [expr $mass1/2] 0.1 0.1;
931     mass $N_A30_L [expr $mass1/2] 0.1 0.1;
932     mass $N_A40_L [expr $mass1/2] 0.1 0.1;
933     mass $N_A50_L [expr $mass1/2] 0.1 0.1;
934     mass $N_A60_L [expr $mass1/2] 0.1 0.1;
935     mass $N_A70_L [expr $mass1/2] 0.1 0.1;
936     mass $N_A80_L [expr $mass1/2] 0.1 0.1;
937     mass $N_A90_L [expr $mass1/2] 0.1 0.1;
938
939     mass $N_B11_L [expr $mass1/2] 0.1 0.1;
940     mass $N_B21_L [expr $mass1/2] 0.1 0.1;
941     mass $N_B31_L [expr $mass1/2] 0.1 0.1;
942     mass $N_B41_L [expr $mass1/2] 0.1 0.1;
943     mass $N_B51_L [expr $mass1/2] 0.1 0.1;
944     mass $N_B61_L [expr $mass1/2] 0.1 0.1;
945     mass $N_B71_L [expr $mass1/2] 0.1 0.1;
946     mass $N_B81_L [expr $mass1/2] 0.1 0.1;
947     mass $N_B91_L [expr $mass1/2] 0.1 0.1;
948
949     mass $N_C12_L [expr $mass1/2] 0.1 0.1;
950     mass $N_C22_L [expr $mass1/2] 0.1 0.1;
951     mass $N_C32_L [expr $mass1/2] 0.1 0.1;
952     mass $N_C42_L [expr $mass1/2] 0.1 0.1;
953     mass $N_C52_L [expr $mass1/2] 0.1 0.1;
954     mass $N_C62_L [expr $mass1/2] 0.1 0.1;
955     mass $N_C72_L [expr $mass1/2] 0.1 0.1;
956     mass $N_C82_L [expr $mass1/2] 0.1 0.1;
957     mass $N_C92_L [expr $mass1/2] 0.1 0.1;
958
959     mass $N_D13_L [expr $mass1/2] 0.1 0.1;
960     mass $N_D23_L [expr $mass1/2] 0.1 0.1;
961     mass $N_D33_L [expr $mass1/2] 0.1 0.1;
962     mass $N_D43_L [expr $mass1/2] 0.1 0.1;
963     mass $N_D53_L [expr $mass1/2] 0.1 0.1;
964     mass $N_D63_L [expr $mass1/2] 0.1 0.1;
965     mass $N_D73_L [expr $mass1/2] 0.1 0.1;
966     mass $N_D83_L [expr $mass1/2] 0.1 0.1;
967     mass $N_D93_L [expr $mass1/2] 0.1 0.1;
968
969
970
971 puts "Model Built"
972
973
974
975 3) Gravity Analysis Procedure:
976

```

```

977 The code generated is the same as Appendix 3
978
979 4) Modal Analysis Procedure:
980
981 #####
982
983 # start analysis
984
985 initialize
986
987 puts "ooo Analysis: ModalAnalysis ooo"
988
989 #####
990
991 # set recorders
992
993 # Node Recorder "EigenVectors": fileName <nodeTag> dof resptype
994 recorder Node -file $dataDir/ModalAnalysis_Node_EigenVectors_EigenVec1.out -node $N_A0 $N_A10_A $N_A20_A $N_A30_A $N
_A40_A $N_A50_A $N_A60_A $N_A70_A $N_A80_A $N_A90_A -dof 1 eigen1
995 recorder Node -file $dataDir/ModalAnalysis_Node_EigenVectors_EigenVec2.out -node $N_A0 $N_A10_A $N_A20_A $N_A30_A $N
_A40_A $N_A50_A $N_A60_A $N_A70_A $N_A80_A $N_A90_A -dof 1 eigen2
996
997 #####
998
999 # analysis options
1000
1001 # Constraint Handler
1002 constraints Transformation
1003
1004 # DOF numberer
1005 numberer Plain
1006
1007 # System of Equations
1008 system BandGeneral
1009
1010 # Convergence Test
1011 test NormDispIncr 1.00000E-5 50 0 2;
1012
1013 # Solution Algorithm
1014 algorithm Newton
1015
1016 # Integrator
1017 integrator Newmark 5.0000000E-01 2.5000000E-01
1018
1019 # Analysis Type
1020 analysis Transient
1021
1022 # Analysis model (and record response)
1023 set pi [expr 2.0*asin(1.0)]; # Definition of pi
1024 set nEigenI 1; # mode i = 1
1025 set nEigenJ 2; # mode j = 2
1026 set lambdaN [eigen [expr $nEigenJ]]; # eigenvalue analysis for nEigenJ modes
1027 set lambdaI [lindex $lambdaN [expr 0]]; # eigenvalue mode i = 1
1028 set lambdaJ [lindex $lambdaN [expr $nEigenJ-1]]; # eigenvalue mode j = 2
1029 set w1 [expr pow(($lambdaI*1000),0.5)]; # w1 (1st mode circular frequency)
1030 set w2 [expr pow(($lambdaJ*1000),0.5)]; # w2 (2nd mode circular frequency)
1031 set T1 [expr 2.0*$pi/$w1]; # 1st mode period of the structure
1032 set T2 [expr 2.0*$pi/$w2]; # 2nd mode period of the structure
1033
1034
1035 puts "T1 is $T1"
1036 puts "T2 is $T2"
1037 # Record eigenvectors
1038 record
1039
1040
1041 # Reset for next analysis case
1042 setTime 0.0
1043 loadConst
1044 remove recorders
1045 wipeAnalysis
1046
1047 puts "Modal analysis completed"
1048
1049 5) Pushover Analysis Procedure:
1050
1051 #####
1052
1053 # start analysis
1054

```

```

1055
1056 puts "ooo Analysis: Pushover ooo"
1057
1058 #####
1059
1060 # set recorders
1061
1062 # Global behaviour
1063
1064 # Node Recorder "Displacements": fileName <nodeTag> dof resptype
1065 recorder Node -file $dataDir/Pushover_Horizontal_Reactions.out -time -node $N_A0 $N_B0 $N_C0 $N_D0 -dof 1 rea
ction
1066 recorder Node -file $dataDir/Pushover_Storey_Displacement.out -time -node $N_A80_L $N_A90_L -dof 1 disp
1067 #recorder Node -file $dataDir/DFree.out -time -node $N_A10_L $N_A20_L -dof 1 2 disp; # displacements of free n
odes
1068 #recorder Element -file $dataDir/stressStrain.out -time -ele 5 6 section fiber y z $R_steel stressStrain
1069 #recorder Element -file $dataDir/force10.out -time -ele 710 section 1 fiber y z $R_steel stressStrain;
1070 #recorder Element -file $dataDir/force90B.out -time -ele 890 section 1 fiber y z $R_steel stressStrain;
1071 recorder Element -file $dataDir/force10B.out -time -ele 810 811 812 820 821 822 830 831 832 840 841 842 850 851 852
860 861 862 870 871 872 880 881 882 890 891 892 localForce;
1072 recorder Element -file $dataDir/SP1.out -time -ele 611 612 613 614 615 616 617 618 619 621 622 623 624 625 626 627 628 629
shearpanel stressStrain
1073 recorder Element -file $dataDir/force10.out -time -ele 710 720 730 740 750 760 711 721 731 741 751 761 localForce
;
1074
1075 # analysis options
1076
1077
1078 set tStart [clock clicks -milliseconds]
1079
1080
1081 # display deformed shape:
1082 set ViewScale 5;
1083 DisplayModel2D DeformedShape $ViewScale ; # display deformed shape, the scaling factor needs to be adjusted for each mode
l
1084
1085 # characteristics of pushover analysis
1086 set Dmax 1000; # maximum displacement of pushover. push to 10% drift.
1087 set Dincr 0.1; # displacement increment for pushover. you want this to be very small, but not too small to slow down the
analysis
1088 set Tol 10;
1089 # create load pattern for lateral pushover load
1090 pattern Plain 200 Linear {; # define load pattern -- generalized
1091 load $N_A90_L 9 0 0
1092 load $N_A80_L 8 0 0
1093 load $N_A70_L 7 0 0
1094 load $N_A60_L 6 0 0
1095 load $N_A50_L 5 0 0
1096 load $N_A40_L 4 0 0
1097 load $N_A30_L 3 0 0
1098 load $N_A20_L 2 0 0
1099 load $N_A10_L 1 0 0
1100
1101
1102 }
1103
1104
1105 # ----- set up analysis parameters
1106
1107 # ## CONSTRAINTS handler >> Determines how the constraint equations are enforced in the analysis
1108
1109 # >> Plain Constraints -- Removes constrained degrees of freedom from the system of equations (only for homogeneous
equations)
1110 # >> Lagrange Multipliers -- Uses the method of Lagrange multipliers to enforce constraints
1111 # >> Penalty Method -- Uses penalty numbers to enforce constraints --good for static analysis with non-homogeneous
eqns (rigidDiaphragm)
1112 # >> Transformation Method -- Performs a condensation of constrained degrees of freedom
1113 variable constraintsTypeStatic Transformation; # default;
1114 constraints $constraintsTypeStatic
1115
1116 # DOF NUMBERER (number the degrees of freedom in the domain):
1117
1118 # Determines the mapping between equation numbers and degrees-of-freedom
1119 # Plain -- Uses the numbering provided by the user
1120 # RCM -- Renumbers the DOF to minimize the matrix band-width using the Reverse Cuthill-McKee algorithm
1121 set numbererTypeStatic RCM
1122 numberer $numbererTypeStatic
1123
1124
1125 # SYSTEM:

```

```

1126 # Linear Equation Solvers (how to store and solve the system of equations in the analysis)
1127 # -- provide the solution of the linear system of equations  $Ku = P$ . Each solver is tailored to a specific matrix topology.
1128 #
1129 # ProfileSPD -- Direct profile solver for symmetric positive definite matrices
1130 # BandGeneral -- Direct solver for banded unsymmetric matrices
1131 # BandSPD -- Direct solver for banded symmetric positive definite matrices
1132 # SparseGeneral -- Direct solver for unsymmetric sparse matrices
1133 # SparseSPD -- Direct solver for symmetric sparse matrices
1134 # UmfPack -- Direct UmfPack solver for unsymmetric matrices
1135 set systemTypeStatic UmfPack; # try UmfPack for large model
1136 system $systemTypeStatic
1137
1138 # TEST: # convergence test to
1139
1140 # -- Accept the current state of the domain as being on the converged solution path
1141 # -- determine if convergence has been achieved at the end of an iteration step
1142 # NormUnbalance -- Specifies a tolerance on the norm of the unbalanced load at the current iteration
1143 # NormDispIncr -- Specifies a tolerance on the norm of the displacement increments at the current iteration
1144 # EnergyIncr-- Specifies a tolerance on the inner product of the unbalanced load and displacement increments at the
current iteration
1145 # RelativeNormUnbalance --
1146 # RelativeNormDispIncr --
1147 # RelativeEnergyIncr --
1148 variable TolStatic 3; # Convergence Test: tolerance
1149 variable maxNumIterStatic 10000; # Convergence Test: maximum number of iterations that will be performed before
re "failure to converge" is returned
1150 variable printFlagStatic 0; # Convergence Test: flag used to print information on convergence (optional)
# 1: print information on each step;
1151 variable testTypeStatic EnergyIncr; # Convergence-test type
1152 test $testTypeStatic $TolStatic $maxNumIterStatic $printFlagStatic;
1153
1154 # Solution ALGORITHM: -- Iterate from the last time step to the current
1155 # Linear -- Uses the solution at the first iteration and continues
1156 # Newton -- Uses the tangent at the current iteration to iterate to convergence
1157 # ModifiedNewton -- Uses the tangent at the first iteration to iterate to convergence
1158 # NewtonLineSearch --
1159 # KrylovNewton --
1160 # BFGS --
1161 # Broyden --
1162 variable algorithmTypeStatic Newton
1163 algorithm $algorithmTypeStatic;
1164
1165 # Static INTEGRATOR: -- determine the next time step for an analysis
1166
1167 # LoadControl -- Specifies the incremental load factor to be applied to the loads in the domain
1168 # DisplacementControl -- Specifies the incremental displacement at a specified DOF in the domain
1169 # Minimum Unbalanced Displacement Norm -- Specifies the incremental load factor such that the residual displacement
norm is minimized
1170 # Arc Length -- Specifies the incremental arc-length of the load-displacement path
1171 # Transient INTEGRATOR: -- determine the next time step for an analysis including inertial effects
1172 # Newmark -- The two parameter time-stepping method developed by Newmark
1173 # HHT -- The three parameter Hilbert-Hughes-Taylor time-stepping method
1174 # Central Difference -- Approximates velocity and acceleration by centered finite differences of displacement
1175 integrator DisplacementControl $N_A90_L 1 $Dincr
1176
1177 # ANALYSIS -- defines what type of analysis is to be performed
1178
1179 # Static Analysis -- solves the  $KU=R$  problem, without the mass or damping matrices.
1180 # Transient Analysis -- solves the time-dependent analysis. The time step in this type of analysis is constant. The
time step in the output is also constant.
1181 # variableTransient Analysis -- performs the same analysis type as the Transient Analysis object. The time step, how
ever, is variable. This method is used when
1182 # there are convergence problems with the Transient Analysis object at a peak or when the time step is too s
mall. The time step in the output is also variable.
1183 set analysisTypeStatic Static
1184 analysis $analysisTypeStatic
1185
1186
1187 # ----- perform Static Pushover Analysis
1188 set Nsteps [expr int($Dmax/$Dincr)]; # number of pushover analysis steps
1189 set ok [analyze $Nsteps]; # this will return zero if no convergence problems were encountered
1190 set fmt1 "%s Pushover analysis: CtrlNode %.24i, dof %.1i, Disp=%.4f %s"; # format for screen/file output of DONE/PROBLEM a
nalysis
1191 if {$ok != 0} {
1192 # if analysis fails, we try some other stuff, performance is slower inside this loop
1193 set Dstep 0.0;
1194 set ok 0
1195 while {$Dstep <= 1.0 && $ok == 0} {
1196 set controlDisp [nodeDisp $N_A90_L 1 ]

```

```

1197     set Dstep [expr $controlDisp/$Dmax]
1198     set ok [analyze 1 ]
1199     # if analysis fails, we try some other stuff
1200     # performance is slower inside this loop global maxNumIterStatic; # max no. of iterations performed before "fail
1201     # ure to converge" is ret'd
1202     if {$ok != 0} {
1203         puts "Trying Newton with Initial Tangent .."
1204         test NormDispIncr $Tol 3000 0
1205         algorithm Newton -initial
1206         set ok [analyze 1]
1207         test $testTypeStatic $TolStatic $maxNumIterStatic 0
1208         algorithm $algorithmTypeStatic
1209     }
1210     if {$ok != 0} {
1211         puts "Trying Broyden .."
1212         algorithm Broyden 8
1213         set ok [analyze 1 ]
1214         algorithm $algorithmTypeStatic
1215     }
1216     if {$ok != 0} {
1217         puts "Trying NewtonWithLineSearch .."
1218         algorithm NewtonLineSearch 0.8
1219         set ok [analyze 1]
1220         algorithm $algorithmTypeStatic
1221     }
1222 }; # end while loop
1223 }; # end if ok !0
1224
1225 # -----
1226 if {$ok != 0} {
1227     puts [format $fmt1 "PROBLEM" $N_A90_L 1 [nodeDisp $N_A90_L 1] "mm"]
1228 } else {
1229     puts [format $fmt1 "DONE" $N_A90_L 1 [nodeDisp $N_A90_L 1] "mm"]
1230 }
1231
1232
1233 # Stop timing of this analysis sequence
1234 set tStop [clock clicks -milliseconds]
1235 puts "o Time taken: [expr ($tStop-$tStart)/1000.0] sec"
1236
1237 puts "pushover analysis completed"
1238
1239 # Reset for next analysis sequence
1240 wipe all;

```

**Appendix 8 – The Code Generated Using the OpenSees Program
to Perform Pushover Analysis for 3B9S MRFs-Non-Ductile Bare
Frame**

Appendix 8: 3B9S Bare Frame with Structural Deficiencies

```
1
2 1) Complementary files were defined to organize and make the procedure easier:
3
4     1. Library for Units
5
6     The code generated is the same as Appendix 3
7
8     2. Building RC Cross-Section (Fiber Approach)
9
10    The code generated is the same as Appendix 3
11
12    3. Display The Model in 2D
13
14    The code generated is the same as Appendix 3
15
16    4. Display Plane Deformed Shape for 2D Model
17
18    The code generated is the same as Appendix 3
19
20
21    5. Procedure for Defining Uniaxial Pinching Material
22
23    The code generated is the same as Appendix 3.
24
25
26 2) 2D Model Definition for 3B9S Bare Frame with structural deficiencies :
27
28    The code generated is the same as Appendix 7. However, some changes were applied to represent structural deficiencies
29
30    1. Consider the effect of stirrups spacing
31
32    The code generated is the same as Appendix 4.
33
34    2. Consider Development Length
35
36    The code generated is the same as Appendix 4.
37
38    3. Beam Column Joint Properties
39
40    The code generated is the same as Appendix 4.
41
42
43 3) Gravity Analysis Procedure:
44
45    The code generated is the same as Appendix 3
46
47 4) Modal Analysis Procedure:
48
49    The code generated is the same as Appendix 7
50
51 5) Pushover Analysis Procedure:
52
53 #####
54
55 # start analysis
56
57 puts "ooo Analysis: Pushover ooo"
58
59 #####
60
61 # set recorders
62
63 # Global behaviour
64
65 # Node Recorder "Displacements": fileName <nodeTag> dof resptype
66 recorder Node -file $dataDir/Pushover_Horizontal_Reactions.out -time -node $N_A0 $N_B0 $N_C0 $N_D0 -dof 1 rea
67 ction
68 recorder Node -file $dataDir/Pushover_Storey_Displacement.out -time -node $N_A80_L $N_A90_L -dof 1 disp
69 #recorder Node -file $dataDir/DFree.out -time -node $N_A10_L $N_A20_L -dof 1 2 disp; # displacements of free nodes
70
71 #recorder Element -file $dataDir/stressStrain.out -time -ele 5 6 section fiber y z $R_steel stressStrain
72 #recorder Element -file $dataDir/force10.out -time -ele 710 section 1 fiber y z $R_steel stressStrain;
73 #recorder Element -file $dataDir/force90B.out -time -ele 890 section 1 fiber y z $R_steel stressStrain;
74 recorder Element -file $dataDir/force10B.out -time -ele 810 820 830 840 850 860 870 880 890 localForce;
75 recorder Element -file $dataDir/SP1.out -time -ele 611 612 613 614 615 616 617 618 619 621 622 623 624 625 626 627 628 629
shearpanel stressStrain
76 recorder Element -file $dataDir/force10.out -time -ele 710 720 730 740 750 760 711 721 731 741 751 761 localForce
```

```

76 ;
77
78 # analysis options
79
80
81 set tStart [clock clicks -milliseconds]
82
83
84 # display deformed shape:
85 set ViewScale 5;
86 DisplayModel2D DeformedShape $ViewScale ; # display deformed shape, the scaling factor needs to be adjusted for each model
87
88 # characteristics of pushover analysis
89 set Dmax 1000; # maximum displacement of pushover. push to 10% drift.
90 set Dincr 0.009; # displacement increment for pushover. you want this to be very small, but not too small to slow down the analysis
91 set Tol 10;
92 # create load pattern for lateral pushover load
93 pattern Plain 200 Linear {; # define load pattern -- generalized
94     load $N_A90_L 9 0 0
95     load $N_A80_L 8 0 0
96     load $N_A70_L 7 0 0
97     load $N_A60_L 6 0 0
98     load $N_A50_L 5 0 0
99     load $N_A40_L 4 0 0
100    load $N_A30_L 3 0 0
101    load $N_A20_L 2 0 0
102    load $N_A10_L 1 0 0
103
104 }
105
106
107
108 # ----- set up analysis parameters
109
110 # ## CONSTRAINTS handler >> Determines how the constraint equations are enforced in the analysis
111
112 # >> Plain Constraints -- Removes constrained degrees of freedom from the system of equations (only for homogeneous equations)
113 # >> Lagrange Multipliers -- Uses the method of Lagrange multipliers to enforce constraints
114 # >> Penalty Method -- Uses penalty numbers to enforce constraints --good for static analysis with non-homogeneous eqns (rigidDiaphragm)
115 # >> Transformation Method -- Performs a condensation of constrained degrees of freedom
116 variable constraintsTypeStatic Transformation; # default;
117 constraints $constraintsTypeStatic
118
119 # DOF NUMBERER (number the degrees of freedom in the domain):
120
121 # Determines the mapping between equation numbers and degrees-of-freedom
122 # Plain -- Uses the numbering provided by the user
123 # RCM -- Renumbers the DOF to minimize the matrix band-width using the Reverse Cuthill-McKee algorithm
124 set numbererTypeStatic RCM
125 numberer $numbererTypeStatic
126
127
128 # SYSTEM:
129
130 # Linear Equation Solvers (how to store and solve the system of equations in the analysis)
131 # -- provide the solution of the linear system of equations  $Ku = P$ . Each solver is tailored to a specific matrix topology.
132
133 # ProfileSPD -- Direct profile solver for symmetric positive definite matrices
134 # BandGeneral -- Direct solver for banded unsymmetric matrices
135 # BandSPD -- Direct solver for banded symmetric positive definite matrices
136 # SparseGeneral -- Direct solver for unsymmetric sparse matrices
137 # SparseSPD -- Direct solver for symmetric sparse matrices
138 # UmfPack -- Direct UmfPack solver for unsymmetric matrices
139 set systemTypeStatic UmfPack; # try UmfPack for large model
140 system $systemTypeStatic
141
142 # TEST: # convergence test to
143
144 # -- Accept the current state of the domain as being on the converged solution path
145 # -- determine if convergence has been achieved at the end of an iteration step
146 # NormUnbalance -- Specifies a tolerance on the norm of the unbalanced load at the current iteration
147 # NormDispIncr -- Specifies a tolerance on the norm of the displacement increments at the current iteration
148 # EnergyIncr-- Specifies a tolerance on the inner product of the unbalanced load and displacement increments at the current iteration
149 # RelativeNormUnbalance --

```



```

149 #           RelativeNormDispIncr --
150 #           RelativeEnergyIncr --
151 variable TolStatic 3;                # Convergence Test: tolerance
152 variable maxNumIterStatic 10000;    # Convergence Test: maximum number of iterations that will be performed before "failure to converge" is returned
153 variable printFlagStatic 0;        # Convergence Test: flag used to print information on convergence (optional)
154 # 1: print information on each step;
155 variable testTypeStatic EnergyIncr ; # Convergence-test type
156 test $testTypeStatic $TolStatic $maxNumIterStatic $printFlagStatic;
157 # Solution ALGORITHM: -- Iterate from the last time step to the current
158 #   Linear -- Uses the solution at the first iteration and continues
159 #   Newton -- Uses the tangent at the current iteration to iterate to convergence
160 #   ModifiedNewton -- Uses the tangent at the first iteration to iterate to convergence
161 #   NewtonLineSearch --
162 #   KrylovNewton --
163 #   BFGS --
164 #   Broyden --
165 variable algorithmTypeStatic Newton
166 algorithm $algorithmTypeStatic;
167
168 # Static INTEGRATOR: -- determine the next time step for an analysis
169
170 #   LoadControl -- Specifies the incremental load factor to be applied to the loads in the domain
171 #   DisplacementControl -- Specifies the incremental displacement at a specified DOF in the domain
172 #   Minimum Unbalanced Displacement Norm -- Specifies the incremental load factor such that the residual displacement norm is minimized
173 #   Arc Length -- Specifies the incremental arc-length of the load-displacement path
174 # Transient INTEGRATOR: -- determine the next time step for an analysis including inertial effects
175 #   Newmark -- The two parameter time-stepping method developed by Newmark
176 #   HHT -- The three parameter Hilbert-Hughes-Taylor time-stepping method
177 #   Central Difference -- Approximates velocity and acceleration by centered finite differences of displacement
178 integrator DisplacementControl $N_A90_L 1 $Dincr
179
180 # ANALYSIS -- defines what type of analysis is to be performed
181
182 #   Static Analysis -- solves the KU=R problem, without the mass or damping matrices.
183 #   Transient Analysis -- solves the time-dependent analysis. The time step in this type of analysis is constant. The time step in the output is also constant.
184 #   variableTransient Analysis -- performs the same analysis type as the Transient Analysis object. The time step, however, is variable. This method is used when
185 #   there are convergence problems with the Transient Analysis object at a peak or when the time step is too small. The time step in the output is also variable.
186 set analysisTypeStatic Static
187 analysis $analysisTypeStatic
188
189
190 # ----- perform Static Pushover Analysis
191 set Nsteps [expr int($Dmax/$Dincr)]; # number of pushover analysis steps
192 set ok [analyze $Nsteps];          # this will return zero if no convergence problems were encountered
193 set fmt1 "%s Pushover analysis: CtrlNode %.24i, dof %.1i, Disp=%.4f %s"; # format for screen/file output of DONE/PROBLEM analysis
194 if {$ok != 0} {
195   # if analysis fails, we try some other stuff, performance is slower inside this loop
196   set Dstep 0.0;
197   set ok 0
198   while {$Dstep <= 1.0 && $ok == 0} {
199     set controlDisp [nodeDisp $N_A90_L 1 ]
200     set Dstep [expr $controlDisp/$Dmax]
201     set ok [analyze 1 ]
202     # if analysis fails, we try some other stuff
203     # performance is slower inside this loop global maxNumIterStatic; # max no. of iterations performed before "failure to converge" is ret'd
204     if {$ok != 0} {
205       puts "Trying Newton with Initial Tangent .."
206       test NormDispIncr $Tol 3000 0
207       algorithm Newton -initial
208       set ok [analyze 1]
209       test $testTypeStatic $TolStatic $maxNumIterStatic 0
210       algorithm $algorithmTypeStatic
211     }
212     if {$ok != 0} {
213       puts "Trying Broyden .."
214       algorithm Broyden 8
215       set ok [analyze 1 ]
216       algorithm $algorithmTypeStatic
217     }
218     if {$ok != 0} {
219       puts "Trying NewtonWithLineSearch .."
220       algorithm NewtonLineSearch 0.8

```

```

221     set ok [analyze 1]
222     algorithm $algorithmTypeStatic
223 }
224
225 }; # end while loop
226 }; # end if ok !0
227
228 # -----
229 if {$ok != 0} {
230     puts [format $fmt1 "PROBLEM" $N_A90_L 1 [nodeDisp $N_A90_L 1] "mm"]
231 } else {
232     puts [format $fmt1 "DONE" $N_A90_L 1 [nodeDisp $N_A90_L 1] "mm"]
233 }
234
235
236 # Stop timing of this analysis sequence
237 set tStop [clock clicks -milliseconds]
238 puts "o Time taken: [expr ($tStop-$tStart)/1000.0] sec"
239
240 puts "pushover analysis completed"
241
242 # Reset for next analysis sequence
243 wipe all;

```

**Appendix 9 – The Code Generated Using the OpenSees Program
to Perform Pushover Analysis for 3B9S MRFs- Masonry-
Concrete Infilled Frames**

Appendix 9: 3B9S Masonry infilled Frame

