ASSESSMENT OF RESPONSE REDUCTION FACTORS OF REINFORCED CONCRETE BUILDINGS USING RESPONSE SPECTRUM ANALYSIS

by

Natalie Simone Bryan,

B.Sc. Mechanical Engineering, University of the West Indies, Trinidad, 2000

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ABSTRACT

Assessment of response reduction factors of reinforced concrete buildings using response spectrum analysis, Natalie Bryan, Civil Engineering, 2017, Ryerson University.

This study provides an in-depth comparative review of the response reduction factors per NBCC 2015 code used to reduce the elastic response of the structure. An assembly of eight (8) reinforced concrete buildings of which four (4) different Seismic Force Resisting System (SFRS) types was included. The models were also categorized based on ductility and overstrength characteristics specifically ductile and conventional construction moment frames as well as ductile and conventional construction shear walls. All eight (8) models were analyzed using elastic Response Spectrum Analysis (RSA). Each SFRS was also analyzed as both a 12 storey and 40 storey building in order to explore the effects / restrictions of building height. The Equivalent Lateral Force Procedure was performed on the assembly of models for comparison to determine if the static procedure as per NBCC 2015 provisions resulted in overly conservative or similar results.

The relevant structural response such as base reactions, storey drifts, storey forces, and member forces were recorded and analyzed.

ACKNOWLEDGEMENTS

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Ar	Response amplification factor to account for type of attachment of mechanical/electrical equipment.
Ax	Amplification factor at level x to account for variation of response of mechanical/electrical equipment with elevation within the building.
Bx	Ratio at level x used to determine torsional sensitivity.
B	Maximum value of Bxr.
CP	Seismic coefficient for mechanical/electrical equipment.
Dnx	Plan dimension of the building at level x perpendicular to the direction of seismic loading being considered.
ex	Distance measured perpendicular to the direction of earthquake loading between centre of mass and centre of rigidity at the level being considered.
ELFP	Equivalent Later Force Procedure
Fa	Acceleration-related foundation/soil factor.
F(PGA	Site coefficient for PGA.
F(PGV)	Site coefficient for PGV.
Fs	Site coefficient.
F(T)	Site coefficient for spectral acceleration.
Ft	Portion of V to be concentrated at the top of the structure.
Fv	Velocity-related foundation/soil factor.
Fx	Lateral force applied to level x.
hv hlV hx	The height above the base (i = 0) to level i, n, or x respectively, where the base of the structure is the level at which horizontal earthquake motions are considered to be imparted to the structure.
hs	Interstorey height (hi - hi-1).
IE	Earthquake importance factor of the structure.
J	Numerical reduction coefficient for base overturning moment.
Jx	Numerical reduction coefficient for overturning moment at level x.
Level i	Any level in the building, i = 1 for first level above the base.
Level n	Level that is uppermost in the main portion of the structure.

Level x	Level that is under design consideration.
Mv	Factor to account for higher mode effect on base shear.
Mx	Overturning moment at level.
N	Total number of storeys above exterior grade to level n.
PGA	Peak Ground Acceleration expressed as a ratio to gravitational acceleration.
PGAref	Reference PGA for determining F(T), F(PGA) and F(PGV).
PGV	Peak Ground Velocity, in m/s.
Rd	Ductility-related force modification factor reflecting the capability of a structure to dissipate energy through reversed cyclic inelastic behaviour.
Ro	Overstrength-related force modification factor accounting for the dependable portion of reserve strength in a structure.
Rs	Combined overstrength and ductility-related modification factor.
RSA	Response Spectrum Analysis
S(T)	Design spectral response acceleration, expressed as a ratio to gravitational acceleration, for a period of T.
Sa(T)	5% damped spectral response acceleration, expressed as a ratio to gravitational acceleration, for a period of T.
SFRS	Seismic Force Resisting System(s) is that part of the structural system that has been considered in the design to provide the required resistance to the earthquake forces and effects.
T	Period in seconds.
Ta	Fundamental lateral period of vibration of the building or structure, ins, in the direction under consideration.
T5	Fundamental lateral period of vibration of the building or structure, ins, in the direction under consideration.
Tx	Floor torque at level x.
V	Lateral earthquake design force at the base of the structure.
Vd	Lateral earthquake design force at the base of the structure.
Ve	Lateral earthquake elastic force at the base of the structure.
Ved	Lateral earthquake design elastic force at the base of the structure.
VP	Lateral force on a part of the structure.
W	Dead load plus 25% of design snow load.

Chapter 1 Introduction

1.1 Background of the Study

1.1.1 Brief history of the development of the NBCC Seismic code

The evolution of the Canadian seismic design codes over the past 70 years has seen many drastic changes. Arguably, the most significant change is the shift from working stress design to ultimate strength design, with load factors and capacity reduction factors, and then to limit states design, with load factors and material resistance factors [6]. Another significant change is the specification of seismic hazard maps and corresponding seismic/site effects across Canada. Table 1 below provides a summary of the significant changes and addition to the National Building Code of Canada regarding the seismic analysis and design of structures.

Table 1: Summary of signification changes per issued NBCC code

Year	Significant Addition
1941	The first National Building Code (NBC), which contained seismic design provisions in an appendix (NRCC 1941) [6], was published (Mitchell d et al, 2010) [6]
1953	Introduction of first Seismic zoning map
1960	Suggested consideration of torsional effects, with no specific guidance provided.
1965	Introduction of Importance factor, a foundation factor and consideration for torsion. Ultimate strength permitted as an alternative method based on the ACI code
1970	Development of truly probalistic seismic zoning map
1975	Permitted the use of dynamic analysis as an alternative procedure. A response spectrum compatible with that proposed by Newmark et al. (1973) with 5% damping was adopted for the dynamic analysis that was scaled to the design ground acceleration, , A, equal to 0, 0.02g, 0.04g, and 0.08g for zones 0, 1, 2, and 3, respectively. [6]
1977	A key change in the dynamic analysis design procedure was the introduction of a minimum base shear equal to 90% of the base shear determined from the static analysis procedure, to limit the difference between the base shears determined from static and dynamic analyses.
1980	Introduction of SI Units. Proposal of a procedure for the determination of the structural eccentricity, e, for each floor level in a structure.

1985	New seismic zoning maps, based on the point source model developed by Cornell (1968) [6], were introduced in 1985 (NRCC 1985) [6]. Introduction of the acceleration-velocity ratio and its influence of the period of the structure. Hence the spectral shape varies geographically in different regions of the country. Also, this was the first time that the code allowed the building period obtained from modal analysis. [6]
1990	Replacement of the K factor by the force modification factor R. The R factor reflecting the ability of the structure to dissipate energy through inelastic behaviour.
1995	The three major changes to the 1995 NBCC (NRCC 1995) were the additional R factors, new expressions for building periods, and new torsional eccentricity expressions. Additional lateral load resisting systems introduced include nominally ductile and ordinary steel plate shear walls (R = 3 and 2, respectively), ductile coupled walls (R = 4), and reinforced masonry walls with nominal ductility (R = 2). [6]
2005	The uniform hazard spectrum (UHS) approach (NEHRP 1997) was adopted essentially giving site-specific response spectral accelerations for numerous locations in Canada (Adams and Atkinson 2003). These spectral accelerations have a probability of exceedance of 2% in 50 years (2475-year return period). Dynamic analysis approach became the preferred method of analysis and must be used for structures with certain irregularities. Introduction of two separate force modification factors, the ductility-related force modification factor, Rd, reflects the capability of a structure to dissipate energy through inelastic behaviour while the overstrength-related force modification factor, Ro, accounts for the dependable portion of reserve strength in a structure. [6]
2010	The values for the UHS for all but western localities were recalculated using an improved fit to the ground motion relations used in 2005. In general short-period hazard in low seismic zones were slightly reduced though long-period hazard increased slightly (e.g., Toronto).
2015	**Flexible Diaphragms -** Buildings with large footprints with flexible steel deck or wood panel diaphragms. Includes design specifications that account for effect of diaphragm flexibility on the period and increased ductility demand on lateral force resisting system**. Seismic Isolation -** Introduces requirement and guidance for three-dimensional non-linear dynamic analysis. Guidance on designing seismically isolated structures and modelling supplementary energy dissipation devices.

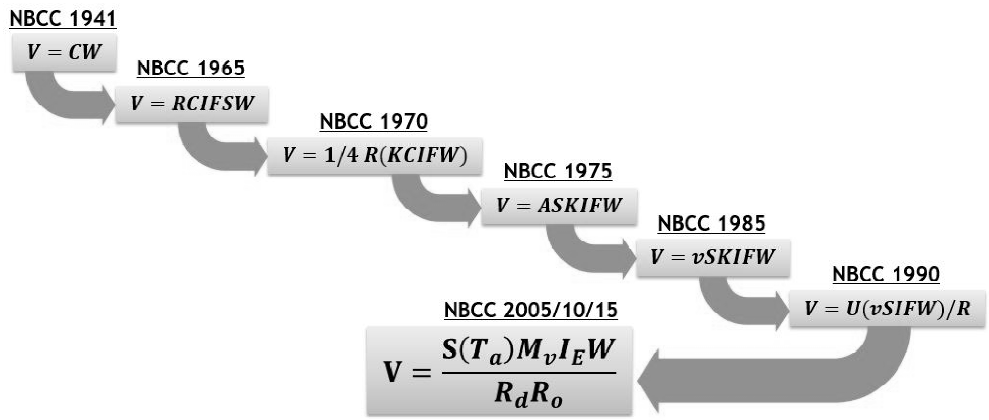


Figure 1: Base Shear (V) formula per NBCC code issuance.

1.1.2 Research significance

The general approach of reducing the seismic forces using a reduction factor to generate the design forces remains the predominant concept in seismic design and incorporated in most if not all international codes. These reduction forces are based on rigorous mathematical analysis, experimentation, past building performance among other data analysis. However, the calibrations of these factors are empirical and the values of which have significant influence on the seismic force-resisting system (SFRS) design. There is little evidence that this approach is likely to change in the near future and so further in-depth research into the calibration of these force reduction factors and their impact on the overall SFRS design remains relevant and necessary. This paper will focus on the latter objective as it delves into four different categories of SFRS based on the NBCC 2015 code and how the different R values of the assigned systems affect various building response and structural member sizes.

The introduction of the ductility and overstrength factors in seismic design results in a more efficient design as the ability of a structure to dissipate energy through inelastic deformation increases its lateral load resistance capability hence reducing the base shear V, applied in structural analysis. As previously mentioned, the introduction of the Force Modification factor /General Ductility (R) factor to replace the K factor was first introduced to the NBCC code in 1990, with structures assigned to three categories, see Figure 2 . A ductile moment-resisting frame per 1990 NBCC code prescribed requirements was assigned a value of 4.0, essentially reducing the idealized elastic base shear by 75%. This demonstrates the significance of a structure's ductility and overstrength in determining its seismic capacity. This paper will attempt to explore the quantitative effects of the code prescribed Force Modification Factors (R_d and R_o) on structural seismic response based on linear dynamic response spectrum analysis. Such effects are to include force-displacement relationship, distribution of lateral force, natural period, and sensitivity to variations in height, and performance and overall capacity.

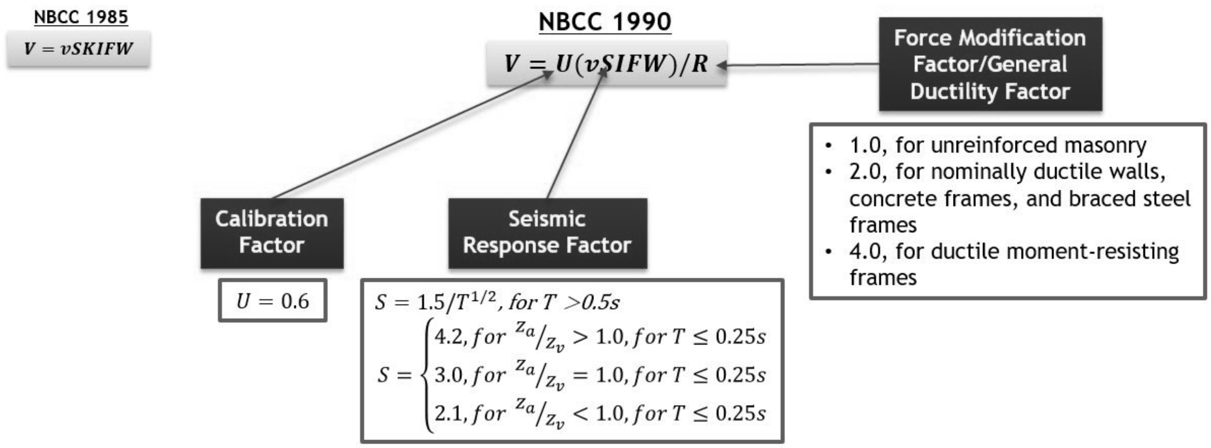


Figure 2: 1990 NBCC code introductions of Force Modification factor / General Ductility (R).

1.2 Seismic Engineering fundamentals

1.2.1 Response Spectra

The response spectrum analysis (RSA) is a linear elastic dynamic analysis of structures. Literature defines RSA as a graphical representation of the dynamic earthquake-related response such as acceleration, velocity, displacement, etc., of a structure having a broad range of periods subjected to a common lateral seismic motion at the base [8]. Accelerograms, such as shown in Figure 3, records the maximum dynamic response, acceleration in this case, for various levels of damping for a given earthquake motion. The erratic nature of ground shaking leads to a response that is very erratic in that a slight change in the natural period of vibration brings about a very large change in response. Hence, to achieve a smooth spectral shape (*design spectra*), several ground motions are averaged and normalized based on a probalistic model, see Figure 4. Realistically, very few structures vibrate as a single-degree-of-freedom system, however, the principles of dynamic modal analysis, allow a reasonable approximation of the maximum response of a multi-degree-of-freedom oscillator, such as a multistory building, if many specific conditions are met. The procedure involves dividing the total response into several natural modes, modeling each mode as an equivalent single degree-of-freedom oscillator, determining the maximum response for each mode from a single-degree-of-freedom response spectrum and then estimating the maximum total response by statistically summing the responses of the individual modes. The provisions does not require consideration of all possible modes of vibration for most buildings because the contribution of the higher modes (lower periods) to the total response is relatively minor. This concept is generally referred to as the participation factor [8].

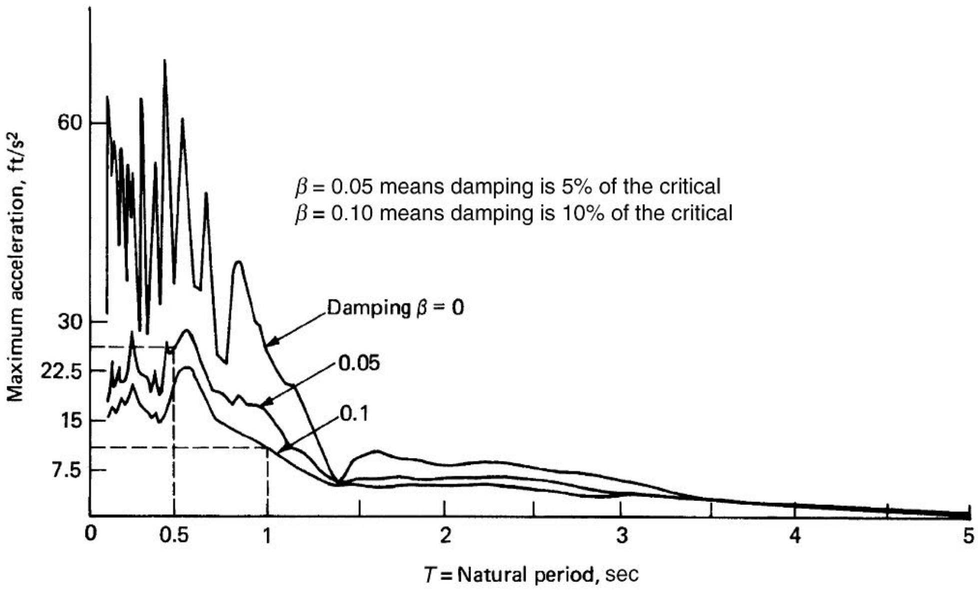


Figure 3: Acceleration spectrum: El Centro earthquake. [8]

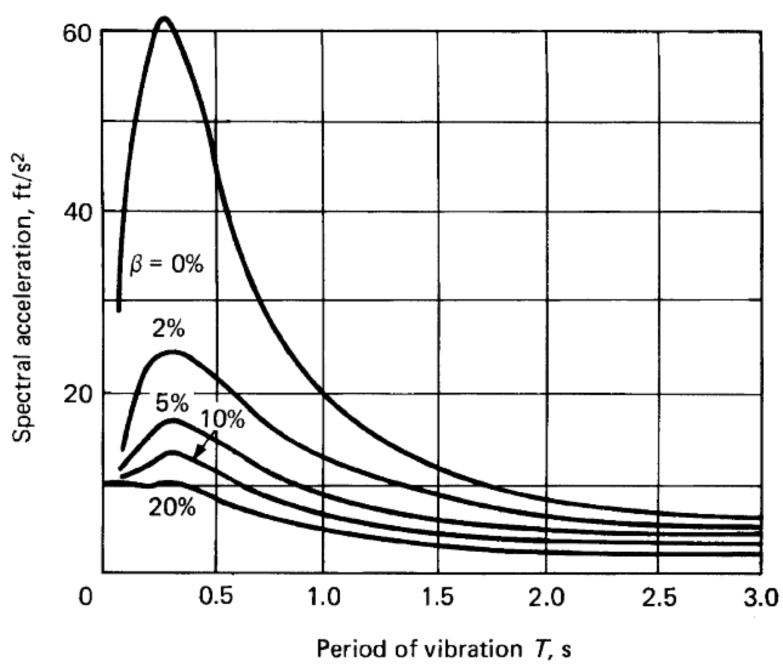


Figure 4: Smoothed acceleration spectra for the El Centro earthquake. [8]

1.2.2 Inelastic response and ductility

Response reduction factors such as R_d and R_o (NBCC 2015) are essentially used to reduce the idealized linear elastic response of a structure. Generally, the three response reduction factors considered in seismic design are due to the ductility of the structure, the various redundancies or options for the load path to foundation and the sources of overstrength incorporated in the design of the structure. The overstrength and redundancy are considered as one component while the damping and ductility are also considered as one component, hence the use of R_d and R_o. Figure 5 gives a simplified graphical representation based on the lateral load-displacement relationship. The idealized elastic load, F_{el} is reduced to the design force due to these above mentioned factors. The combined reduction factor R_dR_o is an empirical numerical value intended to account for damping, overstrength, redundancy and ductility inherent in the structural system at forces large enough to cause displacement beyond the yield displacement, Δ_y but less that the ultimate load displacement Δ_{max} of the system. The general concept is that a well detailed seismic framing system can sustain large inelastic deformations without collapse (ductile behavior) and develop lateral strength in excess of the design strength (overstrength). These concepts will be further explored in Chapter 3.

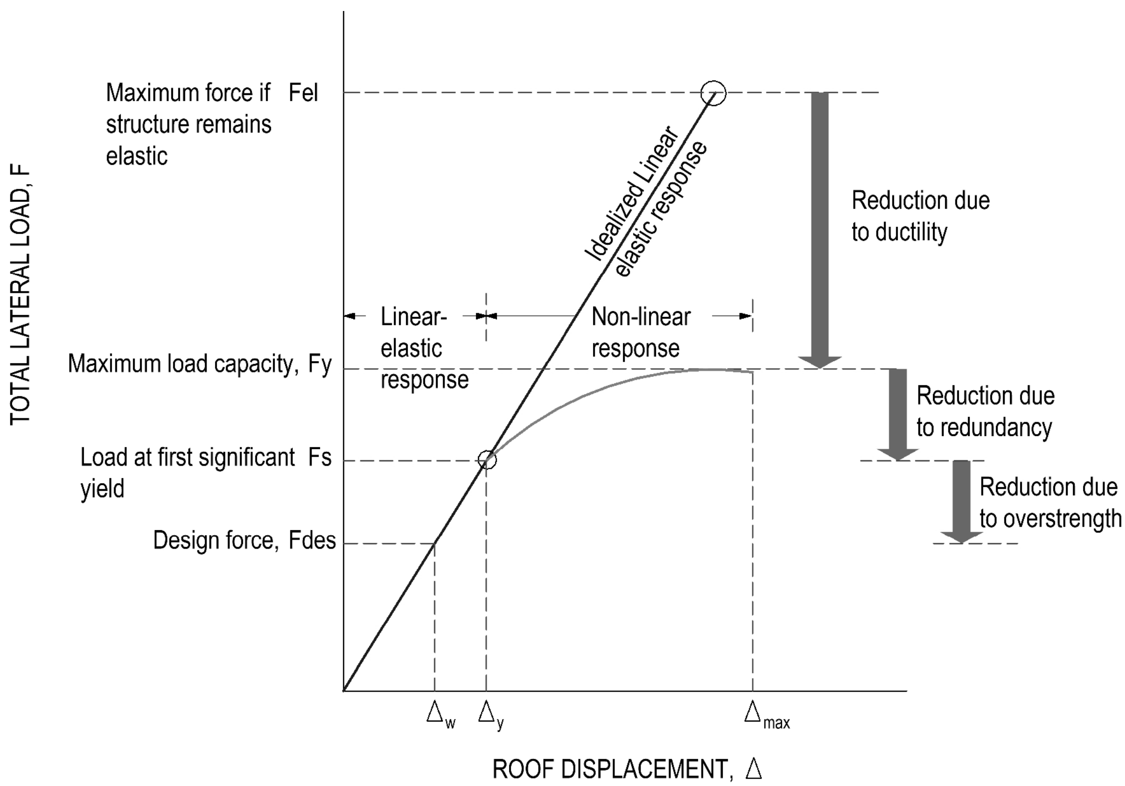


Figure 5: Concept of response reduction factors used for computing the lateral design force.

1.2.3 Reinforced concrete ductility and hysteresis

Over the past four decades, concrete has emerged as the most commonly used material in the construction of tall buildings, see Figure 6 . For this reason, among other factors, concrete SFRS systems were selected for this study. In seismic design, reinforced concrete structures with well detailed and designed members and joints must be able to sustain large deformations without losing their vertical load carrying capacity. When the structure is able to respond inelastically (ductile), it must do so for the full duration of the seismic event, implying many inelastic excursions in each direction [8]. The force-displacement diagram for reinforced concrete, in the inelastic range, follows a hysteresis loop as opposed to the idealized elastic/perfectly plastic (elastoplastic) behavior. Essentially, the hysteresis loop, see Figure 7, represents the ductile behavior of well designed reinforced concrete in that there is excessive strength degradation with increasing displacement or cyclic loading.

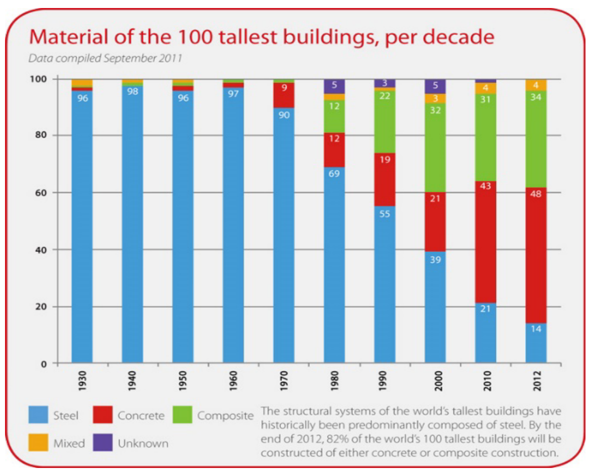


Figure 6: Material of the world's tallest building per decade [15]

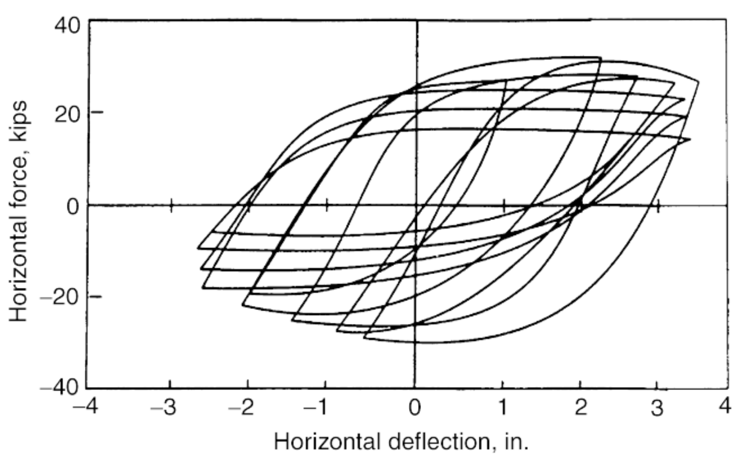


Figure 7: Hysteretic behavior curve representing large energy dissipation [8]

1.3 Brief overview of other Structural Analysis methods for seismic design

1.3.1 Equivalent Lateral Force Analysis

The equivalent lateral force procedure is allowed for the following cases in the NBCC 2015:

i. In cases where $I_eF_aS_a(0.2)$ is less than 0.35,

ii. Regular structures, less than 60 m in height and have a fundamental lateral, Ta period less than 2 s in each of two orthogonal directions; or

iii. Structures with structural irregularity, of type 1, 2, 3, 4, 5, 6 or 8, that are less than 60m in height, have a fundamental lateral period less than 0.5 s in each of two orthogonal directions.

<u>**NBCC 2015**</u>

$$\begin{array}{l} \dfrac{S(4.0)M_vI_EW}{R_dR_o}\begin{cases} walls \\ coupled\ wall \\ wall\ frame \end{cases} \\ \dfrac{S(2.0)M_vI_EW}{R_dR_o}\begin{cases} moment\ resisting\ frame \\ braced\ frame \\ other \end{cases} \end{array} < V = \frac{S(T_a)M_vI_EW}{R_dR_o} \leq larger\ of \begin{cases} \dfrac{\frac{2}{3}S(0.2)I_EW}{R_dR_o} \\ \dfrac{\mathbf{S(0.5)}\boldsymbol{I_EW}}{\boldsymbol{R_dR_o}} \end{cases}$$

Figure 8: Base shear formulation per NBCC 2015, where V is the Seismic Base Shear

1.3.2 Time History Analysis

Unlike Response Spectrum Analysis, time history methods are applicable to both elastic and inelastic analysis. The main distinction between linear elastic response method and Time History Analysis (linear and non-linear) is the assumption of the structures stiffness over time. In the former, the stiffness is considered to be constant over the entire duration of the seismic event, while the latter assumes the stiffness is constant only for a short time ∂_t. For Time History Analysis, the initial stiffness is modified over time to account for cracking, deflection, formation of plastic hinges, etc.

The Numerical Integration Time History Method, involves the determination of the response of a structural model to a specified earthquake ground motion accelorogram through the numerical integration of the equations of motion. The primary advantage of this method to the Modal Response Spectrum Method is that the various response parameters are obtained as time histories providing information on the time-wise fluctuation of the state of deformation of the structure [8].

However, there are several disadvantages as well including the complexity and computing time /costs as well as the heavy reliance of user assumptions can lead to significant uncertainties and errors. Hence this method is rarely used for the analysis of ordinary building structures.