```
1
2 1) Complementary files were defined to organize and make the procedure easier:
3
4     1. Library for Units
5
6     The code generated is the same as Appendix 3
7
8     2. Building RC Cross-Section (Fiber Approach)
9
10    The code generated is the same as Appendix 3
11
12    3. Display The Model in 2D
13
14    The code generated is the same as Appendix 3
15
16    4. Display Plane Deformed Shape for 2D Model
17
18    The code generated is the same as Appendix 3
19
20
21    5. Procedure for Defining Uniaxial Pinching Material
22
23    The code generated is the same as Appendix 3.
24
25
26 2) 2D Model Definition for 3B9S MRFs-Masonry-Concrete Infilled Frame :
27
28
29 #performing nonlinear static pushover analysis on 3B9S MRFs-Masonry-Concrete Infilled Frame
30 #####
31
32     wipe all;
33     # define model builder
34     #   model basic builder -ndm $ndm <-ndf $ndf>
35     #   model basic builder -ndm 2 -ndf 3
36
37     set dataDir Results;           # set up name of data directory
38     file mkdir $dataDir;           # create data directory
39     source Libunits.tcl;           # define basic system units
40     source DisplayModel2D.tcl;     # procedure for displaying a 2D View of model
41     source DisplayPlane.tcl;       # procedure for displaying a plane in a model
42
43 #####
44 # buiding geometry
45 #####
46
47 # dimensions
48
49     set span1 4000.0;
50     set span2 4000.0;
51     set span3 4000.0;
52     set storey1 3000.0;
53     set storey2 3000.0;
54     set storey3 3000.0;
55     set storey4 3000.0;
56     set storey5 3000.0;
57     set storey6 3000.0;
58     set storey7 3000.0;
59     set storey8 3000.0;
60     set storey9 3000.0;
61
62 # main grid lines
63 # vertical axis, x
64     set x1 [expr 0];
65     set x2 [expr $x1+$span1];
66     set x3 [expr $x2+$span2];
67     set x4 [expr $x3+$span3];
68
69 # hoeizontal axis, y
70     set z0 [expr 0];
71     set z1 [expr $z0+$storey1];
72     set z2 [expr $z1+$storey2];
73     set z3 [expr $z2+$storey3];
74     set z4 [expr $z3+$storey4];
75     set z5 [expr $z4+$storey5];
76     set z6 [expr $z5+$storey6];
```

```

77     set z7 [expr $z6+$storey7];
78     set z8 [expr $z7+$storey8];
79     set z9 [expr $z8+$storey9];
80
81 # definition of nodes
82
83     #assigning node tages                                # for axes A,B,C, and D.
84     set N_A0      1;
85     set N_B0      2;
86     set N_C0      3;
87     set N_D0      4;
88     set N_A1      5;
89     set N_B1      6;
90     set N_C1      7;
91     set N_D1      8;
92     set N_A2      9;
93     set N_B2     10;
94     set N_C2     11;
95     set N_D2     12;
96     set N_A3     13;
97     set N_B3     14;
98     set N_C3     15;
99     set N_D3     16;
100    set N_A4     17;
101    set N_B4     18;
102    set N_C4     19;
103    set N_D4     20;
104    set N_A5     21;
105    set N_B5     22;
106    set N_C5     23;
107    set N_D5     24;
108    set N_A6     25;
109    set N_B6     26;
110    set N_C6     27;
111    set N_D6     28;
112    set N_A7     29;
113    set N_B7     30;
114    set N_C7     31;
115    set N_D7     32;
116    set N_A8     33;
117    set N_B8     34;
118    set N_C8     35;
119    set N_D8     36;
120    set N_A9     37;
121    set N_B9     38;
122    set N_C9     39;
123    set N_D9     40;
124
125    set N_A10_R   41;                                # N_Aij_R   i: story level.   j: axis number
126    set N_A10_A   42;
127    set N_A10_L   43;
128    set N_A20_R   44;
129    set N_A20_A   45;
130    set N_A20_L   46;
131    set N_A30_R   47;
132    set N_A30_A   48;
133    set N_A30_L   49;
134    set N_A40_R   50;
135    set N_A40_A   51;
136    set N_A40_L   52;
137    set N_A50_R   53;
138    set N_A50_A   54;
139    set N_A50_L   55;
140    set N_A60_R   56;
141    set N_A60_A   57;
142    set N_A60_L   58;
143    set N_A70_R   59;
144    set N_A70_A   60;
145    set N_A70_L   61;
146    set N_A80_R   62;
147    set N_A80_A   63;
148    set N_A80_L   64;
149    set N_A90_R   65;
150    set N_A90_A   66;
151    set N_A90_L   67;
152
153    set N_B11_R   68;
154    set N_B11_A   69;
155    set N_B11_L   70;
156    set N_B21_R   71;

```

157 set N_B21_A 72;
158 set N_B21_L 73;
159 set N_B31_R 74;
160 set N_B31_A 75;
161 set N_B31_L 76;
162 set N_B41_R 77;
163 set N_B41_A 78;
164 set N_B41_L 79;
165 set N_B51_R 80;
166 set N_B51_A 81;
167 set N_B51_L 82;
168 set N_B61_R 83;
169 set N_B61_A 84;
170 set N_B61_L 85;
171 set N_B71_R 86;
172 set N_B71_A 87;
173 set N_B71_L 88;
174 set N_B81_R 89;
175 set N_B81_A 90;
176 set N_B81_L 91;
177 set N_B91_R 92;
178 set N_B91_A 93;
179 set N_B91_L 94;
180
181 set N_C12_R 95;
182 set N_C12_A 96;
183 set N_C12_L 97;
184 set N_C22_R 98;
185 set N_C22_A 99;
186 set N_C22_L 100;
187 set N_C32_R 101;
188 set N_C32_A 102;
189 set N_C32_L 103;
190 set N_C42_R 104;
191 set N_C42_A 105;
192 set N_C42_L 106;
193 set N_C52_R 107;
194 set N_C52_A 108;
195 set N_C52_L 109;
196 set N_C62_R 110;
197 set N_C62_A 111;
198 set N_C62_L 112;
199 set N_C72_R 113;
200 set N_C72_A 114;
201 set N_C72_L 115;
202 set N_C82_R 116;
203 set N_C82_A 117;
204 set N_C82_L 118;
205 set N_C92_R 119;
206 set N_C92_A 120;
207 set N_C92_L 121;
208
209 set N_D13_R 122;
210 set N_D13_A 123;
211 set N_D13_L 124;
212 set N_D23_R 125;
213 set N_D23_A 126;
214 set N_D23_L 127;
215 set N_D33_R 128;
216 set N_D33_A 129;
217 set N_D33_L 130;
218 set N_D43_R 131;
219 set N_D43_A 132;
220 set N_D43_L 133;
221 set N_D53_R 134;
222 set N_D53_A 135;
223 set N_D53_L 136;
224 set N_D63_R 137;
225 set N_D63_A 138;
226 set N_D63_L 139;
227 set N_D73_R 140;
228 set N_D73_A 141;
229 set N_D73_L 142;
230 set N_D83_R 143;
231 set N_D83_A 144;
232 set N_D83_L 145;
233 set N_D93_R 146;
234 set N_D93_A 147;
235 set N_D93_L 148;
236

```

237 #infill wall nodes
238 set N_W1A_L 3001; # l: means the node at the left side of the panel
239 set N_W1A_R 3002; # R: means the node at the right side of the panel
240 set N_W2A_L 3003;
241 set N_W2A_R 3004;
242 set N_W3A_L 3005;
243 set N_W3A_R 3006;
244 set N_W4A_L 3007;
245 set N_W4A_R 3008;
246 set N_W5A_L 3009;
247 set N_W5A_R 3010;
248 set N_W6A_L 3011;
249 set N_W6A_R 3012;
250 set N_W7A_L 3013;
251 set N_W7A_R 3014;
252 set N_W8A_L 3015;
253 set N_W8A_R 3016;
254 set N_W9A_L 3017;
255 set N_W9A_R 3018;
256
257 set N_W1B_L 3019;
258 set N_W1B_R 3020;
259 set N_W2B_L 3021;
260 set N_W2B_R 3022;
261 set N_W3B_L 3023;
262 set N_W3B_R 3024;
263 set N_W4B_L 3025;
264 set N_W4B_R 3026;
265 set N_W5B_L 3027;
266 set N_W5B_R 3028;
267 set N_W6B_L 3029;
268 set N_W6B_R 3030;
269 set N_W7B_L 3031;
270 set N_W7B_R 3032;
271 set N_W8B_L 3033;
272 set N_W8B_R 3034;
273 set N_W9B_L 3035;
274 set N_W9B_R 3036;
275
276 set N_W1C_L 3037;
277 set N_W1C_R 3038;
278 set N_W2C_L 3039;
279 set N_W2C_R 3040;
280 set N_W3C_L 3041;
281 set N_W3C_R 3042;
282 set N_W4C_L 3043;
283 set N_W4C_R 3044;
284 set N_W5C_L 3045;
285 set N_W5C_R 3046;
286 set N_W6C_L 3047;
287 set N_W6C_R 3048;
288 set N_W7C_L 3049;
289 set N_W7C_R 3050;
290 set N_W8C_L 3051;
291 set N_W8C_R 3052;
292 set N_W9C_L 3053;
293 set N_W9C_R 3054;
294
295
296 #node $nodetag (ndm $coords) <-mass (ndf $massvalues)>
297
298 set col_halfdepA [expr 600/2]; # This is used to define the joint dimensions.
299 set col_halfdepB [expr 600/2];
300 set col_halfdepC [expr 600/2];
301 set col_halfdepD [expr 600/2];
302 set beam_halfdep1 [expr 300/2];
303 set beam_halfdep2 [expr 300/2];
304 set beam_halfdep3 [expr 300/2];
305 set beam_halfdep4 [expr 300/2];
306 set beam_halfdep5 [expr 300/2];
307 set beam_halfdep6 [expr 300/2];
308 set beam_halfdep7 [expr 300/2];
309 set beam_halfdep8 [expr 300/2];
310 set beam_halfdep9 [expr 300/2];
311
312 node $N_A0 $x1 $z0;
313 node $N_B0 $x2 $z0;
314 node $N_C0 $x3 $z0;
315 node $N_D0 $x4 $z0;
316 node $N_A1 $x1 [expr $z1-$beam_halfdep1];

```

```

317     node $N_B1      $x2 [expr $z1-$beam_halfdep1];
318     node $N_C1      $x3 [expr $z1-$beam_halfdep1];
319     node $N_D1      $x4 [expr $z1-$beam_halfdep1];
320     node $N_A2      $x1 [expr $z2-$beam_halfdep2];
321     node $N_B2      $x2 [expr $z2-$beam_halfdep2];
322     node $N_C2      $x3 [expr $z2-$beam_halfdep2];
323     node $N_D2      $x4 [expr $z2-$beam_halfdep2];
324     node $N_A3      $x1 [expr $z3-$beam_halfdep3];
325     node $N_B3      $x2 [expr $z3-$beam_halfdep3];
326     node $N_C3      $x3 [expr $z3-$beam_halfdep3];
327     node $N_D3      $x4 [expr $z3-$beam_halfdep3];
328     node $N_A4      $x1 [expr $z4-$beam_halfdep4];
329     node $N_B4      $x2 [expr $z4-$beam_halfdep4];
330     node $N_C4      $x3 [expr $z4-$beam_halfdep4];
331     node $N_D4      $x4 [expr $z4-$beam_halfdep4];
332     node $N_A5      $x1 [expr $z5-$beam_halfdep5];
333     node $N_B5      $x2 [expr $z5-$beam_halfdep5];
334     node $N_C5      $x3 [expr $z5-$beam_halfdep5];
335     node $N_D5      $x4 [expr $z5-$beam_halfdep5];
336     node $N_A6      $x1 [expr $z6-$beam_halfdep6];
337     node $N_B6      $x2 [expr $z6-$beam_halfdep6];
338     node $N_C6      $x3 [expr $z6-$beam_halfdep6];
339     node $N_D6      $x4 [expr $z6-$beam_halfdep6];
340     node $N_A7      $x1 [expr $z7-$beam_halfdep7];
341     node $N_B7      $x2 [expr $z7-$beam_halfdep7];
342     node $N_C7      $x3 [expr $z7-$beam_halfdep7];
343     node $N_D7      $x4 [expr $z7-$beam_halfdep7];
344     node $N_A8      $x1 [expr $z8-$beam_halfdep8];
345     node $N_B8      $x2 [expr $z8-$beam_halfdep8];
346     node $N_C8      $x3 [expr $z8-$beam_halfdep8];
347     node $N_D8      $x4 [expr $z8-$beam_halfdep8];
348     node $N_A9      $x1 [expr $z9-$beam_halfdep9];
349     node $N_B9      $x2 [expr $z9-$beam_halfdep9];
350     node $N_C9      $x3 [expr $z9-$beam_halfdep9];
351     node $N_D9      $x4 [expr $z9-$beam_halfdep9];
352
353
354
355 ##### add nodes - joints #####
356
357                                     # R: node at the right side of joint
358                                     # A: node above the joint
359                                     # L: node at the left side of the joint
360     node $N_A10_R  [expr $x1+$col_halfdepA] $z1;
361     node $N_A10_A  $x1 [expr $z1+$beam_halfdep1];
362     node $N_A10_L  [expr $x1-$col_halfdepA] $z1;
363     node $N_A20_R  [expr $x1+$col_halfdepA] $z2;
364     node $N_A20_A  $x1 [expr $z2+$beam_halfdep2];
365     node $N_A20_L  [expr $x1-$col_halfdepA] $z2;
366     node $N_A30_R  [expr $x1+$col_halfdepA] $z3;
367     node $N_A30_A  $x1 [expr $z3+$beam_halfdep3];
368     node $N_A30_L  [expr $x1-$col_halfdepA] $z3;
369     node $N_A40_R  [expr $x1+$col_halfdepA] $z4;
370     node $N_A40_A  $x1 [expr $z4+$beam_halfdep4];
371     node $N_A40_L  [expr $x1-$col_halfdepA] $z4;
372     node $N_A50_R  [expr $x1+$col_halfdepA] $z5;
373     node $N_A50_A  $x1 [expr $z5+$beam_halfdep5];
374     node $N_A50_L  [expr $x1-$col_halfdepA] $z5;
375     node $N_A60_R  [expr $x1+$col_halfdepA] $z6;
376     node $N_A60_A  $x1 [expr $z6+$beam_halfdep6];
377     node $N_A60_L  [expr $x1-$col_halfdepA] $z6;
378     node $N_A70_R  [expr $x1+$col_halfdepA] $z7;
379     node $N_A70_A  $x1 [expr $z7+$beam_halfdep7];
380     node $N_A70_L  [expr $x1-$col_halfdepA] $z7;
381     node $N_A80_R  [expr $x1+$col_halfdepA] $z8;
382     node $N_A80_A  $x1 [expr $z8+$beam_halfdep8];
383     node $N_A80_L  [expr $x1-$col_halfdepA] $z8;
384     node $N_A90_R  [expr $x1+$col_halfdepA] $z9;
385     node $N_A90_A  $x1 [expr $z9+$beam_halfdep9];
386     node $N_A90_L  [expr $x1-$col_halfdepA] $z9;
387
388     node $N_B11_R  [expr $x2+$col_halfdepB] $z1;
389     node $N_B11_A  $x2 [expr $z1+$beam_halfdep1];
390     node $N_B11_L  [expr $x2-$col_halfdepB] $z1;
391     node $N_B21_R  [expr $x2+$col_halfdepB] $z2;
392     node $N_B21_A  $x2 [expr $z2+$beam_halfdep2];
393     node $N_B21_L  [expr $x2-$col_halfdepB] $z2;
394     node $N_B31_R  [expr $x2+$col_halfdepB] $z3;
395     node $N_B31_A  $x2 [expr $z3+$beam_halfdep3];
396     node $N_B31_L  [expr $x2-$col_halfdepB] $z3;

```



```

397 node $N_B41_R [expr $x2+$col_halfdepB] $z4;
398 node $N_B41_A $x2 [expr $z4+$beam_halfdep4];
399 node $N_B41_L [expr $x2-$col_halfdepB] $z4;
400 node $N_B51_R [expr $x2+$col_halfdepB] $z5;
401 node $N_B51_A $x2 [expr $z5+$beam_halfdep5];
402 node $N_B51_L [expr $x2-$col_halfdepB] $z5;
403 node $N_B61_R [expr $x2+$col_halfdepB] $z6;
404 node $N_B61_A $x2 [expr $z6+$beam_halfdep6];
405 node $N_B61_L [expr $x2-$col_halfdepB] $z6;
406 node $N_B71_R [expr $x2+$col_halfdepB] $z7;
407 node $N_B71_A $x2 [expr $z7+$beam_halfdep7];
408 node $N_B71_L [expr $x2-$col_halfdepB] $z7;
409 node $N_B81_R [expr $x2+$col_halfdepB] $z8;
410 node $N_B81_A $x2 [expr $z8+$beam_halfdep8];
411 node $N_B81_L [expr $x2-$col_halfdepB] $z8;
412 node $N_B91_R [expr $x2+$col_halfdepB] $z9;
413 node $N_B91_A $x2 [expr $z9+$beam_halfdep9];
414 node $N_B91_L [expr $x2-$col_halfdepB] $z9;
415
416 node $N_C12_R [expr $x3+$col_halfdepC] $z1;
417 node $N_C12_A $x3 [expr $z1+$beam_halfdep1];
418 node $N_C12_L [expr $x3-$col_halfdepC] $z1;
419 node $N_C22_R [expr $x3+$col_halfdepC] $z2;
420 node $N_C22_A $x3 [expr $z2+$beam_halfdep2];
421 node $N_C22_L [expr $x3-$col_halfdepC] $z2;
422 node $N_C32_R [expr $x3+$col_halfdepC] $z3;
423 node $N_C32_A $x3 [expr $z3+$beam_halfdep3];
424 node $N_C32_L [expr $x3-$col_halfdepC] $z3;
425 node $N_C42_R [expr $x3+$col_halfdepC] $z4;
426 node $N_C42_A $x3 [expr $z4+$beam_halfdep4];
427 node $N_C42_L [expr $x3-$col_halfdepC] $z4;
428 node $N_C52_R [expr $x3+$col_halfdepC] $z5;
429 node $N_C52_A $x3 [expr $z5+$beam_halfdep5];
430 node $N_C52_L [expr $x3-$col_halfdepC] $z5;
431 node $N_C62_R [expr $x3+$col_halfdepC] $z6;
432 node $N_C62_A $x3 [expr $z6+$beam_halfdep6];
433 node $N_C62_L [expr $x3-$col_halfdepC] $z6;
434 node $N_C72_R [expr $x3+$col_halfdepC] $z7;
435 node $N_C72_A $x3 [expr $z7+$beam_halfdep7];
436 node $N_C72_L [expr $x3-$col_halfdepC] $z7;
437 node $N_C82_R [expr $x3+$col_halfdepC] $z8;
438 node $N_C82_A $x3 [expr $z8+$beam_halfdep8];
439 node $N_C82_L [expr $x3-$col_halfdepC] $z8;
440 node $N_C92_R [expr $x3+$col_halfdepC] $z9;
441 node $N_C92_A $x3 [expr $z9+$beam_halfdep9];
442 node $N_C92_L [expr $x3-$col_halfdepC] $z9;
443
444 node $N_D13_R [expr $x4+$col_halfdepD] $z1;
445 node $N_D13_A $x4 [expr $z1+$beam_halfdep1];
446 node $N_D13_L [expr $x4-$col_halfdepD] $z1;
447 node $N_D23_R [expr $x4+$col_halfdepD] $z2;
448 node $N_D23_A $x4 [expr $z2+$beam_halfdep2];
449 node $N_D23_L [expr $x4-$col_halfdepD] $z2;
450 node $N_D33_R [expr $x4+$col_halfdepD] $z3;
451 node $N_D33_A $x4 [expr $z3+$beam_halfdep3];
452 node $N_D33_L [expr $x4-$col_halfdepD] $z3;
453 node $N_D43_R [expr $x4+$col_halfdepD] $z4;
454 node $N_D43_A $x4 [expr $z4+$beam_halfdep4];
455 node $N_D43_L [expr $x4-$col_halfdepD] $z4;
456 node $N_D53_R [expr $x4+$col_halfdepD] $z5;
457 node $N_D53_A $x4 [expr $z5+$beam_halfdep5];
458 node $N_D53_L [expr $x4-$col_halfdepD] $z5;
459 node $N_D63_R [expr $x4+$col_halfdepD] $z6;
460 node $N_D63_A $x4 [expr $z6+$beam_halfdep6];
461 node $N_D63_L [expr $x4-$col_halfdepD] $z6;
462 node $N_D73_R [expr $x4+$col_halfdepD] $z7;
463 node $N_D73_A $x4 [expr $z7+$beam_halfdep7];
464 node $N_D73_L [expr $x4-$col_halfdepD] $z7;
465 node $N_D83_R [expr $x4+$col_halfdepD] $z8;
466 node $N_D83_A $x4 [expr $z8+$beam_halfdep8];
467 node $N_D83_L [expr $x4-$col_halfdepD] $z8;
468 node $N_D93_R [expr $x4+$col_halfdepD] $z9;
469 node $N_D93_A $x4 [expr $z9+$beam_halfdep9];
470 node $N_D93_L [expr $x4-$col_halfdepD] $z9;
471
472 ##### add nodes - infill walls #####
473
474 node $N_W1A_R [expr $x2*0.54] [expr $z0+($storey1*0.5)];
475 node $N_W1A_L [expr $x2*0.46] [expr $z0+($storey1*0.5)];
476 node $N_W2A_R [expr $x2*0.54] [expr $z1+($storey1*0.5)];

```

```

477     node $N_W2A_L [expr $x2*0.46] [expr $z1+($storey1*0.5)];
478     node $N_W3A_R [expr $x2*0.54] [expr $z2+($storey1*0.5)];
479     node $N_W3A_L [expr $x2*0.46] [expr $z2+($storey1*0.5)];
480     node $N_W4A_R [expr $x2*0.54] [expr $z3+($storey1*0.5)];
481     node $N_W4A_L [expr $x2*0.46] [expr $z3+($storey1*0.5)];
482     node $N_W5A_R [expr $x2*0.54] [expr $z4+($storey1*0.5)];
483     node $N_W5A_L [expr $x2*0.46] [expr $z4+($storey1*0.5)];
484     node $N_W6A_R [expr $x2*0.54] [expr $z5+($storey1*0.5)];
485     node $N_W6A_L [expr $x2*0.46] [expr $z5+($storey1*0.5)];
486     node $N_W7A_R [expr $x2*0.54] [expr $z6+($storey1*0.5)];
487     node $N_W7A_L [expr $x2*0.46] [expr $z6+($storey1*0.5)];
488     node $N_W8A_R [expr $x2*0.54] [expr $z7+($storey1*0.5)];
489     node $N_W8A_L [expr $x2*0.46] [expr $z7+($storey1*0.5)];
490     node $N_W9A_R [expr $x2*0.54] [expr $z8+($storey1*0.5)];
491     node $N_W9A_L [expr $x2*0.46] [expr $z8+($storey1*0.5)];
492
493     node $N_W1B_R [expr $x2+($span2*0.54)] [expr $z0+($storey1*0.5)];
494     node $N_W1B_L [expr $x2+($span2*0.46)] [expr $z0+($storey1*0.5)];
495     node $N_W2B_R [expr $x2+($span2*0.54)] [expr $z1+($storey1*0.5)];
496     node $N_W2B_L [expr $x2+($span2*0.46)] [expr $z1+($storey1*0.5)];
497     node $N_W3B_R [expr $x2+($span2*0.54)] [expr $z2+($storey1*0.5)];
498     node $N_W3B_L [expr $x2+($span2*0.46)] [expr $z2+($storey1*0.5)];
499     node $N_W4B_R [expr $x2+($span2*0.54)] [expr $z3+($storey1*0.5)];
500     node $N_W4B_L [expr $x2+($span2*0.46)] [expr $z3+($storey1*0.5)];
501     node $N_W5B_R [expr $x2+($span2*0.54)] [expr $z4+($storey1*0.5)];
502     node $N_W5B_L [expr $x2+($span2*0.46)] [expr $z4+($storey1*0.5)];
503     node $N_W6B_R [expr $x2+($span2*0.54)] [expr $z5+($storey1*0.5)];
504     node $N_W6B_L [expr $x2+($span2*0.46)] [expr $z5+($storey1*0.5)];
505     node $N_W7B_R [expr $x2+($span2*0.54)] [expr $z6+($storey1*0.5)];
506     node $N_W7B_L [expr $x2+($span2*0.46)] [expr $z6+($storey1*0.5)];
507     node $N_W8B_R [expr $x2+($span2*0.54)] [expr $z7+($storey1*0.5)];
508     node $N_W8B_L [expr $x2+($span2*0.46)] [expr $z7+($storey1*0.5)];
509     node $N_W9B_R [expr $x2+($span2*0.54)] [expr $z8+($storey1*0.5)];
510     node $N_W9B_L [expr $x2+($span2*0.46)] [expr $z8+($storey1*0.5)];
511
512     node $N_W1C_R [expr $x3+($span2*0.54)] [expr $z0+($storey1*0.5)];
513     node $N_W1C_L [expr $x3+($span2*0.46)] [expr $z0+($storey1*0.5)];
514     node $N_W2C_R [expr $x3+($span2*0.54)] [expr $z1+($storey1*0.5)];
515     node $N_W2C_L [expr $x3+($span2*0.46)] [expr $z1+($storey1*0.5)];
516     node $N_W3C_R [expr $x3+($span2*0.54)] [expr $z2+($storey1*0.5)];
517     node $N_W3C_L [expr $x3+($span2*0.46)] [expr $z2+($storey1*0.5)];
518     node $N_W4C_R [expr $x3+($span2*0.54)] [expr $z3+($storey1*0.5)];
519     node $N_W4C_L [expr $x3+($span2*0.46)] [expr $z3+($storey1*0.5)];
520     node $N_W5C_R [expr $x3+($span2*0.54)] [expr $z4+($storey1*0.5)];
521     node $N_W5C_L [expr $x3+($span2*0.46)] [expr $z4+($storey1*0.5)];
522     node $N_W6C_R [expr $x3+($span2*0.54)] [expr $z5+($storey1*0.5)];
523     node $N_W6C_L [expr $x3+($span2*0.46)] [expr $z5+($storey1*0.5)];
524     node $N_W7C_R [expr $x3+($span2*0.54)] [expr $z6+($storey1*0.5)];
525     node $N_W7C_L [expr $x3+($span2*0.46)] [expr $z6+($storey1*0.5)];
526     node $N_W8C_R [expr $x3+($span2*0.54)] [expr $z7+($storey1*0.5)];
527     node $N_W8C_L [expr $x3+($span2*0.46)] [expr $z7+($storey1*0.5)];
528     node $N_W9C_R [expr $x3+($span2*0.54)] [expr $z8+($storey1*0.5)];
529     node $N_W9C_L [expr $x3+($span2*0.46)] [expr $z8+($storey1*0.5)];
530
531
532 # restraints
533
534     #basefix $nodetag (ndf $constraints)
535     fix $N_A0 1 1 1;
536     fix $N_B0 1 1 1;
537     fix $N_C0 1 1 1;
538     fix $N_D0 1 1 1;
539
540
541 #####
542 ##
543 # material definitions
544 #####
545 ##
546 # Definition of materials IDs
547
548     #set C_confinedB 1;
549     set C_confined 1;
550     set C_unconfined 2;
551     set R_steel 3;
552     set C_unconfinedw 4;
553
554

```

```

555 # basic parameters for materials-con-concrete
556
557 # ConfinedConcrete01 Material
558
559 # $tag integer tag identifying material.
560 # $secType tag for the transverse reinforcement configuration.
561 # $fpc unconfined cylindrical strength of concrete specimen.
562 # $Ec initial elastic modulus of unconfined concrete.
563 # <-epscu $epscu> OR <-gamma $gamma> confined concrete ultimate strain.
564 # <-nu $nu> OR <-varub> OR <-varnoub> Poisson's Ratio.
565 # $L1 length/diameter of square/circular core section measured respect to the hoop center line.
566 # ($L2) additional dimensions when multiple hoops are being used.
567 # $phis hoop diameter. If section arrangement has multiple hoops it refers to the external hoop.
568 # $S hoop spacing.
569 # $fyh yielding strength of the hoop steel.
570 # $Es0 elastic modulus of the hoop steel.
571 # $haRatio hardening ratio of the hoop steel.
572 # $mu ductility factor of the hoop steel.
573 # $phiLon diameter of longitudinal bars.
574
575 # basic parameters for materials-uncon-concrete
576
577 set unconfc -28.0; # compression strength for concrete
578 set unconepsc -0.002; # strain at maximum stress in compression
579 set unconfu [expr $unconfc*0.18]; # ultimate stress for concrete
580 set unconepsu -0.01; # strain at ultimate stress in compression
581 set unconlambda 0.1; # ratio between reloading stiffness and initial stiffness in compression
582 set unconft [expr $unconfc*-0.1]; # maximum stress in tension for concrete
583 set unconEt [expr $unconft/0.002]; # elastic modulus in tension
584 set unconE0 [expr 2*$unconfc/$unconepsc]; # initial elastic tangent
585
586 # basic parameters for material--steel # ReinforcingSteel uniaxial material object. This object is intended to be used
in a reinforced concrete fiber section as the steel reinforcing material.
587
588 set Fy 420.0; # Yield stress in tension
589 set Fu 596.0; # Ultimate stress in tension
590 set Es 200000.0; # Initial elastic tangent
591 set Esh 3100.0; # Tangent at initial strain hardening
592 set esh 0.01; # Strain corresponding to initial strain hardening
593 set eult 0.09; # Strain at peak stress
594
595 #uniaxialMaterial ReinforcingSteel $matTag $fy $fu $Es $Esh $esh $eult Define ReinforcingSteel uniaxial material
596 uniaxialMaterial ReinforcingSteel $R_steel $Fy $Fu $Es $Esh $esh $eult -DMBuck 6 0.8 -CMFatigue 0.2600 0.5000 0.3890 -Iso
Hard 4.3000 0.01
597
598 # definition of ConfinedConcrete01 material
599
600 #uniaxialMaterial ConfinedConcrete01 $tag $secType $fpc $Ec -epscu $epscu $nu $L1 $L2 $phis $S $f
yh $Es0 $haRatio $mu $phiLon -stRatio $stRatio
601 #uniaxialMaterial ConfinedConcrete01 $C_confinedB R -28 24870.1 -epscu -0.04 -varUB 250.0 1450.0 10.0 125.0 4
20.0 200000.0 0.00 3100.0 12.0 -stRatio 0.85
602 #uniaxialMaterial ConfinedConcrete01 $C_confinedC R -28 24870.1 -epscu -0.04 -varUB 550.0 200.0 10.0 125.0 4
20.0 200000.0 0.00 3100.0 18.0 -stRatio 0.85
603
604
605 # basic parameters for materials-con-concrete
606
607 set confc -32.5; # compression strength for concrete
608 set conepsc -0.003; # strain at maximum stress in compression
609 set confu [expr $confc*0.18]; # ultimate stress for concrete
610 set conepsu -0.04; # strain at ultimate stress in compression
611 set conlambda 0.1; # ratio between reloading stiffness and initial stiffness in compression
612 set conft [expr $confc*-0.1]; # maximum stress in tension for concrete
613 set conEt [expr $conft/0.002]; # elastic modulus in tension
614 set conE0 [expr 2*$confc/$conepsc]; # initial elastic tangent
615
616 # uniaxialMaterial Concrete02 $matTag $fpc $epsc0 $fpcu $epsU $lambda $ft $Ets
617 uniaxialMaterial Concrete02 $C_unconfined $unconfc $unconepsc $unconfu $unconepsu $unconlambda $unconft $unco
nEt;
618 uniaxialMaterial Concrete02 $C_confined $confc $conepsc $confu $conepsu $conlambda $conft $conEt;
619
620 #####
621 # definition of the Sections
622 #####
623
624 # define sections IDs
625
626 set col40x60 1;

```

```

627     set beam150x30 2;
628
629 # define section parameters
630
631     set pi          3.141593;
632     set rebar_12   [expr $pi*12.0*12.0/4]; # area rebar 12mm
633     set rebar_16   [expr $pi*16.0*16.0/4];
634     set w_col      400.0; # column width
635     set h_col      600.0; # column height
636     set c_col      20.0; # column cover
637     set w_beam     1500.0; # beam width
638     set h_beam     300.0; # beam height
639     set c_beam     30.0; # beam cover
640
641 # load procedure for fiber section
642
643 source BuildRCrectSection.tcl;
644
645 # build sections
646
647     #BuildRCrectSection $ColSecTag $HSec $BSec $coverH $coverB $coreID $coverID $steelID $numBarsTop $barArea
aTop $numBarsBot $barAreaBot $numBarsIntTot $barAreaInt $nfCoreY $nfCoreZ $nfCoverY $nfCoverZ
648     BuildRCrectSection $col140x60 $h_col $w_col $c_col $c_col $C_confined $C_unconfined $R_steel 9 $rebar_1
649     BuildRCrectSection $beam150x30 $h_beam $w_beam $c_beam $c_beam $C_confined $C_unconfined $R_steel 12 $rebar_1
2 8 $rebar_12 0 $rebar_12 8 8 8 8
650
651
652 #####
653 # beam column joint definition
654 #####
655 ##
656 # dimensions of the joint respectively
657 set JointWidth [expr $h_col]; set JointHeight [expr $h_beam]; set JointDepth $w_col ;
658 set JointVolume [expr $JointWidth*$JointHeight*$JointDepth];
659
660 ##### details for the material models of bar slip of the beam #####
661
662 set bs_fc 28.0; set bs_fs 420.0; set bs_es 200000; set bs_fsu 596; set bs_dbar 12.0; set bs_esh 3100.0;
663 set bs_wid $w_col; set bs_dep $h_beam;
664 set bsT_nbars 12; set bsB_nbars 8;
665 set bs_ljoint $h_col;
666
667 ##### details for the material models of bar slip of the column #####
668
669 set cs_fc 28.0; set cs_fs 420.0; set cs_es 200000.0; set cs_fsu 596; set cs_dbar 16.0; set cs_esh 3100.0;
670 set cs_wid $w_col; set cs_dep $h_col;
671 set cs_nbars 9;
672 set cs_ljoint $h_beam;
673
674 #####
675 #bar slip definition
676
677 # for beam bottom
678
679 set bsid1 11
680 #uniaxialMaterial BarSlip $matTag $fc $fy $Es $fu $Eh $db $ld $nb $depth $height <$anclRatio> $bsFlag $type <$damage $unit>
681 uniaxialMaterial BarSlip $bsid1 $bs_fc $bs_fs $bs_es $bs_fsu $bs_esh $bs_dbar $bs_ljoint $bsB_nbars $bs_wid $bs_dep strong
beambot
682
683 # for beam top
684
685 set bsid2 21
686 #uniaxialMaterial BarSlip $matTag $fc $fy $Es $fu $Eh $db $ld $nb $depth $height <$anclRatio> $bsFlag $type <$damage $unit>
687 uniaxialMaterial BarSlip $bsid2 $bs_fc $bs_fs $bs_es $bs_fsu $bs_esh $bs_dbar $bs_ljoint $bsT_nbars $bs_wid $bs_dep strong
beamtop
688
689 # for columns
690 set bsid3 31
691 #uniaxialMaterial BarSlip $matTag $fc $fy $Es $fu $Eh $db $ld $nb $depth $height <$anclRatio> $bsFlag $type <$damage $unit>
692
693 uniaxialMaterial BarSlip $bsid3 $cs_fc $cs_fs $cs_es $cs_fsu $cs_esh $cs_dbar $cs_ljoint $cs_nbars $cs_wid $cs_dep strong c
olumn
694
695

```

```

696 ##### material for shear panel #####
697
698 ## Positive/Negative envelope Stress
699
700 set spid1 41;
701 set A 0.78;
702 set p1 [expr 2.539*$A]; set p2 [expr 3.393*$A]; set p3 [expr 3.57*$A]; set p4 [expr 0.7143*$A];
703
704 ## stress1 stress2 stress3 stress4
705 set pEnvStrsp [list [expr $p1*$JointVolume] [expr $p2*$JointVolume] [expr $p3*$JointVolume] [expr $p4*$JointVolume]]
706 set nEnvStrsp [list [expr -$p1*$JointVolume] [expr -$p2*$JointVolume] [expr -$p3*$JointVolume] [expr -$p4*$JointVolume]]
707
708 ## Positive/Negative envelope Strain
709 ## strain1 strain2 strain3 strain4
710
711 set pEnvStnsp [list 0.0008 0.015 0.035 0.04]
712 set nEnvStnsp [list -0.0008 -0.015 -0.035 -0.04]
713
714 ## Ratio of maximum deformation at which reloading begins
715 ## Pos_env. Neg_env.
716 set rDispsp [list 0.2 0.2]
717
718 ## Ratio of envelope force (corresponding to maximum deformation) at which reloading begins
719
720 ### Pos_env. Neg_env.
721 set rForcesp [list 0.2 0.2]
722
723
724 ## Ratio of monotonic strength developed upon unloading
725 ### Pos_env. Neg_env.
726
727 set uForcesp [list 0.0 0.0]
728
729
730 ## Coefficients for Unloading Stiffness degradation
731
732 ## gammaK1 gammaK2 gammaK3 gammaK4 gammaKLimit
733
734 #set gammaKsp [list 1.13364492409642 0.0 0.10111033064469 0.0 0.91652498468618]
735
736 set gammaKsp [list 0.0 0.0 0.0 0.0 0.0]
737
738 ##### Coefficients for Reloading Stiffness degradation
739 ### gammaD1 gammaD2 gammaD3 gammaD4 gammaDLimit
740
741 #set gammaDsp [list 0.12 0.0 0.23 0.0 0.95]
742
743 set gammaDsp [list 0.0 0.0 0.0 0.0 0.0]
744 ##### Coefficients for Strength degradation
745 ### gammaF1 gammaF2 gammaF3 gammaF4 gammaFLimit
746
747 #set gammaFsp [list 1.11 0.0 0.319 0.0 0.125]
748 set gammaFsp [list 0.0 0.0 0.0 0.0 0.0]
749
750 set gammaEsp 10.0
751
752 uniaxialMaterial Pinching4 $spid1 [lindex $pEnvStrsp 0] [lindex $pEnvStnsp 0] \
753 [lindex $pEnvStrsp 1] [lindex $pEnvStnsp 1] [lindex $pEnvStrsp 2] \
754 [lindex $pEnvStnsp 2] [lindex $pEnvStrsp 3] [lindex $pEnvStnsp 3] \
755 [lindex $nEnvStrsp 0] [lindex $nEnvStnsp 0] \
756 [lindex $nEnvStrsp 1] [lindex $nEnvStnsp 1] [lindex $nEnvStrsp 2] \
757 [lindex $nEnvStnsp 2] [lindex $nEnvStrsp 3] [lindex $nEnvStnsp 3] \
758 [lindex $rDispsp 0] [lindex $rForcesp 0] [lindex $uForcesp 0] \
759 [lindex $rDispsp 1] [lindex $rForcesp 1] [lindex $uForcesp 1] \
760 [lindex $gammaKsp 0] [lindex $gammaKsp 1] [lindex $gammaKsp 2] [lindex $gammaKsp 3] [lindex $gammaKsp 4] \
761 [lindex $gammaDsp 0] [lindex $gammaDsp 1] [lindex $gammaDsp 2] [lindex $gammaDsp 3] [lindex $gammaDsp 4] \
762 [lindex $gammaFsp 0] [lindex $gammaFsp 1] [lindex $gammaFsp 2] [lindex $gammaFsp 3] [lindex $gammaFsp 4] \
763 $gammaEsp energy
764
765 ##### beam column joint #####
766
767 ##element BeamColumnJoint tag? iNode? jNode? kNode? lNode? matTag1? matTag2? matTag3? matTag4?
768 ## matTag5? matTag6? matTag7? matTag8? matTag9? matTag10? matTag11? matTag12? matTag13?
769 ## <element Height factor?> <element Width factor?>
770 ## please note: the four nodes are in anticlockwise direction around the element
771 ## requires material tags for all 13 different components within the element.
772 ## the first 12 being that of spring and the last of the shear panel
773
774 set jointA1 611
775 set jointA2 612

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776 set jointA3 613
777 set jointA4 614
778 set jointA5 615
779 set jointA6 616
780 set jointA7 617
781 set jointA8 618
782 set jointA9 619
783
784 set jointB1 621
785 set jointB2 622
786 set jointB3 623
787 set jointB4 624
788 set jointB5 625
789 set jointB6 626
790 set jointB7 627
791 set jointB8 628
792 set jointB9 629
793
794 set jointC1 631
795 set jointC2 632
796 set jointC3 633
797 set jointC4 634
798 set jointC5 635
799 set jointC6 636
800 set jointC7 637
801 set jointC8 638
802 set jointC9 639
803
804 set jointD1 641
805 set jointD2 642
806 set jointD3 643
807 set jointD4 644
808 set jointD5 645
809 set jointD6 646
810 set jointD7 647
811 set jointD8 648
812 set jointD9 649
813
814 # add material Properties - command: uniaxialMaterial matType matTag ...
815 #command: uniaxialMaterial Elastic tag? E?
816
817 uniaxialMaterial Elastic 71 1000000000.0
818
819 element beamColumnJoint $jointA1 $N_A1 $N_A10_R $N_A10_A $N_A10_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
820 $bsid2 71 $spid1
821 element beamColumnJoint $jointA2 $N_A2 $N_A20_R $N_A20_A $N_A20_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
822 $bsid2 71 $spid1
823 element beamColumnJoint $jointA3 $N_A3 $N_A30_R $N_A30_A $N_A30_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
824 $bsid2 71 $spid1
825 element beamColumnJoint $jointA4 $N_A4 $N_A40_R $N_A40_A $N_A40_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
826 $bsid2 71 $spid1
827 element beamColumnJoint $jointA5 $N_A5 $N_A50_R $N_A50_A $N_A50_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
828 $bsid2 71 $spid1
829 element beamColumnJoint $jointA6 $N_A6 $N_A60_R $N_A60_A $N_A60_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
830 $bsid2 71 $spid1
831 element beamColumnJoint $jointA7 $N_A7 $N_A70_R $N_A70_A $N_A70_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
832 $bsid2 71 $spid1
833 element beamColumnJoint $jointA8 $N_A8 $N_A80_R $N_A80_A $N_A80_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
834 $bsid2 71 $spid1
835 element beamColumnJoint $jointA9 $N_A9 $N_A90_R $N_A90_A $N_A90_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
836 $bsid2 71 $spid1
837 element beamColumnJoint $jointB1 $N_B1 $N_B11_R $N_B11_A $N_B11_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
838 $bsid2 71 $spid1
839 element beamColumnJoint $jointB2 $N_B2 $N_B21_R $N_B21_A $N_B21_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
840 $bsid2 71 $spid1
841 element beamColumnJoint $jointB3 $N_B3 $N_B31_R $N_B31_A $N_B31_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
842 $bsid2 71 $spid1
843 element beamColumnJoint $jointB4 $N_B4 $N_B41_R $N_B41_A $N_B41_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
844 $bsid2 71 $spid1
845 element beamColumnJoint $jointB5 $N_B5 $N_B51_R $N_B51_A $N_B51_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
846 $bsid2 71 $spid1
847 element beamColumnJoint $jointB6 $N_B6 $N_B61_R $N_B61_A $N_B61_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
848 $bsid2 71 $spid1
849 element beamColumnJoint $jointB7 $N_B7 $N_B71_R $N_B71_A $N_B71_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
850 $bsid2 71 $spid1
851 element beamColumnJoint $jointB8 $N_B8 $N_B81_R $N_B81_A $N_B81_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
852 $bsid2 71 $spid1
853 element beamColumnJoint $jointB9 $N_B9 $N_B91_R $N_B91_A $N_B91_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
854 $bsid2 71 $spid1

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```

838
839 element beamColumnJoint $jointC1 $N_C1 $N_C12_R $N_C12_A $N_C12_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
840 element beamColumnJoint $jointC2 $N_C2 $N_C22_R $N_C22_A $N_C22_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
841 element beamColumnJoint $jointC3 $N_C3 $N_C32_R $N_C32_A $N_C32_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
842 element beamColumnJoint $jointC4 $N_C4 $N_C42_R $N_C42_A $N_C42_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
843 element beamColumnJoint $jointC5 $N_C5 $N_C52_R $N_C52_A $N_C52_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
844 element beamColumnJoint $jointC6 $N_C6 $N_C62_R $N_C62_A $N_C62_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
845 element beamColumnJoint $jointC7 $N_C7 $N_C72_R $N_C72_A $N_C72_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
846 element beamColumnJoint $jointC8 $N_C8 $N_C82_R $N_C82_A $N_C82_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
847 element beamColumnJoint $jointC9 $N_C9 $N_C92_R $N_C92_A $N_C92_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
848
849 element beamColumnJoint $jointD1 $N_D1 $N_D13_R $N_D13_A $N_D13_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
850 element beamColumnJoint $jointD2 $N_D2 $N_D23_R $N_D23_A $N_D23_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
851 element beamColumnJoint $jointD3 $N_D3 $N_D33_R $N_D33_A $N_D33_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
852 element beamColumnJoint $jointD4 $N_D4 $N_D43_R $N_D43_A $N_D43_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
853 element beamColumnJoint $jointD5 $N_D5 $N_D53_R $N_D53_A $N_D53_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
854 element beamColumnJoint $jointD6 $N_D6 $N_D63_R $N_D63_A $N_D63_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
855 element beamColumnJoint $jointD7 $N_D7 $N_D73_R $N_D73_A $N_D73_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
856 element beamColumnJoint $jointD8 $N_D8 $N_D83_R $N_D83_A $N_D83_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
857 element beamColumnJoint $jointD9 $N_D9 $N_D93_R $N_D93_A $N_D93_L $bsid3 $bsid3 71 $bsid1 $bsid2 71 $bsid3 $bsid3 71 $bsid1
    $bsid2 71 $spid1
858
859
860 #####
861 # Elements definitions
862 #####
863
864 # COLUMN definition
865
866 # -----
867 # Define geometric transformation
868 # -----
869 set ColTransfTag 1;          # associate a tag to column transformation
870 geomTransf PDelta $ColTransfTag ; #Columns
871
872 # -----
873 # ---- element connectivity "Columns Definition"-----
874 # -----
875 set numIntPoints 4;
876 set integrationC "Lobatto $col140x60 $numIntPoints"
877
878 element forceBeamColumn 710      $N_A0  $N_A1 $ColTransfTag $integrationC
879 element forceBeamColumn 720      $N_A10_A  $N_A2 $ColTransfTag $integrationC
880 element forceBeamColumn 730      $N_A20_A  $N_A3 $ColTransfTag $integrationC
881 element forceBeamColumn 740      $N_A30_A  $N_A4 $ColTransfTag $integrationC
882 element forceBeamColumn 750      $N_A40_A  $N_A5 $ColTransfTag $integrationC
883 element forceBeamColumn 760      $N_A50_A  $N_A6 $ColTransfTag $integrationC
884 element forceBeamColumn 770      $N_A60_A  $N_A7 $ColTransfTag $integrationC
885 element forceBeamColumn 780      $N_A70_A  $N_A8 $ColTransfTag $integrationC
886 element forceBeamColumn 790      $N_A80_A  $N_A9 $ColTransfTag $integrationC
887
888 element forceBeamColumn 711      $N_B0  $N_B1 $ColTransfTag $integrationC
889 element forceBeamColumn 721      $N_B11_A  $N_B2 $ColTransfTag $integrationC
890 element forceBeamColumn 731      $N_B21_A  $N_B3 $ColTransfTag $integrationC
891 element forceBeamColumn 741      $N_B31_A  $N_B4 $ColTransfTag $integrationC
892 element forceBeamColumn 751      $N_B41_A  $N_B5 $ColTransfTag $integrationC
893 element forceBeamColumn 761      $N_B51_A  $N_B6 $ColTransfTag $integrationC
894 element forceBeamColumn 771      $N_B61_A  $N_B7 $ColTransfTag $integrationC
895 element forceBeamColumn 781      $N_B71_A  $N_B8 $ColTransfTag $integrationC
896 element forceBeamColumn 791      $N_B81_A  $N_B9 $ColTransfTag $integrationC
897
898 element forceBeamColumn 712      $N_C0  $N_C1 $ColTransfTag $integrationC
899 element forceBeamColumn 722      $N_C12_A  $N_C2 $ColTransfTag $integrationC