Chapter 2 Objectives, Case study outline and Methodologies

2.1 Research Objective

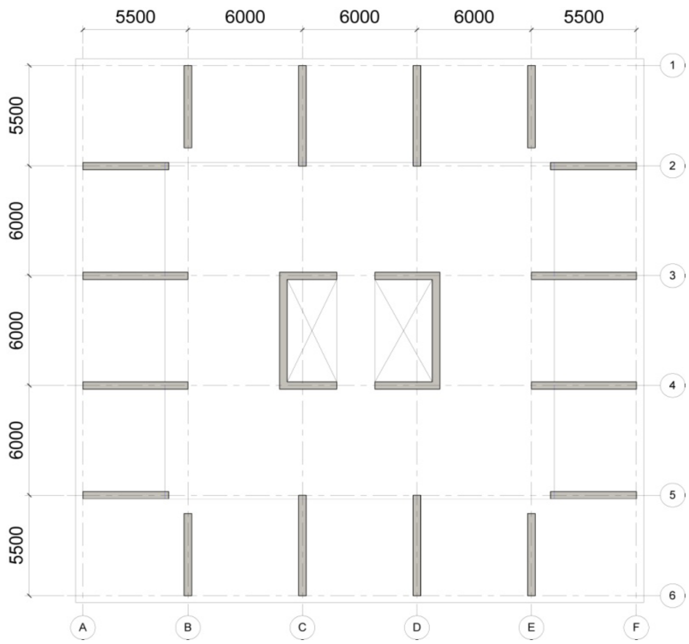
The main research objective is to compare the NBCC code prescribed response reduction factors used for ductile versus conventional construction reinforced concrete SFRS, based on selected building response. The specific objectives of the study are:

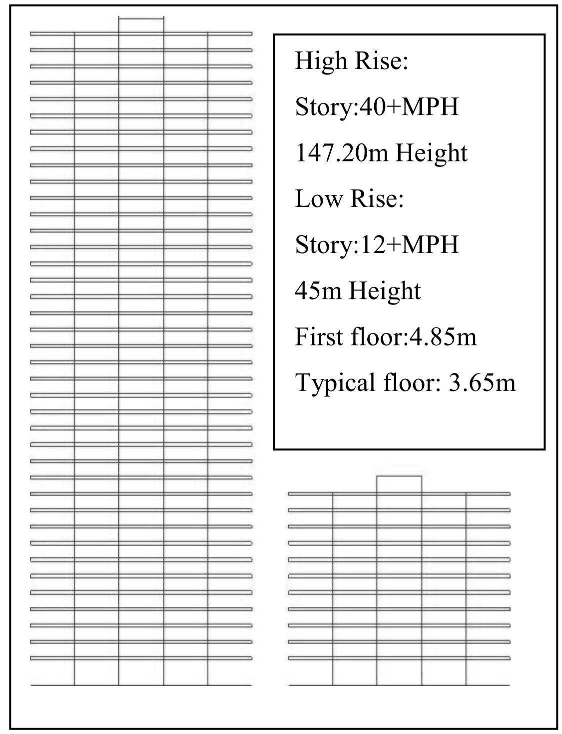
1. Conduct Response analysis on 8 different building structures of varying height, ductility and overstrength modification factors using 3-dimensional mathematical models in Etabs software.
2. Conduct Equivalent Lateral force procedure on all 8 structures and compare the results obtained from the dynamic analysis.
3. Evaluate structural response such as base reactions (seismic base shear), story forces, story drifts and member forces.
4. Review overall building drifts per code provisions.

2.2 Research Methodology / Case Study Outline of selected SFRS

2.2.1 Description of Test Models and loads

An assembly of 8 test models was used in this study. The models were categorized based on height (Low-rise/High-rise), SFRS type (Shear wall/Moment Frame) and SFRS detailing and design (Ductile/Conventional Construction). The low-rise models are 12 storeys high, while the high-rise models are 40 storeys. The building site was located in Montreal, Quebec. The basic structural configuration of the concrete shear wall and concrete moment frame is shown in Figure 9 and Figure 10, which show a typical floor plan. All eight buildings have two basement levels, however the basement levels were not considered in the dynamic analysis. They all have a centrally located elevator core. Each floor consists of a 200mm thick flat plate with 6m interior spans and 5.5m end spans. For the moment frame configurations, the columns are all 550mmx550mm with 550mm wide x 1000mm deep beams spanning each bay (interior and exterior). For the shear wall configuration, the thicknesses of all walls are 400mm. The wall thickness of 400mm initially chosen such that it exceeds $l_u/14$ = 4650/14=332mm (Clause21.5.3). The core walls extend one storey above the roof at the level forming an elevator penthouse at the upper most level. For all eight test models, the main SFRS is designed to take 100% of the lateral load, per NBCC 2015 code prescription. The designs of all 8 buildings are essentially symmetric in both orthogonal directions. Hence, for the purpose or clarity, the results in the E-W (x-axis) direction will be reviewed as both orthogonal directions have produced similar results.

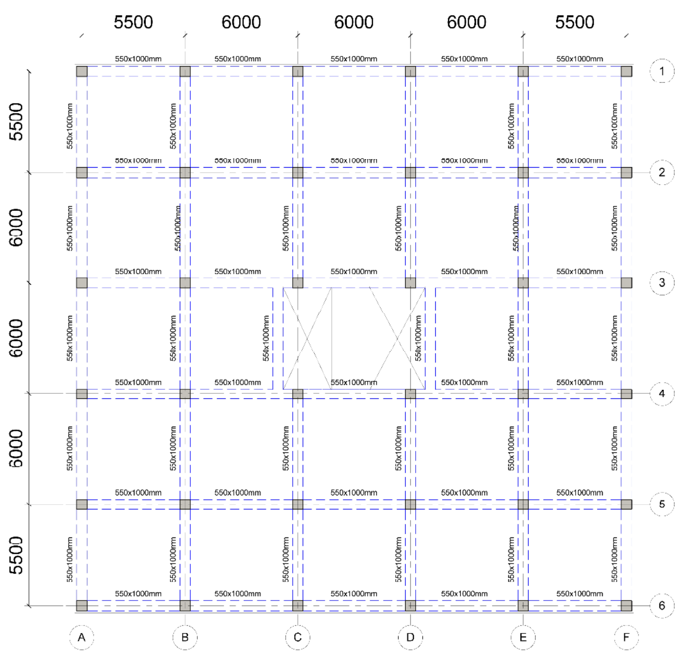




Model 1 – 4 (SFRS: Shear Wall) Plan

200mm Slab. 400m thick walls

Figure 9: Concrete Shear Wall Configuration



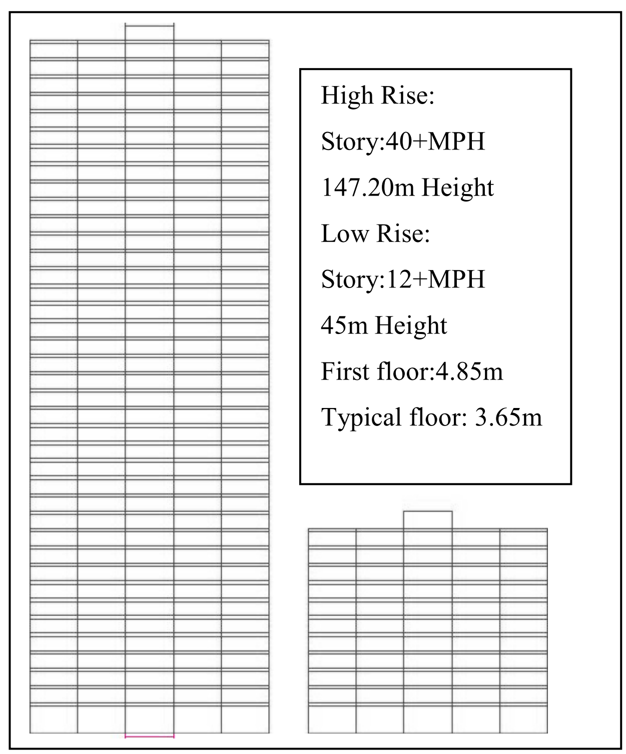


Figure 10: Concrete Moment Frame Configuration

Model 5 – 8 (SFRS: Concrete Moment Frame) Plan

550mm x550mm Columns. 550mm W x 1000mm Deep beams

Table 2: Test Models Description

Test Model Summary				
Classification	Description			
Height	L	Low-Rise		
	H	High Rise		
SFRS Type	SW	Shear Wall		
	MF	Moment Frame		
Construction / Reinforcing	D	Ductile		
	C	Conventional		
Model #	Classification	# of Storeys	Rd	Ro
1	L_SW_D	12	3.5	1.6
2	H_SW_D	40	3.5	1.6
3	L_SW_C	12	1.5	1.3
4	H_SW_C	40	1.5	1.3
5	L_MF_D	12	4.0	1.7
6	H_MF_D	40	4.0	1.7
7	L_MF_C	12	1.5	1.3
8	H_MF_C	40	1.5	1.3

2.2.2 Foundation:

The foundation system is not analyzed in this case study, but is assumed that the structure is founded on stiff soil. Each building has 2 basement levels with concrete walls located around the perimeter of the foundations. The site classification is "D".

2.2.3 Material Properties:

Concrete: Normal density concrete with $f'_c = 30$ MPa.

Reinforcement: $f_y = 400$ MPa.

2.2.4 Gravity Loading

Floor Live Load: 2.4 kN/m^2 on typical office floors

4.8 kN/m^2 on 12m by 12m corridor area around core

Roof Load: 2.5 kN/m^2 full snow load

1.6 kN/m^2 mechanical services loading in 6m wide strip over corridor bay

Dead Loads: self-weight of members calculated at 24 kN/m^3

1.0 kN/m^2 partition loading on all floors

0.5 kN/m^2 ceiling and mechanical services loading on all floors

0.5 kN/m^2 roofing

2.2.5 Load Combinations

The basic strength design load combinations that must be considered are:

1. 1.4D
2. (1.25D or 0.9d) + 1.5L
3. (1.25D or 0.9d) + 1.5S
4. 1.4D + 1.0E

Due to the focus on seismic design, the wind loads were not included in the applied loads and/or load combinations. See Appendix C for detailed lists of principal and companion load combinations.

2.2.6 Period Determination

Requirements for the computation of the building periods were followed as outlined in the NBCC 2015 provisions. For the preliminary design, the approximate fundamental lateral period of vibration, $Ta_{, code}$ was calculated as per Cl.4.1.8.1 (7)

For concrete moment frames:

(1) $$\boldsymbol{T_{a,code} = 0.075(h_n)^{3/4}}$$

For Shear Walls:

(2) $$\boldsymbol{T_{a,code} = 0.05(h_n)^{3/4}}$$

Where h_n is the height above the base in m. This method for determining the approximate period will generally result in periods that are lower (hence, more conservative for use in predicting base shear) than those computed from a more rigorous mathematical model. Therefore, the lateral period of the structure was also determined after performing the Response Spectrum Analysis. Per code provisions, if the building period computed through dynamic analysis is too high, due in part to a variety of possible modeling simplifications and assumptions, then the period is given an upper limit as per Cl. 4.1.8.11(3).

For concrete moment frames:

(3) $$T_a \leq 1.5(T_{a,code})$$

For Shear Walls:

(4) $$T_a \leq 2(T_{a,code})$$

2.2.7 Etabs Model Procedure

The site location of Montreal, Quebec per NBCC 2015 requires dynamic analysis procedure (explored further in Appendix D). Etabs was used as to conduct the elastic dynamic analysis using Response Spectrum. The modeling procedure for Etabs is summarized in Table 3. The detailed Etabs procedure is illustrated in Appendix C.

Table 3: Etabs Modeling Procedure

	Etabs Modeling Procedure
1.	Model Setup 1. **Materials** 2. **Members** 3. **Stiffness Modifiers** 4. **Mass Source**
2.	Loads 1. **Load Patterns/Cases** 2. **Floor Loads** 3. **Lateral Loads**
3.	Modeling 1. **Slab/Wall Meshing** 2. **Releasing Frame Elements** 3. **Coupling Beams**
4.	**Post-Analysis Model Verification**

Table 4: Design and detailing provisions of selected Concrete SFRS [13]

Concrete SFRS			
Type of SFRS	Rd	Ro	Summary of design and detailing requirements
Ductile moment resisting frames	4.0	1.7	Beams capable of flexural hinging with shear failure and bar buckling avoided. Beams and columns must satisfy ductile detailing requirements. Columns properly confined and stronger than beams. Joints properly confined and stronger than beams.
Conventional Construction: Moment resisting frames	1.5	1.3	Beams and columns must have factored resistances greater than or equal to factored loads. Columns and beams must satisfy minimum detailing requirements for conventional construction. Closely spaced hoops required in columns unless factored resistance of columns greater than factored resistance of beams of if RdRo = 1.3
Ductile shear walls	3.5	1.6	Walls must be of flexural yielding without local instability, Shear failure or bar buckling. Walls must satisfy ductile detailing and ductility requirements.
Conventional Construction: Shear walls	1.5	1.3	Walls must have factored resistances greater than or equal to factored loads. Factored shear resistance must exceed shear corresponding to factored flexural resistance or shear corresponding to RdRo = 1.3. Walls must satisfy minimum detailing requirements for conventional construction and minimum ductility requirements.

Chapter 3 Review of selected Literature and international Seismic codes on Response Reduction Factors

3.1 Ductility reduction factor

Ductility is essentially the measure of the ability to deform beyond the yield limit without significant loss of strength. This inelastic deformation absorbs and dissipates energy imposed on a structure such as the cyclic dynamic action of a seismic event. The overall ductility of a structure depends on the ductile properties of the material, structural elements and the design of the connections between both the structural and non-structural elements. The physical manifestation of the ductility of the material is expressed as a function of the stress-strain curve, for the structural element with the moment-curvature diagram and for the structural assembly with the force-displacement diagram.

The ductility-related force modification factor, $R_{d,}$ was first explicitly introduced in the 2005 NBCC codes, however it is essentially corresponds to the R factor used in previous NBCC code. It was the 2005 code that introduced two separate force modification factors, one accounting for the ductility, R_d and the other for the overstrength, R_o of the structure [5]. The factor ranges from 1 for brittle systems such as unreinforced masonry to 5.0 for ductile moment-resisting steel frames. The specified ductility and energy absorption capabilities of the structure are designed per strict specification of the NBCC code in accordance with the CSA standard. For example, in reinforced concrete ductile coupled wall design, the coupling beam must be able to resist a minimum 66% of the base overturning moment by the axial tension and compression forces resulting from shear in the coupling beam. This example of capacity design is used for providing significant yielding in the critical elements (such as coupling beams), while limiting inelastic demands in the other elements (such as shear walls), hence avoiding all potential brittle failure modes. Table 4 illustrates the design and detailing of selected reinforced concrete SFRS.

3.2 Over strength reduction factor

The inclusion of an explicit overstrength –related force modification factor, R_o, was first introduced in the 2005 NBCC code to account for the inherent reserve strength due to a number of design factors. As explored in the report by Mitchell et al (2005) [5], R_o is a product of a four (4) different R factors accounting for the structural member size, R_{size}, design and material resistance factors, R_{Φ}, the underestimation of the minimum specified yield strength versus the actual yield strength, R_{yield}, the ability of strain hardening to develop in the material, Rsh, and the additional resistance that can be developed before a collapse mechanism is formed in the structure, Rmech. Table 5 lists the values assigned to the aforementioned overstrength factors for the different reinforced concrete SFRS's.

(5) $\boldsymbol{R_o = R_{size} R_{\Phi} R_{yield} R_{sh} R_{mech}}$

Table 5: Derivation of overstrength-related force modification factors for reinforced concrete seismic force resisting systems (SFRSs). [5]

Type of SFRS	R_{size}	R_{Φ}	R_{yield}	R_{sh}	R_{mech}	R_o	NBCC 2015 R_o
Ductile moment-resisting frames	1.05	1.18	1.05	1.25	1.05	1.71	1.7
Moderately ductile moment-resisting frames	1.05	1.18	1.05	1.10	1.00	1.43	1.4
Moment-resisting frames with conventional construction	1.05	1.18	1.05	1.00	1.00	1.30	1.3
Ductile coupled walls	1.05	1.18	1.05	1.25	1.05	1.71	1.7
Ductile partially coupled walls	1.05	1.18	1.05	1.25	1.05	1.71	1.7
Ductile shear walls	1.05	1.18	1.05	1.25	1.00	1.63	1.6
Moderately ductile shear walls	1.05	1.18	1.05	1.10	1.00	1.43	1.4
Shear walls with conventional construction	1.05	1.18	1.05	1.00	1.00	1.30	1.3

3.3 Comparison of International code provisions for reduction factors with the NBCC 2015

3.3.1 Response Reduction Factor as per Mexico City Building code (2004 Building Code)

The Mexico City Building Code contains specific requirements to achieve either high or moderate ductility on the structural members and components for each structural material. A reduction factor Q' is used for the determination of the design base shear [10]. The assigned values of the force reduction factors are notably similar to the NBCC 2015 as illustrated in Table 6 .

Table 6: Force modification factors per Mexico City Building Code (2004 Building Code). [10]

Q value	Requirements
4	a) Frame or Dual structural types of steel, concrete or steel-concrete composites with frames able to resist 50% of acting seismic force. b) Dual structural types with masonry walls if the structure without them is able to resist 80% of total lateral forces. c) Minimum lateral strength on any story is within 35% of the total average. d) If steel braced frames are present, they must be eccentrically braced. e) Elements and components designed for high ductility.
3	a) Previous (Q=4) conditions b, d and e are satisfied but either conditions a or c are not (in any story) b) b. Concentric steel braced frames designed for high ductility.
2	a) Frame, wall or dual structural types of steel, concrete, steel-concrete composites or masonry not satisfying any of the requirements for previous (Q= 3 or 4) conditions. b) b. Prefabricated concrete buildings. c. Some types of timber or steel buildings according to their specific norms.
1.5	a) Wall structural types with hollow masonry walls. b) Timber frame buildings.
1	Buildings with other structural materials and without technical justification for higher values.

3.3.2 Response Reduction Factor as per IBC/ASCE-07 Seismic

The ASCE 7-10 incorporates a response modification coefficient R and an overstrength factor in the determination of the base shear. The classification of the SFRS in the ASCE 7-10 design code is more extensive than the NBCC 2015 with a larger number of classifications. Table 7 lists a few of the related SFRS force modification factors for comparison with the SFRS selected in this study. In broad terms, the modification factors per ASCE 7-10 code prescriptions appear less conservative than those stipulated by the NBCC code. For example, the maximum combined force reduction factor related to ductility and overstrength is 6.8 (4*1.7) in comparison to 8 per ACSE 7-10 for special reinforced concrete moment frames.

Table 7: Force modification factors per ASCE 7-10 Building Code (2004 Building Code). [11]

Seismic Force-Resisting System	Response Modification Coefficient, R	Overstrength Factor, Ω
Special reinforced concrete shear walls	5	2.5
Ordinary reinforced concrete shear walls	4	2.5
Ordinary plain concrete shear walls	1.5	2.5
Special reinforced concrete moment frames	8	3
Ordinary reinforced concrete moment frames	3	3

3.3.3 Response Reduction Factor as per Eurocode

The Eurocode 8 (EC8) has three dissipation (ductility) classes, namely Low Ductility (DCL), Medium Ductility (DCM) and High Ductility (DCH) classes [14]. Table 8 below gives the ductility behavior factors for the two most commonly designed ductility class per EC8. It should be noted that Table 8 is a simplified version of the ductility class requirements as there are numerous other factors in consideration such as seismicity of the design site, measure of regularity of the structure, design material, etc.

Table 8: Basic behavior factor, q_o, for systems in regular elevation per Eurocode 8 (EC8). [14]

Structural Type	DCM	DCH
Frame system, dual system, coupled wall system	$3.0\alpha_u / \alpha_1$	$4.5\alpha_u / \alpha_1$
Uncoupled wall system	3.0	$4.0\alpha_u / \alpha_1$
Torsionally flexible system	2.0	3.0
Inverted pendulum system	1.5	2.0

Where α_u / α_1 represents the ratio between the lateral load at which structural instability occurs and that at which the first yield occurs in any member. Default values of between 1.0 and 1.3 are given in the code with an upper limit of 1.5.

3.3.4 Response Reduction Factor in Japanese design code

Per the Japanese Seismic Code (Building Standard law of Japan, 2004), [12], the base shear is computed using the following equation, where the coefficient Ds, represents the ductility response of the structural configuration. This value represents an inverted form of the NBCC 2015, ACSE 7-08 or most other international building codes.

(6) Vun,i = Ds,i Fes,i Vi.

Table 9: D_s values for reinforced concrete structures (for steel reinforced concrete structures, subtract 0.05 from the tabulated value of D_s) [12]

	STRUCTURAL TYPE		
Framing Members	**(a) Rigid frames or very ductile shear wall with $\beta_w \leq 0.5$**	**(b) Very ductile or ductile shear wall with $\beta_w \leq 0.7$**	**(c) Very ductile or ductile shear wall with $\beta_w \leq 0.7$, or less ductile shear wall**
Most Ductile	**0.25**	**0.30**	**0.35**
Very Ductile	**0.30**	**0.35**	**0.40**
Ductile	**0.35**	**0.40**	**0.45**
Others	**0.40**	**0.45**	**0.50**

β_w = ratio of load carried by shear walls to total story shear. The classification of very ductile, ductile, or less ductile shear walls depends mainly on the shear stress level at ultimate and on the mode of failure.

Chapter 4 Analysis and interpretation of results

The tabulated results obtained from both the Response Spectrum Analysis (RSA) and the Equivalent Lateral Force Procedure (ELFP) is provided in Appendix B and Appendix E.

4.1 Lateral Period of the Structure

The modal parameters were combined using the complete quadratic combination (CQC) method. The computed periods and the modal response characteristic of the test models are presented in Table 10 and Table **11**. The number of modes selected was based on the minimum requirement of the accumulated modal mass should equal or exceed 90% of the total mass.

Table 10: Fundamental lateral period, Ta used for design

		Ta_{code} (s)	**Ta_{etabs} (s)**	**Ta_{design} (s)**	**H (m)**
Shear Wall	Model 1	0.87	1.217	1.217	45
	Model 2	2.11	8.826	4.22	174.2
	Model 3	0.87	1.217	1.217	45
	Model 4	2.11	8.826	4.22	147.02
Moment Frame	Model 5	1.30	1.854	1.854	45
	Model 6	3.17	7.382	4.755	147.2
	Model 7	1.30	1.854	1.854	45
	Model 8	3.17	7.382	4.755	147.2

Table 11: Periods and Modal Response Characteristics from Dynamic Analysis

Model	**Period (s)**	**% of Effective Mass Represented by Mode***	**Description**
		X-dir (E-W)	
1	1.217	91.3	Translation in the x-direction
2	8.826	92.4	Translation in the x-direction
3	1.217	91.3	Translation in the x-direction
4	8.826	92.4	Translation in the x-direction
5	1.854	91.9	Translation in the x-direction
6	7.382	93.4	Translation in the x-direction
7	1.854	91.9	Translation in the x-direction
8	7.382	93.4	Translation in the x-direction

4.2 Seismic Base Shear

In accordance with NBCC 2015 Cl.4.1.8.12 (8), if the design base shear, V_d obtained from linear dynamic analysis is less than 80% of the lateral earthquake design force V, obtained from the Equivalent Lateral Force Procedure (Cl. 4.1.8.11), then V_d shall be taken as 0.8V. Based on the results obtained from both the Response Spectrum Analysis (RSA) and the Equivalent Lateral Force Procedure (ELFP), the effect of the ductility and overstrength factors of the structure is notable. Based on the results as shown in Table 11 and Table 13, the following results are highlighted:

1. For shear wall configurations, using RSA, the base shear of both the 12 and 40 story buildings are similar for both the ductile and conventional construction. For e.g. the $V_{RSA,12\ storey}$ = 3749 kN and $V_{RSA,40\ storey}$ = 3350 kN. While this result is unexpected, the significantly larger period for the 40 story structure, as well as the high ductility (flexibility) of both structures might account for these results. The higher the natural period of a structure is an indicator of higher flexibility. Also, the high ductility of the structure means that it is less stiff and therefore considering F=kU, with ductile structures having smaller k values, the base shear tends to be smaller as well since generally flexible structures experiences lower accelerations than a stiffer buildings.
2. For the 12 story buildings, the seismic base shear obtained through both the RSA and ELFP are within 20% or less discrepancy with the RSA results lower for both the ductile and conventional shear wall buildings. This result is also similar for the moment frame buildings as well. These results justify the NBCC code upper limit of 60m in building height above base that can be designed using the static ELFP procedure. The results obtained from the ELFP for the taller structure, (147.2m) is overly conservative. It is observed that for the 40 story buildings, the seismic base shear obtained through the RSA and ELFP are markedly different. For e.g., $V_{RSA,40\ storey}$ = 3350 kN and $V_{ELFP,40\ storey}$ = 6342 Kn indicating a difference of almost 50%. Again, this is an indication that the effect of the ductility of the building is magnified as building height increases due to the increase in the natural period. The results for the moment frame 40 storey buildings follow a similar pattern as well.

Table 12: Design Base Shear Comparison – Shear Wall (SFRS)

Design Base Shear Comparison – Shear Wall (SFRS) X-dir (E-W)				
Model	RSA, V_d (kN)	ELFP, V (kN)	% RSA/ELFP	V_d (Selected) (kN)
1 (L_SW_D)	3749	4452	84.21%	3749
2 (H_SW_D)	3350	6342	52.82%	5074
3 (L_SW_C)	10775	12993	82.93%	10775
4 (H_SW_C)	11968	18213	65.71%	14570

Table 13: Design Base Shear Comparison – Moment Frame (SFRS)

Design Base Shear Comparison – Shear Wall (SFRS)				
Model	RSA, V_d (kN)	ELFP, V (kN)	% RSA/ELFP	V_d (Selected) (kN)
5 (L_MF_D)	1909	2489	76.70%	1991
6 (H_MF_D)	3185	7336	43.42%	5869
7 (L_MF_C)	6667	8680	76.81%	6944
8 (H_MF_C)	11126	25581	43.49%	20465

4.3 Distribution of Lateral Force

The story forces are distributed to the various vertical elements of the seismic force-resisting system based on relative rigidity using the ETABS model. The buildings are modeled using rigid diaphragms at each floor. Since the structures are symmetric in both directions and the distribution of mass is assumed to be uniform, there is no inherent torsion at either building. However, accidental torsion should be considered in accordance with *Cl.* 4.1.8.11 (11). However for the scope of this study, accidental torsion results will not be analyzed. Based on the results shown in Figure 11 to Figure 22 the following are notable observations:

1. The lateral force distribution of shear walls and moment frames were similar, with the lateral loads distributed between the two systems according to their relative stiffness. However, in general, the two systems deform with their own characteristic shapes. The interaction between the two, particularly at the upper levels of the buildings, results in quite a different lateral load distribution.
2. The results obtained from the response spectrum analysis appear to be scaled linearly by the ratio of the RdRo factors of the SFSR configuration. For e.g, the Low-Rise Ductile Shear Wall

building has a base shear of 3749 kN while Low-Rise Conventional Shear Wall building has a base shear of 10775 kN. The ratio of base shear of the respective SFRS is approximately equal to the ratio of the RdRo factors. This result is consistent with all 8 models.

3. The shear wall and frame appear to display constant stiffness throughout the height of the structure based on the similar design of each floor.
4. The slope of the shear wall curves appear to be more steep that the moment frame curves as is expected as the shear wall acts as vertical cantilever column with a greater slope at the top.