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```

900 element forceBeamColumn 732 $N_C22_A $N_C3 $ColTransfTag $integrationC
901 element forceBeamColumn 742 $N_C32_A $N_C4 $ColTransfTag $integrationC
902 element forceBeamColumn 752 $N_C42_A $N_C5 $ColTransfTag $integrationC
903 element forceBeamColumn 762 $N_C52_A $N_C6 $ColTransfTag $integrationC
904 element forceBeamColumn 772 $N_C62_A $N_C7 $ColTransfTag $integrationC
905 element forceBeamColumn 782 $N_C72_A $N_C8 $ColTransfTag $integrationC
906 element forceBeamColumn 792 $N_C82_A $N_C9 $ColTransfTag $integrationC
907
908 element forceBeamColumn 713 $N_D0 $N_D1 $ColTransfTag $integrationC
909 element forceBeamColumn 723 $N_D13_A $N_D2 $ColTransfTag $integrationC
910 element forceBeamColumn 733 $N_D23_A $N_D3 $ColTransfTag $integrationC
911 element forceBeamColumn 743 $N_D33_A $N_D4 $ColTransfTag $integrationC
912 element forceBeamColumn 753 $N_D43_A $N_D5 $ColTransfTag $integrationC
913 element forceBeamColumn 763 $N_D53_A $N_D6 $ColTransfTag $integrationC
914 element forceBeamColumn 773 $N_D63_A $N_D7 $ColTransfTag $integrationC
915 element forceBeamColumn 783 $N_D73_A $N_D8 $ColTransfTag $integrationC
916 element forceBeamColumn 793 $N_D83_A $N_D9 $ColTransfTag $integrationC
917
918
919 #####
920
921 # BEAMS definition
922
923 # -----
924 # Define geometric transformation
925 # -----
926 set BeamTransfTag 2; # associate a tag to beam transformation
927 geomTransf PDelta $BeamTransfTag ; #Beams
928
929 # -----
930 # ---- element connectivity "Beamss Definition"-----
931 # -----
932 set numIntPoints_beams 5;
933 set integrationB "Lobatto $beam150x30 $numIntPoints_beams"
934
935 element forceBeamColumn 810 $N_A10_R $N_B11_L $BeamTransfTag $integrationB
936 element forceBeamColumn 820 $N_A20_R $N_B21_L $BeamTransfTag $integrationB
937 element forceBeamColumn 830 $N_A30_R $N_B31_L $BeamTransfTag $integrationB
938 element forceBeamColumn 840 $N_A40_R $N_B41_L $BeamTransfTag $integrationB
939 element forceBeamColumn 850 $N_A50_R $N_B51_L $BeamTransfTag $integrationB
940 element forceBeamColumn 860 $N_A60_R $N_B61_L $BeamTransfTag $integrationB
941 element forceBeamColumn 870 $N_A70_R $N_B71_L $BeamTransfTag $integrationB
942 element forceBeamColumn 880 $N_A80_R $N_B81_L $BeamTransfTag $integrationB
943 element forceBeamColumn 890 $N_A90_R $N_B91_L $BeamTransfTag $integrationB
944
945 element forceBeamColumn 811 $N_B11_R $N_C12_L $BeamTransfTag $integrationB
946 element forceBeamColumn 821 $N_B21_R $N_C22_L $BeamTransfTag $integrationB
947 element forceBeamColumn 831 $N_B31_R $N_C32_L $BeamTransfTag $integrationB
948 element forceBeamColumn 841 $N_B41_R $N_C42_L $BeamTransfTag $integrationB
949 element forceBeamColumn 851 $N_B51_R $N_C52_L $BeamTransfTag $integrationB
950 element forceBeamColumn 861 $N_B61_R $N_C62_L $BeamTransfTag $integrationB
951 element forceBeamColumn 871 $N_B71_R $N_C72_L $BeamTransfTag $integrationB
952 element forceBeamColumn 881 $N_B81_R $N_C82_L $BeamTransfTag $integrationB
953 element forceBeamColumn 891 $N_B91_R $N_C92_L $BeamTransfTag $integrationB
954
955 element forceBeamColumn 812 $N_C12_R $N_D13_L $BeamTransfTag $integrationB
956 element forceBeamColumn 822 $N_C22_R $N_D23_L $BeamTransfTag $integrationB
957 element forceBeamColumn 832 $N_C32_R $N_D33_L $BeamTransfTag $integrationB
958 element forceBeamColumn 842 $N_C42_R $N_D43_L $BeamTransfTag $integrationB
959 element forceBeamColumn 852 $N_C52_R $N_D53_L $BeamTransfTag $integrationB
960 element forceBeamColumn 862 $N_C62_R $N_D63_L $BeamTransfTag $integrationB
961 element forceBeamColumn 872 $N_C72_R $N_D73_L $BeamTransfTag $integrationB
962 element forceBeamColumn 882 $N_C82_R $N_D83_L $BeamTransfTag $integrationB
963 element forceBeamColumn 892 $N_C92_R $N_D93_L $BeamTransfTag $integrationB
964
965
966 #####
967 # infill walls definitions
968 #####
969
970 ##### METHOD A #####
971
972 # diagonal members
973
974 set dia1A 101;
975 set dia2A 102;
976 set dia3A 103;
977 set dia4A 104;
978 set dia5A 105;
979 set dia6A 106;

```


980 set dia7A 107;
981 set dia8A 108;
982 set dia9A 109;
983 set dia10A 1010;
984 set dia11A 1011;
985 set dia12A 1012;
986 set dia13A 1013;
987 set dia14A 1014;
988 set dia15A 1015;
989 set dia16A 1016;
990 set dia17A 1017;
991 set dia18A 1018;
992 set dia19A 1019;
993 set dia20A 1020;
994 set dia21A 1021;
995 set dia22A 1022;
996 set dia23A 1023;
997 set dia24A 1024;
998 set dia25A 1025;
999 set dia26A 1026;
1000 set dia27A 1027;
1001 set dia28A 1028;
1002 set dia29A 1029;
1003 set dia30A 1030;
1004 set dia31A 1031;
1005 set dia32A 1032;
1006 set dia33A 1033;
1007 set dia34A 1034;
1008 set dia35A 1035;
1009 set dia36A 1036;
1010
1011
1012 set dia1B 1037;
1013 set dia2B 1038;
1014 set dia3B 1039;
1015 set dia4B 1040;
1016 set dia5B 1041;
1017 set dia6B 1042;
1018 set dia7B 1043;
1019 set dia8B 1044;
1020 set dia9B 1045;
1021 set dia10B 1046;
1022 set dia11B 1047;
1023 set dia12B 1048;
1024 set dia13B 1049;
1025 set dia14B 1050;
1026 set dia15B 1051;
1027 set dia16B 1052;
1028 set dia17B 1053;
1029 set dia18B 1054;
1030 set dia19B 1055;
1031 set dia20B 1056;
1032 set dia21B 1057;
1033 set dia22B 1058;
1034 set dia23B 1059;
1035 set dia24B 1060;
1036 set dia25B 1061;
1037 set dia26B 1062;
1038 set dia27B 1063;
1039 set dia28B 1064;
1040 set dia29B 1065;
1041 set dia30B 1066;
1042 set dia31B 1067;
1043 set dia32B 1068;
1044 set dia33B 1069;
1045 set dia34B 1070;
1046 set dia35B 1071;
1047 set dia36B 1072;
1048
1049 set dia1C 1073;
1050 set dia2C 1074;
1051 set dia3C 1075;
1052 set dia4C 1076;
1053 set dia5C 1077;
1054 set dia6C 1078;
1055 set dia7C 1079;
1056 set dia8C 1080;
1057 set dia9C 1081;
1058 set dia10C 1082;
1059 set dia11C 1083;

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1060 set dia12C 1084;
1061 set dia13C 1085;
1062 set dia14C 1086;
1063 set dia15C 1087;
1064 set dia16C 1088;
1065 set dia17C 1089;
1066 set dia18C 1090;
1067 set dia19C 1091;
1068 set dia20C 1092;
1069 set dia21C 1093;
1070 set dia22C 1094;
1071 set dia23C 1095;
1072 set dia24C 1096;
1073 set dia25C 1097;
1074 set dia26C 1098;
1075 set dia27C 1099;
1076 set dia28C 1100;
1077 set dia29C 1101;
1078 set dia30C 1102;
1079 set dia31C 1103;
1080 set dia32C 1104;
1081 set dia33C 1105;
1082 set dia34C 1106;
1083 set dia35C 1107;
1084 set dia36C 1108;
1085
1086 set width_wall 665;          #using equation 16 in the report, the width of the strut based on H=3m,L=4m, and t=0.3m
1087 set t_wall 200;
1088 set Aw [expr $width_wall*$t_wall]; #cross-sectional
1089 set Ew 10000000000.0; #Young's Modulus
1090 set Izw [expr $t_wall*(pow($width_wall,3))/12]; #second moment of area about the local z-axis
1091
1092 set WtransfTag 81;
1093 geomTransf Linear $WtransfTag;
1094
1095 # -----
1096 # ---- element connectivity "diagonal infill walls Definition"-----
1097 # -----
1098
1099 element elasticBeamColumn $dia1A $N_A1 $N_W1A_L $Aw $Ew $Izw $WtransfTag
1100 element elasticBeamColumn $dia2A $N_B1 $N_W1A_L $Aw $Ew $Izw $WtransfTag
1101 element elasticBeamColumn $dia3A $N_A0 $N_W1A_R $Aw $Ew $Izw $WtransfTag
1102 element elasticBeamColumn $dia4A $N_B0 $N_W1A_R $Aw $Ew $Izw $WtransfTag
1103 element elasticBeamColumn $dia5A $N_A2 $N_W2A_L $Aw $Ew $Izw $WtransfTag
1104 element elasticBeamColumn $dia6A $N_B2 $N_W2A_L $Aw $Ew $Izw $WtransfTag
1105 element elasticBeamColumn $dia7A $N_A10_A $N_W2A_R $Aw $Ew $Izw $WtransfTag
1106 element elasticBeamColumn $dia8A $N_B11_A $N_W2A_R $Aw $Ew $Izw $WtransfTag
1107 element elasticBeamColumn $dia9A $N_A3 $N_W3A_L $Aw $Ew $Izw $WtransfTag
1108 element elasticBeamColumn $dia10A $N_B3 $N_W3A_L $Aw $Ew $Izw $WtransfTag
1109 element elasticBeamColumn $dia11A $N_A20_A $N_W3A_R $Aw $Ew $Izw $WtransfTag
1110 element elasticBeamColumn $dia12A $N_B21_A $N_W3A_R $Aw $Ew $Izw $WtransfTag
1111 element elasticBeamColumn $dia13A $N_A4 $N_W4A_L $Aw $Ew $Izw $WtransfTag
1112 element elasticBeamColumn $dia14A $N_B4 $N_W4A_L $Aw $Ew $Izw $WtransfTag
1113 element elasticBeamColumn $dia15A $N_A30_A $N_W4A_R $Aw $Ew $Izw $WtransfTag
1114 element elasticBeamColumn $dia16A $N_B31_A $N_W4A_R $Aw $Ew $Izw $WtransfTag
1115 element elasticBeamColumn $dia17A $N_A5 $N_W5A_L $Aw $Ew $Izw $WtransfTag
1116 element elasticBeamColumn $dia18A $N_B5 $N_W5A_L $Aw $Ew $Izw $WtransfTag
1117 element elasticBeamColumn $dia19A $N_A40_A $N_W5A_R $Aw $Ew $Izw $WtransfTag
1118 element elasticBeamColumn $dia20A $N_B41_A $N_W5A_R $Aw $Ew $Izw $WtransfTag
1119 element elasticBeamColumn $dia21A $N_A6 $N_W6A_L $Aw $Ew $Izw $WtransfTag
1120 element elasticBeamColumn $dia22A $N_B6 $N_W6A_L $Aw $Ew $Izw $WtransfTag
1121 element elasticBeamColumn $dia23A $N_A50_A $N_W6A_R $Aw $Ew $Izw $WtransfTag
1122 element elasticBeamColumn $dia24A $N_B51_A $N_W6A_R $Aw $Ew $Izw $WtransfTag
1123 element elasticBeamColumn $dia25A $N_A7 $N_W7A_L $Aw $Ew $Izw $WtransfTag
1124 element elasticBeamColumn $dia26A $N_B7 $N_W7A_L $Aw $Ew $Izw $WtransfTag
1125 element elasticBeamColumn $dia27A $N_A60_A $N_W7A_R $Aw $Ew $Izw $WtransfTag
1126 element elasticBeamColumn $dia28A $N_B61_A $N_W7A_R $Aw $Ew $Izw $WtransfTag
1127 element elasticBeamColumn $dia29A $N_A8 $N_W8A_L $Aw $Ew $Izw $WtransfTag
1128 element elasticBeamColumn $dia30A $N_B8 $N_W8A_L $Aw $Ew $Izw $WtransfTag
1129 element elasticBeamColumn $dia31A $N_A70_A $N_W8A_R $Aw $Ew $Izw $WtransfTag
1130 element elasticBeamColumn $dia32A $N_B71_A $N_W8A_R $Aw $Ew $Izw $WtransfTag
1131 element elasticBeamColumn $dia33A $N_A9 $N_W9A_L $Aw $Ew $Izw $WtransfTag
1132 element elasticBeamColumn $dia34A $N_B9 $N_W9A_L $Aw $Ew $Izw $WtransfTag
1133 element elasticBeamColumn $dia35A $N_A80_A $N_W9A_R $Aw $Ew $Izw $WtransfTag
1134 element elasticBeamColumn $dia36A $N_B81_A $N_W9A_R $Aw $Ew $Izw $WtransfTag
1135
1136 element elasticBeamColumn $dia1B $N_B1 $N_W1B_L $Aw $Ew $Izw $WtransfTag
1137 element elasticBeamColumn $dia2B $N_C1 $N_W1B_L $Aw $Ew $Izw $WtransfTag
1138 element elasticBeamColumn $dia3B $N_B0 $N_W1B_R $Aw $Ew $Izw $WtransfTag
1139 element elasticBeamColumn $dia4B $N_C0 $N_W1B_R $Aw $Ew $Izw $WtransfTag

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1140 element elasticBeamColumn $dia5B $N_B2 $N_W2B_L $Aw $Ew $Izw $WtransfTag
1141 element elasticBeamColumn $dia6B $N_C2 $N_W2B_L $Aw $Ew $Izw $WtransfTag
1142 element elasticBeamColumn $dia7B $N_B11_A $N_W2B_R $Aw $Ew $Izw $WtransfTag
1143 element elasticBeamColumn $dia8B $N_C12_A $N_W2B_R $Aw $Ew $Izw $WtransfTag
1144 element elasticBeamColumn $dia9B $N_B3 $N_W3B_L $Aw $Ew $Izw $WtransfTag
1145 element elasticBeamColumn $dia10B $N_C3 $N_W3B_L $Aw $Ew $Izw $WtransfTag
1146 element elasticBeamColumn $dia11B $N_B21_A $N_W3B_R $Aw $Ew $Izw $WtransfTag
1147 element elasticBeamColumn $dia12B $N_C22_A $N_W3B_R $Aw $Ew $Izw $WtransfTag
1148 element elasticBeamColumn $dia13B $N_B4 $N_W4B_L $Aw $Ew $Izw $WtransfTag
1149 element elasticBeamColumn $dia14B $N_C4 $N_W4B_L $Aw $Ew $Izw $WtransfTag
1150 element elasticBeamColumn $dia15B $N_B31_A $N_W4B_R $Aw $Ew $Izw $WtransfTag
1151 element elasticBeamColumn $dia16B $N_C32_A $N_W4B_R $Aw $Ew $Izw $WtransfTag
1152 element elasticBeamColumn $dia17B $N_B5 $N_W5B_L $Aw $Ew $Izw $WtransfTag
1153 element elasticBeamColumn $dia18B $N_C5 $N_W5B_L $Aw $Ew $Izw $WtransfTag
1154 element elasticBeamColumn $dia19B $N_B41_A $N_W5B_R $Aw $Ew $Izw $WtransfTag
1155 element elasticBeamColumn $dia20B $N_C42_A $N_W5B_R $Aw $Ew $Izw $WtransfTag
1156 element elasticBeamColumn $dia21B $N_B6 $N_W6B_L $Aw $Ew $Izw $WtransfTag
1157 element elasticBeamColumn $dia22B $N_C6 $N_W6B_L $Aw $Ew $Izw $WtransfTag
1158 element elasticBeamColumn $dia23B $N_B51_A $N_W6B_R $Aw $Ew $Izw $WtransfTag
1159 element elasticBeamColumn $dia24B $N_C52_A $N_W6B_R $Aw $Ew $Izw $WtransfTag
1160 element elasticBeamColumn $dia25B $N_B7 $N_W7B_L $Aw $Ew $Izw $WtransfTag
1161 element elasticBeamColumn $dia26B $N_C7 $N_W7B_L $Aw $Ew $Izw $WtransfTag
1162 element elasticBeamColumn $dia27B $N_B61_A $N_W7B_R $Aw $Ew $Izw $WtransfTag
1163 element elasticBeamColumn $dia28B $N_C62_A $N_W7B_R $Aw $Ew $Izw $WtransfTag
1164 element elasticBeamColumn $dia29B $N_B8 $N_W8B_L $Aw $Ew $Izw $WtransfTag
1165 element elasticBeamColumn $dia30B $N_C8 $N_W8B_L $Aw $Ew $Izw $WtransfTag
1166 element elasticBeamColumn $dia31B $N_B71_A $N_W8B_R $Aw $Ew $Izw $WtransfTag
1167 element elasticBeamColumn $dia32B $N_C72_A $N_W8B_R $Aw $Ew $Izw $WtransfTag
1168 element elasticBeamColumn $dia33B $N_B9 $N_W9B_L $Aw $Ew $Izw $WtransfTag
1169 element elasticBeamColumn $dia34B $N_C9 $N_W9B_L $Aw $Ew $Izw $WtransfTag
1170 element elasticBeamColumn $dia35B $N_B81_A $N_W9B_R $Aw $Ew $Izw $WtransfTag
1171 element elasticBeamColumn $dia36B $N_C82_A $N_W9B_R $Aw $Ew $Izw $WtransfTag
1172
1173 element elasticBeamColumn $dia1C $N_C1 $N_W1C_L $Aw $Ew $Izw $WtransfTag
1174 element elasticBeamColumn $dia2C $N_D1 $N_W1C_L $Aw $Ew $Izw $WtransfTag
1175 element elasticBeamColumn $dia3C $N_C0 $N_W1C_R $Aw $Ew $Izw $WtransfTag
1176 element elasticBeamColumn $dia4C $N_D0 $N_W1C_R $Aw $Ew $Izw $WtransfTag
1177 element elasticBeamColumn $dia5C $N_C2 $N_W2C_L $Aw $Ew $Izw $WtransfTag
1178 element elasticBeamColumn $dia6C $N_D2 $N_W2C_L $Aw $Ew $Izw $WtransfTag
1179 element elasticBeamColumn $dia7C $N_C12_A $N_W2C_R $Aw $Ew $Izw $WtransfTag
1180 element elasticBeamColumn $dia8C $N_D13_A $N_W2C_R $Aw $Ew $Izw $WtransfTag
1181 element elasticBeamColumn $dia9C $N_C3 $N_W3C_L $Aw $Ew $Izw $WtransfTag
1182 element elasticBeamColumn $dia10C $N_D3 $N_W3C_L $Aw $Ew $Izw $WtransfTag
1183 element elasticBeamColumn $dia11C $N_C22_A $N_W3C_R $Aw $Ew $Izw $WtransfTag
1184 element elasticBeamColumn $dia12C $N_D23_A $N_W3C_R $Aw $Ew $Izw $WtransfTag
1185 element elasticBeamColumn $dia13C $N_C4 $N_W4C_L $Aw $Ew $Izw $WtransfTag
1186 element elasticBeamColumn $dia14C $N_D4 $N_W4C_L $Aw $Ew $Izw $WtransfTag
1187 element elasticBeamColumn $dia15C $N_C32_A $N_W4C_R $Aw $Ew $Izw $WtransfTag
1188 element elasticBeamColumn $dia16C $N_D33_A $N_W4C_R $Aw $Ew $Izw $WtransfTag
1189 element elasticBeamColumn $dia17C $N_C5 $N_W5C_L $Aw $Ew $Izw $WtransfTag
1190 element elasticBeamColumn $dia18C $N_D5 $N_W5C_L $Aw $Ew $Izw $WtransfTag
1191 element elasticBeamColumn $dia19C $N_C42_A $N_W5C_R $Aw $Ew $Izw $WtransfTag
1192 element elasticBeamColumn $dia20C $N_D43_A $N_W5C_R $Aw $Ew $Izw $WtransfTag
1193 element elasticBeamColumn $dia21C $N_C6 $N_W6C_L $Aw $Ew $Izw $WtransfTag
1194 element elasticBeamColumn $dia22C $N_D6 $N_W6C_L $Aw $Ew $Izw $WtransfTag
1195 element elasticBeamColumn $dia23C $N_C52_A $N_W6C_R $Aw $Ew $Izw $WtransfTag
1196 element elasticBeamColumn $dia24C $N_D53_A $N_W6C_R $Aw $Ew $Izw $WtransfTag
1197 element elasticBeamColumn $dia25C $N_C7 $N_W7C_L $Aw $Ew $Izw $WtransfTag
1198 element elasticBeamColumn $dia26C $N_D7 $N_W7C_L $Aw $Ew $Izw $WtransfTag
1199 element elasticBeamColumn $dia27C $N_C62_A $N_W7C_R $Aw $Ew $Izw $WtransfTag
1200 element elasticBeamColumn $dia28C $N_D63_A $N_W7C_R $Aw $Ew $Izw $WtransfTag
1201 element elasticBeamColumn $dia29C $N_C8 $N_W8C_L $Aw $Ew $Izw $WtransfTag
1202 element elasticBeamColumn $dia30C $N_D8 $N_W8C_L $Aw $Ew $Izw $WtransfTag
1203 element elasticBeamColumn $dia31C $N_C72_A $N_W8C_R $Aw $Ew $Izw $WtransfTag
1204 element elasticBeamColumn $dia32C $N_D73_A $N_W8C_R $Aw $Ew $Izw $WtransfTag
1205 element elasticBeamColumn $dia33C $N_C9 $N_W9C_L $Aw $Ew $Izw $WtransfTag
1206 element elasticBeamColumn $dia34C $N_D9 $N_W9C_L $Aw $Ew $Izw $WtransfTag
1207 element elasticBeamColumn $dia35C $N_C82_A $N_W9C_R $Aw $Ew $Izw $WtransfTag
1208 element elasticBeamColumn $dia36C $N_D83_A $N_W9C_R $Aw $Ew $Izw $WtransfTag
1209
1210 # Central member
1211
1212 set cen1A 2001;
1213 set cen2A 2002;
1214 set cen3A 2003;
1215 set cen4A 2004;
1216 set cen5A 2005;
1217 set cen6A 2006;
1218 set cen7A 2007;
1219 set cen8A 2008;

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```

1220 set cen9A 2009;
1221 set cen1B 20010;
1222 set cen2B 20011;
1223 set cen3B 20012;
1224 set cen4B 20013;
1225 set cen5B 20014;
1226 set cen6B 20015;
1227 set cen7B 20016;
1228 set cen8B 20017;
1229 set cen9B 20018;
1230 set cen1C 20019;
1231 set cen2C 20020;
1232 set cen3C 20021;
1233 set cen4C 20022;
1234 set cen5C 20023;
1235 set cen6C 20024;
1236 set cen7C 20025;
1237 set cen8C 20026;
1238 set cen9C 20027;
1239
1240 # -----
1241 # Define geometric transformation
1242 # -----
1243 #set wallTransfTag 82;          # associate a tag to wall transformation
1244 #geomTransf Linear $wallTransfTag ; #walls
1245
1246 # -----
1247 # --- element connectivity "wall Definition"-----
1248 # -----
1249 #set numIntPoints_wall 2;
1250
1251 set wall_sec 91;
1252 set wall_mat 92;
1253
1254
1255
1256
1257
1258 ##### material for infill walls #####
1259
1260 ## Positive/Negative envelope Stress
1261
1262 set A 1;
1263 set p1 [expr 0.4*$A]; set p2 [expr 1.025*$A]; set p3 [expr 2.05*$A]; set p4 [expr 0.41*$A];
1264
1265 ## stress1 stress2 stress3 stress4
1266 set pEnvStrsp [list [expr $p1] [expr $p2] [expr $p3] [expr $p4]]
1267 set nEnvStrsp [list [expr -$p1] [expr -$p2] [expr -$p3] [expr -$p4]]
1268
1269 ## Positive/Negative envelope Strain
1270 ## strain1 strain2 strain3 strain4
1271
1272 set pEnvStnsp [list 0.000065 0.00385 0.00771 0.0120]
1273 set nEnvStnsp [list -0.000065 -0.00385 -0.00771 -0.0120]
1274
1275 ## Ratio of maximum deformation at which reloading begins
1276 ## Pos_env. Neg_env.
1277 set rDispsp [list 0.2 0.2]
1278
1279 ## Ratio of envelope force (corresponding to maximum deformation) at which reloading begins
1280
1281 ### Pos_env. Neg_env.
1282 set rForcesp [list 0.2 0.2]
1283
1284
1285 ## Ratio of monotonic strength developed upon unloading
1286 ### Pos_env. Neg_env.
1287
1288 set uForcesp [list 0.0 0.0]
1289
1290
1291 ## Coefficients for Unloading Stiffness degradation
1292
1293 ## gammaK1 gammaK2 gammaK3 gammaK4 gammaKLimit
1294
1295 #set gammaKsp [list 1.13364492409642 0.0 0.10111033064469 0.0 0.91652498468618]
1296
1297 set gammaKsp [list 0.0 0.0 0.0 0.0 0.0]
1298
1299 ##### Coefficients for Reloading Stiffness degradation

```

```

1300   ### gammaD1 gammaD2 gammaD3 gammaD4 gammaDLimit
1301
1302   #set gammaDsp [list 0.12 0.0 0.23 0.0 0.95]
1303
1304   set gammaDsp [list 0.0 0.0 0.0 0.0 0.0]
1305   ##### Coefficients for Strength degradation
1306   ### gammaF1 gammaF2 gammaF3 gammaF4 gammaFLimit
1307
1308   #set gammaFsp [list 1.11 0.0 0.319 0.0 0.125]
1309   set gammaFsp [list 0.0 0.0 0.0 0.0 0.0]
1310
1311   set gammaEsp 10.0
1312
1313   uniaxialMaterial Pinching4 $wall_mat [lindex $pEnvStrsp 0] [lindex $pEnvStnsp 0] \
1314   [lindex $pEnvStrsp 1] [lindex $pEnvStnsp 1] [lindex $pEnvStrsp 2] \
1315   [lindex $pEnvStnsp 2] [lindex $pEnvStrsp 3] [lindex $pEnvStnsp 3] \
1316   [lindex $nEnvStrsp 0] [lindex $nEnvStnsp 0] \
1317   [lindex $nEnvStrsp 1] [lindex $nEnvStnsp 1] [lindex $nEnvStrsp 2] \
1318   [lindex $nEnvStnsp 2] [lindex $nEnvStrsp 3] [lindex $nEnvStnsp 3] \
1319   [lindex $rDispsp 0] [lindex $rForcesp 0] [lindex $uForcesp 0] \
1320   [lindex $rDispsp 1] [lindex $rForcesp 1] [lindex $uForcesp 1] \
1321   [lindex $gammaKsp 0] [lindex $gammaKsp 1] [lindex $gammaKsp 2] [lindex $gammaKsp 3] [lindex $gammaKsp 4] \
1322   [lindex $gammaDsp 0] [lindex $gammaDsp 1] [lindex $gammaDsp 2] [lindex $gammaDsp 3] [lindex $gammaDsp 4] \
1323   [lindex $gammaFsp 0] [lindex $gammaFsp 1] [lindex $gammaFsp 2] [lindex $gammaFsp 3] [lindex $gammaFsp 4] \
1324   $gammaEsp energy
1325
1326   ##### wall section #####
1327   #####
1328   #BuildRCrectSection $ColSecTag $HSec      $BSec  $coverH  $coverB  $coreID      $coverID      $steelID $numBarsTop $barArea
1329   aTop $numBarsBot $barAreaBot $numBarsIntTot $barAreaInt $nfCoreY $nfCoreZ $nfCoverY $nfCoverZ
1330   BuildRCrectSection $wall_sec $width_wall $t_wall 20      20      $wall_mat  $wall_mat      $wall_mat 0      $reba
1331   r_16 0      $rebar_16 0      $rebar_16 8      8      8      8
1332
1333   set wallTransfTag 3;          # associate a tag to column transformation
1334   geomTransf PDelta $wallTransfTag ; #Columns
1335
1336   # -----
1337   # ---- element connectivity "Columns Definition"-----
1338   # -----
1339   set numIntPoints_wall 4;
1340   set integrationw "Lobatto $wall_sec $numIntPoints_wall"
1341
1342   element forceBeamColumn $cen1A      $N_W1A_L $N_W1A_R      $wallTransfTag $integrationw
1343   element forceBeamColumn $cen2A      $N_W2A_L $N_W2A_R      $wallTransfTag $integrationw
1344   element forceBeamColumn $cen3A      $N_W3A_L $N_W3A_R      $wallTransfTag $integrationw
1345   element forceBeamColumn $cen4A      $N_W4A_L $N_W4A_R      $wallTransfTag $integrationw
1346   element forceBeamColumn $cen5A      $N_W5A_L $N_W5A_R      $wallTransfTag $integrationw
1347   element forceBeamColumn $cen6A      $N_W6A_L $N_W6A_R      $wallTransfTag $integrationw
1348   element forceBeamColumn $cen7A      $N_W7A_L $N_W7A_R      $wallTransfTag $integrationw
1349   element forceBeamColumn $cen8A      $N_W8A_L $N_W8A_R      $wallTransfTag $integrationw
1350   element forceBeamColumn $cen9A      $N_W9A_L $N_W9A_R      $wallTransfTag $integrationw
1351
1352   element forceBeamColumn $cen1B      $N_W1B_L $N_W1B_R      $wallTransfTag $integrationw
1353   element forceBeamColumn $cen2B      $N_W2B_L $N_W2B_R      $wallTransfTag $integrationw
1354   element forceBeamColumn $cen3B      $N_W3B_L $N_W3B_R      $wallTransfTag $integrationw
1355   element forceBeamColumn $cen4B      $N_W4B_L $N_W4B_R      $wallTransfTag $integrationw
1356   element forceBeamColumn $cen5B      $N_W5B_L $N_W5B_R      $wallTransfTag $integrationw
1357   element forceBeamColumn $cen6B      $N_W6B_L $N_W6B_R      $wallTransfTag $integrationw
1358   element forceBeamColumn $cen7B      $N_W7B_L $N_W7B_R      $wallTransfTag $integrationw
1359   element forceBeamColumn $cen8B      $N_W8B_L $N_W8B_R      $wallTransfTag $integrationw
1360   element forceBeamColumn $cen9B      $N_W9B_L $N_W9B_R      $wallTransfTag $integrationw
1361
1362   element forceBeamColumn $cen1C      $N_W1C_L $N_W1C_R      $wallTransfTag $integrationw
1363   element forceBeamColumn $cen2C      $N_W2C_L $N_W2C_R      $wallTransfTag $integrationw
1364   element forceBeamColumn $cen3C      $N_W3C_L $N_W3C_R      $wallTransfTag $integrationw
1365   element forceBeamColumn $cen4C      $N_W4C_L $N_W4C_R      $wallTransfTag $integrationw
1366   element forceBeamColumn $cen5C      $N_W5C_L $N_W5C_R      $wallTransfTag $integrationw
1367   element forceBeamColumn $cen6C      $N_W6C_L $N_W6C_R      $wallTransfTag $integrationw
1368   element forceBeamColumn $cen7C      $N_W7C_L $N_W7C_R      $wallTransfTag $integrationw
1369   element forceBeamColumn $cen8C      $N_W8C_L $N_W8C_R      $wallTransfTag $integrationw
1370   element forceBeamColumn $cen9C      $N_W9C_L $N_W9C_R      $wallTransfTag $integrationw
1371
1372   ##### METHOD B ##### Can be used in case of convergence problem
1373   s (Validated Method Experimentally)
1374
1375   #set width_wall 665;          #using equation 16 in the report, the width of the strut based on H=3m,L=4m, and t=0.3m

```

```

1376 #set t_wall 200;
1377 #set Aw [expr $width_wall*$t_wall]; #cross-sectional
1378 #set Ew 10000000000.0; #Young's Modulus
1379 #set Izw [expr $t_wall*(pow($width_wall,3))/12]; #second moment of area about the local z-axis
1380
1381
1382 # Central member
1383
1384 #set cenA1 111; #A: means that the diagonal strut start from axis A to B, and the rest in that analogy
.
1385 #set cenA2 112;
1386 #set cenA3 113;
1387 #set cenA4 114;
1388 #set cenA5 115;
1389 #set cenA6 116;
1390 #set cenA7 117;
1391 #set cenA8 118;
1392 #set cenA9 119;
1393
1394 #set cenB1 121;
1395 #set cenB2 122;
1396 #set cenB3 123;
1397 #set cenB4 124;
1398 #set cenB5 125;
1399 #set cenB6 126;
1400 #set cenB7 127;
1401 #set cenB8 128;
1402 #set cenB9 129;
1403
1404 #set cenC1 131;
1405 #set cenC2 132;
1406 #set cenC3 133;
1407 #set cenC4 134;
1408 #set cenC5 135;
1409 #set cenC6 136;
1410 #set cenC7 137;
1411 #set cenC8 138;
1412 #set cenC9 139;
1413
1414 # -----
1415 # ---- element connectivity "wall Definition"-----
1416 # -----
1417
1418 #set wall_sec 91;
1419 #set wall_mat 92;
1420
1421
1422
1423
1424
1425 ##### material for infill walls #####
1426
1427 ## Positive/Negative envelope Stress
1428
1429 # set unconfcw -2.05; # compression strength for concrete
1430 # set unconepscw -0.000352; # strain at maximum stress in compression
1431 # set unconfw [expr $unconfcw*0.4]; # ultimate stress for concrete
1432 # set unconepsuw -0.012; # strain at ultimate stress in compression
1433 # set unconlambdaw 0.1; # ratio between reloading stiffness and itial stiffness in compression
1434 # set unconftw [expr $unconfcw*-0.0001]; # maximum stress in tension for concrete
1435 # set unconEtw [expr $unconftw/0.2]; # elastic modulus in tension
1436 # set unconE0w 8000; #intial elastic tangent
1437
1438 # uniaxialMaterial Concrete02 $C_unconfinedw $unconfcw $unconepscw $unconfw $unconepsuw $unconlambdaw $unconftw
w $unconEtw;
1439
1440
1441
1442 ##### wall section #####
#####
1443
1444 #BuildRCrectSection $ColSecTag $HSec $BSec $coverH $coverB $coreID $coverID $steelID $numBarsTop $barArea
aTop $numBarsBot $barAreaBot $numBarsIntTot $barAreaInt $nfCoreY $nfCoreZ $nfCoverY $nfCoverZ
1445 #BuildRCrectSection $wall_sec $width_wall $t_wall 20 20 $C_unconfinedw $C_unconfinedw $C_unconfinedw 0
$rebar_16 0 $rebar_16 0 $rebar_16 8 8 8 8
1446
1447 #set wallTransfTag 3; # associate a tag to column transformation
1448 #geomTransf PDelta $wallTransfTag ; #Columns
1449
1450