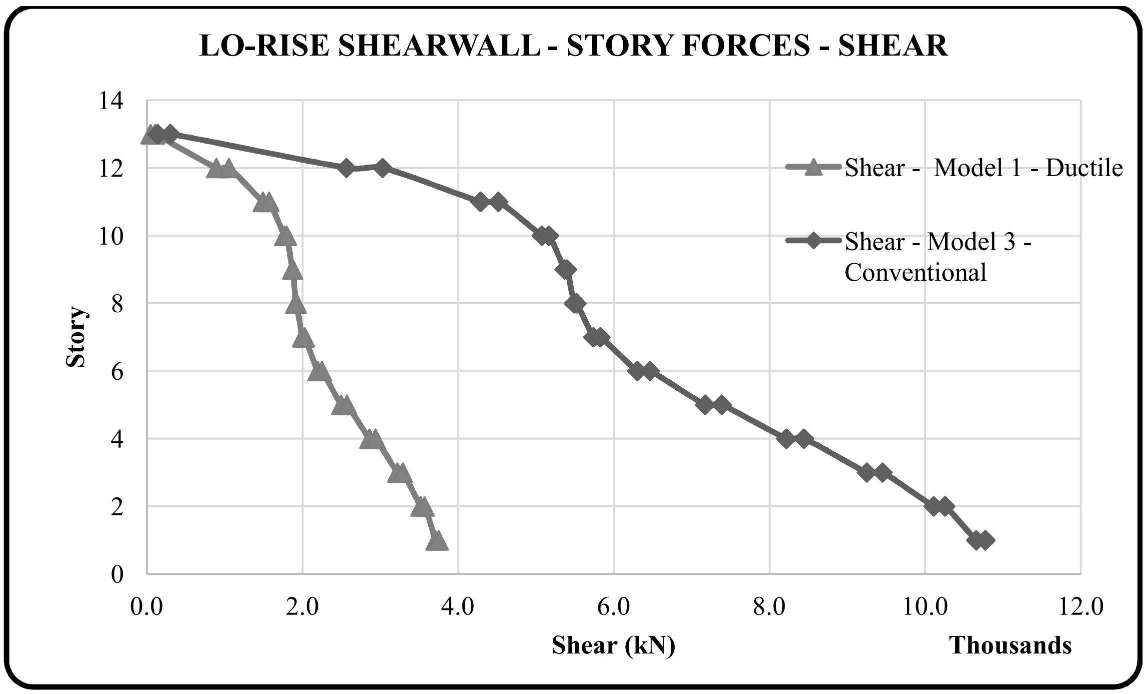


Figure 11: Low Rise Shear Wall SFRS: Lateral Force Distribution - SHEAR

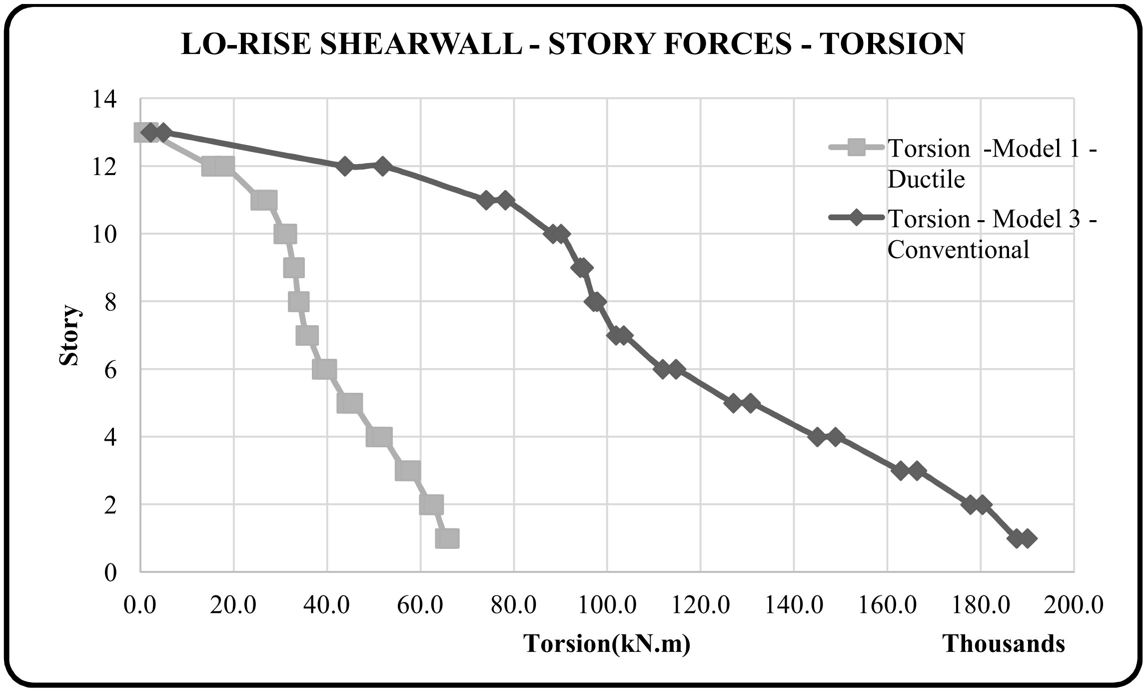


Figure 12: Low Rise Shear Wall SFRS: Lateral Force Distribution - TORSION

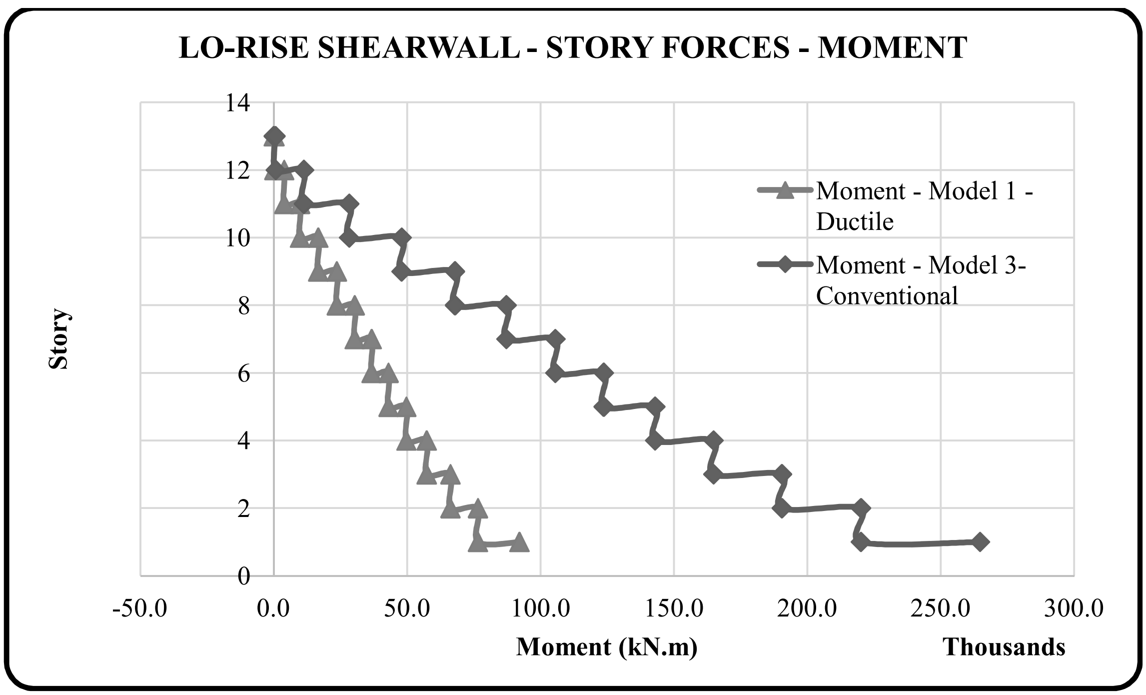


Figure 13: Low Rise Shear Wall SFRS: Lateral Force Distribution - MOMENT

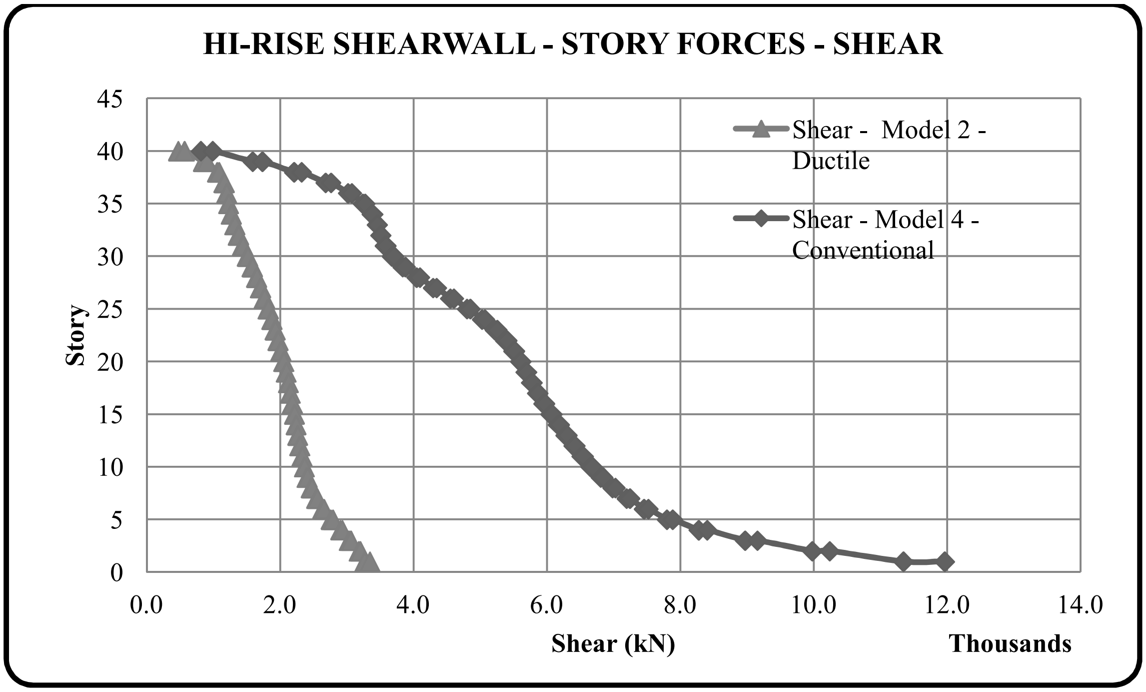


Figure 14: High Rise Shear Wall SFRS: Lateral Force Distribution - SHEAR

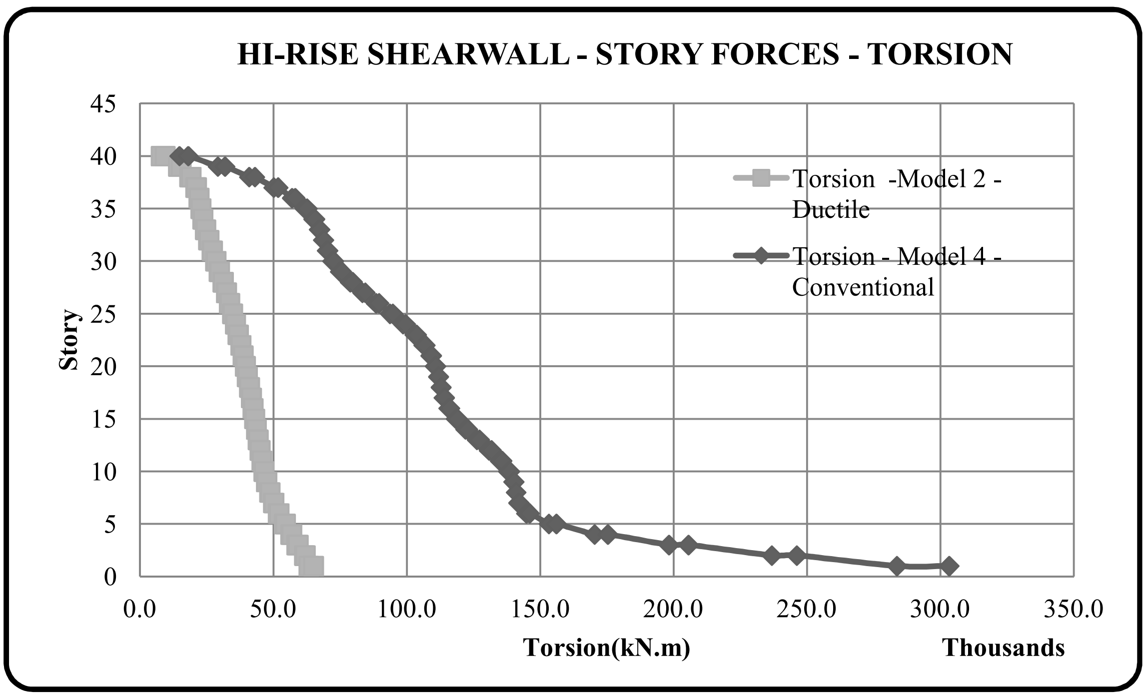


Figure 15: High Rise Shear Wall SFRS: Lateral Force Distribution - TORSION

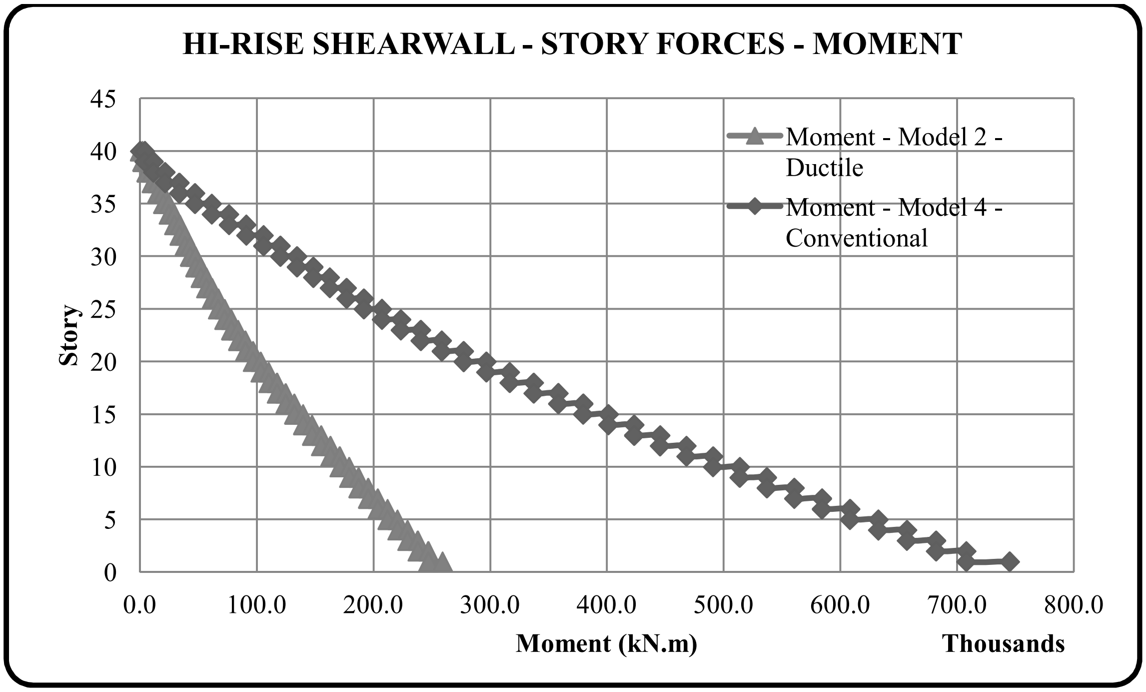


Figure 16: High Rise Shear Wall SFRS: Lateral Force Distribution - MOMENT

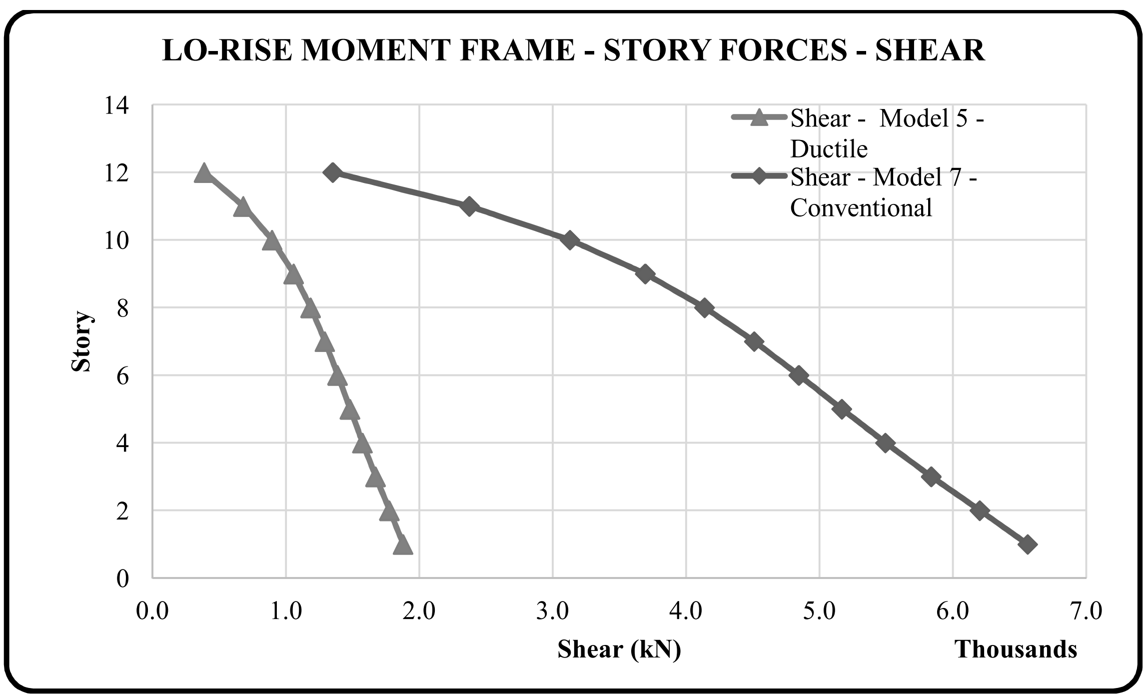


Figure 17: Low Rise Moment Frame SFRS: Lateral Force Distribution - SHEAR

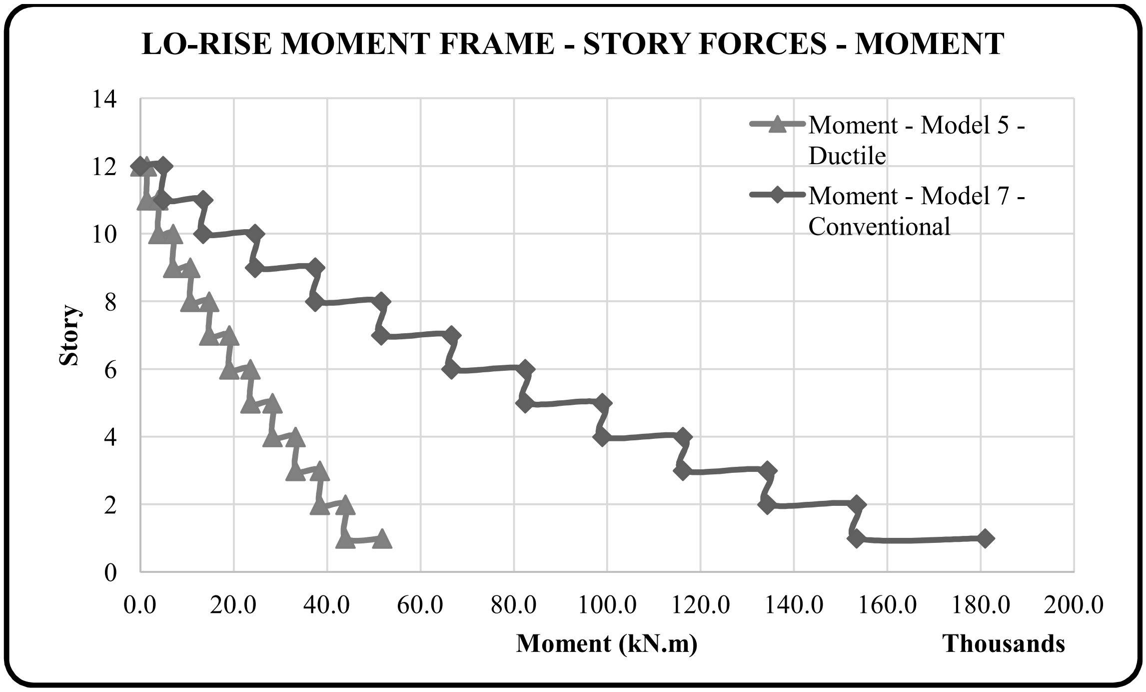


Figure 18: Low Rise Moment Frame SFRS: Lateral Force Distribution - MOMENT

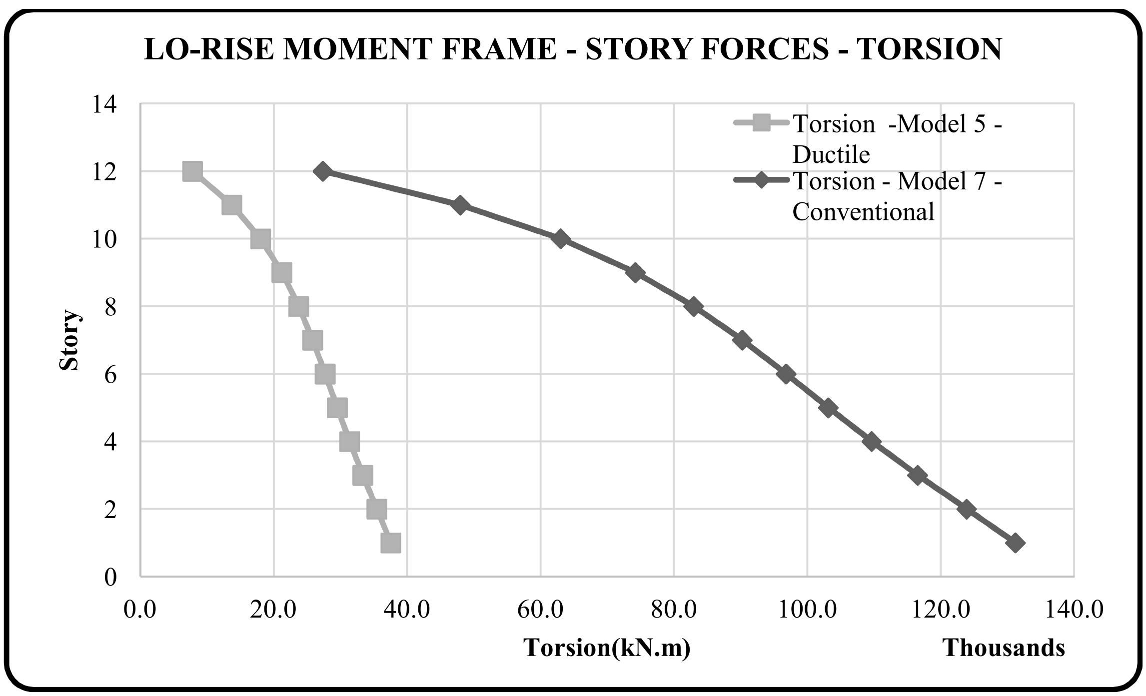


Figure 19: Low Rise Moment Frame SFRS: Lateral Force Distribution - TORSION

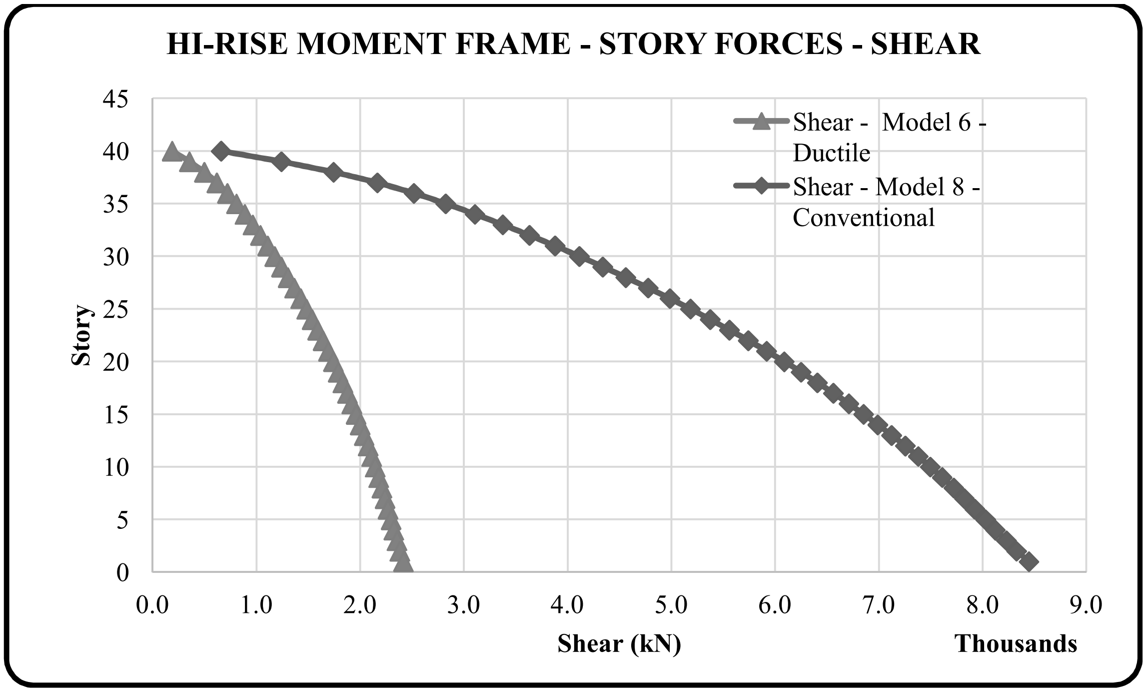


Figure 20: High Rise Moment Frame SFRS: Lateral Force Distribution - SHEAR

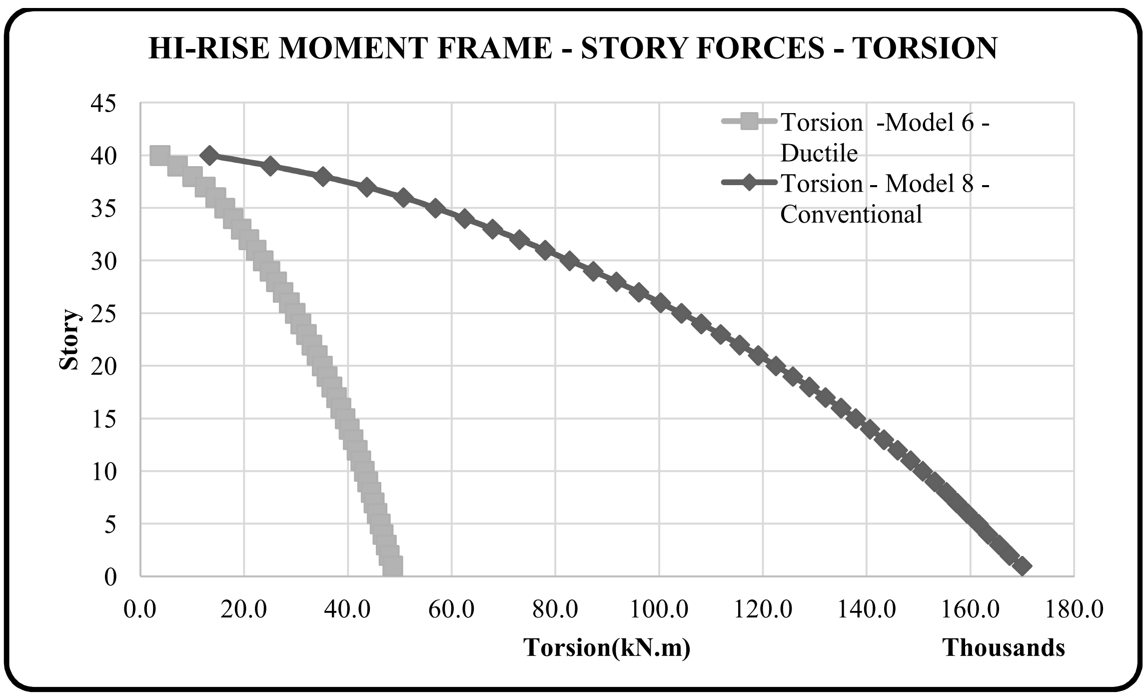


Figure 21: High Rise Moment Frame SFRS: Lateral Force Distribution - TORSION

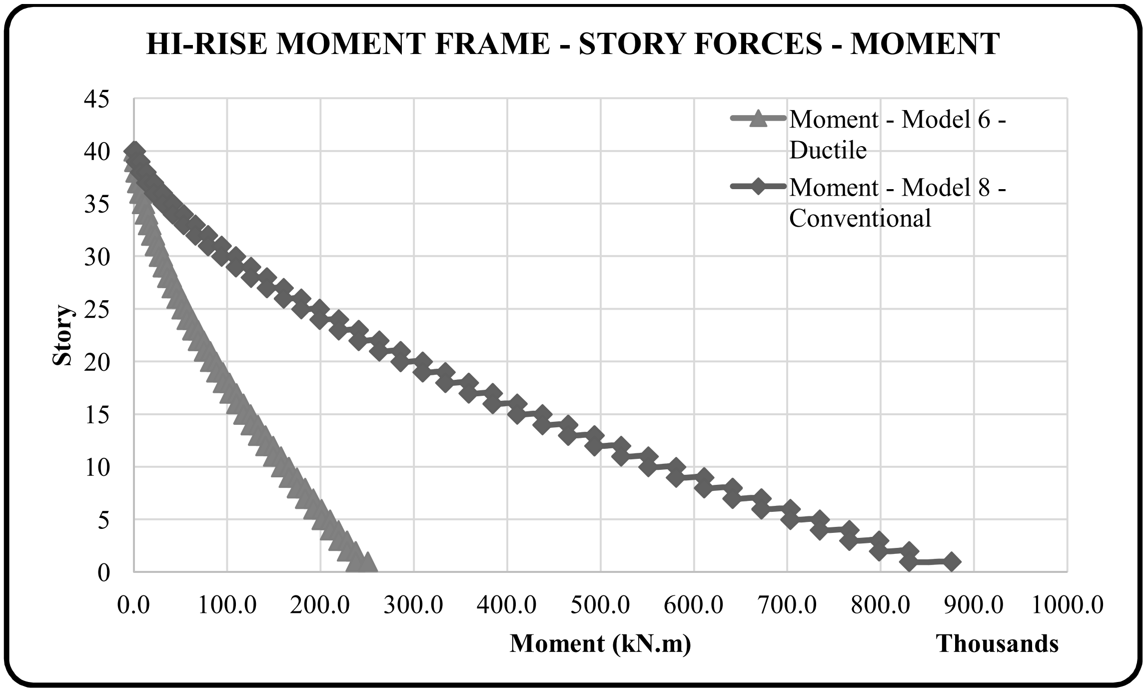


Figure 22: High Rise Moment Frame SFRS: Lateral Force Distribution - MOMENT

4.4 Drift Checks and Drift profile

The limit on deflections and interstorey drifts limits are in accordance with Cl. 4.1.8.13, where the lateral deflections obtained from linear elastic analysis shall be multiplied by $RdRo/I_E$ to give realistic values of anticipated deflections. Per NBCC 2015 provisions, an upper limit of $0.025h_s$ was imposed as the acceptable interstorey drift criteria check. The interstorey drift limit for the first floor is 0.12125m and for all other floors is 0.09125m. Based on the results shown in Figure 23 to Figure 26, the following are notable observations:

1. As stated previously, the deflection modes of shear walls and moment frames were similar because the lateral loads would be distributed between the two systems more or less, according to their relative stiffness. However, in general, the two systems deform with their own characteristic shapes. The interaction between the two, particularly at the upper levels of the buildings, results in quite a different lateral load distribution.
2. The lateral deflections of the shear wall deflect similar to those of a cantilever column where near the bottom, the shear wall is relatively stiff, and therefore, the floor-to-floor deflections are less than half the values near the top. At top floors, the deflections increase rather rapidly, mainly from the cumulative effect of wall rotation.
3. Moment frames, on the other hand, deform predominantly in a shear mode. The relative story deflections depend primarily on the magnitude of shear applied at each story level. Although the deflections are larger near the bottom and smaller near the top as compared to the shear walls, the floor-to-floor deflections can be considered more nearly uniform throughout the height.
4. The results obtained from the response spectrum analysis appear to be scaled linearly by the ratio of the RdRo factors of the SFSR configuration.
5. The interstorey drifts for all 8 models were with code accepted limts.

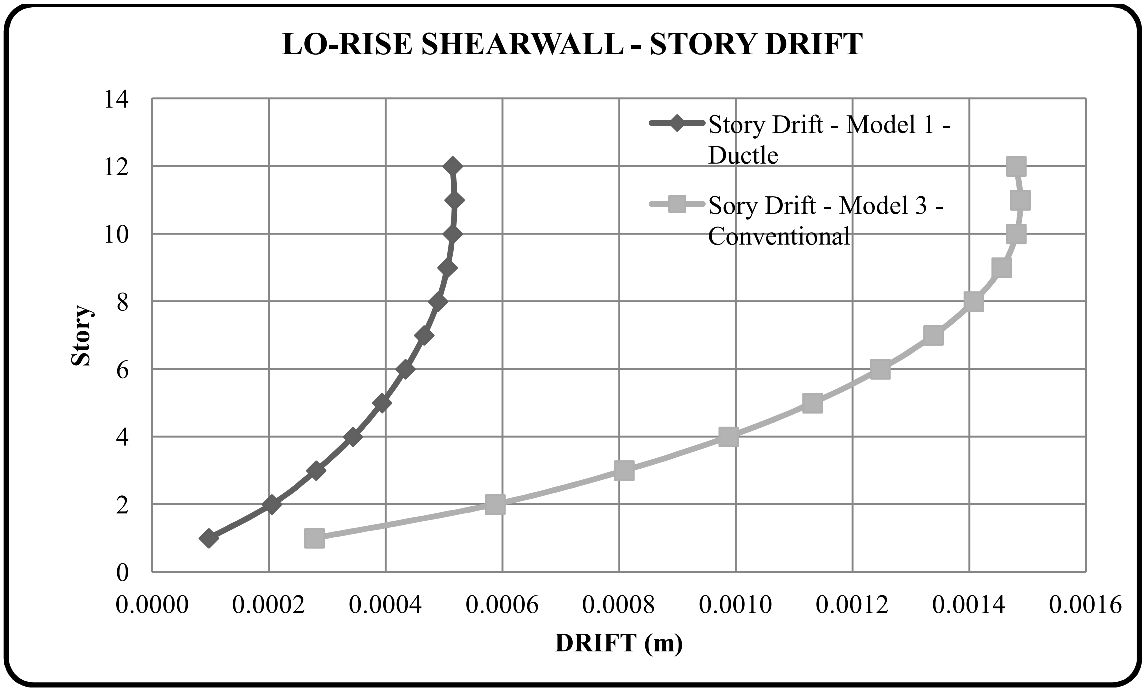


Figure 23: Low Rise Shear Wall SFRS: STORY DRIFT

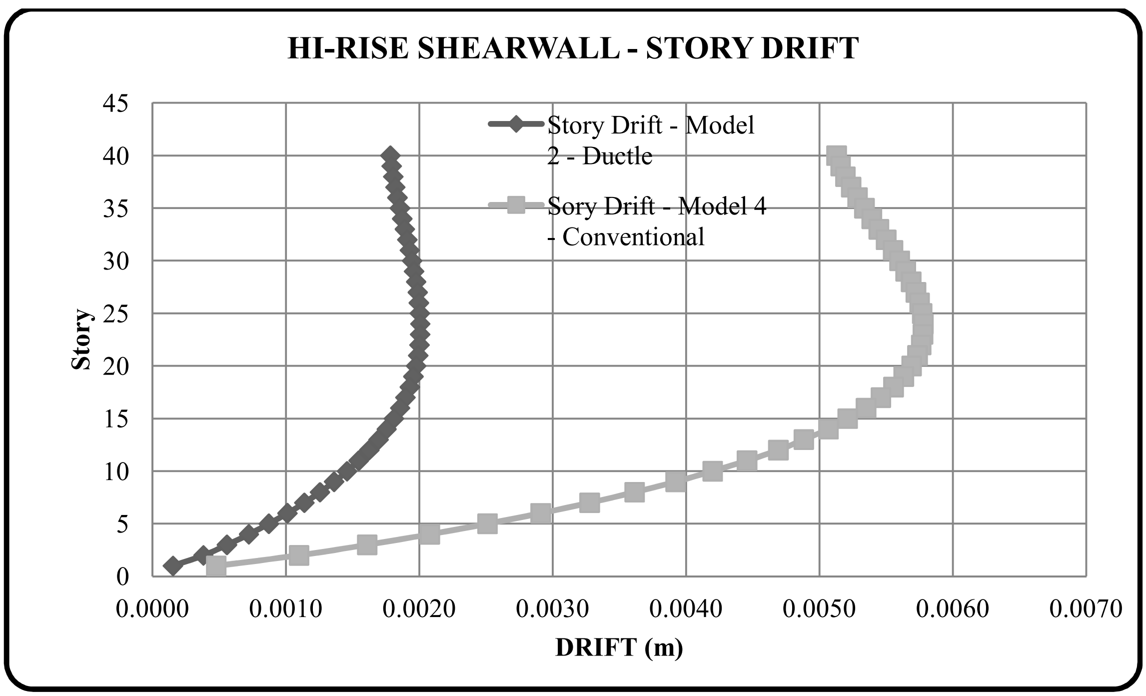


Figure 24: High Rise Shear Wall SFRS: STORY DRIFT

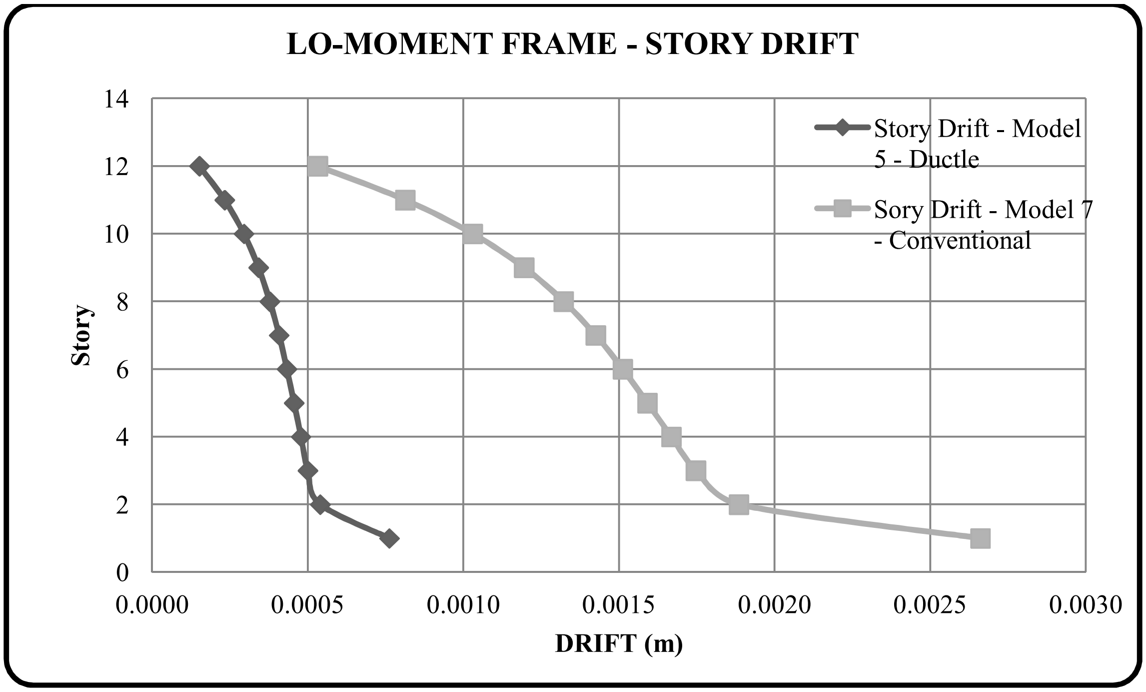


Figure 25: Low Rise Moment Frame SFRS: STORY DRIFT

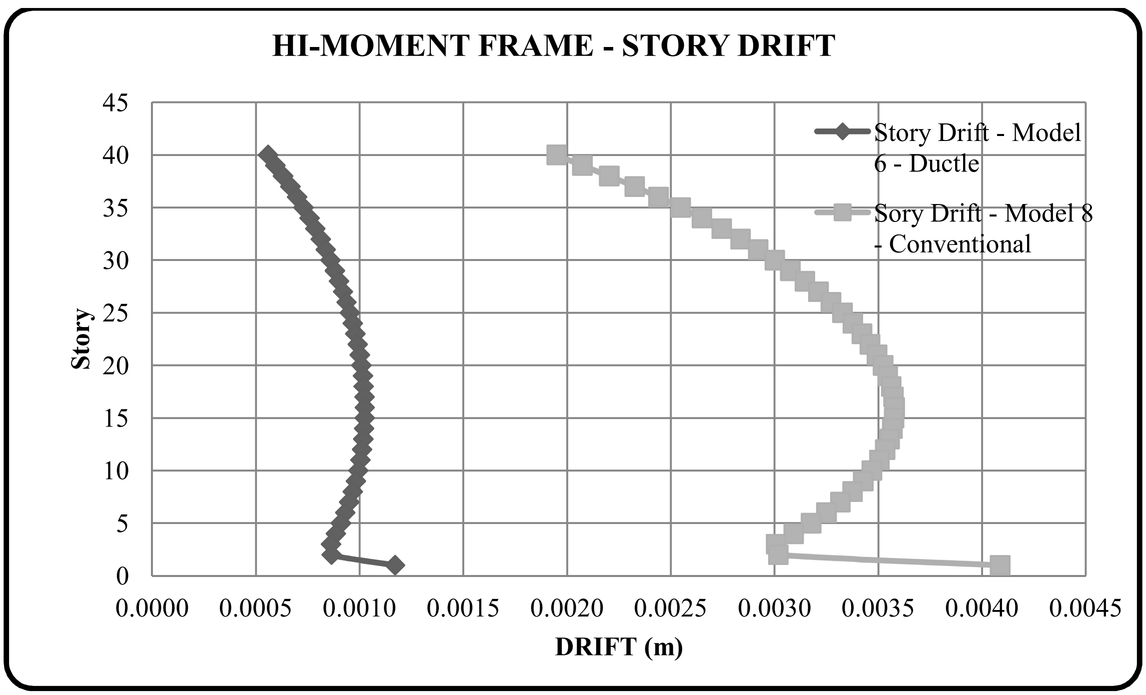


Figure 26: High Rise Moment Frame SFRS: STORY DRIFT

4.5 Member Forces: Shear Wall

The exterior wall at the S-E corner of the building was selected to provide sample results. Based on the results shown in Figure 27 to Figure 34Figure 26, the following are notable observations:

1. As expected, the slope of the conventional construction curves is significantly steeper than the ductile curves. The wall forces distributed throughout the height of the building is much more uniform for the ductile configuration hence the member sizes and capacity demand is more uniform for the ductile configuration as opposed to conventional construction. This means that similar wall and slab thickness would be required on the lower floors for a ductile configuration as opposed to a conventional construction that would require significantly larger members on the lower floors in order to meet the capacity demand requirements.
2. The conventional construction configurations, especially in the taller buildings appear to be sensitive to torsional effects at the lower floors when exposed to dynamic earthquake force. This is likely a contributing factor for the 20m and 40m height limitation in regions of mid to high seismicity, ≤ 0.35 ($I_E F_a S_a(0.2)$) ≤ 0.75 for moment resisting frames and shear wall respectively.