```

```

1451 # -----
1452 # ---- element connectivity "Wall Definition"-----
1453 # -----
1454 #set numIntPoints_wall 4;
1455 #set integrationw "Lobatto $wall_sec $numIntPoints_wall"
1456
1457 #element forceBeamColumn $cenA1 $N_A1 $N_B0 $wallTransfTag $integrationw
1458 #element forceBeamColumn $cenA2 $N_A2 $N_B11_A $wallTransfTag $integrationw
1459 #element forceBeamColumn $cenA3 $N_A3 $N_B21_A $wallTransfTag $integrationw
1460 #element forceBeamColumn $cenA4 $N_A4 $N_B31_A $wallTransfTag $integrationw
1461 #element forceBeamColumn $cenA5 $N_A5 $N_B41_A $wallTransfTag $integrationw
1462 #element forceBeamColumn $cenA6 $N_A6 $N_B51_A $wallTransfTag $integrationw
1463 #element forceBeamColumn $cenA7 $N_A7 $N_B61_A $wallTransfTag $integrationw
1464 #element forceBeamColumn $cenA8 $N_A8 $N_B71_A $wallTransfTag $integrationw
1465 #element forceBeamColumn $cenA9 $N_A9 $N_B81_A $wallTransfTag $integrationw
1466
1467 #element forceBeamColumn $cenB1 $N_B1 $N_C0 $wallTransfTag $integrationw
1468 #element forceBeamColumn $cenB2 $N_B2 $N_C12_A $wallTransfTag $integrationw
1469 #element forceBeamColumn $cenB3 $N_B3 $N_C22_A $wallTransfTag $integrationw
1470 #element forceBeamColumn $cenB4 $N_B4 $N_C32_A $wallTransfTag $integrationw
1471 #element forceBeamColumn $cenB5 $N_B5 $N_C42_A $wallTransfTag $integrationw
1472 #element forceBeamColumn $cenB6 $N_B6 $N_C52_A $wallTransfTag $integrationw
1473 #element forceBeamColumn $cenB7 $N_B7 $N_C62_A $wallTransfTag $integrationw
1474 #element forceBeamColumn $cenB8 $N_B8 $N_C72_A $wallTransfTag $integrationw
1475 #element forceBeamColumn $cenB9 $N_B9 $N_C82_A $wallTransfTag $integrationw
1476
1477 #element forceBeamColumn $cenC1 $N_C1 $N_D0 $wallTransfTag $integrationw
1478 #element forceBeamColumn $cenC2 $N_C2 $N_D13_A $wallTransfTag $integrationw
1479 #element forceBeamColumn $cenC3 $N_C3 $N_D23_A $wallTransfTag $integrationw
1480 #element forceBeamColumn $cenC4 $N_C4 $N_D33_A $wallTransfTag $integrationw
1481 #element forceBeamColumn $cenC5 $N_C5 $N_D43_A $wallTransfTag $integrationw
1482 #element forceBeamColumn $cenC6 $N_C6 $N_D53_A $wallTransfTag $integrationw
1483 #element forceBeamColumn $cenC7 $N_C7 $N_D63_A $wallTransfTag $integrationw
1484 #element forceBeamColumn $cenC8 $N_C8 $N_D73_A $wallTransfTag $integrationw
1485 #element forceBeamColumn $cenC9 $N_C9 $N_D83_A $wallTransfTag $integrationw
1486
1487
1488
1489
1490 #####
1491 # display the model with the node numbers
1492 DisplayModel2D NodeNumbers
1493
1494 #####
1495 # gravity and masses load
1496 #####
1497
1498 # timeSeries "LinearDefault": tsTag cFactor
1499 timeSeries Linear 1 -factor 1;
1500
1501 # distributed loads
1502
1503 #set DL 11000.0; # self weight add as point load (N)
1504 set TLE 68100.0; # TLE: Total Load at the middle columns
1505 set TLM 136100.0; # TLM: Total Load at the middle columns
1506
1507 # pattern PatternType $PatternID TimeSeriesType
1508 pattern Plain 1 1 {
1509 #load $nodeTag (ndf $LoadValues)
1510 load $N_A10_A 0 [expr -$TLE] 0;
1511 load $N_A20_A 0 [expr -$TLE] 0;
1512 load $N_A30_A 0 [expr -$TLE] 0;
1513 load $N_A40_A 0 [expr -$TLE] 0;
1514 load $N_A50_A 0 [expr -$TLE] 0;
1515 load $N_A60_A 0 [expr -$TLE] 0;
1516 load $N_A70_A 0 [expr -$TLE] 0;
1517 load $N_A80_A 0 [expr -$TLE] 0;
1518 load $N_A90_A 0 [expr -$TLE] 0;
1519
1520 load $N_B11_A 0 [expr -$TLM] 0;
1521 load $N_B21_A 0 [expr -$TLM] 0;
1522 load $N_B31_A 0 [expr -$TLM] 0;
1523 load $N_B41_A 0 [expr -$TLM] 0;
1524 load $N_B51_A 0 [expr -$TLM] 0;
1525 load $N_B61_A 0 [expr -$TLM] 0;
1526 load $N_B71_A 0 [expr -$TLM] 0;
1527 load $N_B81_A 0 [expr -$TLM] 0;

```

```

1528     load  $N_B91_A 0 [expr -$TLM] 0;
1529
1530     load  $N_C12_A 0 [expr -$TLM] 0;
1531     load  $N_C22_A 0 [expr -$TLM] 0;
1532     load  $N_C32_A 0 [expr -$TLM] 0;
1533     load  $N_C42_A 0 [expr -$TLM] 0;
1534     load  $N_C52_A 0 [expr -$TLM] 0;
1535     load  $N_C62_A 0 [expr -$TLM] 0;
1536     load  $N_C72_A 0 [expr -$TLM] 0;
1537     load  $N_C82_A 0 [expr -$TLM] 0;
1538     load  $N_C92_A 0 [expr -$TLM] 0;
1539
1540     load  $N_D13_A 0 [expr -$TLE] 0;
1541     load  $N_D23_A 0 [expr -$TLE] 0;
1542     load  $N_D33_A 0 [expr -$TLE] 0;
1543     load  $N_D43_A 0 [expr -$TLE] 0;
1544     load  $N_D53_A 0 [expr -$TLE] 0;
1545     load  $N_D63_A 0 [expr -$TLE] 0;
1546     load  $N_D73_A 0 [expr -$TLE] 0;
1547     load  $N_D83_A 0 [expr -$TLE] 0;
1548     load  $N_D93_A 0 [expr -$TLE] 0;
1549
1550     #eleLoad -ele $eleTag1 <$eleTag2> -type -beamuniformload $wy
1551     #eleLoad -ele 5 6 -type -beamUniform [expr -$DL];
1552
1553 }
1554
1555
1556 # masses
1557
1558     set mass1 20420;
1559     set mass2 20420;
1560     set mass3 20420;
1561     set mass4 20420;
1562     set mass5 20420;
1563     set mass6 20420;
1564     set mass7 20420;
1565     set mass8 20420;
1566     set mass9 20420;
1567
1568
1569
1570 # assign mass to nodes
1571
1572 #mass $nodetag (ndf $massvalues)
1573 mass $N_A10_L [expr $mass1/2] 0.1 0.1;
1574 mass $N_A20_L [expr $mass1/2] 0.1 0.1;
1575 mass $N_A30_L [expr $mass1/2] 0.1 0.1;
1576 mass $N_A40_L [expr $mass1/2] 0.1 0.1;
1577 mass $N_A50_L [expr $mass1/2] 0.1 0.1;
1578 mass $N_A60_L [expr $mass1/2] 0.1 0.1;
1579 mass $N_A70_L [expr $mass1/2] 0.1 0.1;
1580 mass $N_A80_L [expr $mass1/2] 0.1 0.1;
1581 mass $N_A90_L [expr $mass1/2] 0.1 0.1;
1582
1583 mass $N_B11_L [expr $mass1/2] 0.1 0.1;
1584 mass $N_B21_L [expr $mass1/2] 0.1 0.1;
1585 mass $N_B31_L [expr $mass1/2] 0.1 0.1;
1586 mass $N_B41_L [expr $mass1/2] 0.1 0.1;
1587 mass $N_B51_L [expr $mass1/2] 0.1 0.1;
1588 mass $N_B61_L [expr $mass1/2] 0.1 0.1;
1589 mass $N_B71_L [expr $mass1/2] 0.1 0.1;
1590 mass $N_B81_L [expr $mass1/2] 0.1 0.1;
1591 mass $N_B91_L [expr $mass1/2] 0.1 0.1;
1592
1593 mass $N_C12_L [expr $mass1/2] 0.1 0.1;
1594 mass $N_C22_L [expr $mass1/2] 0.1 0.1;
1595 mass $N_C32_L [expr $mass1/2] 0.1 0.1;
1596 mass $N_C42_L [expr $mass1/2] 0.1 0.1;
1597 mass $N_C52_L [expr $mass1/2] 0.1 0.1;
1598 mass $N_C62_L [expr $mass1/2] 0.1 0.1;
1599 mass $N_C72_L [expr $mass1/2] 0.1 0.1;
1600 mass $N_C82_L [expr $mass1/2] 0.1 0.1;
1601 mass $N_C92_L [expr $mass1/2] 0.1 0.1;
1602
1603 mass $N_D13_L [expr $mass1/2] 0.1 0.1;
1604 mass $N_D23_L [expr $mass1/2] 0.1 0.1;
1605 mass $N_D33_L [expr $mass1/2] 0.1 0.1;
1606 mass $N_D43_L [expr $mass1/2] 0.1 0.1;
1607 mass $N_D53_L [expr $mass1/2] 0.1 0.1;

```



```

1608     mass   $N_D63_L   [expr $mass1/2] 0.1 0.1;
1609     mass   $N_D73_L   [expr $mass1/2] 0.1 0.1;
1610     mass   $N_D83_L   [expr $mass1/2] 0.1 0.1;
1611     mass   $N_D93_L   [expr $mass1/2] 0.1 0.1;
1612
1613
1614
1615 puts "Model Built"
1616
1617
1618 3) Gravity Analysis Procedure:
1619
1620 The code generated is the same as Appendix 3
1621
1622 4) Modal Analysis Procedure:
1623
1624 The code generated is the same as Appendix 7
1625
1626 5) Pushover Analysis Procedure:
1627
1628 #####
1629
1630 # start analysis
1631
1632
1633 puts "ooo Analysis: Pushover ooo"
1634
1635 #####
1636
1637 # set recorders
1638
1639 # Global behaviour
1640
1641 # Node Recorder "Displacements": fileName <nodeTag> dof resptype
1642 recorder Node -file $dataDir/Pushover_Horizontal_Reactions.out -time -node $N_A0 $N_B0 $N_C0 $N_D0 -dof 1 rea
ction
1643 recorder Node -file $dataDir/Pushover_Storey_Displacement.out -time -node $N_A8 $N_A9 -dof 1 disp
1644 recorder Node -file $dataDir/DFree.out -time -node $N_A1 $N_A2 -dof 1 2 disp; # displacements of free nodes
1645 #recorder Element -file $dataDir/stressStrain.out -time -ele 5 6 section fiber y z $R_steel stressStrain
1646 recorder Element -file $dataDir/force10B.out -time -ele 810 820 830 840 850 860 870 880 890 localForce;
1647 recorder Element -file $dataDir/SP1.out -time -ele 611 612 613 614 615 616 617 618 619 621 622 623 624 625 626 627 628 629
shearpanel stressStrain
1648 recorder Element -file $dataDir/Strut1.out -time -ele 111 112 113 114 115 116 117 118 119 121 122 123 124 125 126 1
27 128 129 section 1 fiber y z stressStrain;
1649 recorder Element -file $dataDir/force10.out -time -ele 710 720 730 740 750 760 711 721 731 741 751 761 localForce
;
1650 # analysis options
1651
1652
1653 set tStart [clock clicks -milliseconds]
1654
1655
1656 # display deformed shape:
1657 set ViewScale 5;
1658 DisplayModel2D DeformedShape $ViewScale ; # display deformed shape, the scaling factor needs to be adjusted for each mode
1
1659
1660 # characteristics of pushover analysis
1661 set Dmax 1000; # maximum displacement of pushover. push to 10% drift.
1662 set Dincr 0.1; # displacement increment for pushover. you want this to be very small, but not too small to slow down the
analysis
1663 set Tol 10;
1664 # create load pattern for lateral pushover load
1665 pattern Plain 200 Linear {}; # define load pattern -- generalized
1666     load $N_A9 9 0 0
1667     load $N_A8 8 0 0
1668     load $N_A7 7 0 0
1669     load $N_A6 6 0 0
1670     load $N_A5 5 0 0
1671     load $N_A4 4 0 0
1672     load $N_A3 3 0 0
1673     load $N_A2 2 0 0
1674     load $N_A1 1 0 0
1675
1676
1677 }
1678
1679
1680 # ----- set up analysis parameters
1681

```

```

1682 # ## CONSTRAINTS handler >> Determines how the constraint equations are enforced in the analysis
1683
1684 # >> Plain Constraints -- Removes constrained degrees of freedom from the system of equations (only for homogeneous
    equations)
1685 # >> Lagrange Multipliers -- Uses the method of Lagrange multipliers to enforce constraints
1686 # >> Penalty Method -- Uses penalty numbers to enforce constraints --good for static analysis with non-homogeneous
    eqns (rigidDiaphragm)
1687 # >> Transformation Method -- Performs a condensation of constrained degrees of freedom
1688 variable constraintsTypeStatic Transformation; # default;
1689 constraints $constraintsTypeStatic
1690
1691 # DOF NUMBERER (number the degrees of freedom in the domain):
1692
1693 # Determines the mapping between equation numbers and degrees-of-freedom
1694 # Plain -- Uses the numbering provided by the user
1695 # RCM -- Renumbers the DOF to minimize the matrix band-width using the Reverse Cuthill-McKee algorithm
1696 set numbererTypeStatic RCM
1697 numberer $numbererTypeStatic
1698
1699
1700 # SYSTEM:
1701
1702 # Linear Equation Solvers (how to store and solve the system of equations in the analysis)
1703 # -- provide the solution of the linear system of equations  $Ku = P$ . Each solver is tailored to a specific matrix topology.
1704
1705 # ProfileSPD -- Direct profile solver for symmetric positive definite matrices
1706 # BandGeneral -- Direct solver for banded unsymmetric matrices
1707 # BandSPD -- Direct solver for banded symmetric positive definite matrices
1708 # SparseGeneral -- Direct solver for unsymmetric sparse matrices
1709 # SparseSPD -- Direct solver for symmetric sparse matrices
1710 # UmfPack -- Direct UmfPack solver for unsymmetric matrices
1711 set systemTypeStatic UmfPack; # try UmfPack for large model
1712 system $systemTypeStatic
1713
1714 # TEST: # convergence test to
1715 # -- Accept the current state of the domain as being on the converged solution path
1716 # -- determine if convergence has been achieved at the end of an iteration step
1717 # NormUnbalance -- Specifies a tolerance on the norm of the unbalanced load at the current iteration
1718 # NormDispIncr -- Specifies a tolerance on the norm of the displacement increments at the current iteration
1719 # EnergyIncr-- Specifies a tolerance on the inner product of the unbalanced load and displacement increments at the
    current iteration
1720 # RelativeNormUnbalance --
1721 # RelativeNormDispIncr --
1722 # RelativeEnergyIncr --
1723 variable TolStatic 10; # Convergence Test: tolerance
1724 variable maxNumIterStatic 10000; # Convergence Test: maximum number of iterations that will be performed befo
    re "failure to converge" is returned
1725 variable printFlagStatic 0; # Convergence Test: flag used to print information on convergence (optional)
    # 1: print information on each step;
1726 variable testTypeStatic EnergyIncr ; # Convergence-test type
1727 test $testTypeStatic $TolStatic $maxNumIterStatic $printFlagStatic;
1728
1729 # Solution ALGORITHM: -- Iterate from the last time step to the current
1730 # Linear -- Uses the solution at the first iteration and continues
1731 # Newton -- Uses the tangent at the current iteration to iterate to convergence
1732 # ModifiedNewton -- Uses the tangent at the first iteration to iterate to convergence
1733 # NewtonLineSearch --
1734 # KrylovNewton --
1735 # BFGS --
1736 # Broyden --
1737 variable algorithmTypeStatic Newton
1738 algorithm $algorithmTypeStatic;
1739
1740 # Static INTEGRATOR: -- determine the next time step for an analysis
1741
1742 # LoadControl -- Specifies the incremental load factor to be applied to the loads in the domain
1743 # DisplacementControl -- Specifies the incremental displacement at a specified DOF in the domain
1744 # Minimum Unbalanced Displacement Norm -- Specifies the incremental load factor such that the residual displacement
    norm is minimized
1745 # Arc Length -- Specifies the incremental arc-length of the load-displacement path
1746 # Transient INTEGRATOR: -- determine the next time step for an analysis including inertial effects
1747 # Newmark -- The two parameter time-stepping method developed by Newmark
1748 # HHT -- The three parameter Hilbert-Hughes-Taylor time-stepping method
1749 # Central Difference -- Approximates velocity and acceleration by centered finite differences of displacement
1750 integrator DisplacementControl $N_A9 1 $Dincr
1751
1752 # ANALYSIS -- defines what type of analysis is to be performed
1753
1754 # Static Analysis -- solves the  $KU=R$  problem, without the mass or damping matrices.

```

```

1755 # Transient Analysis -- solves the time-dependent analysis. The time step in this type of analysis is constant. The
1756 # time step in the output is also constant.
1757 # variableTransient Analysis -- performs the same analysis type as the Transient Analysis object. The time step, ho
1758 # wever, is variable. This method is used when
1759 # there are convergence problems with the Transient Analysis object at a peak or when the time step is too s
1760 # mall. The time step in the output is also variable.
1761 set analysisTypeStatic Static
1762 analysis $analysisTypeStatic
1763 # ----- perform Static Pushover Analysis
1764 set Nsteps [expr int($Dmax/$Dincr)]; # number of pushover analysis steps
1765 set ok [analyze $Nsteps]; # this will return zero if no convergence problems were encountered
1766 set fmt1 "%s Pushover analysis: CtrlNode %.24i, dof %.1i, Disp=%.4f %s"; # format for screen/file output of DONE/PROBLEM a
1767 nalysis
1768 if {$ok != 0} {
1769 # if analysis fails, we try some other stuff, performance is slower inside this loop
1770 set Dstep 0.0;
1771 set ok 0
1772 while {$Dstep <= 1.0 && $ok == 0} {
1773 set controlDisp [nodeDisp $N_A9 1 ]
1774 set Dstep [expr $controlDisp/$Dmax]
1775 set ok [analyze 1 ]
1776 # if analysis fails, we try some other stuff
1777 # performance is slower inside this loop global maxNumIterStatic; # max no. of iterations performed before "fai
1778 lure to converge" is ret'd
1779 if {$ok != 0} {
1780 puts "Trying Newton with Initial Tangent .."
1781 test NormDispIncr $Tol 3000 0
1782 algorithm Newton -initial
1783 set ok [analyze 1]
1784 test $testTypeStatic $TolStatic $maxNumIterStatic 0
1785 algorithm $algorithmTypeStatic
1786 }
1787 if {$ok != 0} {
1788 puts "Trying Broyden .."
1789 algorithm Broyden 8
1790 set ok [analyze 1 ]
1791 algorithm $algorithmTypeStatic
1792 }
1793 if {$ok != 0} {
1794 puts "Trying NewtonWithLineSearch .."
1795 algorithm NewtonLineSearch 0.8
1796 set ok [analyze 1]
1797 algorithm $algorithmTypeStatic
1798 }
1799 }; # end while loop
1800 }; # end if ok !0
1801 # -----
1802 if {$ok != 0} {
1803 puts [format $fmt1 "PROBLEM" $N_A9 1 [nodeDisp $N_A9 1] "mm"]
1804 } else {
1805 puts [format $fmt1 "DONE" $N_A9 1 [nodeDisp $N_A9 1] "mm"]
1806 }
1807 # Stop timing of this analysis sequence
1808 set tStop [clock clicks -milliseconds]
1809 puts "o Time taken: [expr ($tStop-$tStart)/1000.0] sec"
1810 puts "pushover analysis completed"
1811 # Reset for next analysis sequence
1812 wipe all;

```

**Appendix 10 – The Code Generated Using the OpenSees Program
to Perform Pushover Analysis for 3B9S MRFs- Masonry-
Concrete Infilled Frames without Ground Infills**

Appendix 10: 3B9S masonry infilled Frame without ground infills

```
1
2 1) Complementry files were defined to organize and make the procedure easier:
3
4     1. Library for Units
5
6     The code generated is the same as Appendix 3
7
8     2. Building RC Cross-Section (Fiber Approach)
9
10    The code generated is the same as Appendix 3
11
12    3. Display The Model in 2D
13
14    The code generated is the same as Appendix 3
15
16    4. Display Plane Deformed Shape for 2D Model
17
18    The code generated is the same as Appendix 3
19
20
21    5. Procedure for Defining Uniaxial Pinching Material
22
23    The code generated is the same as Appendix 3.
24
25
26 2) 2D Model Definition for 3B9S MRFs-Masonry-Concrete Infilled Frame without ground infills:
27
28    The code generated is the same as Appendix 9. However, infill walls at ground level shall be removed as the following:
29
30    -These elements must be removed:
31
32    1. Diagonal members
33
34    element elasticBeamColumn $dia1A $N_A1 $N_W1A_L $Aw $Ew $Izw $WtransfTag
35    element elasticBeamColumn $dia2A $N_B1 $N_W1A_L $Aw $Ew $Izw $WtransfTag
36    element elasticBeamColumn $dia3A $N_A0 $N_W1A_R $Aw $Ew $Izw $WtransfTag
37    element elasticBeamColumn $dia4A $N_B0 $N_W1A_R $Aw $Ew $Izw $WtransfTag
38
39    element elasticBeamColumn $dia1B $N_B1 $N_W1B_L $Aw $Ew $Izw $WtransfTag
40    element elasticBeamColumn $dia2B $N_C1 $N_W1B_L $Aw $Ew $Izw $WtransfTag
41    element elasticBeamColumn $dia3B $N_B0 $N_W1B_R $Aw $Ew $Izw $WtransfTag
42    element elasticBeamColumn $dia4B $N_C0 $N_W1B_R $Aw $Ew $Izw $WtransfTag
43
44    element elasticBeamColumn $dia1C $N_C1 $N_W1C_L $Aw $Ew $Izw $WtransfTag
45    element elasticBeamColumn $dia2C $N_D1 $N_W1C_L $Aw $Ew $Izw $WtransfTag
46    element elasticBeamColumn $dia3C $N_C0 $N_W1C_R $Aw $Ew $Izw $WtransfTag
47    element elasticBeamColumn $dia4C $N_D0 $N_W1C_R $Aw $Ew $Izw $WtransfTag
48
49    2. Central members
50
51    element forceBeamColumn $cen1A $N_W1A_L $N_W1A_R $wallTransfTag $integrationw
52    element forceBeamColumn $cen1B $N_W1B_L $N_W1B_R $wallTransfTag $integrationw
53    element forceBeamColumn $cen1C $N_W1C_L $N_W1C_R $wallTransfTag $integrationw
54
55
56 3) Gravity Analysis Procedure:
57
58    The code generated is the same as Appendix 3
59
60 4) Modal Analysis Procedure:
61
62    The code generated is the same as Appendix 7
63
64 5) Pushover Analysis Procedure:
65
66    #####
67
68    # start analysis
69
70
71    puts "ooo Analysis: Pushover ooo"
72
73    #####
74
75    # set recorders
76
77    # Global behaviour
78
```

```

79 # Node Recorder "Displacements": fileName <nodeTag> dof resptype
80 recorder Node -file $dataDir/Pushover_Horizontal_Reactions.out -time -node $N_A0 $N_B0 $N_C0 $N_D0 -dof 1 rea
tion
81 recorder Node -file $dataDir/Pushover_Storey_Displacement.out -time -node $N_A8 $N_A9 -dof 1 disp
82 recorder Node -file $dataDir/DFree.out -time -node $N_A1 $N_A2 -dof 1 2 disp; # displacements of free nodes
83 #recorder Element -file $dataDir/stressStrain.out -time -ele 5 6 section fiber y z $R_steel stressStrain
84 recorder Element -file $dataDir/force10B.out -time -ele 810 820 830 840 850 860 870 880 890 localForce;
85 recorder Element -file $dataDir/SP1.out -time -ele 611 612 613 614 615 616 617 618 619 621 622 623 624 625 626 627 628 629
shearpanel stressStrain
86 recorder Element -file $dataDir/Strut1.out -time -ele 112 113 114 115 116 117 118 119 122 123 124 125 126 127 128
129 section 1 fiber y z stressStrain;
87 recorder Element -file $dataDir/force10.out -time -ele 710 720 730 740 750 760 711 721 731 741 751 761 localForce
;
88 # analysis options
89
90
91 set tStart [clock clicks -milliseconds]
92
93
94 # display deformed shape:
95 set ViewScale 5;
96 DisplayModel2D DeformedShape $ViewScale ; # display deformed shape, the scaling factor needs to be adjusted for each model

97
98 # characteristics of pushover analysis
99 set Dmax 1000; # maximum displacement of pushover. push to 10% drift.
100 set Dincr 0.1; # displacement increment for pushover. you want this to be very small, but not too small to slow down the
analysis
101 set Tol 0.0001;
102 # create load pattern for lateral pushover load
103 pattern Plain 200 Linear {; # define load pattern -- generalized
104     load $N_A9 9 0 0
105     load $N_A8 8 0 0
106     load $N_A7 7 0 0
107     load $N_A6 6 0 0
108     load $N_A5 5 0 0
109     load $N_A4 4 0 0
110     load $N_A3 3 0 0
111     load $N_A2 2 0 0
112     load $N_A1 1 0 0
113
114 }
115
116
117 # ----- set up analysis parameters
118
119 # ## CONSTRAINTS handler >> Determines how the constraint equations are enforced in the analysis
120
121 # >> Plain Constraints -- Removes constrained degrees of freedom from the system of equations (only for homogeneous
equations)
122 # >> Lagrange Multipliers -- Uses the method of Lagrange multipliers to enforce constraints
123 # >> Penalty Method -- Uses penalty numbers to enforce constraints --good for static analysis with non-homogeneous
eqns (rigidDiaphragm)
124 # >> Transformation Method -- Performs a condensation of constrained degrees of freedom
125 variable constraintsTypeStatic Transformation; # default;
126 constraints $constraintsTypeStatic
127
128 # DOF NUMBERER (number the degrees of freedom in the domain):
129
130 # Determines the mapping between equation numbers and degrees-of-freedom
131 # Plain -- Uses the numbering provided by the user
132 # RCM -- Renumbers the DOF to minimize the matrix band-width using the Reverse Cuthill-McKee algorithm
133 set numbererTypeStatic RCM
134 numberer $numbererTypeStatic
135
136
137 # SYSTEM:
138
139 # Linear Equation Solvers (how to store and solve the system of equations in the analysis)
140 # -- provide the solution of the linear system of equations Ku = P. Each solver is tailored to a specific matrix topology.
141
142 # ProfileSPD -- Direct profile solver for symmetric positive definite matrices
143 # BandGeneral -- Direct solver for banded unsymmetric matrices
144 # BandSPD -- Direct solver for banded symmetric positive definite matrices
145 # SparseGeneral -- Direct solver for unsymmetric sparse matrices
146 # SparseSPD -- Direct solver for symmetric sparse matrices
147 # UmfPack -- Direct UmfPack solver for unsymmetric matrices
148 set systemTypeStatic UmfPack; # try UmfPack for large model
149 system $systemTypeStatic