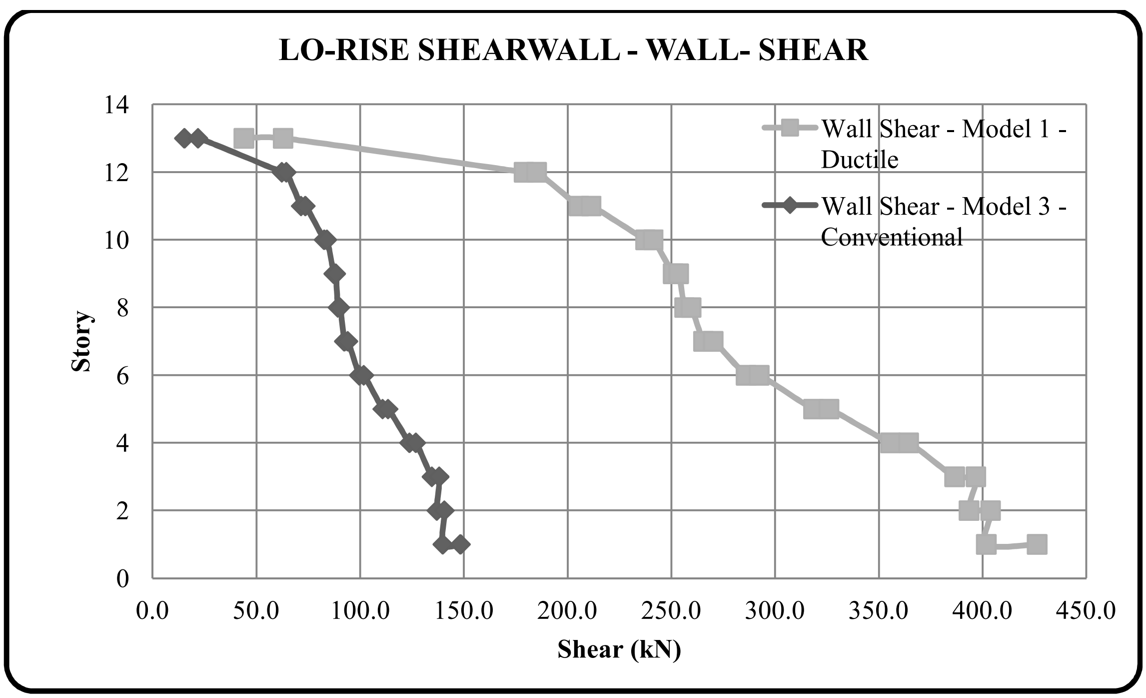


Figure 27: Low Rise Shear Wall SFRS: WALL SHEAR

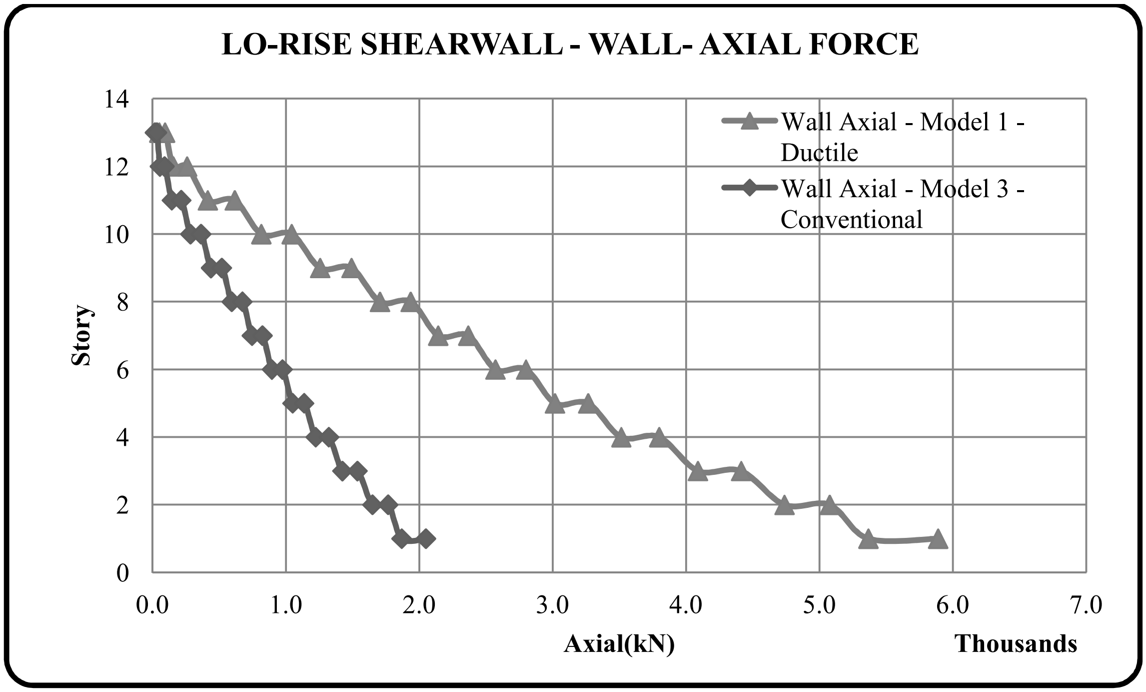


Figure 28: Low Rise Shear Wall SFRS: WALL AXIAL FORCE

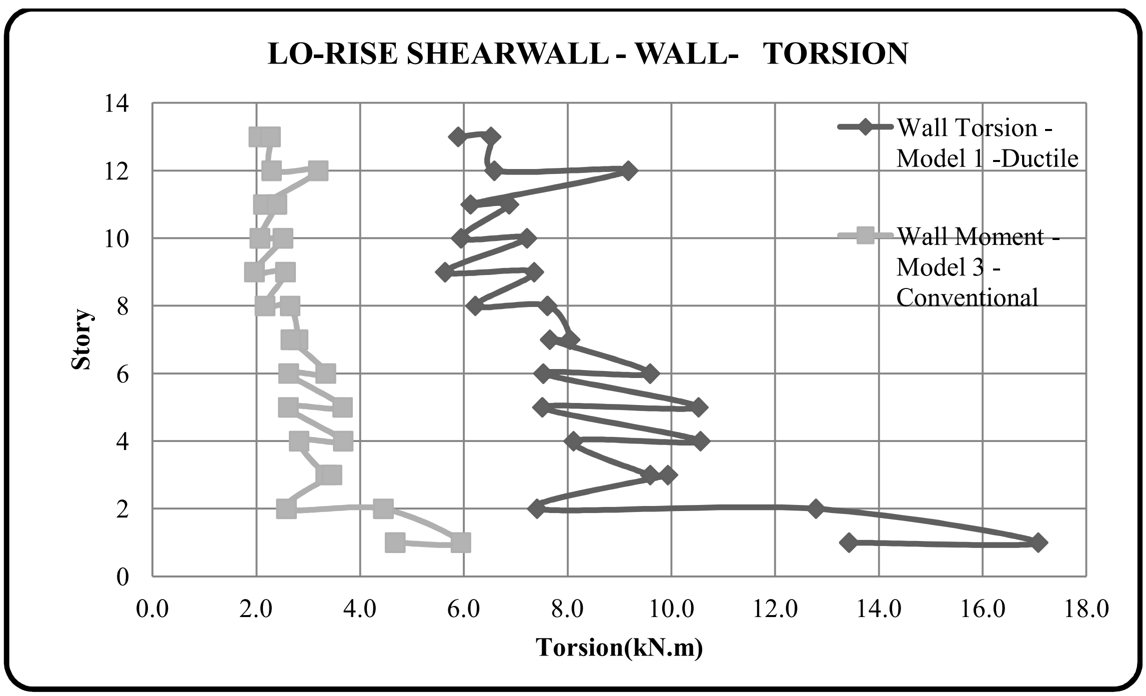


Figure 29: Low Rise Shear Wall SFRS: WALL TORSION

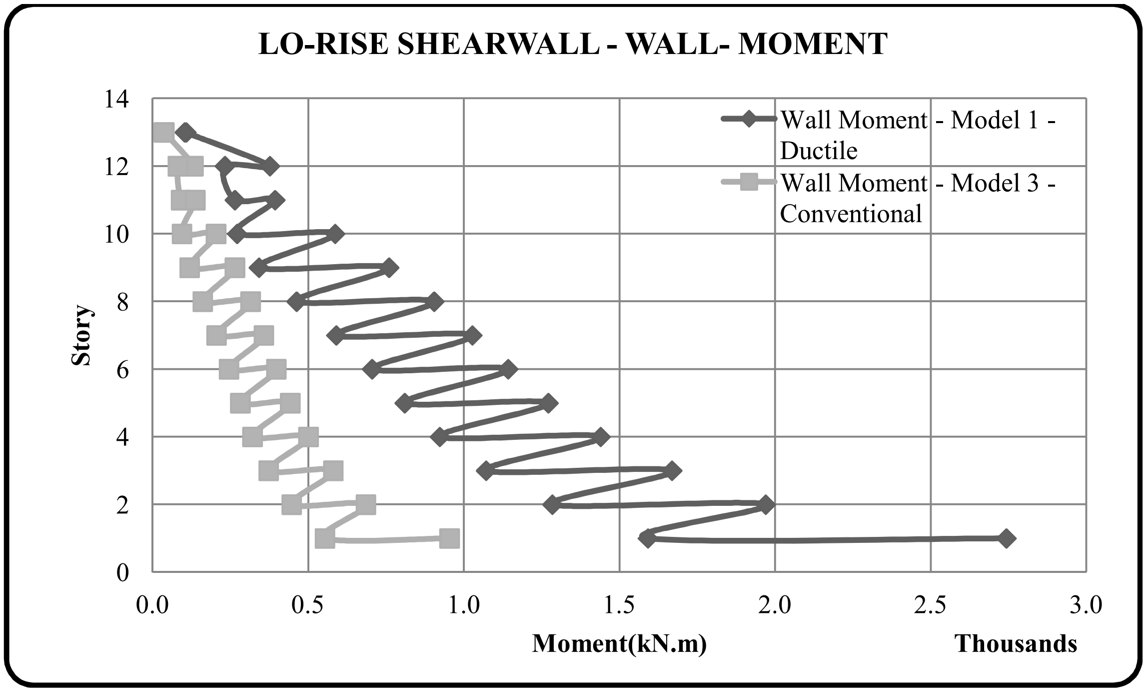


Figure 30: Low Rise Shear Wall SFRS: WALL MOMENT

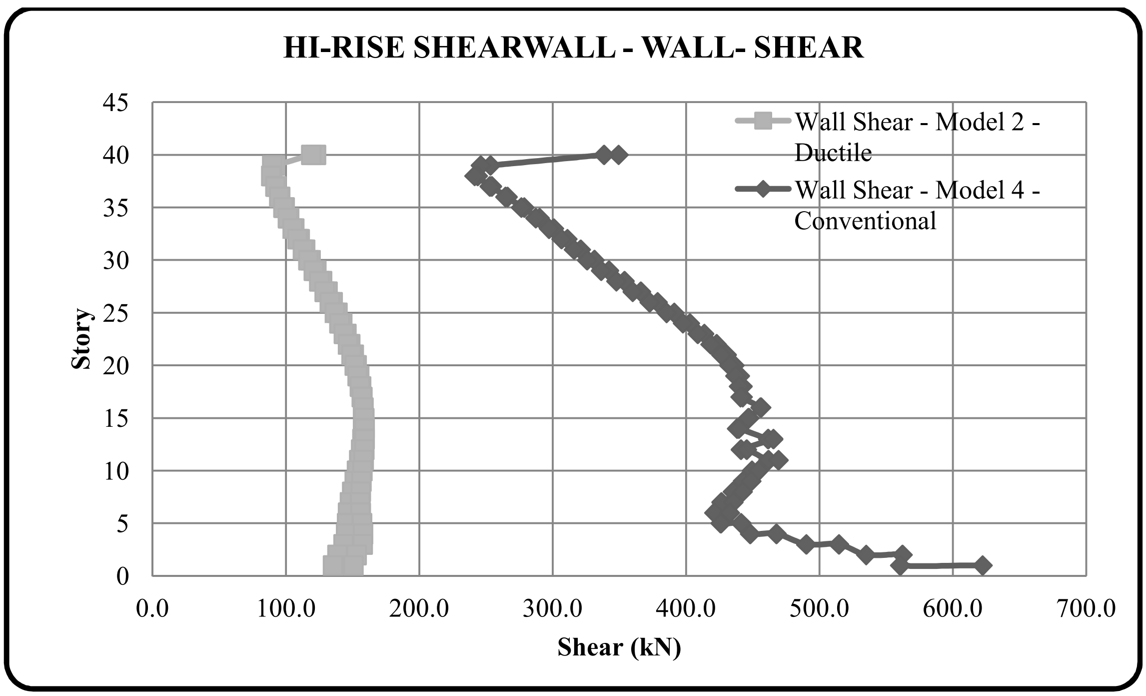


Figure 31: High Rise Shear Wall SFRS: WALL SHEAR

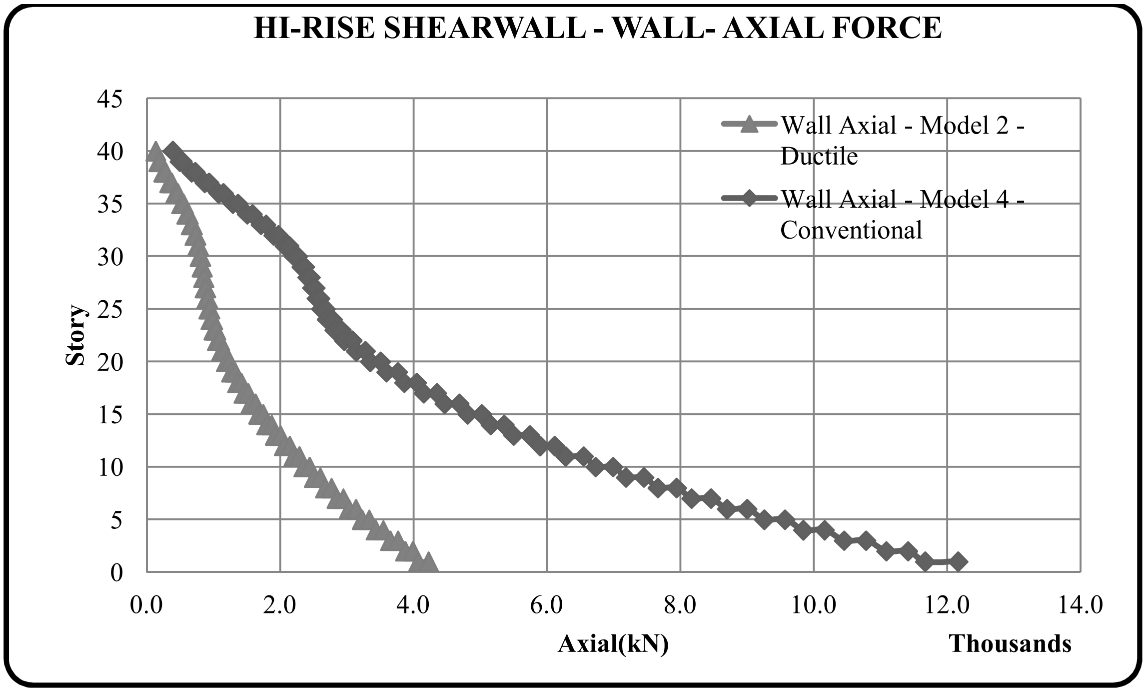


Figure 32: High Rise Shear Wall SFRS: WALL AXIAL FORCE

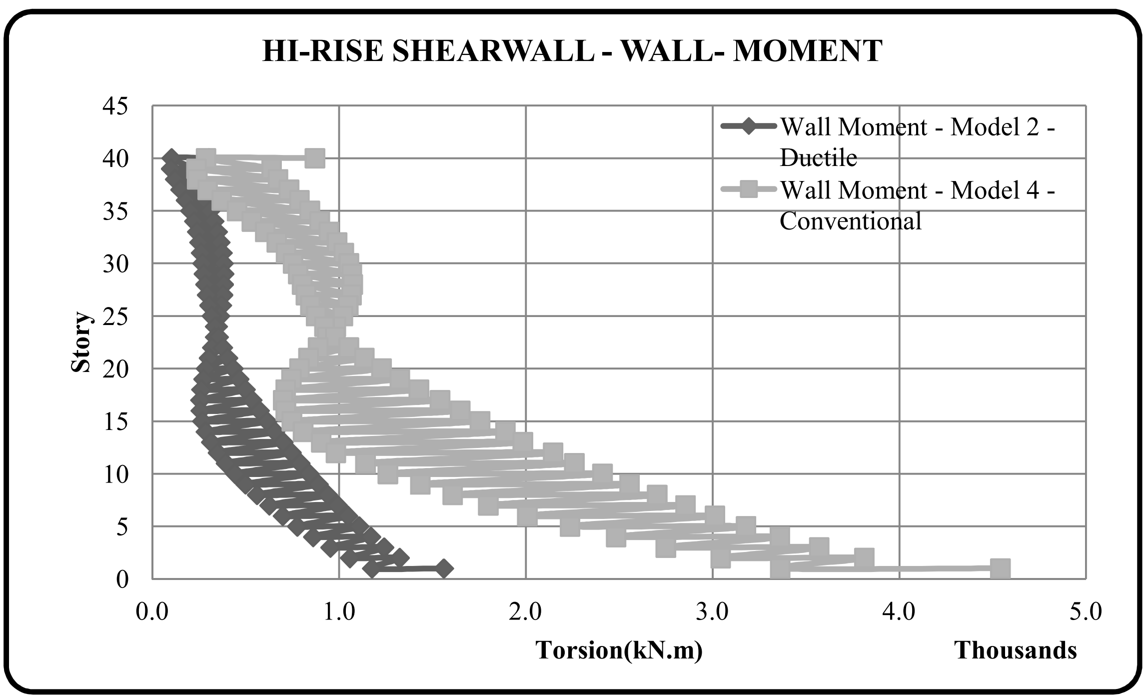


Figure 33: High Rise Shear Wall SFRS: WALL MOMENT

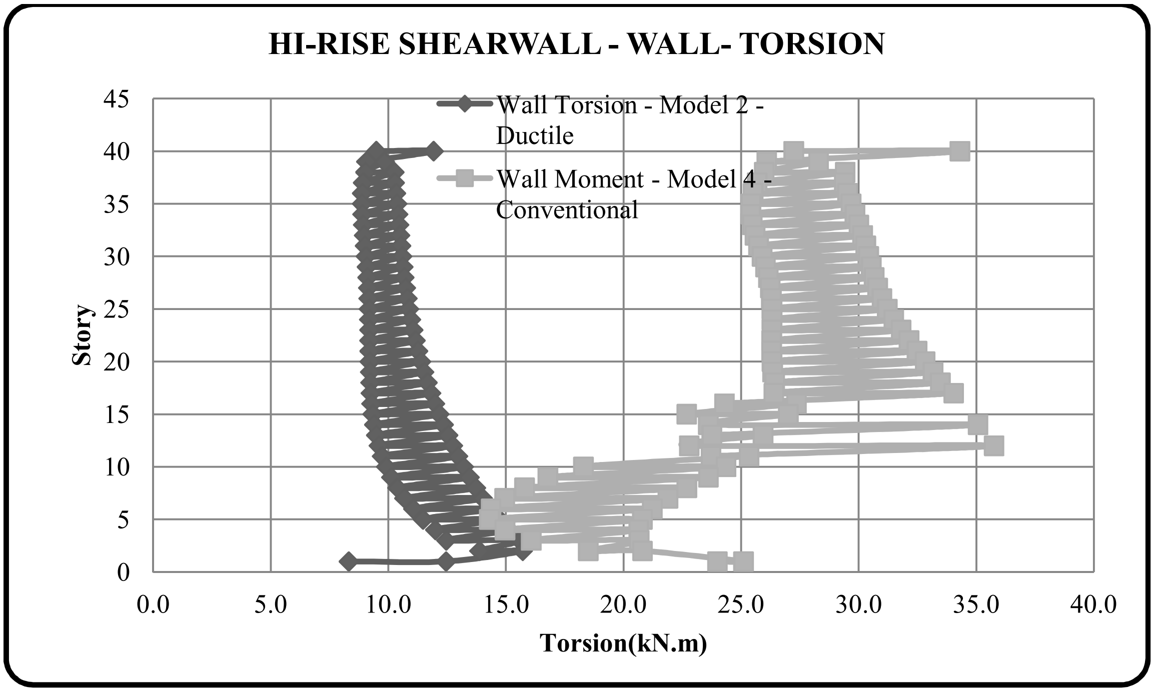


Figure 34: High Rise Shear Wall SFRS: WALL TORSION

4.6 Member Forces: Moment Frame

The exterior beam at the N-W corner of the building was selected to provide sample results. Based on the results shown in Figure 35 toFigure 34Figure 26, the following are notable observations:

1. As expected, the slope of the conventional construction curves is significantly steeper than the ductile curves. The beam forces distributed throughout the height of the building is much more uniform for the ductile configuration hence the member sizes and capacity demand is more uniform for the ductile configuration as opposed to conventional construction. This means that similar beam and slab thickness would be required on the lower floors for a ductile configuration as opposed to a conventional construction that would require significantly larger members on the lower floors in order to meet the capacity demand requirements.
2. The conventional construction configurations, especially in the taller buildings appear to be sensitive to torsional effects at the lower floors when exposed to dynamic earthquake force. This is likely a contributing factor for the 20m and 40m height limitation in regions of mid to high seismicity, ≤ 0.35 ($I_E F_a S_a(0.2)$) ≤ 0.75 for moment resisting frames and shear wall respectively.

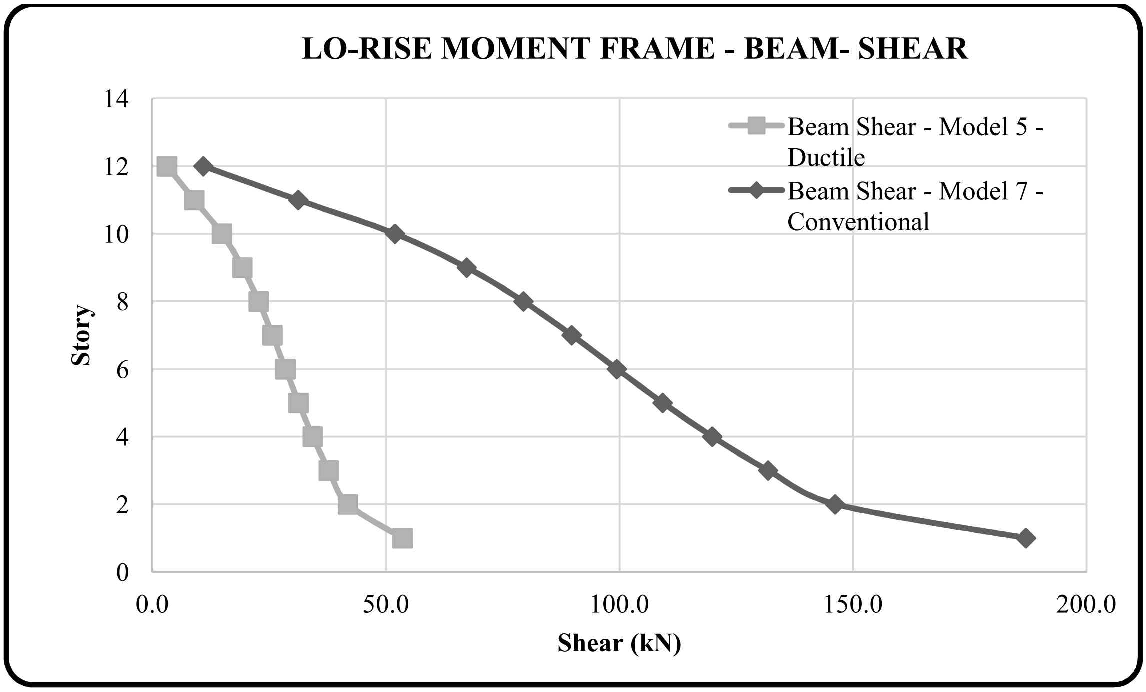


Figure 35: Low Rise Moment Frame SFRS: BEAM SHEAR

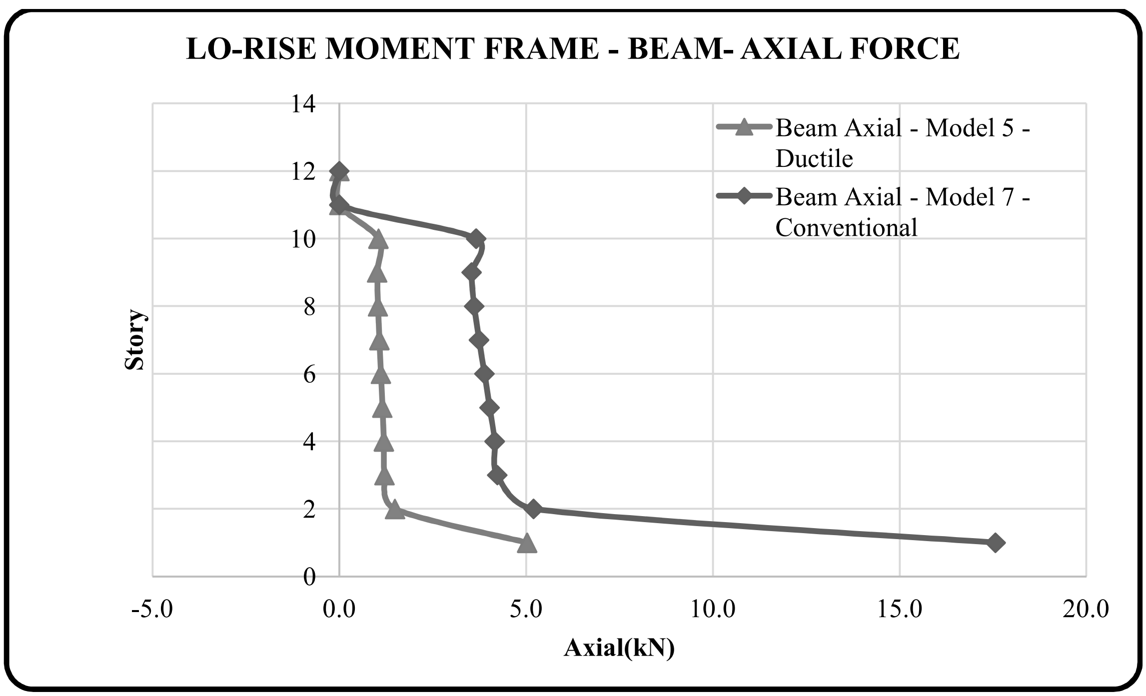


Figure 36: Low Rise Moment Frame SFRS: BEAM AXIAL FORCE

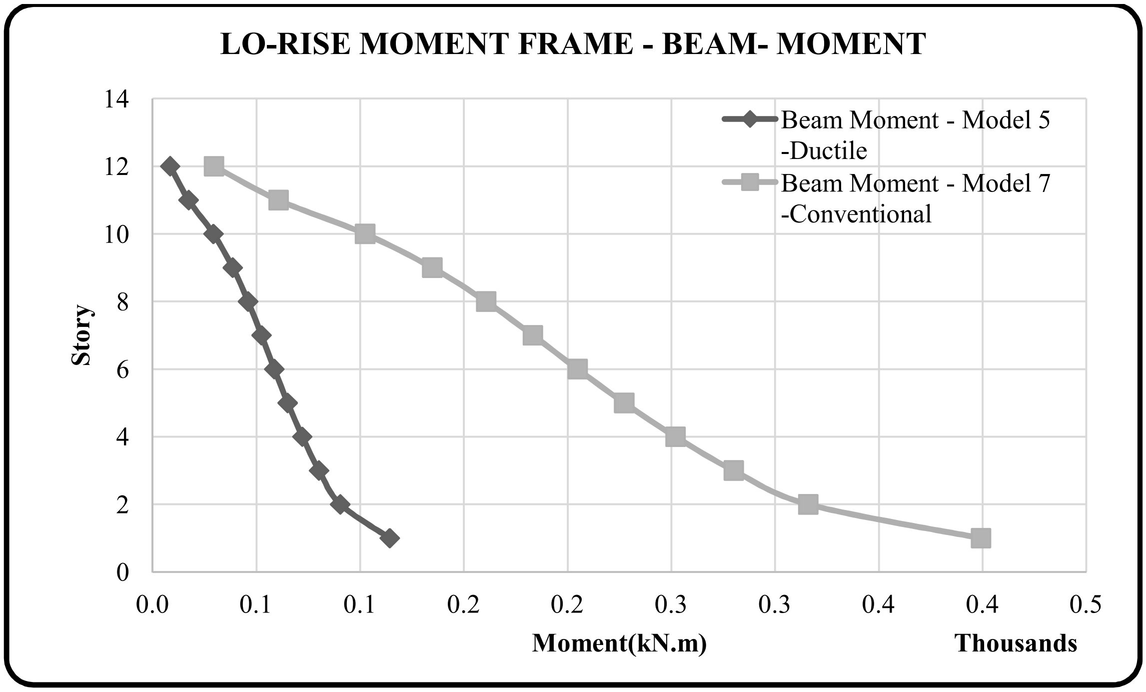


Figure 37: Low Rise Moment Frame SFRS: BEAM MOMENT

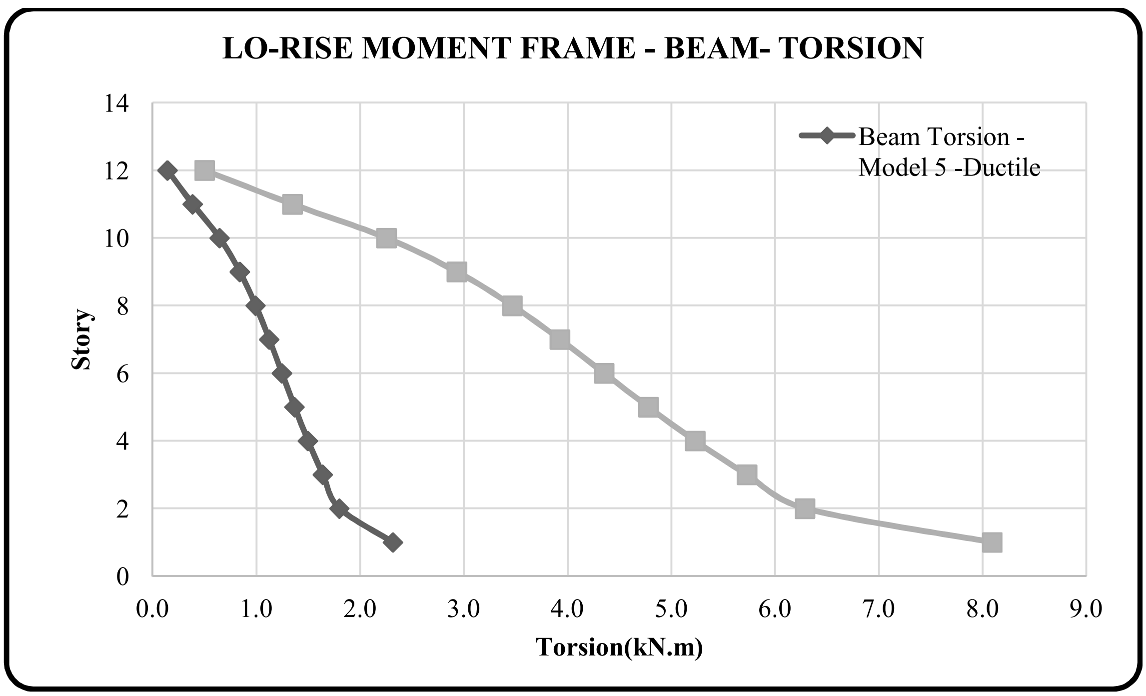


Figure 38: Low Rise Moment Frame SFRS: BEAM TORSION

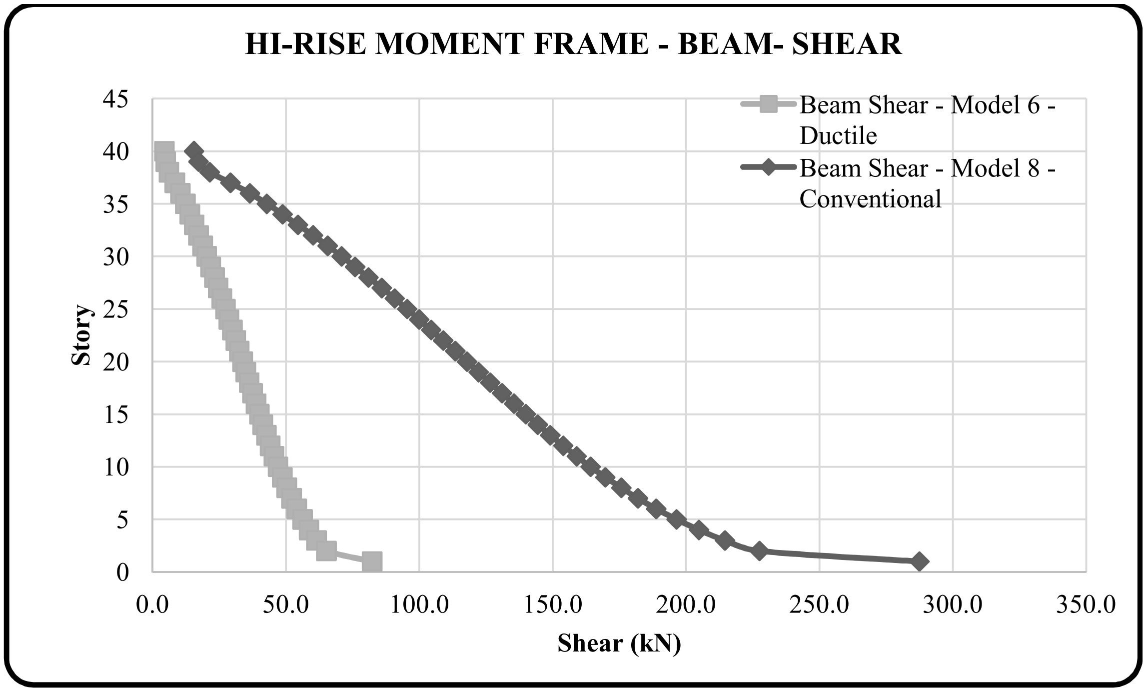


Figure 39: High Rise Moment Frame SFRS: BEAM SHEAR

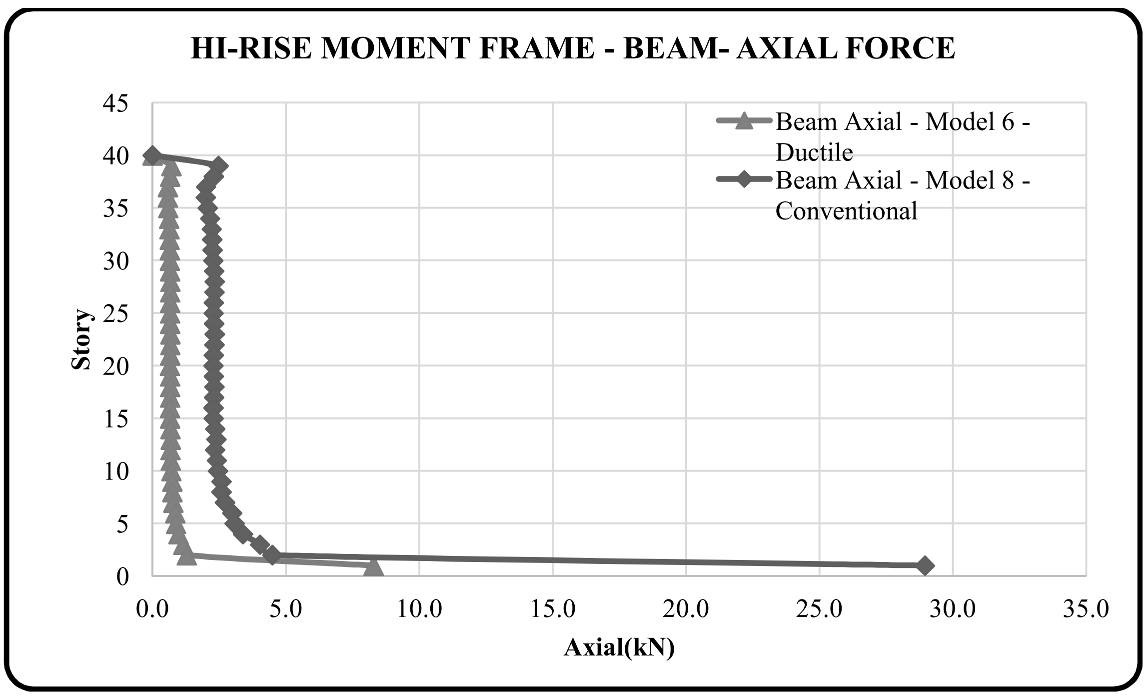


Figure 40: High Rise Moment Frame SFRS: BEAM AXIAL FORCE

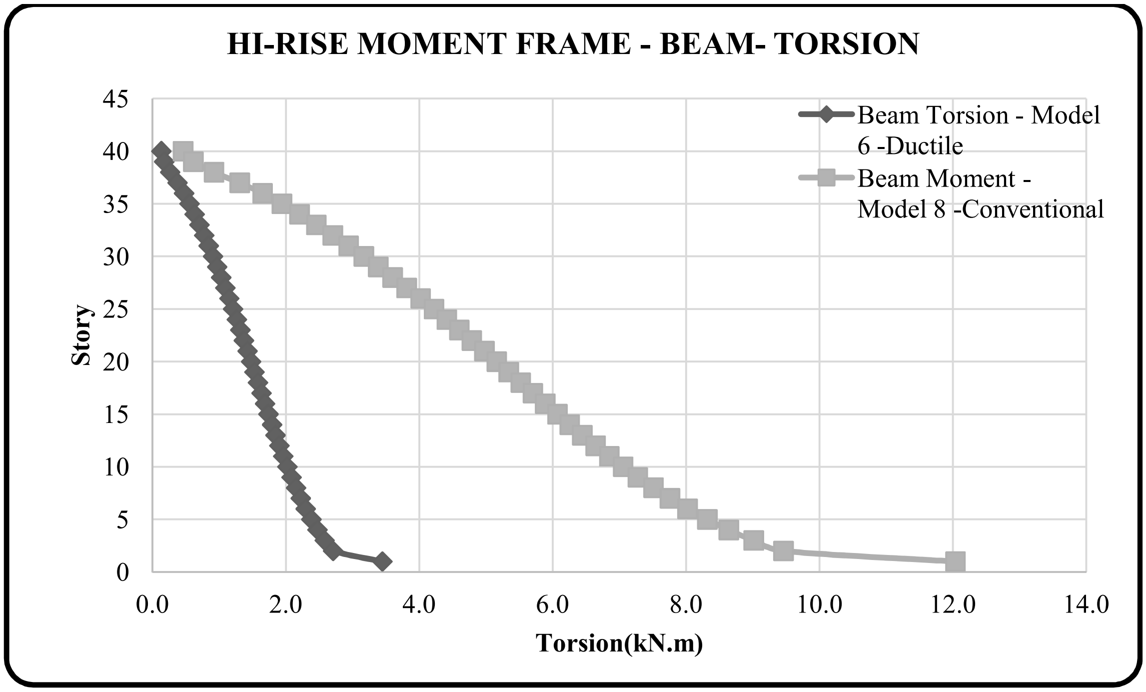


Figure 41: High Rise Moment Frame SFRS: BEAM TORSION

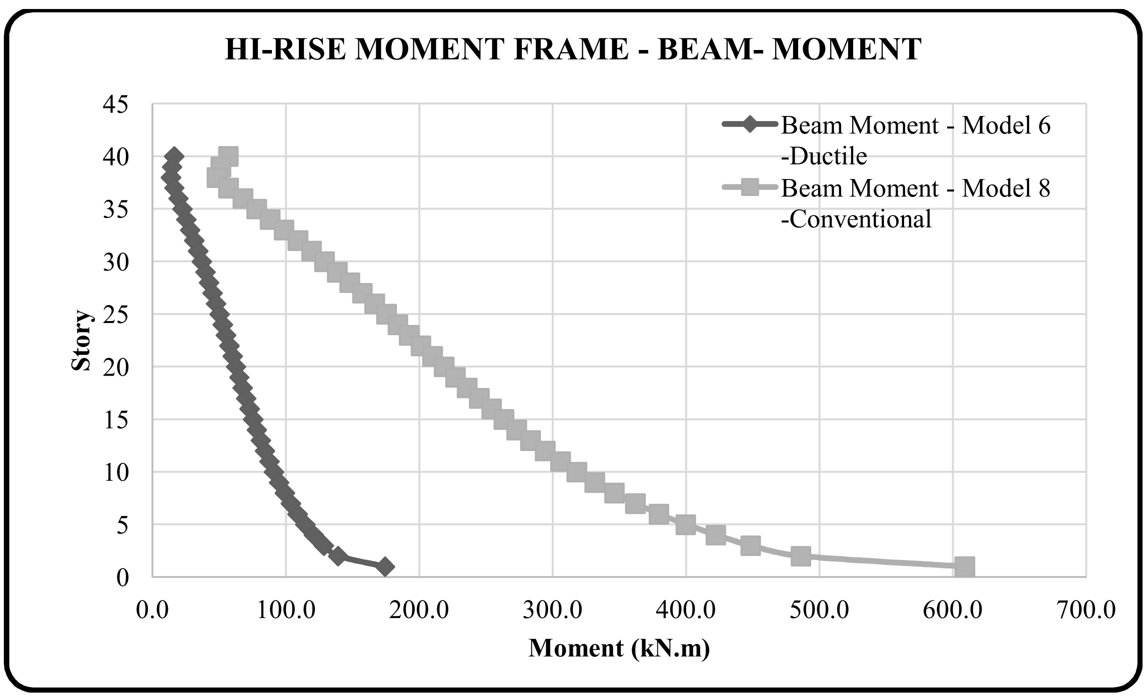


Figure 42: High Rise Moment Frame SFRS: BEAM MOMENT

Chapter 5 Conclusions and recommendations

5.1 Conclusions

Response Spectrum Analysis of an assembly of 8 buildings located in Montreal, Quebec, with varying heights, SFRS types and ductility and overstrength factors was performed in Etabs. The obtained results from the dynamic analysis were also compared to the static Equivalent Lateral Force Procedure as stipulated in the NBCC 2015 Seismic code provisions. The following are conclusions deducted from the analysis and interpretation of the results.

1. For shear wall configurations, using RSA, the base shear of both the 12 and 40 story buildings are similar for both the ductile and conventional construction. While this result is unexpected, the significantly larger period for the 40 story structure, as well as the high ductility (flexibility) of both structures might account for these results. The higher the natural period of a structure is an indicator of higher flexibility, with ductile structures having smaller k values; hence the base shear tends to be smaller as well since generally flexible structures experiences lower accelerations than stiffer buildings.
2. For the 12 story buildings, the seismic base shear obtained through both the RSA and ELFP are within 20% or less discrepancy with the RSA results lower for both the ductile and conventional shear wall buildings. This result is also similar for the moment frame buildings as well. These results justify the NBCC code upper limit of 60m in building height above base that can be designed using the static ELFP procedure.
3. The results obtained from the ELFP for the taller structure, (147.2m) is overly conservative. It is observed that for the 40 story buildings, the seismic base shear obtained through the RSA and ELFP are markedly different. Again, this is an indication that the effect of the ductility of the building is magnified as building height increases due to the increase in the natural period. The results for the moment frame 40 storey buildings follow a similar pattern as well.
5. The lateral force distribution of shear walls and moment frames were similar, with the lateral loads distributed between the two systems according to their relative stiffness. However, in general, the two systems deform with their own characteristic shapes. The interaction between the two, particularly at the upper levels of the buildings, results in quite a different lateral load distribution.
6. The results obtained from the response spectrum analysis appear to be scaled linearly by the ratio of the RdRo factors of the SFSR configuration. This result is consistent with all 8

models.

7. The shear wall and frame appear to display constant stiffness throughout the height of the structure based on the similar design of each floor.
4. The slope of the shear wall curves appear to be more steep that the moment frame curves as is expected as the shear wall acts as vertical cantilever column with a greater slope at the top.
5. As expected, the slope of the conventional construction curves is significantly steeper than the ductile curves. The wall forces distributed throughout the height of the building is much more uniform for the ductile configuration hence the member sizes and capacity demand is more uniform for the ductile configuration as opposed to conventional construction. This means that similar wall and slab thickness would be required on the lower floors for a ductile configuration as opposed to a conventional construction that would require significantly larger members on the lower floors in order to meet the capacity demand requirements.
6. The conventional construction configurations, especially in the taller buildings appear to be sensitive to torsional effects at the lower floors when exposed to dynamic earthquake force. This is likely a contributing factor for the 20m and 40m height limitation in regions of mid to high seismicity, ≤ 0.35 (I_EFaSa(0.2)) ≤ 0.75 for moment resisting frames and shear wall respectively.

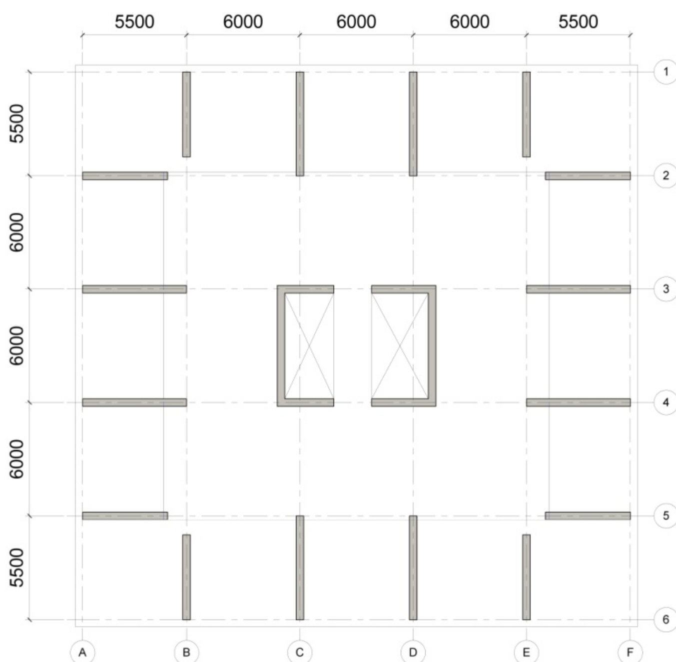
5.2 Limitations of the Study

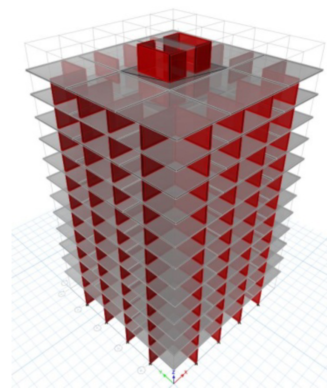
1. Only the effects of the horizontal force were considered.
2. The practical limitations of mathematical response spectrum analysis modeling including interacting effects of inelastic elements to determine the effects of ductility and plastic hinge development demands, strong column-weak beam demands, etc was not performed.
3. The performance / capacity demand and design was outside the scope of this study.
4. The hysteretic behavior of members was assumed which might pose limitations on the results obtained.
5. Soil structure and foundation interactions were not considered.
6. The accidental torsional effects as per NBCC 2015 Seismic Code provisions were also outside the scope of this study.

5.3 Recommendations for further study

1. A non-linear time history analysis of the eight buildings to determine the inelastic deformation demands such as the criteria for "Strong Column – Weak Beam" or the high ductility demands of the moment frame joints and the column/beam capacity ratio.
2. An in-depth review of the detailing and design requirements per CSA A23.3-14 code provisions to achieve high ductility in the respective concrete SFRS. An overall cost comparison of the ductile and conventional framed building would also be worthwhile.
3. The inclusion of the wind load in addition to the earthquake load to compare the seismic shear demands with the wind shears.
4. Further study of the effects of structural irregularities such as Vertical Stiffness, Weight (Mass), or Out-of-Plane offset irregularities on the results obtained.

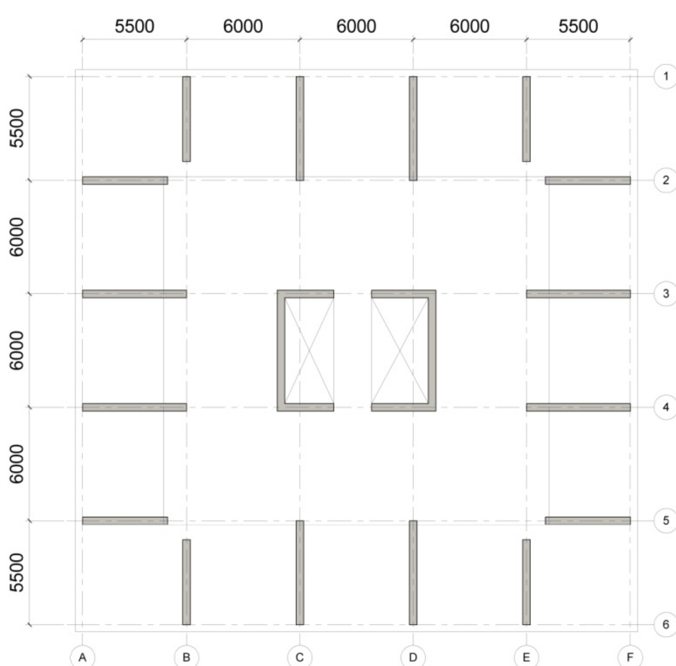
Appendix A: Plans, Elevations, Material & Section properties and Loading

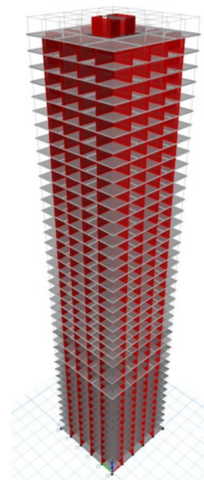




f_c: 30MPa
Walls: 400mm

Model 1: Lo-Rise Shear Wall - Ductile	Rd = 3.5, Ro = 1.5,





f_c: 30MPa
Walls: 400mm

Model 2: Hi-Rise Shear Wall - Ductile	Rd = 3.5, Ro = 1.5,

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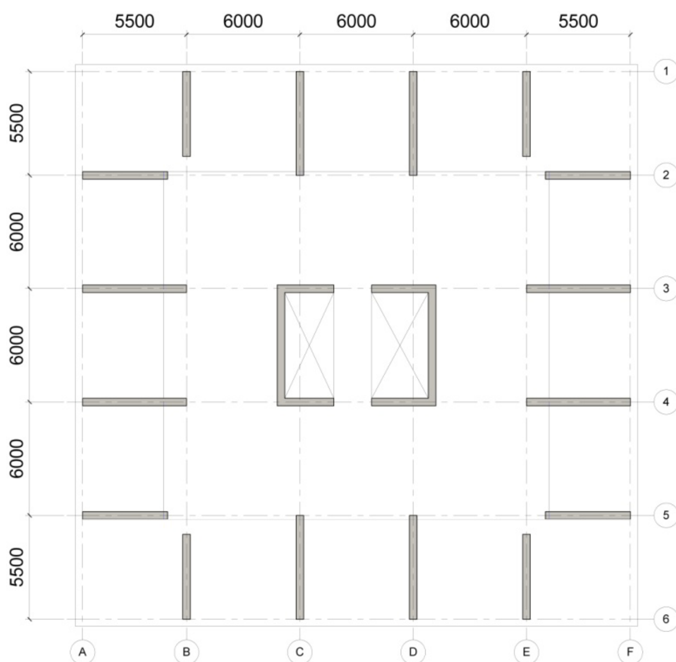
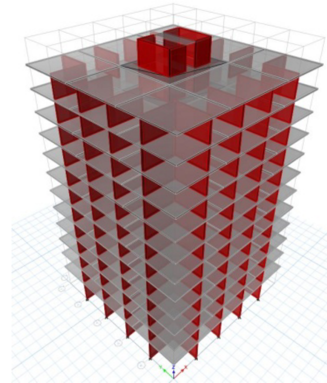
<td></td>
<td>
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Walls: 400mm</td>
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<td>Model 3: Lo-Rise Shear Wall – Conventional</td>
<td>Rd = 1.6, Ro = 1.3,</td>
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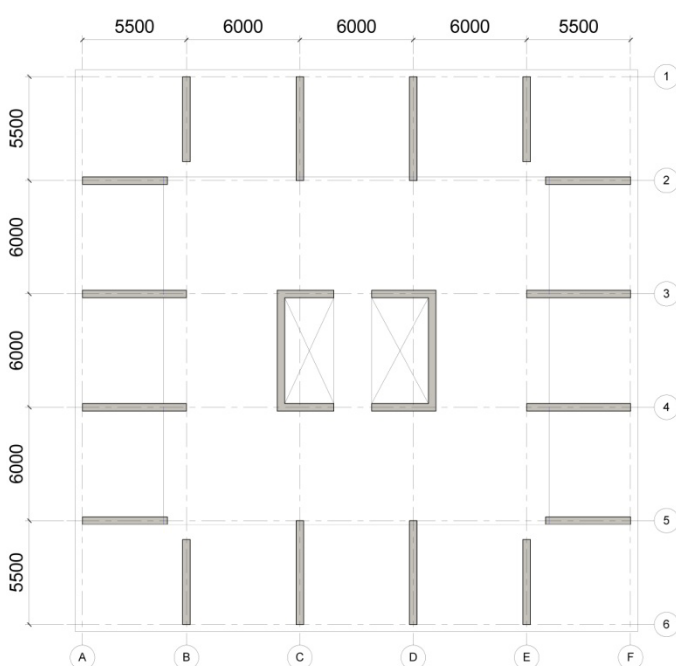
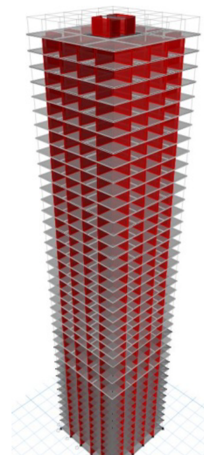
<td></td>
<td>
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Walls: 400mm</td>
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<td>Model 4: Hi-Rise Shear Wall – Conventional</td>
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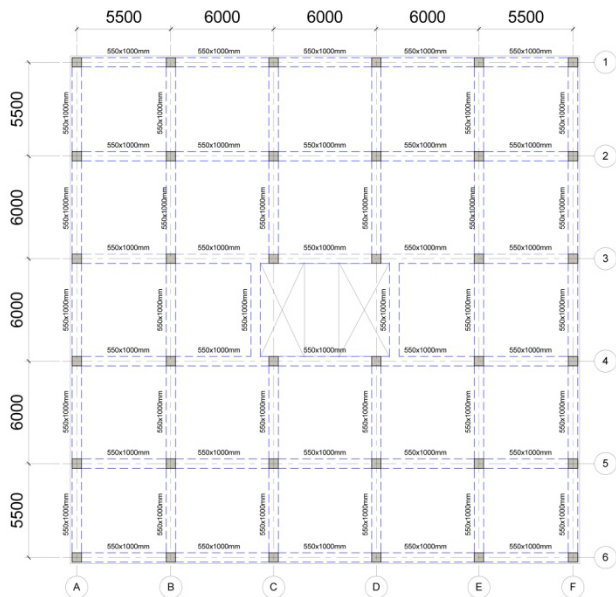

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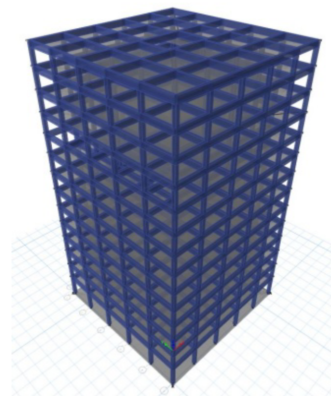
f_c: 30MPa
Beams: 550mm W x 1000mm D
Cols: 550mm x550mm
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</tr>
<tr>
<td>Model 5: Lo-Rise Moment Frame - Ductile</td>
<td>Rd = 4.0, Ro = 1.7,</td>
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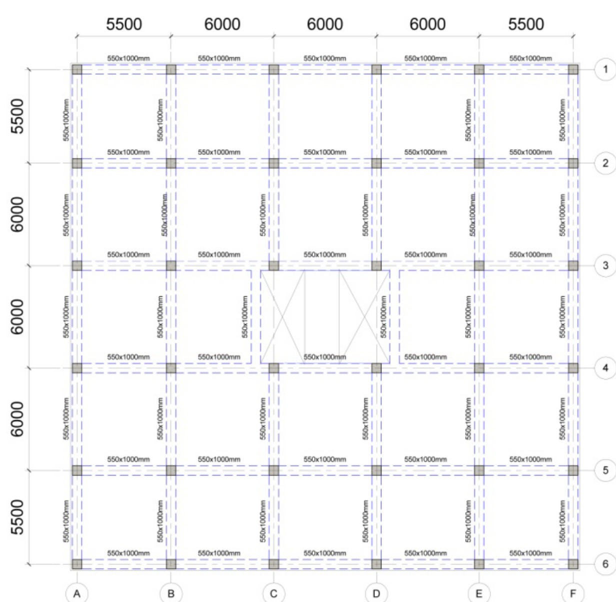

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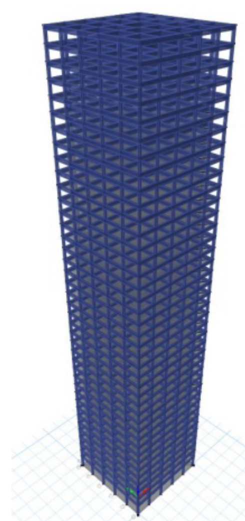
f_c: 30MPa
Beams: 550mm W x 1000mm D
Cols: 550mmx550mm
</td>
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<tr>
<td>Model 6: Hi-Moment Frame - Ductile</td>
<td>Rd = 4.0, Ro = 1.7,</td>
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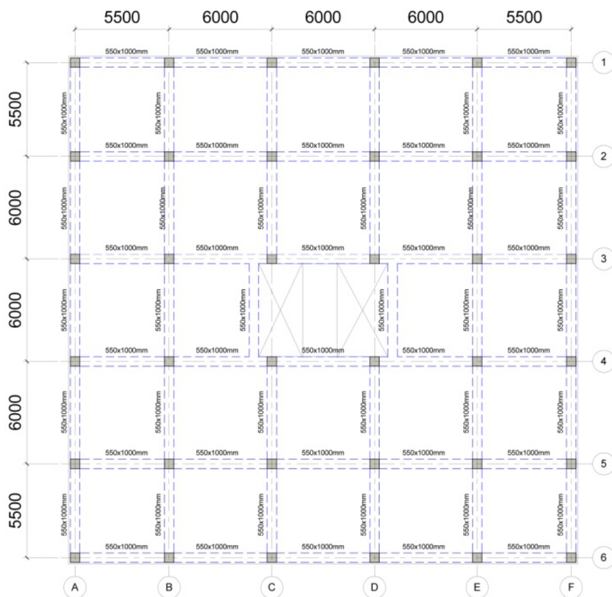
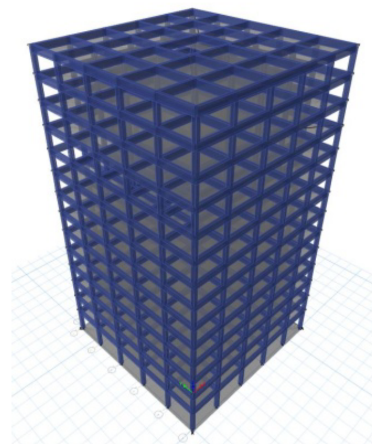
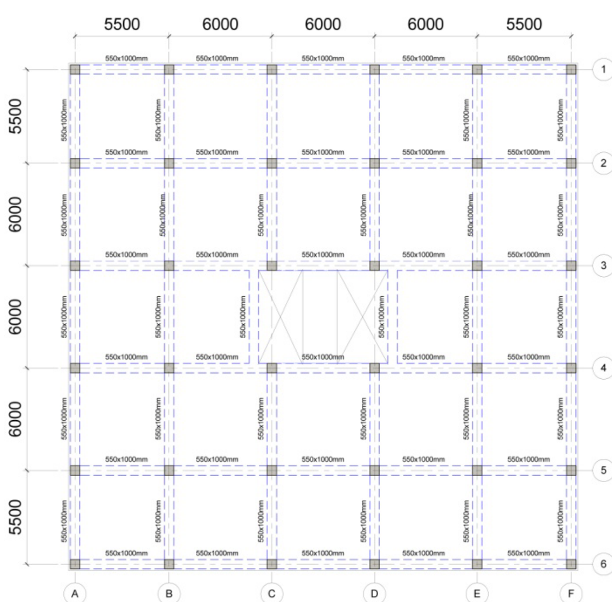
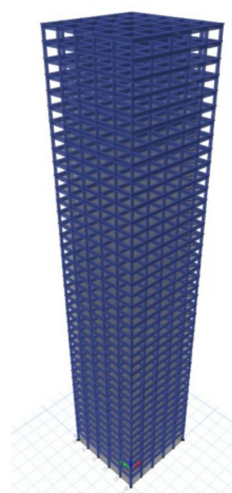
	 f_c: 30MPa Beams: 550mm Wx 1000mm D Cols: 550mmx550mm
Model 7: Lo-Rise Moment Frame – Conventional	Rd = 1.6, Ro = 1.3,
	 f_c: 30MPa Beams: 550mm Wx 1000mm D Cols: 550mmx550mm
Model 8: Hi-Rise Moment Frame – Conventional	Rd = 1.6, Ro = 1.3,

Appendix B: Response Spectrum Analysis Results

Part I – Concrete Shear Wall - Low – Rise (Ductile /Conventional Framing)

STORY DRIFTS		
	MODEL 1	MODEL 3
Story	**Drift (m)**	**Drift (m)**
12	0.000515	0.001481
11	0.000518	0.001488
10	0.000515	0.001481
9	0.000506	0.001456
8	0.00049	0.001408
7	0.000466	0.001339
6	0.000434	0.001248
5	0.000394	0.001132
4	0.000344	0.000988
3	0.000281	0.000809
2	0.000205	0.000588
1	0.000097	0.000278

BASE REACTIONS - MODEL 1						
Load Case/Combo	**FX**	**FY**	**FZ**	**MX**	**MY**	**MZ**
	kN	kN	kN	kN-m	kN-m	kN-m
SPECX1 Max	3749	4050	0	92124	83619	66162
BASE REACTIONS - MODEL 3						
Load Case/Combo	**FX**	**FY**	**FZ**	**MX**	**MY**	**MZ**
	kN	kN	kN	kN-m	kN-m	kN-m
SPECX1 Max	10775	11641	0	264789	240345	190033

STORY FORCES - MODEL 1						
Story	**Location**	**VX**	**VY**	**T**	**MX**	**MY**
		kN	kN	kN-m	kN-m	kN-m
12	Top	892	921	15268	262	278
12	Bottom	1053	1094	18083	3948	3832
11	Top	1492	1575	25803	3948	3832
11	Bottom	1571	1665	27229	9854	9405
10	Top	1765	1891	30776	9854	9405
10	Bottom	1797	1929	31380	16690	15745
9	Top	1868	2019	32811	16689	15744
9	Bottom	1878	2034	33055	23653	22116
8	Top	1910	2082	33816	23652	22115
8	Bottom	1921	2097	34059	30353	28161
7	Top	1996	2185	35478	30352	28159
7	Bottom	2027	2220	36046	36735	33836
6	Top	2193	2400	38964	36733	33834
6	Bottom	2249	2461	39949	43044	39393
5	Top	2496	2726	44236	43043	39391
5	Bottom	2570	2805	45509	49748	45291
4	Top	2859	3111	50491	49747	45288
4	Bottom	2937	3194	51843	57364	52045
3	Top	3219	3492	56707	57363	52043
3	Bottom	3289	3566	57921	66274	60045
2	Top	3518	3807	61916	66273	60043
2	Bottom	3568	3860	62804	76590	69407
1	Top	3708	4007	65354	76589	69405
1	Bottom	3749	4050	66162	92124	83619

STORY FORCES - MODEL 3						
Story	**Location**	**VX**	**VY**	**T**	**MX**	**MY**
		kN	kN	kN-m	kN-m	kN-m
12	Top	2563	2648	43852	753	799
12	Bottom	3028	3145	51936	11349	11016
11	Top	4287	4528	74110	11349	11016
11	Bottom	4516	4787	78205	28324	27034
10	Top	5074	5435	88393	28322	27032
10	Bottom	5166	5544	90127	47972	45256
9	Top	5368	5803	94240	47969	45253
9	Bottom	5398	5847	94940	67985	63568
8	Top	5489	5985	97128	67981	63564
8	Bottom	5522	6028	97824	87244	80942
7	Top	5737	6280	101900	87240	80938
7	Bottom	5827	6381	103533	105586	97254
6	Top	6302	6898	111913	105581	97249
6	Bottom	6464	7073	114743	123722	113226
5	Top	7174	7835	127055	123717	113220
5	Bottom	7386	8061	130712	142991	130178
4	Top	8217	8943	145021	142986	130171
4	Bottom	8443	9182	148902	164882	149593
3	Top	9252	10037	162874	164876	149587
3	Bottom	9453	10249	166359	190491	172585
2	Top	10112	10942	177835	190487	172580
2	Bottom	10256	11094	180385	220141	199495
1	Top	10658	11517	187712	220138	199491
1	Bottom	10775	11641	190033	264789	240345

WALL FORCES - MODEL 1						
Story	**Pier**	**Location**	**P(kN)**	**V2(kN)**	**T(kN.m)**	**M3(kN.m)**
12	W17	Top	158	178.98	6.59	377.09
12	W17	Bottom	259	185.03	9.17	232.78
11	W17	Top	414	205.51	6.13	264.41
11	W17	Bottom	617	211.37	6.88	393.76
10	W17	Top	816	237.55	5.95	271.76
10	W17	Bottom	1044	241.26	7.22	586.86
9	W17	Top	1257	250.89	5.64	342.01
9	W17	Bottom	1492	253.53	7.36	759.9
8	W17	Top	1705	256.35	6.22	463.08
8	W17	Bottom	1935	259.47	7.61	904.98
7	W17	Top	2142	265.5	8.05	590.6
7	W17	Bottom	2366	270.17	7.66	1027.7
6	W17	Top	2571	286.04	9.59	705.41
6	W17	Bottom	2800	292.3	7.53	1142.6
5	W17	Top	3017	318.47	10.5	810.13
5	W17	Bottom	3266	325.95	7.51	1271.9
4	W17	Top	3514	355.61	10.6	923.01
4	W17	Bottom	3799	364.31	8.11	1439.9
3	W17	Top	4089	386.57	9.59	1071.7
3	W17	Bottom	4413	396.78	9.94	1669.1
2	W17	Top	4737	393.47	7.41	1284.7
2	W17	Bottom	5077	403.85	12.8	1970.1
1	W17	Top	5367	401.75	17.1	1591.6
1	W17	Bottom	5890	426.27	13.4	2743.3

WALL FORCES - MODEL 3						
Story	**Pier**	**Location**	**P(kN)**	**V2(kN)**	**T(kN.m)**	**M3(kN.m)**
12	W17	Top	54.846	62.297	2.294	131.1985
12	W17	Bottom	90.267	64.402	3.194	81.0161
11	W17	Top	144.09	71.548	2.134	92.0177
11	W17	Bottom	214.62	73.587	2.394	137.0226
10	W17	Top	283.85	82.701	2.07	94.5871

10	W17	Bottom	363.15	83.995	2.514	204.1981
9	W17	Top	437.26	87.348	1.963	119.0281
9	W17	Bottom	519.07	88.266	2.562	264.4002
8	W17	Top	593.12	89.252	2.167	161.1456
8	W17	Bottom	673.34	90.338	2.651	314.8744
7	W17	Top	745.17	92.44	2.801	205.5059
7	W17	Bottom	823.34	94.063	2.667	357.5546
6	W17	Top	894.63	99.59	3.338	245.4499
6	W17	Bottom	974.06	101.77	2.623	397.5562
5	W17	Top	1049.8	110.88	3.662	281.8899
5	W17	Bottom	1136.3	113.48	2.616	442.5275
4	W17	Top	1222.7	123.8	3.675	321.1651
4	W17	Bottom	1321.7	126.84	2.825	500.9785
3	W17	Top	1422.7	134.58	3.338	372.9083
3	W17	Bottom	1535.4	138.14	3.458	580.7475
2	W17	Top	1648.3	136.99	2.58	446.9937
2	W17	Bottom	1766.4	140.61	4.45	685.4367
1	W17	Top	1867.4	139.84	5.943	553.7638
1	W17	Bottom	2049.4	148.37	4.675	954.4202

Part II – Concrete Shear Wall - High – Rise (Ductile /Conventional Framing)