```

```

150 # TEST: # convergence test to
151 #
152 #
153 # -- Accept the current state of the domain as being on the converged solution path
154 # -- determine if convergence has been achieved at the end of an iteration step
155 # NormUnbalance -- Specifies a tolerance on the norm of the unbalanced load at the current iteration
156 # NormDispIncr -- Specifies a tolerance on the norm of the displacement increments at the current iteration
157 # EnergyIncr-- Specifies a tolerance on the inner product of the unbalanced load and displacement increments at the
current iteration
158 # RelativeNormUnbalance --
159 # RelativeNormDispIncr --
160 # RelativeEnergyIncr --
161 variable TolStatic 20; # Convergence Test: tolerance
162 variable maxNumIterStatic 10000; # Convergence Test: maximum number of iterations that will be performed befo
re "failure to converge" is returned
163 variable printFlagStatic 0; # Convergence Test: flag used to print information on convergence (optional)
# 1: print information on each step;
164 variable testTypeStatic EnergyIncr ; # Convergence-test type
165 test $testTypeStatic $TolStatic $maxNumIterStatic $printFlagStatic;
166 #
167 # Solution ALGORITHM: -- Iterate from the last time step to the current
168 # Linear -- Uses the solution at the first iteration and continues
169 # Newton -- Uses the tangent at the current iteration to iterate to convergence
170 # ModifiedNewton -- Uses the tangent at the first iteration to iterate to convergence
171 # NewtonLineSearch --
172 # KrylovNewton --
173 # BFGS --
174 # Broyden --
175 variable algorithmTypeStatic Newton
176 algorithm $algorithmTypeStatic;
177 #
178 # Static INTEGRATOR: -- determine the next time step for an analysis
179 #
180 # LoadControl -- Specifies the incremental load factor to be applied to the loads in the domain
181 # DisplacementControl -- Specifies the incremental displacement at a specified DOF in the domain
182 # Minimum Unbalanced Displacement Norm -- Specifies the incremental load factor such that the residual displacement
norm in minimized
183 # Arc Length -- Specifies the incremental arc-length of the load-displacement path
184 # Transient INTEGRATOR: -- determine the next time step for an analysis including inertial effects
185 # Newmark -- The two parameter time-stepping method developed by Newmark
186 # HHT -- The three parameter Hilbert-Hughes-Taylor time-stepping method
187 # Central Difference -- Approximates velocity and acceleration by centered finite differences of displacement
188 integrator DisplacementControl $N_A9 1 $Dincr
189 #
190 # ANALYSIS -- defines what type of analysis is to be performed
191 #
192 # Static Analysis -- solves the KU=R problem, without the mass or damping matrices.
193 # Transient Analysis -- solves the time-dependent analysis. The time step in this type of analysis is constant. The
time step in the output is also constant.
194 # variableTransient Analysis -- performs the same analysis type as the Transient Analysis object. The time step, ho
wever, is variable. This method is used when
195 # there are convergence problems with the Transient Analysis object at a peak or when the time step is too s
mall. The time step in the output is also variable.
196 set analysisTypeStatic Static
197 analysis $analysisTypeStatic
198 #
199 #
200 # ----- perform Static Pushover Analysis
201 set Nsteps [expr int($Dmax/$Dincr)]; # number of pushover analysis steps
202 set ok [analyze $Nsteps]; # this will return zero if no convergence problems were encountered
203 set fmt1 "%s Pushover analysis: CtrlNode %.24i, dof %.1i, Disp=%.4f %s"; # format for screen/file output of DONE/PROBLEM an
alysis
204 if {$ok != 0} {
205 # if analysis fails, we try some other stuff, performance is slower inside this loop
206 set Dstep 0.0;
207 set ok 0
208 while {$Dstep <= 1.0 && $ok == 0} {
209 set controlDisp [nodeDisp $N_A9 1 ]
210 set Dstep [expr $controlDisp/$Dmax]
211 set ok [analyze 1 ]
212 # if analysis fails, we try some other stuff
213 # performance is slower inside this loop global maxNumIterStatic; # max no. of iterations performed before "failur
e to converge" is ret'd
214 if {$ok != 0} {
215 puts "Trying Newton with Initial Tangent .."
216 test NormDispIncr $Tol 3000 0
217 algorithm Newton -initial
218 set ok [analyze 1]
219 test $testTypeStatic $TolStatic $maxNumIterStatic 0
220 algorithm $algorithmTypeStatic

```

```

221     }
222     if {$ok != 0} {
223         puts "Trying Broyden .."
224         algorithm Broyden 8
225         set ok [analyze 1 ]
226         algorithm $algorithmTypeStatic
227     }
228     if {$ok != 0} {
229         puts "Trying NewtonWithLineSearch .."
230         algorithm NewtonLineSearch 0.8
231         set ok [analyze 1]
232         algorithm $algorithmTypeStatic
233     }
234
235 }; # end while loop
236 }; # end if ok !0
237
238 # -----
239 if {$ok != 0} {
240     puts [format $fmt1 "PROBLEM" $N_A9 1 [nodeDisp $N_A9 1] "mm"]
241 } else {
242     puts [format $fmt1 "DONE" $N_A9 1 [nodeDisp $N_A9 1] "mm"]
243 }
244
245
246 # Stop timing of this analysis sequence
247 set tStop [clock clicks -milliseconds]
248 puts "o Time taken: [expr ($tStop-$tStart)/1000.0] sec"
249
250 puts "pushover analysis completed"
251
252 # Reset for next analysis sequence
253 wipe all;

```


**Appendix 11 – The Code Generated Using the OpenSees Program
to Perform Pushover Analysis for 3B6S MRFs- Stone-Concrete
Infilled Frames**

Appendix 11: 3B6S stone infilled Frame

```
1
2 1) Complementary files were defined to organize and make the procedure easier:
3
4     1. Library for Units
5
6     The code generated is the same as Appendix 3
7
8     2. Building RC Cross-Section (Fiber Approach)
9
10    The code generated is the same as Appendix 3
11
12    3. Display The Model in 2D
13
14    The code generated is the same as Appendix 3
15
16    4. Display Plane Deformed Shape for 2D Model
17
18    The code generated is the same as Appendix 3
19
20
21    5. Procedure for Defining Uniaxial Pinching Material
22
23    The code generated is the same as Appendix 3.
24
25
26 2) 2D Model Definition for 3B6S MRFs-Stone-Concrete Infilled Frame:
27
28    The code generated is the same as Appendix 5. However, constitutive model of stone-concrete infilled frame and dimensions of
29    infill elements shall be used as the following
30
31    ##### material for infill walls #####
32
33    ## Positive/Negative envelope Stress
34
35    set A 1;
36    set p1 [expr 4.36*$A]; set p2 [expr 5.16*$A]; set p3 [expr 5.16*$A]; set p4 [expr 1.03*$A];
37
38    ## stress1 stress2 stress3 stress4
39    set pEnvStrsp [list [expr $p1] [expr $p2] [expr $p3] [expr $p4]]
40    set nEnvStrsp [list [expr -$p1] [expr -$p2] [expr -$p3] [expr -$p4]]
41
42    ## Positive/Negative envelope Strain
43    ## strain1 strain2 strain3 strain4
44
45    set pEnvStnsp [list 0.000258 0.0021 0.004158 0.013]
46    set nEnvStnsp [list -0.000258 -0.0021 -0.004158 -0.013]
47
48    ## Ratio of maximum deformation at which reloading begins
49    ## Pos_env. Neg_env.
50    set rDisp [list 0.2 0.2]
51
52    ## Ratio of envelope force (corresponding to maximum deformation) at which reloading begins
53    ### Pos_env. Neg_env.
54    set rForcesp [list 0.2 0.2]
55
56
57    ## Ratio of monotonic strength developed upon unloading
58    ### Pos_env. Neg_env.
59
60    set uForcesp [list 0.0 0.0]
61
62
63    ## Coefficients for Unloading Stiffness degradation
64
65    ## gammaK1 gammaK2 gammaK3 gammaK4 gammaKLimit
66
67    #set gammaKsp [list 1.13364492409642 0.0 0.10111033064469 0.0 0.91652498468618]
68
69    set gammaKsp [list 0.0 0.0 0.0 0.0 0.0]
70
71    ##### Coefficients for Reloading Stiffness degradation
72    ## gammaD1 gammaD2 gammaD3 gammaD4 gammaDLimit
73
74    #set gammaDsp [list 0.12 0.0 0.23 0.0 0.95]
75
76    set gammaDsp [list 0.0 0.0 0.0 0.0 0.0]
77
78    ##### Coefficients for Strength degradation
```

```

78 ### gammaF1 gammaF2 gammaF3 gammaF4 gammaFLimit
79
80 #set gammaFsp [list 1.11 0.0 0.319 0.0 0.125]
81 set gammaFsp [list 0.0 0.0 0.0 0.0 0.0]
82
83 set gammaEsp 10.0
84
85 uniaxialMaterial Pinching4 $wall_mat [lindex $pEnvStrsp 0] [lindex $pEnvStnsp 0] \
86 [lindex $pEnvStrsp 1] [lindex $pEnvStnsp 1] [lindex $pEnvStrsp 2] \
87 [lindex $pEnvStrsp 2] [lindex $pEnvStrsp 3] [lindex $pEnvStnsp 3] \
88 [lindex $nEnvStrsp 0] [lindex $nEnvStnsp 0] \
89 [lindex $nEnvStrsp 1] [lindex $nEnvStnsp 1] [lindex $nEnvStrsp 2] \
90 [lindex $nEnvStrsp 2] [lindex $nEnvStrsp 3] [lindex $nEnvStnsp 3] \
91 [lindex $rDispsp 0] [lindex $rForcesp 0] [lindex $uForcesp 0] \
92 [lindex $rDispsp 1] [lindex $rForcesp 1] [lindex $uForcesp 1] \
93 [lindex $gammaKsp 0] [lindex $gammaKsp 1] [lindex $gammaKsp 2] [lindex $gammaKsp 3] [lindex $gammaKsp 4] \
94 [lindex $gammaDsp 0] [lindex $gammaDsp 1] [lindex $gammaDsp 2] [lindex $gammaDsp 3] [lindex $gammaDsp 4] \
95 [lindex $gammaFsp 0] [lindex $gammaFsp 1] [lindex $gammaFsp 2] [lindex $gammaFsp 3] [lindex $gammaFsp 4] \
96 $gammaEsp energy
97
98 and the dimensions of each element should be replaced as the following:
99
100 set width_wall 615;      #using equation 16 in the report, the width of the strut based on H=3m,L=4m, and t=0.3m
101 set t_wall 300;
102
103 3) Gravity Analysis Procedure:
104
105 The code generated is the same as Appendix 3
106
107 4) Modal Analysis Procedure:
108
109 The code generated is the same as Appendix 3
110
111 5) Pushover Analysis Procedure:
112
113 #####
114
115 # start analysis
116
117
118 puts "ooo Analysis: Pushover ooo"
119
120 #####
121
122 # set recorders
123
124 # Global behaviour
125
126 # Node Recorder "Displacements": fileName <nodeTag> dof resptype
127 recorder Node -file $dataDir/Pushover_Horizontal_Reactions.out -time -node $N_A0 $N_B0 $N_C0 $N_D0 -dof 1 rea
tion
128 recorder Node -file $dataDir/Pushover_Storey_Displacement.out -time -node $N_A5 $N_A6 -dof 1 disp
129 recorder Node -file $dataDir/DFree.out -time -node $N_A1 $N_A2 -dof 1 2 disp; # displacements of free nodes
130 #recorder Element -file $dataDir/stressStrain.out -time -ele 5 6 section fiber y z $R_steel stressStrain
131 # analysis options
132
133
134 set tStart [clock clicks -milliseconds]
135
136
137 # display deformed shape:
138 set ViewScale 5;
139 DisplayModel2D DeformedShape $ViewScale ; # display deformed shape, the scaling factor needs to be adjusted for each mode
1
140
141 # characteristics of pushover analysis
142 set Dmax 1800; # maximum displacement of pushover. push to 10% drift.
143 set Dincr 0.01; # displacement increment for pushover. you want this to be very small, but not too small to slow down t
he analysis
144 set Tol 1;
145 # create load pattern for lateral pushover load
146 pattern Plain 200 Linear {}; # define load pattern -- generalized
147 load $N_A6 6 0 0
148 load $N_A5 5 0 0
149 load $N_A4 4 0 0
150 load $N_A3 3 0 0
151 load $N_A2 2 0 0
152 load $N_A1 1 0 0
153
154

```

```

155     }
156
157
158 # ----- set up analysis parameters
159
160 # ## CONSTRAINTS handler >> Determines how the constraint equations are enforced in the analysis
161
162 #     >> Plain Constraints -- Removes constrained degrees of freedom from the system of equations (only for homogeneous
163 #     equations)
164 #     >> Lagrange Multipliers -- Uses the method of Lagrange multipliers to enforce constraints
165 #     >> Penalty Method -- Uses penalty numbers to enforce constraints --good for static analysis with non-homogeneous
166 #     eqns (rigidDiaphragm)
167 #     >> Transformation Method -- Performs a condensation of constrained degrees of freedom
168 #     variable constraintsTypeStatic Transformation; # default;
169 #     constraints $constraintsTypeStatic
170
171 # DOF NUMBERER (number the degrees of freedom in the domain):
172
173 #     Determines the mapping between equation numbers and degrees-of-freedom
174 #     Plain -- Uses the numbering provided by the user
175 #     RCM -- Renumbers the DOF to minimize the matrix band-width using the Reverse Cuthill-McKee algorithm
176 #     set numbererTypeStatic RCM
177 #     numberer $numbererTypeStatic
178
179 # SYSTEM:
180
181 # Linear Equation Solvers (how to store and solve the system of equations in the analysis)
182 # -- provide the solution of the linear system of equations  $Ku = P$ . Each solver is tailored to a specific matrix topology.
183
184 # ProfileSPD -- Direct profile solver for symmetric positive definite matrices
185 # BandGeneral -- Direct solver for banded unsymmetric matrices
186 # BandSPD -- Direct solver for banded symmetric positive definite matrices
187 # SparseGeneral -- Direct solver for unsymmetric sparse matrices
188 # SparseSPD -- Direct solver for symmetric sparse matrices
189 # UmfPack -- Direct UmfPack solver for unsymmetric matrices
190 # set systemTypeStatic UmfPack; # try UmfPack for large model
191 # system $systemTypeStatic
192
193 # TEST: # convergence test to
194
195 # -- Accept the current state of the domain as being on the converged solution path
196 # -- determine if convergence has been achieved at the end of an iteration step
197 # NormUnbalance -- Specifies a tolerance on the norm of the unbalanced load at the current iteration
198 # NormDispIncr -- Specifies a tolerance on the norm of the displacement increments at the current iteration
199 # EnergyIncr-- Specifies a tolerance on the inner product of the unbalanced load and displacement increments at the
200 # current iteration
201 # RelativeNormUnbalance --
202 # RelativeNormDispIncr --
203 # RelativeEnergyIncr --
204 # variable TolStatic 0.01; # Convergence Test: tolerance
205 # variable maxNumIterStatic 10000; # Convergence Test: maximum number of iterations that will be performed befo
206 # re "failure to converge" is returned
207 # variable printFlagStatic 0; # Convergence Test: flag used to print information on convergence (optional)
208 # # 1: print information on each step;
209 # variable testTypeStatic EnergyIncr ; # Convergence-test type
210 # test $testTypeStatic $TolStatic $maxNumIterStatic $printFlagStatic;
211
212 # Solution ALGORITHM: -- Iterate from the last time step to the current
213 # Linear -- Uses the solution at the first iteration and continues
214 # Newton -- Uses the tangent at the current iteration to iterate to convergence
215 # ModifiedNewton -- Uses the tangent at the first iteration to iterate to convergence
216 # NewtonLineSearch --
217 # KrylovNewton --
218 # BFGS --
219 # Broyden --
220 # variable algorithmTypeStatic Newton
221 # algorithm $algorithmTypeStatic;
222
223 # Static INTEGRATOR: -- determine the next time step for an analysis
224
225 # LoadControl -- Specifies the incremental load factor to be applied to the loads in the domain
226 # DisplacementControl -- Specifies the incremental displacement at a specified DOF in the domain
227 # Minimum Unbalanced Displacement Norm -- Specifies the incremental load factor such that the residual displacement
228 # norm is minimized
229 # Arc Length -- Specifies the incremental arc-length of the load-displacement path
230 # Transient INTEGRATOR: -- determine the next time step for an analysis including inertial effects
231 # Newmark -- The two parameter time-stepping method developed by Newmark
232 # HHT -- The three parameter Hilbert-Hughes-Taylor time-stepping method
233 # Central Difference -- Approximates velocity and acceleration by centered finite differences of displacement

```

```

228 integrator DisplacementControl $N_A6 1 $Dincr
229
230 # ANALYSIS -- defines what type of analysis is to be performed
231
232 # Static Analysis -- solves the KU=R problem, without the mass or damping matrices.
233 # Transient Analysis -- solves the time-dependent analysis. The time step in this type of analysis is constant. The
time step in the output is also constant.
234 # variableTransient Analysis -- performs the same analysis type as the Transient Analysis object. The time step, ho
wever, is variable. This method is used when
235 # there are convergence problems with the Transient Analysis object at a peak or when the time step is too s
mall. The time step in the output is also variable.
236 set analysisTypeStatic Static
237 analysis $analysisTypeStatic
238
239
240 # ----- perform Static Pushover Analysis
241 set Nsteps [expr int($Dmax/$Dincr)]; # number of pushover analysis steps
242 set ok [analyze $Nsteps]; # this will return zero if no convergence problems were encountered
243 set fmt1 "%s Pushover analysis: CtrlNode %.24i, dof %.1i, Disp=%.4f %s"; # format for screen/file output of DONE/PROBLEM a
nalysis
244 if {$ok != 0} {
245 # if analysis fails, we try some other stuff, performance is slower inside this loop
246 set Dstep 0.0;
247 set ok 0
248 while {$Dstep <= 1.0 && $ok == 0} {
249 set controlDisp [nodeDisp $N_A6 1 ]
250 set Dstep [expr $controlDisp/$Dmax]
251 set ok [analyze 1 ]
252 # if analysis fails, we try some other stuff
253 # performance is slower inside this loop global maxNumIterStatic; # max no. of iterations performed before "fai
lure to converge" is ret'd
254 if {$ok != 0} {
255 puts "Trying Newton with Initial Tangent .."
256 test NormDispIncr $Tol 3000 0
257 algorithm Newton -initial
258 set ok [analyze 1]
259 test $testTypeStatic $TolStatic $maxNumIterStatic 0
260 algorithm $algorithmTypeStatic
261 }
262 if {$ok != 0} {
263 puts "Trying Broyden .."
264 algorithm Broyden 8
265 set ok [analyze 1 ]
266 algorithm $algorithmTypeStatic
267 }
268 if {$ok != 0} {
269 puts "Trying NewtonWithLineSearch .."
270 algorithm NewtonLineSearch 0.8
271 set ok [analyze 1]
272 algorithm $algorithmTypeStatic
273 }
274
275 }; # end while loop
276 }; # end if ok !0
277
278 # -----
279 if {$ok != 0} {
280 puts [format $fmt1 "PROBLEM" $N_A6 1 [nodeDisp $N_A6 1 ] "mm"]
281 } else {
282 puts [format $fmt1 "DONE" $N_A6 1 [nodeDisp $N_A6 1 ] "mm"]
283 }
284
285
286 # Stop timing of this analysis sequence
287 set tStop [clock clicks -milliseconds]
288 puts "o Time taken: [expr ($tStop-$tStart)/1000.0] sec"
289
290 puts "pushover analysis completed"
291
292 # Reset for next analysis sequence
293 wipe all;

```

**Appendix 12 – The Code Generated Using the OpenSees Program
to Perform Pushover Analysis for 3B6S MRFs- Stone-Concrete
Infilled Frames without Ground Infills**

Appendix 12: 3B6S stone infilled Frame without ground infills

```
1
2 1) Complementary files were defined to organize and make the procedure easier:
3
4     1. Library for Units
5
6     The code generated is the same as Appendix 3
7
8     2. Building RC Cross-Section (Fiber Approach)
9
10    The code generated is the same as Appendix 3
11
12    3. Display The Model in 2D
13
14    The code generated is the same as Appendix 3
15
16    4. Display Plane Deformed Shape for 2D Model
17
18    The code generated is the same as Appendix 3
19
20
21    5. Procedure for Defining Uniaxial Pinching Material
22
23    The code generated is the same as Appendix 3.
24
25
26 2) 2D Model Definition for 3B6S MRFs-Stone-Concrete Infilled Frame without ground infills:
27
28    The code generated is the same as Appendix 11. However, infill walls at ground level shall be removed as the following:
29
30    -These elements must be removed:
31
32    1. Diagonal members
33
34    element elasticBeamColumn $dia1A $N_A1 $N_W1A_L $Aw $Ew $Izw $WtransfTag
35    element elasticBeamColumn $dia2A $N_B1 $N_W1A_L $Aw $Ew $Izw $WtransfTag
36    element elasticBeamColumn $dia3A $N_A0 $N_W1A_R $Aw $Ew $Izw $WtransfTag
37    element elasticBeamColumn $dia4A $N_B0 $N_W1A_R $Aw $Ew $Izw $WtransfTag
38
39    element elasticBeamColumn $dia1B $N_B1 $N_W1B_L $Aw $Ew $Izw $WtransfTag
40    element elasticBeamColumn $dia2B $N_C1 $N_W1B_L $Aw $Ew $Izw $WtransfTag
41    element elasticBeamColumn $dia3B $N_B0 $N_W1B_R $Aw $Ew $Izw $WtransfTag
42    element elasticBeamColumn $dia4B $N_C0 $N_W1B_R $Aw $Ew $Izw $WtransfTag
43
44    element elasticBeamColumn $dia1C $N_C1 $N_W1C_L $Aw $Ew $Izw $WtransfTag
45    element elasticBeamColumn $dia2C $N_D1 $N_W1C_L $Aw $Ew $Izw $WtransfTag
46    element elasticBeamColumn $dia3C $N_C0 $N_W1C_R $Aw $Ew $Izw $WtransfTag
47    element elasticBeamColumn $dia4C $N_D0 $N_W1C_R $Aw $Ew $Izw $WtransfTag
48
49    2. Central members
50
51    element forceBeamColumn $cen1A $N_W1A_L $N_W1A_R $wallTransfTag $integrationw
52    element forceBeamColumn $cen1B $N_W1B_L $N_W1B_R $wallTransfTag $integrationw
53    element forceBeamColumn $cen1C $N_W1C_L $N_W1C_R $wallTransfTag $integrationw
54
55
56 3) Gravity Analysis Procedure:
57
58    The code generated is the same as Appendix 3
59
60 4) Modal Analysis Procedure:
61
62    The code generated is the same as Appendix 3
63
64 5) Pushover Analysis Procedure:
65
66    #####
67
68    # start analysis
69
70
71    puts "ooo Analysis: Pushover ooo"
72
73    #####
74
75    # set recorders
76
77    # Global behaviour
78
```

```

79 # Node Recorder "Displacements": fileName <nodeTag> dof resptype
80 #recorder Node -file $dataDir/Pushover_Horizontal_Reactions.out -time -node $N_A0 $N_B0 $N_C0 $N_D0 -dof 1 re
action
81 #recorder Node -file $dataDir/Pushover_Storey_Displacement.out -time -node $N_A5 $N_A6 -dof 1 disp
82 #recorder Node -file $dataDir/DFree.out -time -node $N_A1 $N_A2 -dof 1 2 disp; # displacements of free nodes
83 #recorder Element -file $dataDir/stressStrain.out -time -ele 5 6 section fiber y z $R_steel stressStrain
84 #recorder Element -file $dataDir/force10.out -time -ele 710 section 1 fiber y z $R_steel stressStrain;
85 #recorder Element -file $dataDir/force60B.out -time -ele 860 section 1 fiber y z $R_steel stressStrain;
86 recorder Element -file $dataDir/force10B.out -time -ele 810 820 830 840 850 860 localForce;
87 recorder Element -file $dataDir/SP1.out -time -ele 611 612 613 614 615 616 621 622 623 624 625 626 shearpanel stressStrain

88 recorder Element -file $dataDir/Strut1.out -time -ele 112 113 114 115 116 122 123 124 125 126 section 1 fiber y
z stressStrain;
89 recorder Element -file $dataDir/force10.out -time -ele 710 720 730 740 750 760 711 721 731 741 751 761 localForce
;
90 # analysis options
91
92
93 set tStart [clock clicks -milliseconds]
94
95
96 # display deformed shape:
97 set ViewScale 5;
98 DisplayModel2D DeformedShape $ViewScale ; # display deformed shape, the scaling factor needs to be adjusted for each model

99
100 # characteristics of pushover analysis
101 set Dmax 1800; # maximum displacement of pushover. push to 10% drift.
102 set Dincr 0.01; # displacement increment for pushover. you want this to be very small, but not too small to slow down the
analysis
103 set Tol 1;
104 # create load pattern for lateral pushover load
105 pattern Plain 200 Linear {; # define load pattern -- generalized
106 load $N_A6 6 0 0
107 load $N_A5 5 0 0
108 load $N_A4 4 0 0
109 load $N_A3 3 0 0
110 load $N_A2 2 0 0
111 load $N_A1 1 0 0
112
113 }
114
115
116 # ----- set up analysis parameters
117
118 # ## CONSTRAINTS handler >> Determines how the constraint equations are enforced in the analysis
119
120 # >> Plain Constraints -- Removes constrained degrees of freedom from the system of equations (only for homogeneous
equations)
121 # >> Lagrange Multipliers -- Uses the method of Lagrange multipliers to enforce constraints
122 # >> Penalty Method -- Uses penalty numbers to enforce constraints --good for static analysis with non-homogeneous
eqns (rigidDiaphragm)
123 # >> Transformation Method -- Performs a condensation of constrained degrees of freedom
124 #
125 variable constraintsTypeStatic Transformation; # default;
126 constraints $constraintsTypeStatic
127
128 # DOF NUMBERER (number the degrees of freedom in the domain):
129
130 # Determines the mapping between equation numbers and degrees-of-freedom
131 # Plain -- Uses the numbering provided by the user
132 # RCM -- Renumbers the DOF to minimize the matrix band-width using the Reverse Cuthill-McKee algorithm
133 set numbererTypeStatic RCM
134 numberer $numbererTypeStatic
135
136
137 # SYSTEM:
138
139 # Linear Equation Solvers (how to store and solve the system of equations in the analysis)
140 # -- provide the solution of the linear system of equations Ku = P. Each solver is tailored to a specific matrix topology.

141 # ProfileSPD -- Direct profile solver for symmetric positive definite matrices
142 # BandGeneral -- Direct solver for banded unsymmetric matrices
143 # BandSPD -- Direct solver for banded symmetric positive definite matrices
144 # SparseGeneral -- Direct solver for unsymmetric sparse matrices
145 # SparseSPD -- Direct solver for symmetric sparse matrices
146 # UmfPack -- Direct UmfPack solver for unsymmetric matrices
147 set systemTypeStatic UmfPack; # try UmfPack for large model
148 system $systemTypeStatic
149