STORY DRIFTS					
	MODEL 2	MODEL 4		MODEL 2	MODEL 4
Story	**Drift (m)**	**Drift (m)**	**Story**	**Drift (m)**	**Drift (m)**
40	0.001783	0.005128	20	0.001976	0.00569
39	0.001793	0.005158	19	0.001955	0.005631
38	0.001805	0.005194	18	0.001929	0.005555
37	0.00182	0.005237	17	0.001896	0.00546
36	0.001836	0.005285	16	0.001856	0.005349
35	0.001854	0.005337	15	0.00181	0.005211
34	0.001872	0.005391	14	0.001755	0.005067
33	0.001891	0.005445	13	0.001694	0.004882
32	0.00191	0.005499	12	0.001624	0.004691
31	0.001928	0.005551	11	0.001545	0.004456
30	0.001945	0.0056	10	0.001458	0.004199
29	0.001961	0.005646	9	0.001361	0.003921
28	0.001976	0.005687	8	0.001255	0.003614
27	0.001988	0.005722	7	0.001138	0.003277
26	0.001997	0.00575	6	0.001011	0.00291
25	0.002004	0.005769	5	0.000872	0.002511
24	0.002007	0.005778	4	0.000722	0.002078
23	0.002006	0.005776	3	0.000558	0.001609
22	0.002001	0.005762	2	0.000381	0.001098
21	0.001991	0.005734	1	0.000153	0.000477

BASE REACTIONS - MODEL 2						
Load Case/Combo	**FX**	**FY**	**FZ**	**MX**	**MY**	**MZ**
	kN	**kN**	**kN**	**kN-m**	**kN-m**	**kN-m**
SPECX1 Max	3350	3705	0	259285	263691	65090
BASE REACTIONS - MODEL 4						
Load Case/Combo	**FX**	**FY**	**FZ**	**MX**	**MY**	**MZ**
	kN	**kN**	**kN**	**kN-m**	**kN-m**	**kN-m**
SPECX1 Max	11968	14277	0	745131	756673	303333

STORY FORCES - MODEL 2						
Story	**Location**	**VX**	**VY**	**T**	**MX**	**MY**
		kN	**kN**	**kN-m**	**kN-m**	**kN-m**
40	Top	476	510	7864	138	134
40	Bottom	569	612	9461	2209	2063
39	Top	847	926	14402	2209	2063
39	Bottom	904	993	15470	5762	5305
38	Top	1059	1183	18582	5762	5305
38	Bottom	1087	1219	19208	10211	9277
37	Top	1156	1312	20903	10211	9277
37	Bottom	1168	1328	21220	15076	13536
36	Top	1196	1363	22060	15076	13536
36	Bottom	1202	1369	22226	20020	17814
35	Top	1226	1384	22765	20020	17814
35	Bottom	1233	1389	22910	24863	22004
34	Top	1266	1409	23517	24863	22004
34	Bottom	1276	1416	23704	29550	26105
33	Top	1315	1448	24493	29550	26105
33	Bottom	1326	1458	24727	34102	30165
32	Top	1371	1496	25658	34102	30165
32	Bottom	1383	1507	25921	38573	34246

31	Top	1434	1549	26936	38573	34246
31	Bottom	1448	1561	27215	43023	38414
30	Top	1504	1609	28279	43023	38414
30	Bottom	1520	1623	28569	47515	42739
29	Top	1576	1676	29655	47515	42739
29	Bottom	1591	1690	29946	52111	47284
28	Top	1642	1744	31013	52111	47284
28	Bottom	1656	1759	31292	56873	52095
27	Top	1702	1808	32301	56873	52095
27	Bottom	1714	1820	32561	61845	57196
26	Top	1759	1863	33496	61845	57196
26	Bottom	1771	1874	33737	67051	62598
25	Top	1817	1912	34613	67051	62598
25	Bottom	1829	1923	34842	72503	68311
24	Top	1873	1962	35682	72503	68311
24	Bottom	1884	1972	35904	78205	74339
23	Top	1922	2012	36716	78205	74339
23	Bottom	1932	2023	36928	84161	80676
22	Top	1966	2060	37697	84161	80676
22	Bottom	1975	2069	37895	90370	87309
21	Top	2009	2100	38603	90370	87309
21	Bottom	2018	2108	38784	96825	94222
20	Top	2051	2135	39430	96825	94222
20	Bottom	2060	2142	39597	103511	101400
19	Top	2090	2170	40205	103511	101400
19	Bottom	2097	2178	40365	110408	108826
18	Top	2122	2206	40955	110408	108826
18	Bottom	2128	2214	41111	117502	116476
17	Top	2151	2241	41678	117502	116476
17	Bottom	2158	2248	41824	124778	124327
16	Top	2182	2272	42345	124778	124327
16	Bottom	2189	2277	42478	132216	132353

15	Top	2213	2300	42959	132216	132353
15	Bottom	2219	2307	43087	139796	140535
14	Top	2239	2333	43576	139796	140535
14	Bottom	2244	2341	43713	147498	148847
13	Top	2263	2373	44248	147498	148847
13	Bottom	2269	2381	44396	155308	157264
12	Top	2293	2413	44945	155308	157264
12	Bottom	2300	2421	45090	163212	165762
11	Top	2327	2454	45623	163212	165762
11	Bottom	2334	2463	45769	171194	174320
10	Top	2361	2506	46370	171194	174320
10	Bottom	2368	2519	46555	179243	182918
9	Top	2402	2578	47359	179243	182918
9	Bottom	2414	2596	47604	187356	191535
8	Top	2464	2667	48595	187356	191535
8	Bottom	2480	2688	48877	195537	200159
7	Top	2543	2770	49992	195537	200159
7	Bottom	2561	2795	50321	203798	208785
6	Top	2637	2901	51753	203798	208785
6	Bottom	2660	2934	52204	212155	217412
5	Top	2763	3063	54083	212155	217412
5	Bottom	2794	3098	54609	220642	226048
4	Top	2907	3219	56482	220642	226048
4	Bottom	2936	3250	56956	229290	234710
3	Top	3035	3366	58792	229290	234710
3	Bottom	3064	3399	59357	238109	243402
2	Top	3181	3524	61582	238109	243402
2	Bottom	3205	3548	62011	247107	252120
1	Top	3269	3617	63272	247107	252120
1	Bottom	3349	3705	65087	259285	263691

STORY FORCES - MODEL 4						
Story	Location	VX	VY	T	MX	MY
		kN	kN	kN-m	kN-m	kN-m
40	Top	814	960	14836	243	207
40	Bottom	992	1170	18107	4227	3605
39	Top	1592	1873	29224	4227	3605
39	Bottom	1736	2041	31924	11580	9900
38	Top	2213	2594	40957	11580	9900
38	Bottom	2325	2723	43110	21617	18529
37	Top	2684	3133	50161	21617	18529
37	Bottom	2766	3225	51803	33680	28962
36	Top	3021	3505	57038	33680	28962
36	Bottom	3077	3564	58222	47162	40710
35	Top	3243	3731	61882	47162	40710
35	Bottom	3277	3763	62683	61522	53344
34	Top	3376	3844	65090	61522	53344
34	Bottom	3396	3856	65605	76308	66513
33	Top	3452	3880	67157	76308	66513
33	Bottom	3464	3882	67502	91172	79957
32	Top	3507	3883	68650	91172	79957
32	Bottom	3519	3884	68949	105886	93514
31	Top	3574	3897	70149	105886	93514
31	Bottom	3592	3905	70518	120339	107122
30	Top	3680	3959	72158	120339	107122
30	Bottom	3709	3980	72684	134541	120812
29	Top	3840	4087	75012	134541	120812
29	Bottom	3880	4122	75738	148598	134692
28	Top	4050	4280	78812	148598	134692
28	Bottom	4100	4328	79728	162691	148921
27	Top	4295	4522	83422	162691	148921
27	Bottom	4350	4577	84474	177037	163682

26	Top	4554	4787	88530	177037	163682
26	Bottom	4608	4843	89637	191853	179149
25	Top	4804	5047	93737	191853	179149
25	Bottom	4854	5100	94813	207322	195462
24	Top	5030	5283	98649	207322	195462
24	Bottom	5073	5328	99617	223572	212706
23	Top	5222	5480	102938	223572	212706
23	Bottom	5258	5516	103742	240663	230911
22	Top	5377	5636	106393	240663	230911
22	Bottom	5406	5664	107007	258596	250054
21	Top	5501	5755	108945	258596	250054
21	Bottom	5523	5776	109375	277321	270071
20	Top	5600	5847	110682	277321	270071
20	Bottom	5619	5865	110964	296761	290879
19	Top	5685	5927	111839	296761	290879
19	Bottom	5702	5943	112043	316827	312385
18	Top	5767	6004	112783	316827	312385
18	Bottom	5785	6020	112996	337432	334501
17	Top	5855	6086	113945	337432	334501
17	Bottom	5874	6105	114259	358503	357151
16	Top	5952	6180	115733	358503	357151
16	Bottom	5973	6202	116221	379891	380182
15	Top	6058	6289	118422	379788	380072
15	Bottom	6081	6314	119114	401439	403423
14	Top	6170	6416	122045	401335	403312
14	Bottom	6194	6445	122911	423386	427106
13	Top	6284	6562	126350	423386	427106
13	Bottom	6309	6596	127305	445721	451208
12	Top	6401	6730	130861	445615	451094
12	Bottom	6427	6768	131783	468213	475449
11	Top	6524	6920	134969	468213	475449
11	Bottom	6551	6964	135730	491070	500010

10	Top	6658	7138	138134	490971	499901
10	Bottom	6688	7188	138645	513998	524522
9	Top	6810	7387	140056	513904	524419
9	Bottom	6845	7443	140308	537194	549136
8	Top	6987	7661	140943	537105	549038
8	Bottom	7028	7721	141075	560662	573804
7	Top	7198	7947	141830	560579	573711
7	Bottom	7248	8009	142198	584401	598483
6	Top	7459	8248	144874	584324	598397
6	Bottom	7523	8317	146086	608399	623144
5	Top	7801	8618	153290	608330	623067
5	Bottom	7889	8715	156091	632644	647774
4	Top	8279	9175	170431	632585	647706
4	Bottom	8405	9331	175404	657175	672397
3	Top	8975	10059	198308	657126	672341
3	Bottom	9159	10300	205609	682162	697118
2	Top	9982	11399	236856	682125	697077
2	Bottom	10242	11756	246237	708032	722170
1	Top	11348	13338	283759	708009	722145
1	Bottom	11968	14279	303342	745131	756673

WALL FORCES - MODEL 2						
Story	**Pier**	**Location**	**P**	**V2**	**T**	**M3**
40	W17	Top	137	122	9	304
40	W17	Bottom	137	119	12	104
39	W17	Top	179	92	9	223
39	W17	Bottom	199	90	10	101
38	W17	Top	255	90	9	235
38	W17	Bottom	285	89	10	122
37	W17	Top	344	93	9	259
37	W17	Bottom	379	92	10	152

36	W17	Top	436	96	9	284
36	W17	Bottom	470	95	10	181
35	W17	Top	522	99	9	309
35	W17	Bottom	555	98	10	205
34	W17	Top	600	102	9	331
34	W17	Bottom	628	101	10	225
33	W17	Top	666	106	9	350
33	W17	Bottom	690	105	10	240
32	W17	Top	721	110	9	365
32	W17	Bottom	740	109	10	252
31	W17	Top	765	114	9	376
31	W17	Bottom	781	113	11	262
30	W17	Top	800	118	9	382
30	W17	Bottom	813	117	11	270
29	W17	Top	828	123	9	385
29	W17	Bottom	840	121	11	277
28	W17	Top	851	127	9	384
28	W17	Bottom	864	125	11	285
27	W17	Top	874	131	9	379
27	W17	Bottom	889	129	11	295
26	W17	Top	898	135	9	372
26	W17	Bottom	918	133	11	306
25	W17	Top	927	139	9	362
25	W17	Bottom	951	137	11	319
24	W17	Top	962	142	9	350
24	W17	Bottom	992	140	11	336
23	W17	Top	1006	145	9	336
23	W17	Bottom	1041	143	11	356
22	W17	Top	1058	148	9	321
22	W17	Bottom	1099	146	11	379
21	W17	Top	1120	151	9	305
21	W17	Bottom	1167	149	11	405

20	W17	Top	1191	153	9	289
20	W17	Bottom	1243	152	11	434
19	W17	Top	1271	155	9	275
19	W17	Bottom	1328	154	12	466
18	W17	Top	1360	156	9	264
18	W17	Bottom	1421	155	12	500
17	W17	Top	1457	157	9	258
17	W17	Bottom	1523	157	12	537
16	W17	Top	1563	158	9	259
16	W17	Bottom	1633	158	12	575
15	W17	Top	1677	158	9	269
15	W17	Bottom	1751	159	12	616
14	W17	Top	1798	158	9	287
14	W17	Bottom	1875	159	12	658
13	W17	Top	1927	157	9	315
13	W17	Bottom	2007	159	13	701
12	W17	Top	2062	156	10	351
12	W17	Bottom	2146	159	13	746
11	W17	Top	2205	155	10	394
11	W17	Bottom	2292	158	13	793
10	W17	Top	2355	153	10	444
10	W17	Bottom	2445	157	13	841
9	W17	Top	2513	152	10	500
9	W17	Bottom	2605	157	13	890
8	W17	Top	2678	150	10	561
8	W17	Bottom	2774	156	14	941
7	W17	Top	2852	148	11	627
7	W17	Bottom	2951	156	14	993
6	W17	Top	3035	147	11	699
6	W17	Bottom	3139	156	14	1049
5	W17	Top	3230	146	11	777
5	W17	Bottom	3339	157	15	1107

4	W17	Top	3437	145	12	862
4	W17	Bottom	3550	158	15	1171
3	W17	Top	3654	143	12	954
3	W17	Bottom	3771	158	16	1242
2	W17	Top	3879	139	14	1059
2	W17	Bottom	3993	153	16	1325
1	W17	Top	4073	135	12	1177
1	W17	Bottom	4229	151	8	1561
			kN	**kN**	**kN-m**	**kN-m**

TABLE: WALL FORCES - MODEL 4

Story	Pier	Location	P	V2	T	M3
40	W17	Top	394	349	27	872
40	W17	Bottom	391	338	34	288
39	W17	Top	501	253	26	639
39	W17	Bottom	538	246	28	237
38	W17	Top	675	244	26	673
38	W17	Bottom	730	241	29	241
37	W17	Top	873	254	26	732
37	W17	Bottom	937	253	29	296
36	W17	Top	1,080	266	26	788
36	W17	Bottom	1,152	265	30	372
35	W17	Top	1,294	279	25	844
35	W17	Bottom	1,372	276	30	454
34	W17	Top	1,508	290	25	897
34	W17	Bottom	1,588	287	30	533
33	W17	Top	1,715	301	25	946
33	W17	Bottom	1,793	297	30	605
32	W17	Top	1,905	311	26	990
32	W17	Bottom	1,977	307	30	667
31	W17	Top	2,073	321	26	1,026
31	W17	Bottom	2,136	316	30	716
30	W17	Top	2,214	331	26	1,053

30	W17	Bottom	2,268	326	30	754
29	W17	Top	2,326	342	26	1,069
29	W17	Bottom	2,372	336	31	782
28	W17	Top	2,414	354	26	1,074
28	W17	Bottom	2,456	348	31	803
27	W17	Top	2,485	366	26	1,067
27	W17	Bottom	2,529	360	31	823
26	W17	Top	2,550	379	26	1,049
26	W17	Bottom	2,600	373	31	846
25	W17	Top	2,620	391	26	1,021
25	W17	Bottom	2,684	385	31	878
24	W17	Top	2,708	403	26	983
24	W17	Bottom	2,788	398	31	922
23	W17	Top	2,821	414	26	938
23	W17	Bottom	2,920	409	32	981
22	W17	Top	2,965	423	26	889
22	W17	Bottom	3,084	418	32	1,052
21	W17	Top	3,143	430	26	837
21	W17	Bottom	3,281	426	32	1,136
20	W17	Top	3,354	436	26	788
20	W17	Bottom	3,510	433	33	1,228
19	W17	Top	3,596	440	26	745
19	W17	Bottom	3,768	437	33	1,326
18	W17	Top	3,865	442	26	714
18	W17	Bottom	4,050	440	33	1,428
17	W17	Top	4,157	442	26	701
17	W17	Bottom	4,353	441	34	1,541
16	W17	Top	4,469	456	24	715
16	W17	Bottom	4,689	456	27	1,649
15	W17	Top	4,814	447	23	748
15	W17	Bottom	5,026	447	27	1,755
14	W17	Top	5,159	438	24	808

14	W17	Bottom	5,362	440	35	1,891
13	W17	Top	5,503	462	24	905
13	W17	Bottom	5,747	465	26	1,984
12	W17	Top	5,899	441	23	983
12	W17	Bottom	6,119	445	36	2,147
11	W17	Top	6,284	462	24	1,142
11	W17	Bottom	6,554	469	25	2,260
10	W17	Top	6,733	449	18	1,262
10	W17	Bottom	6,995	454	24	2,411
9	W17	Top	7,188	443	17	1,435
9	W17	Bottom	7,458	449	24	2,556
8	W17	Top	7,666	435	16	1,609
8	W17	Bottom	7,947	442	23	2,704
7	W17	Top	8,172	426	15	1,800
7	W17	Bottom	8,463	435	22	2,856
6	W17	Top	8,704	421	14	2,009
6	W17	Bottom	9,005	433	21	3,013
5	W17	Top	9,262	426	14	2,237
5	W17	Bottom	9,572	441	21	3,180
4	W17	Top	9,846	448	15	2,484
4	W17	Bottom	10,166	468	21	3,361
3	W17	Top	10,458	490	16	2,750
3	W17	Bottom	10,787	515	21	3,571
2	W17	Top	11,092	535	18	3,044
2	W17	Bottom	11,417	562	21	3,813
1	W17	Top	11,674	561	25	3,362
1	W17	Bottom	12,167	622	24	4,542
			kN	**kN**	**kN-m**	**kN-m**

Part III Concrete Moment Frame– Low – Rise (Ductile /Conventional Framing)

STORY DRIFTS		
	MODEL 5	MODEL 7
Story	**Drift(m)**	**Drift(m)**
12	0.000152	0.000532
11	0.000233	0.000813
10	0.000295	0.00103
9	0.000342	0.001195
8	0.000378	0.001322
7	0.000408	0.001425
6	0.000433	0.001512
5	0.000456	0.001591
4	0.000478	0.001668
3	0.0005	0.001747
2	0.00054	0.001885
1	0.000762	0.002661

BASE REACTIONS - MODEL 5						
Load Case/Combo	**FX**	**FY**	**FZ**	**MX**	**MY**	**MZ**
	kN	kN	kN	kN-m	kN-m	kN-m
SPECX1 Max	1909	1847	0	51809	53805	38157
BASE REACTIONS - MODEL 7						
Load Case/Combo	**FX**	**FY**	**FZ**	**MX**	**MY**	**MZ**
	kN	kN	kN	kN-m	kN-m	kN-m
SPECX1 Max	6667	6452	0	180970	187942	133285

STORY FORCES - MODEL 5						
Story	Location	VX	VY	T	MX	MY
		kN	kN	kN-m	kN-m	kN-m
12	Top	387	383	7837	0	0
12	Bottom	387	383	7837	1404	1418
11	Top	680	670	13732	1404	1418
11	Bottom	680	670	13732	3856	3906
10	Top	896	878	18045	3856	3906
10	Bottom	896	878	18045	7041	7155
9	Top	1058	1032	21250	7041	7155
9	Bottom	1058	1032	21250	10730	10938
8	Top	1185	1151	23751	10730	10938
8	Bottom	1185	1151	23751	14775	15108
7	Top	1291	1250	25838	14775	15108
7	Bottom	1291	1250	25838	19083	19573
6	Top	1387	1339	27717	19083	19573
6	Bottom	1387	1339	27717	23609	24285
5	Top	1479	1425	29532	23609	24285
5	Bottom	1479	1425	29532	28336	29226
4	Top	1573	1514	31393	28336	29226
4	Bottom	1573	1514	31393	33275	34401
3	Top	1671	1610	33366	33275	34401
3	Bottom	1671	1610	33366	38456	39835
2	Top	1775	1713	35470	38456	39835
2	Bottom	1775	1713	35470	43927	45568
1	Top	1878	1816	37564	43927	45568
1	Bottom	1878	1816	37564	51809	53805

STORY FORCES - MODEL 7						
Story	Location	VX	VY	T	MX	MY
		kN	kN	kN-m	kN-m	kN-m
12	Top	1351	1337	27373.7	0	0
12	Bottom	1351	1337	27373.7	4903.3	4952.76
11	Top	2375	2340	47968.2	4903.3	4952.76

11	Bottom	2375	2340	47968.2	13469	13644
10	Top	3129	3068	63033.1	13469	13644
10	Bottom	3129	3068	63033.1	24594	24991.3
9	Top	3694	3605	74227.3	24593	24991.3
9	Bottom	3694	3605	74227.3	37481	38207.2
8	Top	4138	4021	82963.5	37481	38207.2
8	Bottom	4138	4021	82963.5	51609	52773
7	Top	4510	4366	90254.3	51609	52773
7	Bottom	4510	4366	90254.3	66660	68370.8
6	Top	4845	4676	96816.5	66660	68370.7
6	Bottom	4845	4676	96816.5	82466	84830
5	Top	5167	4978	103160	82466	84829.9
5	Bottom	5167	4978	103160	98978	102089
4	Top	5494	5290	109657	98978	102089
4	Bottom	5494	5290	109657	116230	120166
3	Top	5838	5625	116549	116230	120166
3	Bottom	5838	5625	116549	134328	139146
2	Top	6202	5984	123900	134328	139146
2	Bottom	6202	5984	123900	153441	159173
1	Top	6561	6343	131213	153440	159173
1	Bottom	6561	6343	131213	180970	187942

BEAM FORCES - MODEL 5					
Story	**Beam**	**P (kN)**	**V2 (kN)**	**T(kN-m)**	**M3(kN-m)**
12	B11	0.00	3.12	0.14	8.5
11	B11	0.00	8.93	0.39	17.4
10	B11	1.05	14.87	0.65	29.3
9	B11	1.01	19.26	0.84	38.6
8	B11	1.03	22.74	0.99	46.0
7	B11	1.07	25.70	1.12	52.5
6	B11	1.11	28.46	1.25	58.6
5	B11	1.15	31.28	1.37	65.1
4	B11	1.19	34.32	1.50	72.2

3	B11	1.21	37.74	1.64	80.2
2	B11	1.49	41.85	1.80	90.5
1	B11	5.03	53.54	2.32	114.3

BEAM FORCES - MODEL 7					
Story	**Beam**	**P (kN)**	**V2 (kN)**	**T(kN-m)**	**M3(kN-m)**
12	B11	0.00	10.892	0.50	29.6
11	B11	0.00	31.202	1.35	60.7
10	B11	3.66	51.931	2.25	102.4
9	B11	3.54	67.285	2.93	134.8
8	B11	3.61	79.435	3.47	160.8
7	B11	3.74	89.766	3.93	183.3
6	B11	3.88	99.428	4.35	204.9
5	B11	4.02	109.25	4.78	227.3
4	B11	4.16	119.87	5.23	252.0
3	B11	4.23	131.82	5.73	280.1
2	B11	5.20	146.18	6.29	316.0
1	B11	17.57	187.01	8.09	399.2

Part IV Concrete Moment Frame– High – Rise (Ductile /Conventional Framing)

STORY DRIFTS					
	MODEL 6	MODEL 8		MODEL 6	MODEL 8
Story	**Drift**	**Drift**	**Story**	**Drift**	**Drift**
40	0.000558	0.001949	20	0.001008	0.003522
39	0.000593	0.002073	19	0.001015	0.003544
38	0.00063	0.002202	18	0.001019	0.003561
37	0.000666	0.002325	17	0.001023	0.003572
36	0.000698	0.00244	16	0.001024	0.003577
35	0.000729	0.002547	15	0.001024	0.003575
34	0.000758	0.002649	14	0.001021	0.003567
33	0.000786	0.002744	13	0.001017	0.003553
32	0.000812	0.002835	12	0.001011	0.003532
31	0.000836	0.00292	11	0.001003	0.003504
30	0.000859	0.003	10	0.000993	0.003468
29	0.00088	0.003075	9	0.000981	0.003426
28	0.0009	0.003145	8	0.000966	0.003375
27	0.000919	0.003211	7	0.000949	0.003316
26	0.000936	0.003271	6	0.00093	0.003249
25	0.000952	0.003326	5	0.000909	0.003175
24	0.000966	0.003376	4	0.000885	0.003091
23	0.000979	0.00342	3	0.000861	0.003006
22	0.00099	0.003459	2	0.000864	0.003017
21	0.001	0.003493	1	0.00117	0.004086

BASE REACTIONS - MODEL 6						
Load Case/Combo	**FX**	**FY**	**FZ**	**MX**	**MY**	**MZ**
	kN	kN	kN	kN-m	kN-m	kN-m
SPECX1 Max	3185	3051	0	250786	249074	63518
BASE REACTIONS - MODEL 8						
Load Case/Combo	**FX**	**FY**	**FZ**	**MX**	**MY**	**MZ**
	kN	kN	kN	kN-m	kN-m	kN-m
SPECX1 Max	11126	10656	0	876010	870031	221880

STORY FORCES - MODEL 6						
Story	**Location**	**VX**	**VY**	**T**	**MX**	**MY**
		kN	kN	kN-m	kN-m	kN-m
40	Top	189	190	3829	0	0
40	Bottom	189	190	3829	709	708
39	Top	356	355	7184	708	706
39	Bottom	356	355	7184	2044	2041
38	Top	500	498	10082	2044	2042
38	Bottom	500	498	10082	3927	3927
37	Top	620	617	12505	3927	3926
37	Bottom	620	617	12505	6267	6274
36	Top	721	717	14530	6267	6274
36	Bottom	721	717	14530	8988	9006
35	Top	809	804	16289	8988	9006
35	Bottom	809	804	16289	12031	12062
34	Top	890	885	17905	12031	12062
34	Bottom	890	885	17905	15364	15405
33	Top	966	962	19447	15364	15405
33	Bottom	966	962	19447	18969	19016
32	Top	1040	1036	20930	18969	19016
32	Bottom	1040	1036	20930	22839	22887
31	Top	1111	1106	22345	22839	22887
31	Bottom	1111	1106	22345	26971	27014

30	Top	1178	1173	23695	26971	27014
30	Bottom	1178	1173	23695	31358	31394
29	Top	1242	1238	24999	31358	31394
29	Bottom	1242	1238	24999	35999	36023
28	Top	1306	1302	26274	35999	36022
28	Bottom	1306	1302	26274	40891	40897
27	Top	1368	1364	27519	40891	40897
27	Bottom	1368	1364	27519	46032	46016
26	Top	1427	1423	28718	46032	46016
26	Bottom	1427	1423	28718	51419	51377
25	Top	1484	1480	29862	51419	51377
25	Bottom	1484	1480	29862	57047	56975
24	Top	1539	1535	30960	57047	56975
24	Bottom	1539	1535	30960	62911	62805
23	Top	1592	1588	32031	62911	62805
23	Bottom	1592	1588	32031	69005	68859
22	Top	1644	1641	33082	69005	68859
22	Bottom	1644	1641	33082	75323	75132
21	Top	1694	1692	34103	75323	75132
21	Bottom	1694	1692	34103	81862	81620
20	Top	1743	1740	35079	81862	81620
20	Bottom	1743	1740	35079	88614	88316
19	Top	1789	1787	36014	88614	88316
19	Bottom	1789	1787	36014	95574	95215
18	Top	1834	1832	36923	95574	95215
18	Bottom	1834	1832	36923	102735	102309
17	Top	1879	1877	37814	102735	102309
17	Bottom	1879	1877	37814	110089	109592
16	Top	1921	1919	38674	110089	109592
16	Bottom	1921	1919	38674	117631	117058
15	Top	1962	1959	39489	117631	117057
15	Bottom	1962	1959	39489	125350	124698
14	Top	2001	1998	40270	125350	124698
14	Bottom	2001	1998	40270	133239	132505