```



```

150 # TEST: # convergence test to
151
152 # -- Accept the current state of the domain as being on the converged solution path
153 # -- determine if convergence has been achieved at the end of an iteration step
154 # NormUnbalance -- Specifies a tolerance on the norm of the unbalanced load at the current iteration
155 # NormDispIncr -- Specifies a tolerance on the norm of the displacement increments at the current iteration
156 # EnergyIncr-- Specifies a tolerance on the inner product of the unbalanced load and displacement increments at the
    current iteration
157 # RelativeNormUnbalance --
158 # RelativeNormDispIncr --
159 # RelativeEnergyIncr --
160 variable TolStatic 1; # Convergence Test: tolerance
161 variable maxNumIterStatic 10000; # Convergence Test: maximum number of iterations that will be performed befo
re "failure to converge" is returned
162 variable printFlagStatic 0; # Convergence Test: flag used to print information on convergence (optional)
    # 1: print information on each step;
163 variable testTypeStatic EnergyIncr ; # Convergence-test type
164 test $testTypeStatic $TolStatic $maxNumIterStatic $printFlagStatic;
165
166 # Solution ALGORITHM: -- Iterate from the last time step to the current
167 # Linear -- Uses the solution at the first iteration and continues
168 # Newton -- Uses the tangent at the current iteration to iterate to convergence
169 # ModifiedNewton -- Uses the tangent at the first iteration to iterate to convergence
170 # NewtonLineSearch --
171 # KrylovNewton --
172 # BFGS --
173 # Broyden --
174 variable algorithmTypeStatic Newton
175 algorithm $algorithmTypeStatic;
176
177 # Static INTEGRATOR: -- determine the next time step for an analysis
178
179 # LoadControl -- Specifies the incremental load factor to be applied to the loads in the domain
180 # DisplacementControl -- Specifies the incremental displacement at a specified DOF in the domain
181 # Minimum Unbalanced Displacement Norm -- Specifies the incremental load factor such that the residual displacement
    norm in minimized
182 # Arc Length -- Specifies the incremental arc-length of the load-displacement path
183 # Transient INTEGRATOR: -- determine the next time step for an analysis including inertial effects
184 # Newmark -- The two parameter time-stepping method developed by Newmark
185 # HHT -- The three parameter Hilbert-Hughes-Taylor time-stepping method
186 # Central Difference -- Approximates velocity and acceleration by centered finite differences of displacement
187 integrator DisplacementControl $N_A6 1 $Dincr
188
189 # ANALYSIS -- defines what type of analysis is to be performed
190
191 # Static Analysis -- solves the KU=R problem, without the mass or damping matrices.
192 # Transient Analysis -- solves the time-dependent analysis. The time step in this type of analysis is constant. The
    time step in the output is also constant.
193 # variableTransient Analysis -- performs the same analysis type as the Transient Analysis object. The time step, ho
wever, is variable. This method is used when
194 # there are convergence problems with the Transient Analysis object at a peak or when the time step is too s
mall. The time step in the output is also variable.
195 set analysisTypeStatic Static
196 analysis $analysisTypeStatic
197
198
199 # ----- perform Static Pushover Analysis
200 set Nsteps [expr int($Dmax/$Dincr)]; # number of pushover analysis steps
201 set ok [analyze $Nsteps]; # this will return zero if no convergence problems were encountered
202 set fmt1 "%s Pushover analysis: CtrlNode %.24i, dof %.1i, Disp=%.4f %s"; # format for screen/file output of DONE/PROBLEM an
alysis
203 if {$ok != 0} {
204 # if analysis fails, we try some other stuff, performance is slower inside this loop
205 set Dstep 0.0;
206 set ok 0
207 while {$Dstep <= 1.0 && $ok == 0} {
208 set controlDisp [nodeDisp $N_A6 1 ]
209 set Dstep [expr $controlDisp/$Dmax]
210 set ok [analyze 1 ]
211 # if analysis fails, we try some other stuff
212 # performance is slower inside this loop global maxNumIterStatic; # max no. of iterations performed before "failur
e to converge" is ret'd
213 if {$ok != 0} {
214 puts "Trying Newton with Initial Tangent .."
215 test NormDispIncr $Tol 3000 0
216 algorithm Newton -initial
217 set ok [analyze 1]
218 test $testTypeStatic $TolStatic $maxNumIterStatic 0
219 algorithm $algorithmTypeStatic
220 }

```

```

221     if {$ok != 0} {
222         puts "Trying Broyden .."
223         algorithm Broyden 8
224         set ok [analyze 1 ]
225         algorithm $algorithmTypeStatic
226     }
227     if {$ok != 0} {
228         puts "Trying NewtonWithLineSearch .."
229         algorithm NewtonLineSearch 0.8
230         set ok [analyze 1]
231         algorithm $algorithmTypeStatic
232     }
233
234 }; # end while loop
235 }; # end if ok !0
236
237 # -----
238 if {$ok != 0} {
239     puts [format $fmt1 "PROBLEM" $N_A6 1 [nodeDisp $N_A6 1] "mm"]
240 } else {
241     puts [format $fmt1 "DONE" $N_A6 1 [nodeDisp $N_A6 1] "mm"]
242 }
243
244
245 # Stop timing of this analysis sequence
246 set tStop [clock clicks -milliseconds]
247 puts "o Time taken: [expr ($tStop-$tStart)/1000.0] sec"
248
249 puts "pushover analysis completed"
250
251 # Reset for next analysis sequence
252 wipe all;

```

**Appendix 13 – The Code Generated Using the OpenSees Program
to Perform Pushover Analysis for 3B9S MRFs- Stone-Concrete
Infilled Frames**

Appendix 13: 3B9S Stone infilled Frame

```
1
2 1) Complementary files were defined to organize and make the procedure easier:
3
4     1. Library for Units
5
6     The code generated is the same as Appendix 3
7
8     2. Building RC Cross-Section (Fiber Approach)
9
10    The code generated is the same as Appendix 3
11
12    3. Display The Model in 2D
13
14    The code generated is the same as Appendix 3
15
16    4. Display Plane Deformed Shape for 2D Model
17
18    The code generated is the same as Appendix 3
19
20
21    5. Procedure for Defining Uniaxial Pinching Material
22
23    The code generated is the same as Appendix 3.
24
25
26 2) 2D Model Definition for 3B9S MRFs-Stone-Concrete Infilled Frame:
27
28    The code generated is the same as Appendix 9. However, constitutive model of stone-concrete infilled frame and dimensions of
29    infill elements shall be used as the following
30
31    ##### material for infill walls #####
32
33    ## Positive/Negative envelope Stress
34
35    set A 1;
36    set p1 [expr 4.36*$A]; set p2 [expr 5.16*$A]; set p3 [expr 5.16*$A]; set p4 [expr 1.03*$A];
37
38    ## stress1 stress2 stress3 stress4
39    set pEnvStrsp [list [expr $p1] [expr $p2] [expr $p3] [expr $p4]]
40    set nEnvStrsp [list [expr -$p1] [expr -$p2] [expr -$p3] [expr -$p4]]
41
42    ## Positive/Negative envelope Strain
43    ## strain1 strain2 strain3 strain4
44
45    set pEnvStnsp [list 0.000258 0.0021 0.004158 0.013]
46    set nEnvStnsp [list -0.000258 -0.0021 -0.004158 -0.013]
47
48    ## Ratio of maximum deformation at which reloading begins
49    ## Pos_env. Neg_env.
50    set rDisp [list 0.2 0.2]
51
52    ## Ratio of envelope force (corresponding to maximum deformation) at which reloading begins
53    ### Pos_env. Neg_env.
54    set rForcesp [list 0.2 0.2]
55
56
57    ## Ratio of monotonic strength developed upon unloading
58    ### Pos_env. Neg_env.
59
60    set uForcesp [list 0.0 0.0]
61
62
63    ## Coefficients for Unloading Stiffness degradation
64
65    ## gammaK1 gammaK2 gammaK3 gammaK4 gammaKLimit
66
67    #set gammaKsp [list 1.13364492409642 0.0 0.10111033064469 0.0 0.91652498468618]
68
69    set gammaKsp [list 0.0 0.0 0.0 0.0 0.0]
70
71    ##### Coefficients for Reloading Stiffness degradation
72    ## gammaD1 gammaD2 gammaD3 gammaD4 gammaDLimit
73
74    #set gammaDsp [list 0.12 0.0 0.23 0.0 0.95]
75
76    set gammaDsp [list 0.0 0.0 0.0 0.0 0.0]
77
78    ##### Coefficients for Strength degradation
```

```

78  ### gammaF1 gammaF2 gammaF3 gammaF4 gammaFLimit
79
80  #set gammaFsp [list 1.11 0.0 0.319 0.0 0.125]
81  set gammaFsp [list 0.0 0.0 0.0 0.0 0.0]
82
83  set gammaEsp 10.0
84
85  uniaxialMaterial Pinching4 $wall_mat [lindex $pEnvStrsp 0] [lindex $pEnvStnsp 0] \
86  [lindex $pEnvStrsp 1] [lindex $pEnvStnsp 1] [lindex $pEnvStrsp 2] \
87  [lindex $pEnvStrsp 2] [lindex $pEnvStrsp 3] [lindex $pEnvStnsp 3] \
88  [lindex $nEnvStrsp 0] [lindex $nEnvStnsp 0] \
89  [lindex $nEnvStrsp 1] [lindex $nEnvStnsp 1] [lindex $nEnvStrsp 2] \
90  [lindex $nEnvStrsp 2] [lindex $nEnvStrsp 3] [lindex $nEnvStnsp 3] \
91  [lindex $rDispsp 0] [lindex $rForcesp 0] [lindex $uForcesp 0] \
92  [lindex $rDispsp 1] [lindex $rForcesp 1] [lindex $uForcesp 1] \
93  [lindex $gammaKsp 0] [lindex $gammaKsp 1] [lindex $gammaKsp 2] [lindex $gammaKsp 3] [lindex $gammaKsp 4] \
94  [lindex $gammaDsp 0] [lindex $gammaDsp 1] [lindex $gammaDsp 2] [lindex $gammaDsp 3] [lindex $gammaDsp 4] \
95  [lindex $gammaFsp 0] [lindex $gammaFsp 1] [lindex $gammaFsp 2] [lindex $gammaFsp 3] [lindex $gammaFsp 4] \
96  $gammaEsp energy
97
98  and the dimensions of each element should be replaced as the following:
99
100  set width_wall 615;      #using equation 16 in the report, the width of the strut based on H=3m,L=4m, and t=0.3m
101  set t_wall 300;
102
103  3) Gravity Analysis Procedure:
104
105  The code generated is the same as Appendix 3
106
107  4) Modal Analysis Procedure:
108
109  The code generated is the same as Appendix 7
110
111  5) Pushover Analysis Procedure:
112
113  #####
114
115  # start analysis
116
117
118  puts "ooo Analysis: Pushover ooo"
119
120  #####
121
122  # set recorders
123
124  # Global behaviour
125
126  # Node Recorder "Displacements": fileName          <nodeTag>          dof  resptype
127  #recorder Node -file $dataDir/Pushover_Horizontal_Reactions.out -time -node $N_A0 $N_B0 $N_C0 $N_D0 -dof 1 re
  action
128  #recorder Node -file $dataDir/Pushover_Storey_Displacement.out -time -node $N_A8 $N_A9 -dof 1 disp
129  #recorder Node -file $dataDir/DFree.out -time -node $N_A1 $N_A2 -dof 1 2 disp; # displacements of free nodes
130  #recorder Element -file $dataDir/stressStrain.out -time -ele 5 6 section fiber y z $R_steel stressStrain
131  recorder Element -file $dataDir/force10B.out -time -ele 810 820 830 840 850 860 870 880 890 localForce;
132  recorder Element -file $dataDir/SP1.out -time -ele 611 612 613 614 615 616 617 618 619 621 622 623 624 625 626 627 628 629
  shearpanel stressStrain
133  recorder Element -file $dataDir/Strut1.out -time -ele 111 112 113 114 115 116 117 118 119 121 122 123 124 125 126 1
  27 128 129 section 1 fiber y z stressStrain;
134  recorder Element -file $dataDir/force10.out -time -ele 710 720 730 740 750 760 711 721 731 741 751 761 localForce
  ;
135  # analysis options
136
137
138  set tStart [clock clicks -milliseconds]
139
140
141  # display deformed shape:
142  set ViewScale 5;
143  DisplayModel2D DeformedShape $ViewScale ; # display deformed shape, the scaling factor needs to be adjusted for each mode
  1
144
145  # characteristics of pushover analysis
146  set Dmax 1000; # maximum displacement of pushover. push to 10% drift.
147  set Dincr 0.1; # displacement increment for pushover. you want this to be very small, but not too small to slow down the
  analysis
148  set Tol 0.01;
149  # create load pattern for lateral pushover load
150  pattern Plain 200 Linear {}; # define load pattern -- generalized
151  load $N_A9 9 0 0

```

```

152         load $N_A8 8 0 0
153         load $N_A7 7 0 0
154         load $N_A6 6 0 0
155         load $N_A5 5 0 0
156         load $N_A4 4 0 0
157         load $N_A3 3 0 0
158         load $N_A2 2 0 0
159         load $N_A1 1 0 0
160
161
162     }
163
164
165 # ----- set up analysis parameters
166
167 # ## CONSTRAINTS handler >> Determines how the constraint equations are enforced in the analysis
168
169 #     >> Plain Constraints -- Removes constrained degrees of freedom from the system of equations (only for homogeneous
170 #     >> Lagrange Multipliers -- Uses the method of Lagrange multipliers to enforce constraints
171 #     >> Penalty Method -- Uses penalty numbers to enforce constraints --good for static analysis with non-homogeneous
172 #     >> Transformation Method -- Performs a condensation of constrained degrees of freedom
173 #     >> Transformation Method -- Performs a condensation of constrained degrees of freedom
174 #     >> Transformation Method -- Performs a condensation of constrained degrees of freedom
175 #     >> Transformation Method -- Performs a condensation of constrained degrees of freedom
176 #     >> Transformation Method -- Performs a condensation of constrained degrees of freedom
177
178 #     Determines the mapping between equation numbers and degrees-of-freedom
179 #     Plain -- Uses the numbering provided by the user
180 #     RCM -- Renumbers the DOF to minimize the matrix band-width using the Reverse Cuthill-McKee algorithm
181 #     RCM -- Renumbers the DOF to minimize the matrix band-width using the Reverse Cuthill-McKee algorithm
182 #     RCM -- Renumbers the DOF to minimize the matrix band-width using the Reverse Cuthill-McKee algorithm
183 #     RCM -- Renumbers the DOF to minimize the matrix band-width using the Reverse Cuthill-McKee algorithm
184
185 # SYSTEM:
186
187 # Linear Equation Solvers (how to store and solve the system of equations in the analysis)
188 # -- provide the solution of the linear system of equations  $Ku = P$ . Each solver is tailored to a specific matrix topology.
189
190 # ProfileSPD -- Direct profile solver for symmetric positive definite matrices
191 # BandGeneral -- Direct solver for banded unsymmetric matrices
192 # BandSPD -- Direct solver for banded symmetric positive definite matrices
193 # SparseGeneral -- Direct solver for unsymmetric sparse matrices
194 # SparseSPD -- Direct solver for symmetric sparse matrices
195 # UmfPack -- Direct UmfPack solver for unsymmetric matrices
196 # UmfPack -- Direct UmfPack solver for unsymmetric matrices
197 # UmfPack -- Direct UmfPack solver for unsymmetric matrices
198 # UmfPack -- Direct UmfPack solver for unsymmetric matrices
199
200 # set systemTypeStatic UmfPack; # try UmfPack for large model
201 # set systemTypeStatic UmfPack; # try UmfPack for large model
202 # set systemTypeStatic UmfPack; # try UmfPack for large model
203 # set systemTypeStatic UmfPack; # try UmfPack for large model
204 # set systemTypeStatic UmfPack; # try UmfPack for large model
205 # set systemTypeStatic UmfPack; # try UmfPack for large model
206 # set systemTypeStatic UmfPack; # try UmfPack for large model
207 # set systemTypeStatic UmfPack; # try UmfPack for large model
208 # set systemTypeStatic UmfPack; # try UmfPack for large model
209 # set systemTypeStatic UmfPack; # try UmfPack for large model
210 # set systemTypeStatic UmfPack; # try UmfPack for large model
211 # set systemTypeStatic UmfPack; # try UmfPack for large model
212 # set systemTypeStatic UmfPack; # try UmfPack for large model
213 # set systemTypeStatic UmfPack; # try UmfPack for large model
214 # set systemTypeStatic UmfPack; # try UmfPack for large model
215 # set systemTypeStatic UmfPack; # try UmfPack for large model
216 # set systemTypeStatic UmfPack; # try UmfPack for large model
217 # set systemTypeStatic UmfPack; # try UmfPack for large model
218 # set systemTypeStatic UmfPack; # try UmfPack for large model
219 # set systemTypeStatic UmfPack; # try UmfPack for large model
220 # set systemTypeStatic UmfPack; # try UmfPack for large model
221 # set systemTypeStatic UmfPack; # try UmfPack for large model
222 # set systemTypeStatic UmfPack; # try UmfPack for large model
223 # set systemTypeStatic UmfPack; # try UmfPack for large model
224 # set systemTypeStatic UmfPack; # try UmfPack for large model
225 # set systemTypeStatic UmfPack; # try UmfPack for large model

```

```

226
227 # LoadControl -- Specifies the incremental load factor to be applied to the loads in the domain
228 # DisplacementControl -- Specifies the incremental displacement at a specified DOF in the domain
229 # Minimum Unbalanced Displacement Norm -- Specifies the incremental load factor such that the residual displacement
norm in minimized
230 # Arc Length -- Specifies the incremental arc-length of the load-displacement path
231 # Transient INTEGRATOR: -- determine the next time step for an analysis including inertial effects
232 # Newmark -- The two parameter time-stepping method developed by Newmark
233 # HHT -- The three parameter Hilbert-Hughes-Taylor time-stepping method
234 # Central Difference -- Approximates velocity and acceleration by centered finite differences of displacement
235 integrator DisplacementControl $N_A9 1 $Dincr
236
237 # ANALYSIS -- defines what type of analysis is to be performed
238
239 # Static Analysis -- solves the KU=R problem, without the mass or damping matrices.
240 # Transient Analysis -- solves the time-dependent analysis. The time step in this type of analysis is constant. The
time step in the output is also constant.
241 # variableTransient Analysis -- performs the same analysis type as the Transient Analysis object. The time step, ho
wever, is variable. This method is used when
242 # there are convergence problems with the Transient Analysis object at a peak or when the time step is too s
mall. The time step in the output is also variable.
243 set analysisTypeStatic Static
244 analysis $analysisTypeStatic
245
246
247 # ----- perform Static Pushover Analysis
248 set Nsteps [expr int($Dmax/$Dincr)]; # number of pushover analysis steps
249 set ok [analyze $Nsteps]; # this will return zero if no convergence problems were encountered
250 set fmt1 "%s Pushover analysis: CtrlNode %.24i, dof %.1i, Disp=%.4f %s"; # format for screen/file output of DONE/PROBLEM a
nalysis
251 if {$ok != 0} {
252 # if analysis fails, we try some other stuff, performance is slower inside this loop
253 set Dstep 0.0;
254 set ok 0
255 while {$Dstep <= 1.0 && $ok == 0} {
256 set controlDisp [nodeDisp $N_A9 1 ]
257 set Dstep [expr $controlDisp/$Dmax]
258 set ok [analyze 1 ]
259 # if analysis fails, we try some other stuff
260 # performance is slower inside this loop global maxNumIterStatic; # max no. of iterations performed before "fai
lure to converge" is ret'd
261 if {$ok != 0} {
262 puts "Trying Newton with Initial Tangent .."
263 test NormDispIncr $Tol 3000 0
264 algorithm Newton -initial
265 set ok [analyze 1]
266 test $testTypeStatic $TolStatic $maxNumIterStatic 0
267 algorithm $algorithmTypeStatic
268 }
269 if {$ok != 0} {
270 puts "Trying Broyden .."
271 algorithm Broyden 8
272 set ok [analyze 1 ]
273 algorithm $algorithmTypeStatic
274 }
275 if {$ok != 0} {
276 puts "Trying NewtonWithLineSearch .."
277 algorithm NewtonLineSearch 0.8
278 set ok [analyze 1]
279 algorithm $algorithmTypeStatic
280 }
281 }
282 }; # end while loop
283 }; # end if ok !0
284
285 # -----
286 if {$ok != 0} {
287 puts [format $fmt1 "PROBLEM" $N_A9 1 [nodeDisp $N_A9 1] "mm"]
288 } else {
289 puts [format $fmt1 "DONE" $N_A9 1 [nodeDisp $N_A9 1] "mm"]
290 }
291
292
293 # Stop timing of this analysis sequence
294 set tStop [clock clicks -milliseconds]
295 puts "o Time taken: [expr ($tStop-$tStart)/1000.0] sec"
296
297 puts "pushover analysis completed"
298
299 # Reset for next analysis sequence

```

300 wipe all;

**Appendix 14 – The Code Generated Using the OpenSees Program
to Perform Pushover Analysis for 3B9S MRFs- Stone-Concrete
Infilled Frames without Ground Infills**

Appendix 14: 3B9S stone infilled Frame without ground infills

```
1
2 1) Complementary files were defined to organize and make the procedure easier:
3
4   1. Library for Units
5
6   The code generated is the same as Appendix 3
7
8   2. Building RC Cross-Section (Fiber Approach)
9
10  The code generated is the same as Appendix 3
11
12  3. Display The Model in 2D
13
14  The code generated is the same as Appendix 3
15
16  4. Display Plane Deformed Shape for 2D Model
17
18  The code generated is the same as Appendix 3
19
20
21  5. Procedure for Defining Uniaxial Pinching Material
22
23  The code generated is the same as Appendix 3.
24
25
26 2) 2D Model Definition for 3B9S MRFs-Stone-Concrete Infilled Frame without ground infills:
27
28  The code generated is the same as Appendix 13. However, infill walls at ground level shall be removed as the following:
29
30 -These elements must be removed:
31
32   1. Diagonal members
33
34  element elasticBeamColumn $dia1A $N_A1 $N_W1A_L $Aw $Ew $Izw $WtransfTag
35  element elasticBeamColumn $dia2A $N_B1 $N_W1A_L $Aw $Ew $Izw $WtransfTag
36  element elasticBeamColumn $dia3A $N_A0 $N_W1A_R $Aw $Ew $Izw $WtransfTag
37  element elasticBeamColumn $dia4A $N_B0 $N_W1A_R $Aw $Ew $Izw $WtransfTag
38
39  element elasticBeamColumn $dia1B $N_B1 $N_W1B_L $Aw $Ew $Izw $WtransfTag
40  element elasticBeamColumn $dia2B $N_C1 $N_W1B_L $Aw $Ew $Izw $WtransfTag
41  element elasticBeamColumn $dia3B $N_B0 $N_W1B_R $Aw $Ew $Izw $WtransfTag
42  element elasticBeamColumn $dia4B $N_C0 $N_W1B_R $Aw $Ew $Izw $WtransfTag
43
44  element elasticBeamColumn $dia1C $N_C1 $N_W1C_L $Aw $Ew $Izw $WtransfTag
45  element elasticBeamColumn $dia2C $N_D1 $N_W1C_L $Aw $Ew $Izw $WtransfTag
46  element elasticBeamColumn $dia3C $N_C0 $N_W1C_R $Aw $Ew $Izw $WtransfTag
47  element elasticBeamColumn $dia4C $N_D0 $N_W1C_R $Aw $Ew $Izw $WtransfTag
48
49   2. Central members
50
51  element forceBeamColumn $cen1A $N_W1A_L $N_W1A_R $wallTransfTag $integrationw
52  element forceBeamColumn $cen1B $N_W1B_L $N_W1B_R $wallTransfTag $integrationw
53  element forceBeamColumn $cen1C $N_W1C_L $N_W1C_R $wallTransfTag $integrationw
54
55
56 3) Gravity Analysis Procedure:
57
58  The code generated is the same as Appendix 3
59
60 4) Modal Analysis Procedure:
61
62  The code generated is the same as Appendix 7
63
64 5) Pushover Analysis Procedure:
65
66  #####
67
68  # start analysis
69
70
71  puts "ooo Analysis: Pushover ooo"
72
73  #####
74
75  # set recorders
76
77  # Global behaviour
78
```

```

79 # Node Recorder "Displacements": fileName <nodeTag> dof resptype
80 recorder Node -file $dataDir/Pushover_Horizontal_Reactions.out -time -node $N_A0 $N_B0 $N_C0 $N_D0 -dof 1 rea
tion
81 recorder Node -file $dataDir/Pushover_Storey_Displacement.out -time -node $N_A8 $N_A9 -dof 1 disp
82 recorder Node -file $dataDir/DFree.out -time -node $N_A1 $N_A2 -dof 1 2 disp; # displacements of free nodes
83 #recorder Element -file $dataDir/stressStrain.out -time -ele 5 6 section fiber y z $R_steel stressStrain
84 recorder Element -file $dataDir/force10B.out -time -ele 810 820 830 840 850 860 870 880 890 localForce;
85 recorder Element -file $dataDir/SP1.out -time -ele 611 612 613 614 615 616 617 618 619 621 622 623 624 625 626 627 628 629
shearpanel stressStrain
86 recorder Element -file $dataDir/Strut1.out -time -ele 112 113 114 115 116 117 118 119 122 123 124 125 126 127 128
129 section 1 fiber y z stressStrain;
87 recorder Element -file $dataDir/force10.out -time -ele 710 720 730 740 750 760 711 721 731 741 751 761 localForce
;
88 # analysis options
89
90
91 set tStart [clock clicks -milliseconds]
92
93
94 # display deformed shape:
95 set ViewScale 5;
96 DisplayModel2D DeformedShape $ViewScale ; # display deformed shape, the scaling factor needs to be adjusted for each model

97
98 # characteristics of pushover analysis
99 set Dmax 1000; # maximum displacement of pushover. push to 10% drift.
100 set Dincr 0.1; # displacement increment for pushover. you want this to be very small, but not too small to slow down the
analysis
101 set Tol 1;
102 # create load pattern for lateral pushover load
103 pattern Plain 200 Linear {; # define load pattern -- generalized
104     load $N_A9 9 0 0
105     load $N_A8 8 0 0
106     load $N_A7 7 0 0
107     load $N_A6 6 0 0
108     load $N_A5 5 0 0
109     load $N_A4 4 0 0
110     load $N_A3 3 0 0
111     load $N_A2 2 0 0
112     load $N_A1 1 0 0
113
114 }
115
116
117 # ----- set up analysis parameters
118
119 # ## CONSTRAINTS handler >> Determines how the constraint equations are enforced in the analysis
120
121 # >> Plain Constraints -- Removes constrained degrees of freedom from the system of equations (only for homogeneous
equations)
122 # >> Lagrange Multipliers -- Uses the method of Lagrange multipliers to enforce constraints
123 # >> Penalty Method -- Uses penalty numbers to enforce constraints --good for static analysis with non-homogeneous
eqns (rigidDiaphragm)
124 # >> Transformation Method -- Performs a condensation of constrained degrees of freedom
125 variable constraintsTypeStatic Transformation; # default;
126 constraints $constraintsTypeStatic
127
128 # DOF NUMBERER (number the degrees of freedom in the domain):
129
130 # Determines the mapping between equation numbers and degrees-of-freedom
131 # Plain -- Uses the numbering provided by the user
132 # RCM -- Renumbers the DOF to minimize the matrix band-width using the Reverse Cuthill-McKee algorithm
133 set numbererTypeStatic RCM
134 numberer $numbererTypeStatic
135
136
137 # SYSTEM:
138
139 # Linear Equation Solvers (how to store and solve the system of equations in the analysis)
140 # -- provide the solution of the linear system of equations Ku = P. Each solver is tailored to a specific matrix topology.
141
142 # ProfileSPD -- Direct profile solver for symmetric positive definite matrices
143 # BandGeneral -- Direct solver for banded unsymmetric matrices
144 # BandSPD -- Direct solver for banded symmetric positive definite matrices
145 # SparseGeneral -- Direct solver for unsymmetric sparse matrices
146 # SparseSPD -- Direct solver for symmetric sparse matrices
147 # UmfPack -- Direct UmfPack solver for unsymmetric matrices
148 set systemTypeStatic UmfPack; # try UmfPack for large model
149 system $systemTypeStatic

```

```

150 # TEST: # convergence test to
151
152
153 # -- Accept the current state of the domain as being on the converged solution path
154 # -- determine if convergence has been achieved at the end of an iteration step
155 #     NormUnbalance -- Specifies a tolerance on the norm of the unbalanced load at the current iteration
156 #     NormDispIncr -- Specifies a tolerance on the norm of the displacement increments at the current iteration
157 #     EnergyIncr-- Specifies a tolerance on the inner product of the unbalanced load and displacement increments at the
    current iteration
158 #     RelativeNormUnbalance --
159 #     RelativeNormDispIncr --
160 #     RelativeEnergyIncr --
161 variable TolStatic 10; # Convergence Test: tolerance
162 variable maxNumIterStatic 10000; # Convergence Test: maximum number of iterations that will be performed befo
    re "failure to converge" is returned
163 variable printFlagStatic 0; # Convergence Test: flag used to print information on convergence (optional)
    # 1: print information on each step;
164 variable testTypeStatic EnergyIncr ; # Convergence-test type
165 test $testTypeStatic $TolStatic $maxNumIterStatic $printFlagStatic;
166
167 # Solution ALGORITHM: -- Iterate from the last time step to the current
168 #     Linear -- Uses the solution at the first iteration and continues
169 #     Newton -- Uses the tangent at the current iteration to iterate to convergence
170 #     ModifiedNewton -- Uses the tangent at the first iteration to iterate to convergence
171 #     NewtonLineSearch --
172 #     KrylovNewton --
173 #     BFGS --
174 #     Broyden --
175 variable algorithmTypeStatic Newton
176 algorithm $algorithmTypeStatic;
177
178 # Static INTEGRATOR: -- determine the next time step for an analysis
179
180 #     LoadControl -- Specifies the incremental load factor to be applied to the loads in the domain
181 #     DisplacementControl -- Specifies the incremental displacement at a specified DOF in the domain
182 #     Minimum Unbalanced Displacement Norm -- Specifies the incremental load factor such that the residual displacement
    norm in minimized
183 #     Arc Length -- Specifies the incremental arc-length of the load-displacement path
184 # Transient INTEGRATOR: -- determine the next time step for an analysis including inertial effects
185 #     Newmark -- The two parameter time-stepping method developed by Newmark
186 #     HHT -- The three parameter Hilbert-Hughes-Taylor time-stepping method
187 #     Central Difference -- Approximates velocity and acceleration by centered finite differences of displacement
188 integrator DisplacementControl $N_A9 1 $Dincr
189
190 # ANALYSIS -- defines what type of analysis is to be performed
191
192 #     Static Analysis -- solves the KU=R problem, without the mass or damping matrices.
193 #     Transient Analysis -- solves the time-dependent analysis. The time step in this type of analysis is constant. The
    time step in the output is also constant.
194 #     variableTransient Analysis -- performs the same analysis type as the Transient Analysis object. The time step, ho
    wever, is variable. This method is used when
195 #         there are convergence problems with the Transient Analysis object at a peak or when the time step is too s
    mall. The time step in the output is also variable.
196 set analysisTypeStatic Static
197 analysis $analysisTypeStatic
198
199
200 # ----- perform Static Pushover Analysis
201 set Nsteps [expr int($Dmax/$Dincr)]; # number of pushover analysis steps
202 set ok [analyze $Nsteps]; # this will return zero if no convergence problems were encountered
203 set fmt1 "%s Pushover analysis: CtrlNode %.24i, dof %.1i, Disp=%.4f %s"; # format for screen/file output of DONE/PROBLEM an
    alysis
204 if {$ok != 0} {
205     # if analysis fails, we try some other stuff, performance is slower inside this loop
206     set Dstep 0.0;
207     set ok 0
208     while {$Dstep <= 1.0 && $ok == 0} {
209         set controlDisp [nodeDisp $N_A9 1 ]
210         set Dstep [expr $controlDisp/$Dmax]
211         set ok [analyze 1 ]
212         # if analysis fails, we try some other stuff
213         # performance is slower inside this loop global maxNumIterStatic; # max no. of iterations performed before "failur
    e to converge" is ret'd
214         if {$ok != 0} {
215             puts "Trying Newton with Initial Tangent .."
216             test NormDispIncr $Tol 3000 0
217             algorithm Newton -initial
218             set ok [analyze 1]
219             test $testTypeStatic $TolStatic $maxNumIterStatic 0
220             algorithm $algorithmTypeStatic

```

```

221     }
222     if {$ok != 0} {
223         puts "Trying Broyden .."
224         algorithm Broyden 8
225         set ok [analyze 1 ]
226         algorithm $algorithmTypeStatic
227     }
228     if {$ok != 0} {
229         puts "Trying NewtonWithLineSearch .."
230         algorithm NewtonLineSearch 0.8
231         set ok [analyze 1]
232         algorithm $algorithmTypeStatic
233     }
234
235 }; # end while loop
236 }; # end if ok !0
237
238 # -----
239 if {$ok != 0} {
240     puts [format $fmt1 "PROBLEM" $N_A9 1 [nodeDisp $N_A9 1] "mm"]
241 } else {
242     puts [format $fmt1 "DONE" $N_A9 1 [nodeDisp $N_A9 1] "mm"]
243 }
244
245
246 # Stop timing of this analysis sequence
247 set tStop [clock clicks -milliseconds]
248 puts "o Time taken: [expr ($tStop-$tStart)/1000.0] sec"
249
250 puts "pushover analysis completed"
251
252 # Reset for next analysis sequence
253 wipe all;

```

**Appendix 15 – The Data Analysis of 3B6S and 3B9S MRFs-Stone-
Concrete Infilled Frames with/without Ground Infills**

3B6S and 3B9S MRFs-Stone-Concrete Infilled Frame with/without ground infills

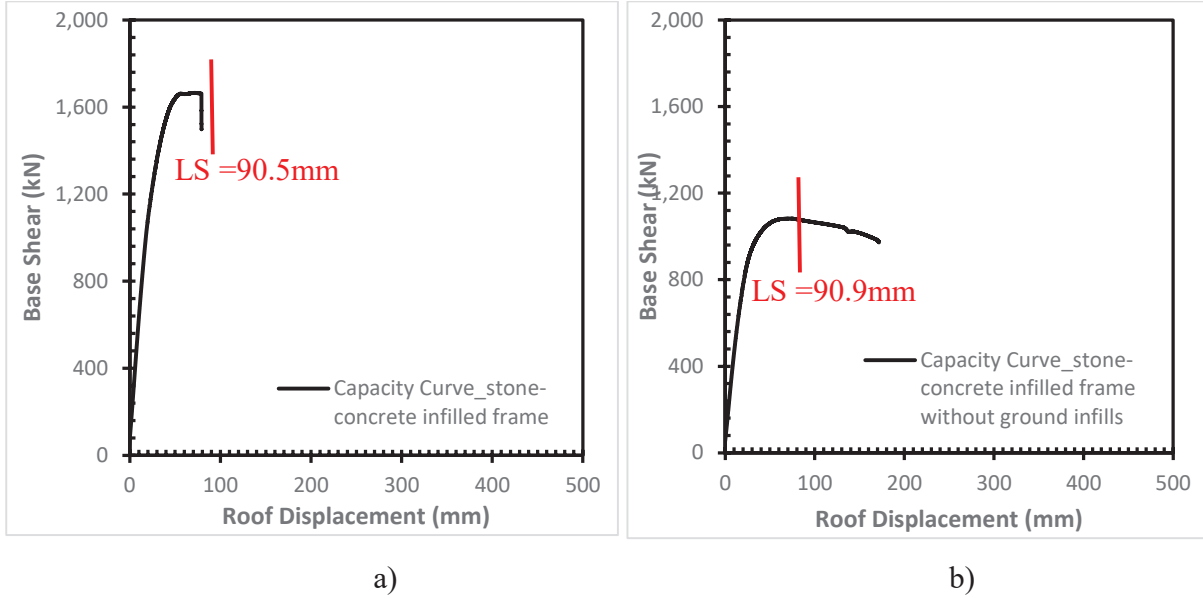


Fig 1: a) Performance point for 3B6S MRFs- stone-concrete infilled frame. b) Performance point for 3B6S MRFs- stone-concrete infilled frame without ground infills.

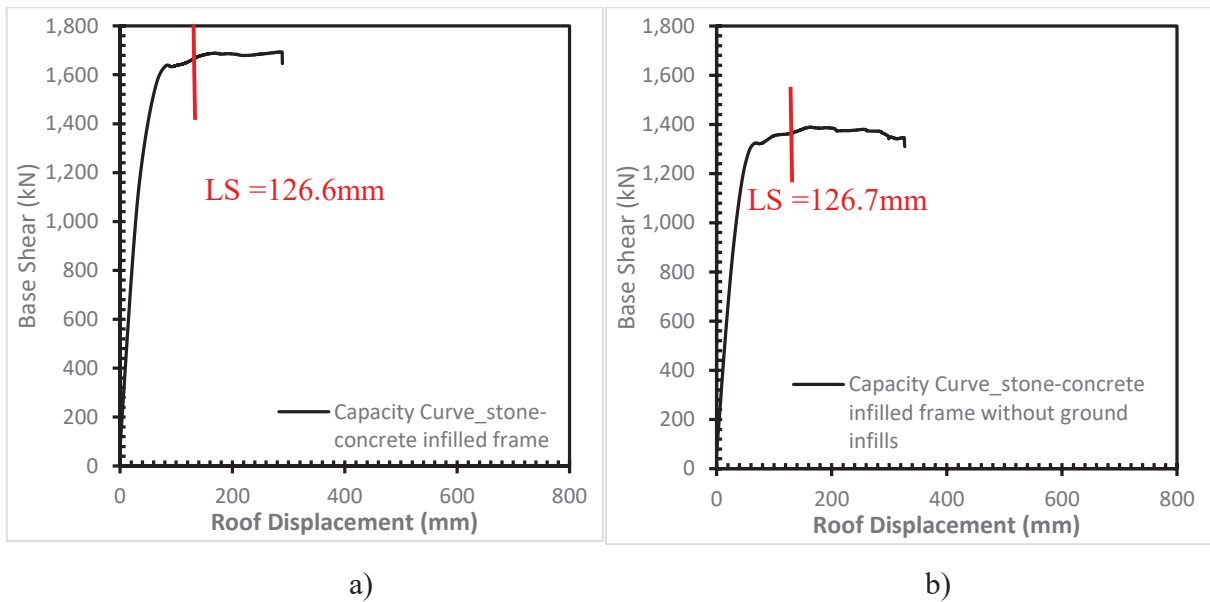


Fig 2: a) Performance point for 3B9S MRFs- stone-concrete infilled frame. b) Performance point for 3B9S MRFs- stone-concrete infilled frame without ground infills.

Legend	
Hinge Formulation in Joints and Infills	Hinge Formulation in B&C Elements
First Yielding	First Yielding
IO	IO
LS	LS
CP	CP

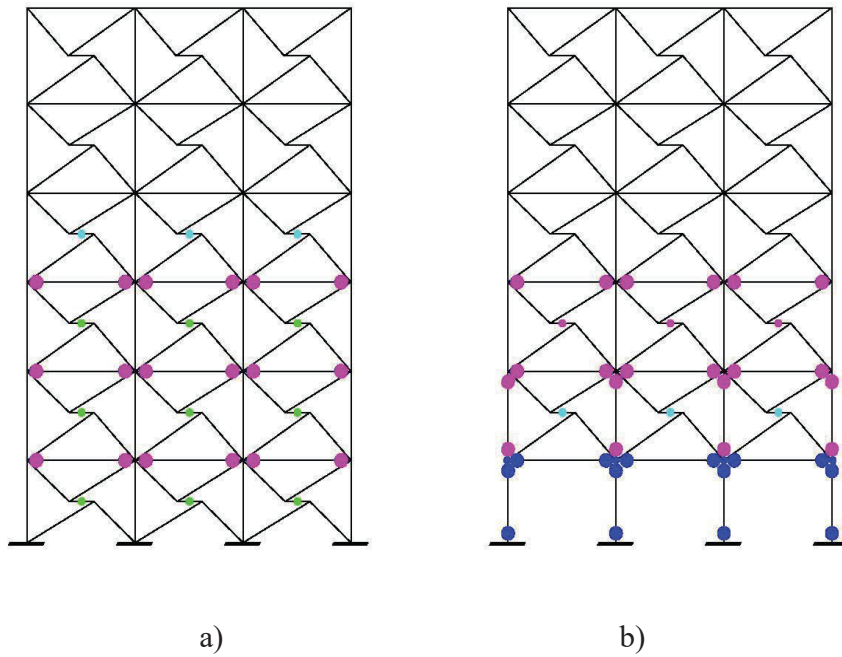


Fig 3: a) Hinge formation at the assigned elements in 3B6S MRFs- stone-concrete infilled frame.
 b) Hinge formation at the assigned elements in 3B6S MRFs- stone-concrete infilled frame without ground infills.

Legend	
Hinge Formulation in Joints and Infills	Hinge Formulation in B&C Elements
First Yielding	First Yielding
IO	IO
LS	LS
CP	CP

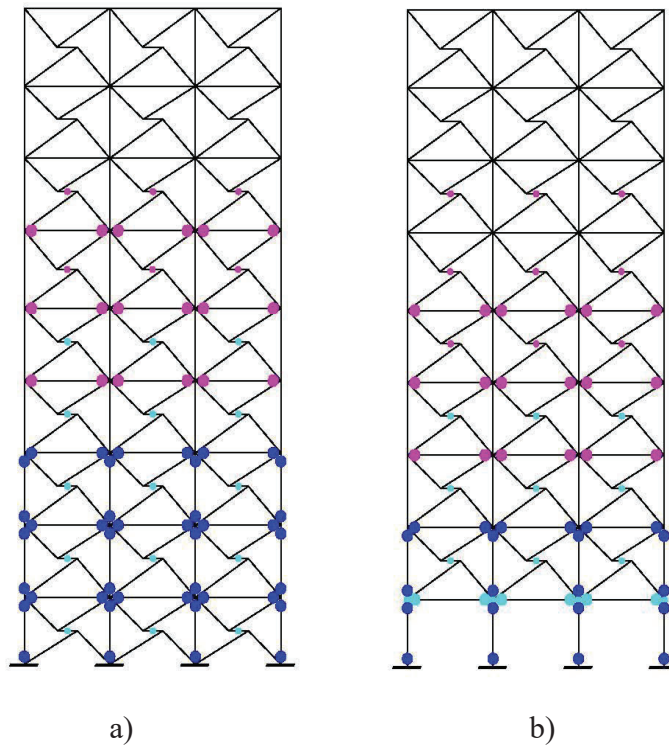
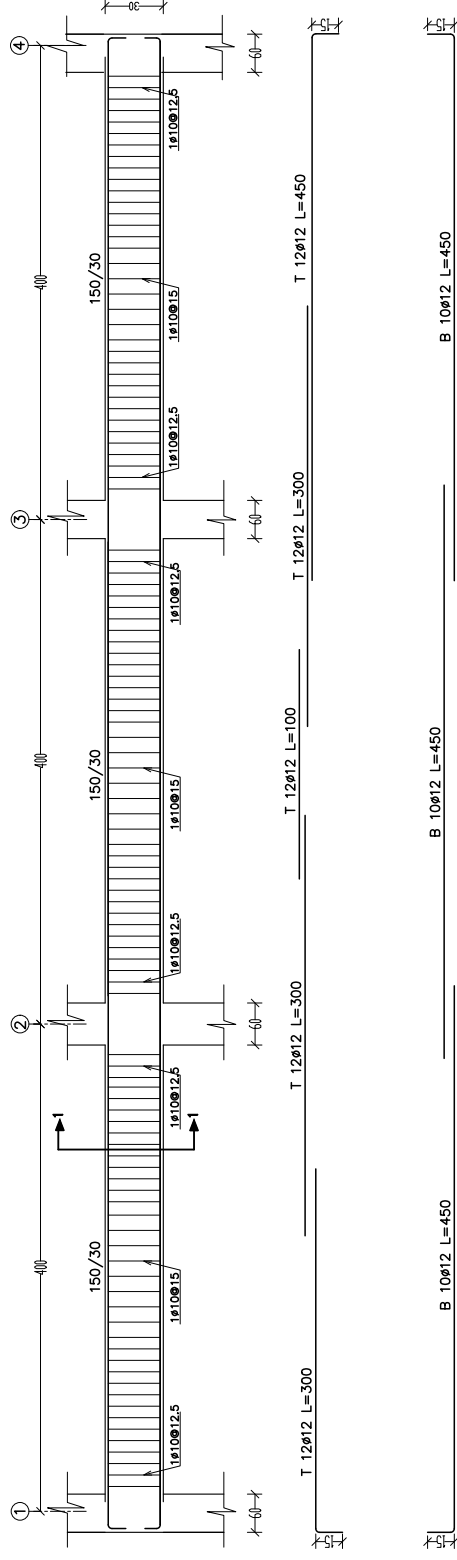


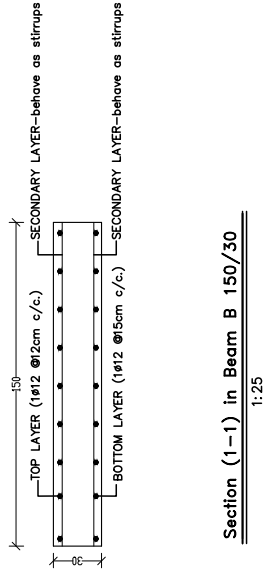
Fig 4: a) Hinge formation at the assigned elements in 3B9S MRFs- stone-concrete infilled frame.
 b) Hinge formation at the assigned elements in 3B9S MRFs- stone-concrete infilled frame without ground infills.

Appendix 16 – Full Structural Detailing for 3B6S and 3B9S Ductile and Non-Ductile Frame Systems

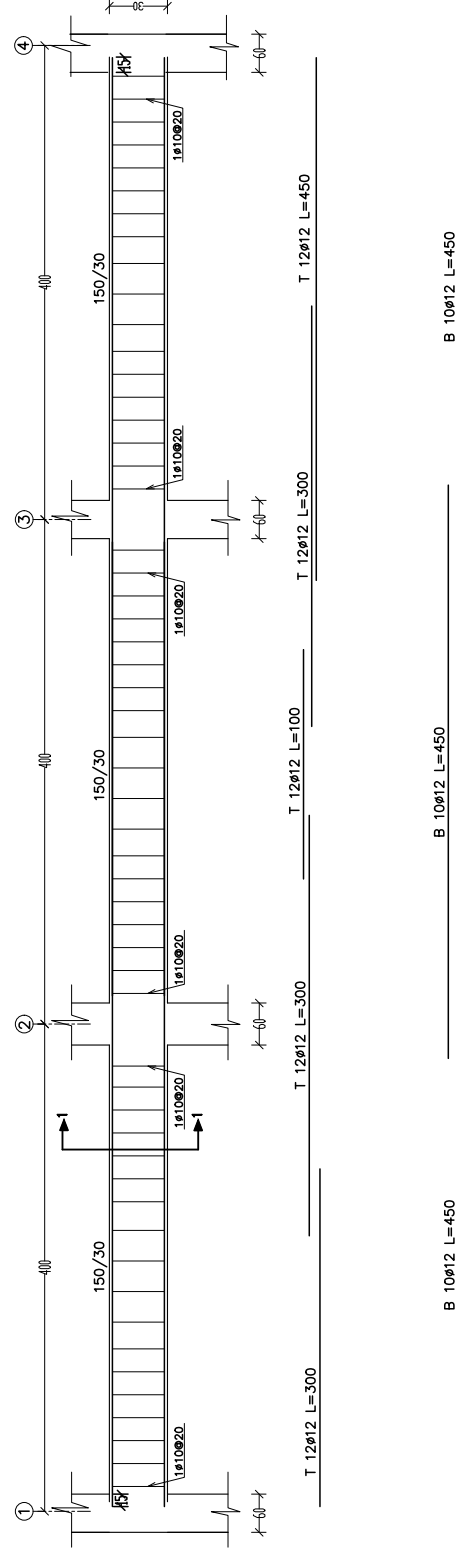


Typical Beam Detailing of Ductile 3B6S and 3B9S Frame System

1:50-H
1:20-V

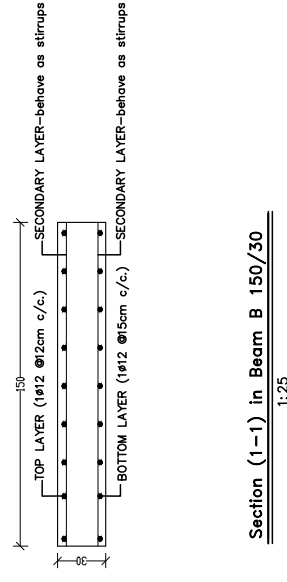


Section (1-1) in Beam B 150/30
1:25

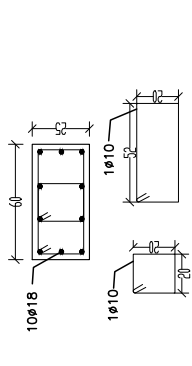
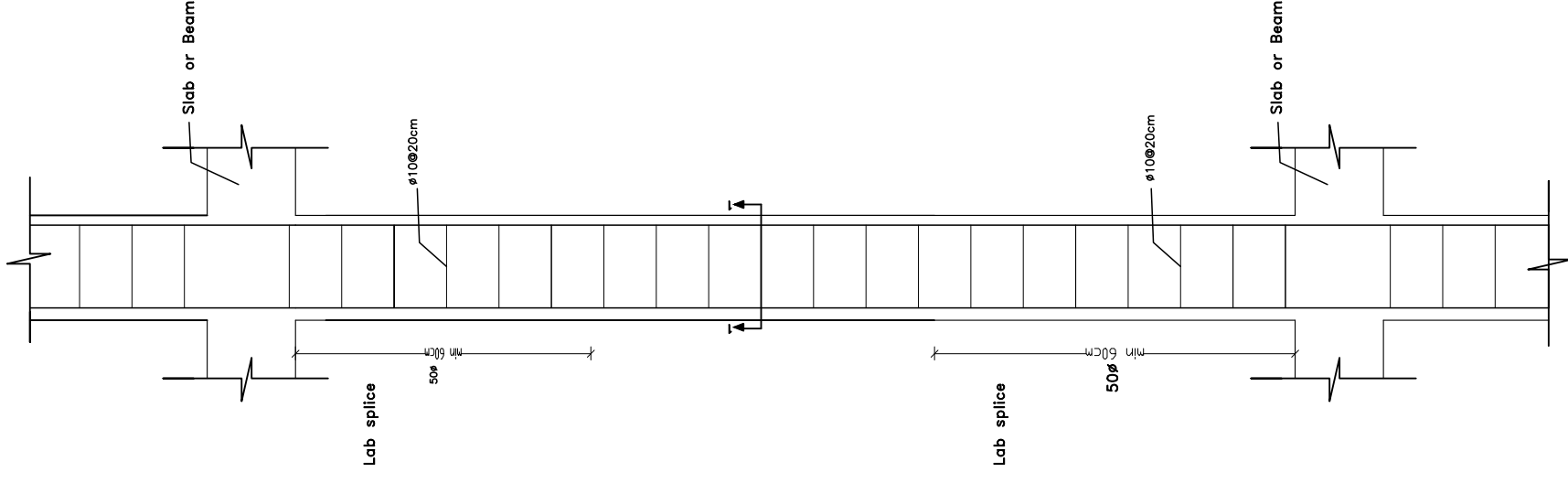


Typical Beam Detailing of Non-Ductile 3B6S and 3B9S Frame System

1:50-H
1:20-V

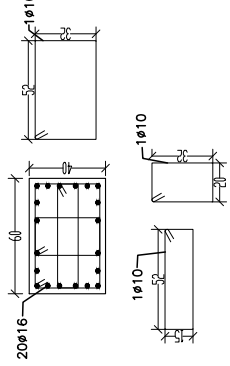


Section (1-1) in Beam B 150/30
1:25



Stirrups spacing as per general column elevation

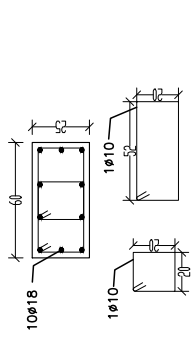
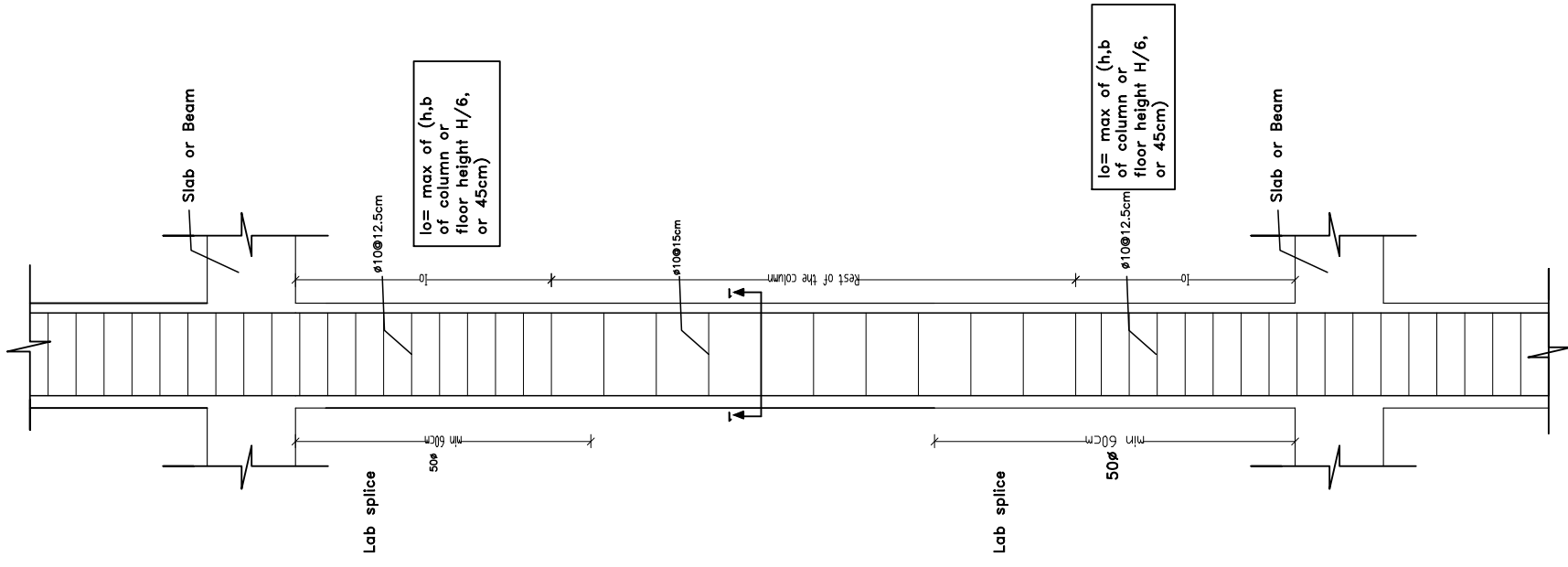
Section (1-1) in Typical 3B6S Columns



Stirrups spacing as per general column elevation

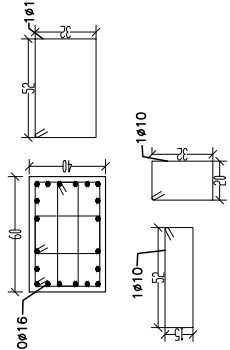
Section (1-1) in Typical 3B9S Columns

General Columns Detailing for 3B6S and 3B9S Non-Ductile Frame System



Stirrups spacing as per general column elevation

Section (1-1) in Typical 3B6S Columns



Stirrups spacing as per general column elevation

Section (1-1) in Typical 3B9S Columns

General Columns Detailing for 3B6S and 3B9S Ductile Frame System