13	Top	2039	2037	41042	133239	132504
13	Bottom	2039	2037	41042	141289	140470
12	Top	2077	2074	41798	141289	140470
12	Bottom	2077	2074	41798	149492	148586
11	Top	2113	2108	42510	149492	148586
11	Bottom	2113	2108	42510	157840	156846
10	Top	2146	2142	43181	157840	156846
10	Bottom	2146	2142	43181	166321	165240
9	Top	2179	2175	43845	166321	165240
9	Bottom	2179	2175	43845	174927	173760
8	Top	2211	2206	44486	174927	173760
8	Bottom	2211	2206	44486	183648	182396
7	Top	2240	2234	45067	183648	182396
7	Bottom	2240	2234	45067	192471	191139
6	Top	2269	2264	45647	192471	191139
6	Bottom	2269	2264	45647	201386	199976
5	Top	2299	2292	46243	201386	199976
5	Bottom	2299	2292	46243	210382	208899
4	Top	2326	2319	46787	210381	208899
4	Bottom	2326	2319	46787	219446	217897
3	Top	2356	2350	47407	219445	217897
3	Bottom	2356	2350	47407	228569	226962
2	Top	2384	2377	47974	228569	226962
2	Bottom	2384	2377	47974	237788	236128
1	Top	2418	2410	48670	237788	236128
1	Bottom	2418	2410	48670	250786	249074

STORY FORCES - MODEL 8						
Story	**Location**	**VX**	**VY**	**T**	**MX**	**MY**
		kN	kN	kN-m	kN-m	kN-m
40	Top	661	662	13376	0	0
40	Bottom	661	662	13376	2478	2472
39	Top	1242	1241	25094	2473	2466

39	Bottom	1242	1241	25094	7141	7131
38	Top	1745	1739	35218	7141	7131
38	Bottom	1745	1739	35218	13717	13716
37	Top	2166	2156	43682	13716	13715
37	Bottom	2166	2156	43682	21892	21917
36	Top	2520	2505	50755	21892	21917
36	Bottom	2520	2505	50755	31395	31459
35	Top	2826	2810	56898	31395	31459
35	Bottom	2826	2810	56898	42026	42134
34	Top	3108	3092	62543	42026	42134
34	Bottom	3108	3092	62543	53667	53810
33	Top	3376	3361	67930	53667	53810
33	Bottom	3376	3361	67930	66260	66423
32	Top	3633	3618	73110	66260	66423
32	Bottom	3633	3618	73110	79780	79945
31	Top	3879	3863	78054	79779	79945
31	Bottom	3879	3863	78054	94210	94362
30	Top	4114	4097	82771	94210	94362
30	Bottom	4114	4097	82771	109536	109661
29	Top	4340	4324	87326	109536	109661
29	Bottom	4340	4324	87326	125747	125829
28	Top	4561	4547	91780	125746	125829
28	Bottom	4561	4547	91780	142833	142856
27	Top	4777	4763	96128	142833	142856
27	Bottom	4777	4763	96128	160791	160737
26	Top	4986	4971	100317	160791	160737
26	Bottom	4986	4971	100317	179609	179463
25	Top	5185	5170	104313	179609	179463
25	Bottom	5185	5170	104313	199270	199018
24	Top	5375	5361	108147	199270	199017
24	Bottom	5375	5361	108147	219753	219380
23	Top	5560	5548	111887	219753	219380
23	Bottom	5560	5548	111887	241038	240528
22	Top	5742	5732	115559	241038	240527

22	Bottom	5742	5732	115559	263109	262441
21	Top	5919	5909	119126	263108	262440
21	Bottom	5919	5909	119126	285948	285102
20	Top	6088	6079	122537	285947	285102
20	Bottom	6088	6079	122537	309535	308493
19	Top	6251	6242	125801	309534	308493
19	Bottom	6251	6242	125801	333846	332591
18	Top	6408	6401	128976	333846	332591
18	Bottom	6408	6401	128976	358858	357372
17	Top	6562	6556	132090	358858	357371
17	Bottom	6562	6556	132090	384548	382812
16	Top	6712	6704	135093	384548	382811
16	Bottom	6712	6704	135093	410891	408889
15	Top	6854	6844	137939	410890	408888
15	Bottom	6854	6844	137939	437856	435576
14	Top	6990	6980	140669	437855	435576
14	Bottom	6990	6980	140669	465412	462846
13	Top	7124	7114	143364	465412	462845
13	Bottom	7124	7114	143364	493532	490669
12	Top	7256	7244	146005	493531	490668
12	Bottom	7256	7244	146005	522185	519019
11	Top	7380	7365	148492	522185	519019
11	Bottom	7380	7365	148492	551343	547872
10	Top	7497	7481	150838	551342	547871
10	Bottom	7497	7481	150838	580969	577194
9	Top	7612	7597	153157	580968	577193
9	Bottom	7612	7597	153157	611030	606954
8	Top	7723	7706	155395	611029	606953
8	Bottom	7723	7706	155395	641492	637121
7	Top	7825	7805	157426	641491	637120
7	Bottom	7825	7805	157426	672314	667658
6	Top	7925	7907	159451	672313	667657
6	Bottom	7925	7907	159451	703454	698528
5	Top	8029	8008	161533	703453	698527

5	Bottom	8029	8008	161533	734875	729695
4	Top	8124	8101	163432	734874	729695
4	Bottom	8124	8101	163432	766535	761126
3	Top	8231	8209	165599	766535	761125
3	Bottom	8231	8209	165599	798405	792791
2	Top	8328	8304	167579	798404	792790
2	Bottom	8328	8304	167579	830607	824808
1	Top	8447	8420	170009	830606	824807
1	Bottom	8447	8420	170009	876010	870031

BEAM FORCES - MODEL 6					
Story	**Beam**	**P (kN)**	**V2 (kN)**	**T(kN-m)**	**M3(kN-m)**
40	B11	0	4.4	0.13	16.3
39	B11	0.7075	4.9	0.18	14.6
38	B11	0.657	6.1	0.26	13.8
37	B11	0.5731	8.4	0.37	16.3
36	B11	0.5713	10.4	0.47	19.4
35	B11	0.5917	12.3	0.56	22.4
34	B11	0.618	14.0	0.63	25.2
33	B11	0.6347	15.6	0.70	28.2
32	B11	0.641	17.2	0.77	31.2
31	B11	0.6448	18.8	0.84	34.1
30	B11	0.6523	20.3	0.91	36.9
29	B11	0.6617	21.7	0.97	39.6
28	B11	0.6665	23.2	1.03	42.3
27	B11	0.6635	24.6	1.09	45.0
26	B11	0.6572	26.0	1.15	47.7
25	B11	0.6556	27.3	1.21	50.2
24	B11	0.6609	28.6	1.26	52.6
23	B11	0.6666	29.9	1.32	55.1
22	B11	0.6651	31.2	1.37	57.6
21	B11	0.6573	32.5	1.42	60.1
20	B11	0.6526	33.7	1.48	62.6

19	B11	0.6568	35.0	1.53	65.0
18	B11	0.6633	36.2	1.58	67.5
17	B11	0.6612	37.5	1.63	70.1
16	B11	0.6534	38.8	1.69	72.8
15	B11	0.6558	40.1	1.74	75.4
14	B11	0.6728	41.3	1.79	78.2
13	B11	0.6855	42.7	1.84	81.1
12	B11	0.6705	44.1	1.90	84.3
11	B11	0.6851	45.5	1.96	87.6
10	B11	0.7019	47.0	2.02	91.1
9	B11	0.7385	48.6	2.08	94.9
8	B11	0.7399	50.3	2.15	99.1
7	B11	0.7779	52.1	2.22	103.6
6	B11	0.8546	54.0	2.30	108.7
5	B11	0.8808	56.2	2.38	114.4
4	B11	0.9689	58.6	2.47	120.9
3	B11	1.1531	61.4	2.58	128.4
2	B11	1.2859	65.1	2.71	139.1
1	B11	8.2882	82.3	3.45	174.3

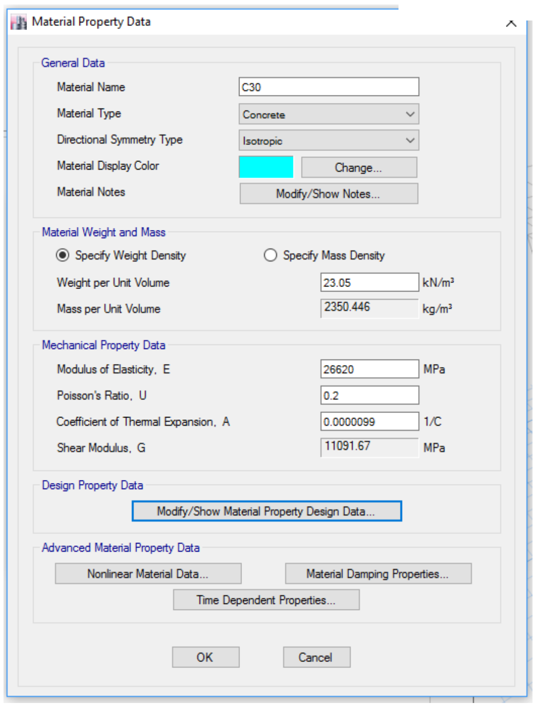
BEAM FORCES - MODEL 8					
Story	**Beam**	**P (kN)**	**V2 (kN)**	**T(kN-m)**	**M3(kN-m)**
40	B11	0.00	16	0.46	56.8
39	B11	2.47	17	0.61	51.1
38	B11	2.29	21	0.92	48.3
37	B11	2.00	29	1.31	57.0
36	B11	2.00	36	1.65	67.8
35	B11	2.07	43	1.94	78.1
34	B11	2.16	49	2.20	88.2
33	B11	2.22	54	2.45	98.5
32	B11	2.24	60	2.70	109.0
31	B11	2.25	66	2.94	119.2
30	B11	2.28	71	3.17	128.9

29	B11	2.31	76	3.38	138.4
28	B11	2.33	81	3.60	147.9
27	B11	2.32	86	3.81	157.3
26	B11	2.30	91	4.02	166.5
25	B11	2.29	95	4.22	175.4
24	B11	2.31	100	4.41	183.9
23	B11	2.33	104	4.60	192.4
22	B11	2.32	109	4.79	201.1
21	B11	2.30	113	4.97	209.9
20	B11	2.28	118	5.16	218.5
19	B11	2.29	122	5.34	227.1
18	B11	2.32	127	5.52	235.8
17	B11	2.31	131	5.70	244.9
16	B11	2.28	135	5.89	254.2
15	B11	2.29	140	6.07	263.5
14	B11	2.35	144	6.25	273.1
13	B11	2.39	149	6.44	283.3
12	B11	2.34	154	6.64	294.3
11	B11	2.41	159	6.85	305.9
10	B11	2.45	164	7.06	318.1
9	B11	2.58	170	7.28	331.5
8	B11	2.58	176	7.51	346.2
7	B11	2.72	182	7.76	362.0
6	B11	2.99	189	8.02	379.6
5	B11	3.08	196	8.32	399.7
4	B11	3.39	205	8.64	422.3
3	B11	4.03	215	9.01	448.4
2	B11	4.49	228	9.46	486.0
1	B11	28.95	287	12.04	609.0

Appendix C: Etabs Modeling Procedure

MODEL SETUP

1. **Materials: 30MPa Concrete**



2. **Members:**

Walls: 400mm Thick

Beams: 550mm Wide x1000mm Deep

Columns: 550mmx550mm

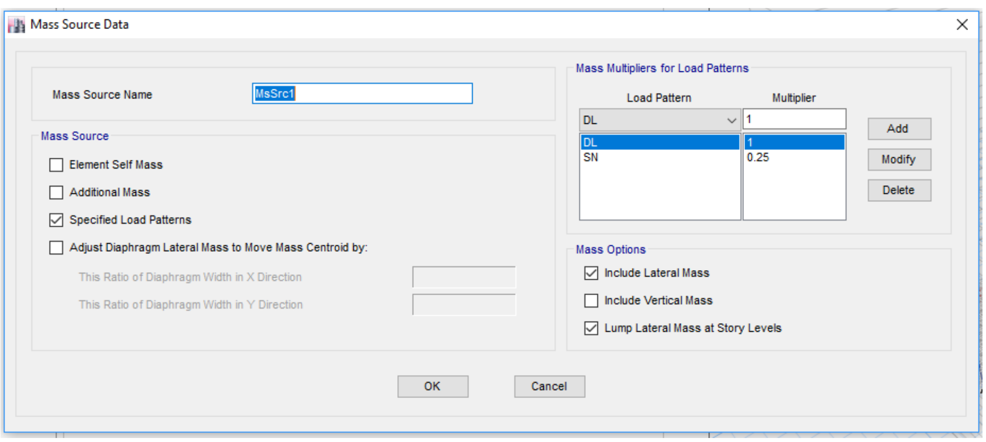
Slabs: 200mm Deep

3. Stiffness Modifiers

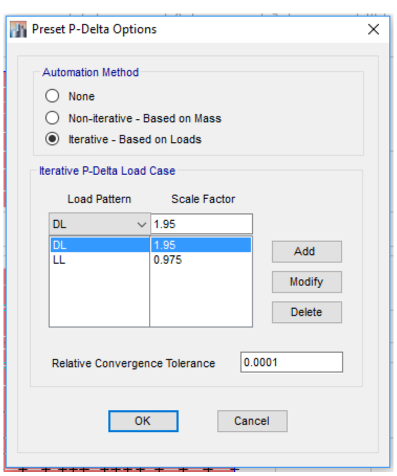
Stiffness of members reduced according to Clause 10.14.1 and 21.2.5.1 of CSA A23.3

Member	Property	SLS Reduction Factor	ULS Reduction Factor
Columns	GJ	0.2	0.15
	I_2, I_3	1.0	0.7
Walls (Uncracked)	f_{11}, f_{22}, f_{12}	1.0	0.7
	m_{11}, m_{22}, m_{12}	0.35	0.35
Walls (Cracked)	f_{11}, f_{22}, f_{12}	0.5	0.35
	m_{11}, m_{22}, m_{12}	0.35	0.35
Floor Slabs	m_{11}, m_{22}, m_{12}	0.35	0.2
Typical Beams	GJ	0.2	0.15
	I_3	0.5	0.4
Coupling Beams (Frame Section)	A_{v2}	1.0	0.15
	GJ	0.2	0.15
	I_3	0.5	0.4

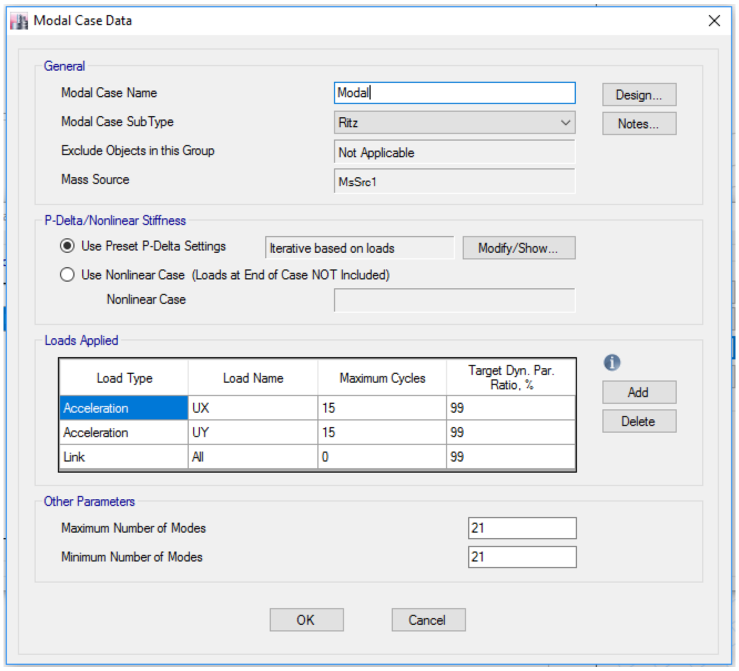
4. Mass Source



5. P-Delta Options



6. Modal Cases



LOADS:

1. Load Patterns/Cases

Num	Name	Load	Description
1	DL	Dead Load	Self-weight and superimposed dead load
2	LL	Live Load	Live loads based on associated occupancy
3	SN	Snow	Snow loading including drifts

2. Floor Load:

a. Surface loads applied directly to slab elements

b. Line loads applied to frame elements such as beams. These frame elements shall in turn be fully supported by slab elements.

c. Point loads applied to the nodes of slab elements.

3. Lateral Loads:

a. Scale factor e calculated as $g \times I_E/(R_d R_o)$, where g is the standard acceleration due to gravity. for $I_E = 1$, $R_d = 1.5$, $R_o = 1.3$ and metre as unit of length, Scale Factor shall be 5.031.

$$S.F. = \frac{g \times I_E}{R_d \times R_o}$$	Where g = gravity (9.81 m/s²) IE = Importance Factor Rd = Ductility Factor
Normal Importance Conventional Construction: **S.F. = 5.031**	IE = 1.0 Rd = 1.5 Ro = 1.3

b. *"Modal Load Case* for *"Modal Combination Method"*. Select SRSS for *"Directional Combination Type"*.

c. *"Diaphragm Eccentricity"* 0.05 as required by code.

d. Lateral Siesmic loads patterns:

Num	Name	Load	Description
1	SPECX	Dynamic Earthquake	SPECX - straight earthquake force in X direction (and straight earthquake force in X direction, plus 30% of SPECY if required by 4.1.8.8.(1).(c) of OBC 2012)
2	SPECXE		SPECXE - earthquake force plus accidental torsion in X direction (and earthquake force plus accidental torsion in X direction, plus 30% of SPECYE if required by
3	SPECY		SPECY - straight earthquake force in Y direction (and straight earthquake force in Y direction, plus 30% of SPECX if required by 4.1.8.8.(1).(c) of OBC 2012)
4	SPECYE		SPECYE - earthquake force plus accidental torsion in Y direction (and earthquake force plus accidental torsion in Y direction, plus 30% of SPECXE if required by 4.1.8.8.(1).(c) of OBC 2012)

4. Load Combinations:

a. All loading combinations are derived based on the following principle of permanent and variable loads as described in the NBC 2015 Structural Commentaries (Part 4 of Division B). See Table below.

b.

Case	Load Combinations		
	Principal Loads	**Secondary Principal**	**Companion Loads**
1	1.4**D**	-	-
2a	(1.25**D** + 1.5**L** or 1.25**L**)	1.5**H**(1) 1.25**T**(1) 1.0**P**(1)	-(1)
2b			1.0**S**(6)
2c			1.0**L**Roof(6)
2d			0.4**W**
2d	0.9**D**(4) + (1.5**L** or 1.25**L**)(5)	1.5**H**(1) 1.25**T**(1) 1.0**P**(1)	-(1)
2e			1.0**S**(6)
2f			1.0**L**Roof(6)
2g			0.4**W**
3a	(1.25**D**)(3) + 1.5**S**	1.5**H**(1) 1.25**T**(1) 1.0**P**(1)	-(1)
3b			(0.5**L** or 1.0**L**) (6)(7)
3c			0.4**W**
3d	0.9**D**(4) + 1.5**S**	1.5**H**(1) 1.25**T**(1) 1.0**P**(1)	-(1)
3e			(0.5**L** or 1.0**L**) (6)(7)
3f			0.4**W**
4a	1.25**D**(3) + 1.4**W**	1.5**H**(1) 1.25**T**(1) 1.0**P**(1)	-(1)
4b			(0.5**L** or 1.0**L**) (7)
4c			0.5**S**
4d	0.9**D**(4) + 1.4**W**	1.5**H**(1) 1.25**T**(1) 1.0**P**(1)	-(1)
4e			(0.5**L** or 1.0**L**) (7)
4f			0.5**S**
5a	1.0**D**(4) + 1.0**E**(8)	1.0**H**(1)	-(1)
5b			(0.5**L** or 1.0**L**) (6)(7) + 0.25**S**(6)

MODELING:

1. Slab/Wall Meshing
   a. Slabs and walls automatically meshed at 2m increments for all 8 models. Mesh also constrained to maximum 2:1 aspect ratio.
   b. *"Auto Line Constraint"* applied to the whole model.
   c. Releasing Frame Elements:
      Release only one end – Ensure load transfer between elements.
   d. Coupling beams modeled as frame elements.
   e. Diaphragm Assignment: Semi Rigid

POST-ANALYSIS MODEL VERIFICATION

1. **Last Analysis run log checked to verify the following items:**
   a. Verify there are no negative stiffness, structural instability, ill-conditioned structure, or lost digits of accuracy.
   b. P-Delta iteration has converged.
   c. Global force balance should be reasonably small. The difference reported in Last Analysis Run Log shall have differences in FX, FY and FZ that are smaller than 0.001 and usually around 1x10-5 while those in MX, MY and MZ shall be less than 5 and usually around 0.01.
   d. Mode shapes reviewed after analysis and trivial modes due to insufficient restraint/constraint of specific members were eliminated.
   e. Modal participating mass ratios shall be checked:
      i. SumUX and SumUY of the last mode shall be greater than 90, preferably 95. Otherwise the maximum number of modes were increased: The Maximum Number of Modes increased until SumUX and SumUY of the last mode are greater than 90

Appendix D: NBCC 2015 Seismic Provisions

Seismic Data for Montreal:

Table C-3
Seismic Design Data for Selected Locations in Canada

Province and Location	Seismic Data							
	$S_a(0.2)$	$S_a(0.5)$	$S_a(1.0)$	$S_a(2.0)$	$S_a(5.0)$	$S_a(10.0)$	PGA	PGV
Dorval	0.600	0.316	0.151	0.069	0.018	0.0062	0.382	0.259
Laval	0.595	0.311	0.148	0.068	0.018	0.0062	0.379	0.256
Montréal (City Hall)	0.595	0.311	0.148	0.068	0.018	0.0062	0.379	0.255
Montréal-Est	0.586	0.305	0.145	0.067	0.017	0.0062	0.374	0.250
Montréal-Nord	0.593	0.309	0.147	0.068	0.017	0.0062	0.378	0.254

For determining PGA_{ref} per Cl 4.1.8.4.(4):

a) 0.8 PGA, where the ratio $S_a(0.2)/PGA < 2.0$, and
b) PGA, otherwise.

For determining site class coefficient per Table 4.1.8.4.(B - G): Therefore, using linear interpolation for PGA_{ref} = .303s

Table 4.1.8.4.-B
Values of F(0.2) as a Function of Site Class and PGA_{ref}
Forming Part of Sentences 4.1.8.4.(4) and (5)

Site Class	Values of F(0.2)				
	$PGA_{ref} \le 0.1$	$PGA_{ref} = 0.2$	$PGA_{ref} = 0.3$	$PGA_{ref} = 0.4$	$PGA_{ref} \ge 0.5$
A	0.69	0.69	0.69	0.69	0.69
B	0.77	0.77	0.77	0.77	0.77
C	1.00	1.00	1.00	1.00	1.00
D	1.24	1.09	1.00	0.94	0.90
E	1.64	1.24	1.05	0.93	0.85
F	(1)	(1)	(1)	(1)	(1)

Table 4.1.8.4.-C
Values of F(0.5) as a Function of Site Class and PGA_{ref}
Forming Part of Sentences 4.1.8.4.(4) and (5)

Site Class	Values of F(0.5)				
	$PGA_{ref} \le 0.1$	$PGA_{ref} = 0.2$	$PGA_{ref} = 0.3$	$PGA_{ref} = 0.4$	$PGA_{ref} \ge 0.5$
A	0.57	0.57	0.57	0.57	0.57
B	0.65	0.65	0.65	0.65	0.65
C	1.00	1.00	1.00	1.00	1.00
D	1.47	1.30	1.20	1.14	1.10
E	2.47	1.80	1.48	1.30	1.17
F	(1)	(1)	(1)	(1)	(1)

Table 4.1.8.4.-D
Values of F(1.0) as a Function of Site Class and PGA_{ref}
Forming Part of Sentences 4.1.8.4.(4) and (5)

Site Class	Values of F(1.0)				
	$PGA_{ref} \le 0.1$	$PGA_{ref} = 0.2$	$PGA_{ref} = 0.3$	$PGA_{ref} = 0.4$	$PGA_{ref} \ge 0.5$
A	0.57	0.57	0.57	0.57	0.57
B	0.63	0.63	0.63	0.63	0.63
C	1.00	1.00	1.00	1.00	1.00
D	1.55	1.39	1.31	1.25	1.21
E	2.81	2.08	1.74	1.53	1.39
F	(1)	(1)	(1)	(1)	(1)

Table 4.1.8.4.-E
Values of F(2.0) as a Function of Site Class and PGA_{ref}
Forming Part of Sentences 4.1.8.4.(4) and (5)

Site Class	Values of F(2.0)				
	$PGA_{ref} \le 0.1$	$PGA_{ref} = 0.2$	$PGA_{ref} = 0.3$	$PGA_{ref} = 0.4$	$PGA_{ref} \ge 0.5$
A	0.58	0.58	0.58	0.58	0.58
B	0.63	0.63	0.63	0.63	0.63
C	1.00	1.00	1.00	1.00	1.00
D	1.57	1.44	1.36	1.31	1.27
E	2.90	2.24	1.92	1.72	1.58
F	(1)	(1)	(1)	(1)	(1)

Table 4.1.8.4.-F
Values of F(5.0) as a Function of Site Class and PGA_{ref}
Forming Part of Sentences 4.1.8.4.(4) and (5)

Site Class	Values of F(5.0)				
	$PGA_{ref} \le 0.1$	$PGA_{ref} = 0.2$	$PGA_{ref} = 0.3$	$PGA_{ref} = 0.4$	$PGA_{ref} \ge 0.5$
A	0.61	0.61	0.61	0.61	0.61
B	0.64	0.64	0.64	0.64	0.64
C	1.00	1.00	1.00	1.00	1.00
D	1.58	1.48	1.41	1.37	1.34
E	2.93	2.40	2.14	1.96	1.84
F	(1)	(1)	(1)	(1)	(1)

	T≤0.2	T=0.5	T=1.0	T=2.0	T=5.0
Sa(T)	0.595	0.311	0.148	0.068	0.018
F(T)	0.998	1.198	1.308	1.358	1.409
S(T)	0.594	0.373	0.194	0.092	0.025

For determining design spectral analysis S(T) per Cl 4.1.8.4.(9):

S(T) = $F(0.2)S_a(0.2)$ or $F(0.5)S_a(0.5)$, whichever is larger, for $T \le 0.2$ s
= $F(0.5)S_a(0.5)$ for $T = 0.5$ s
= $F(1.0)S_a(1.0)$ for $T = 1.0$ s
= $F(2.0)S_a(2.0)$ for $T = 2.0$ s
= $F(5.0)S_a(5.0)$ for $T = 5.0$ s
= $F(10.0)S_a(10.0)$ for $T \ge 10.0$ s

Direction of Loading

Both orthogonal directions (SFRS) = Ductile Shear Wall, R_D =3.5 and R_O = 1.6

Both orthogonal directions (SFRS) = Ductile Moment Frame, R_D =4.0 and R_O = 1.7

For building period, Ts per Cl 4.1.8.1.(7):

T_s = fundamental lateral period of vibration of the *building*, as defined in Article 4.1.8.2.,
= $0.085(h_n)^{3/4}$ for steel moment frames,
= $0.075(h_n)^{3/4}$ for concrete moment frames,
= 0.1 N for other moment frames,
= $0.025h_n$ for braced frames, and
= $0.05(h_n)^{3/4}$ for shear walls and other structures,

For determining force modifications factors R_D and R_O Table 4.1.8.9:

Table 4.1.8.9. (Continued)

Type of SFRS	R_d	R_o	Restrictions(2)				
			Cases Where $I_EF_aS_a(0.2)$				Cases Where $I_EF_vS_a(1.0)$
			< 0.2	≥ 0.2 to < 0.35	≥ 0.35 to ≤ 0.75	> 0.75	> 0.3
Concrete Structures Designed and Detailed According to CSA A23.3							
Ductile moment-resisting frames	4.0	1.7	NL	NL	NL	NL	NL
Moderately ductile moment-resisting frames	2.5	1.4	NL	NL	60	40	40
Ductile coupled walls	4.0	1.7	NL	NL	NL	NL	NL
Moderately ductile coupled walls	2.5	1.4	NL	NL	NL	60	60
Ductile partially coupled walls	3.5	1.7	NL	NL	NL	NL	NL
Moderately ductile partially coupled walls	2.0	1.4	NL	NL	NL	60	60
Ductile shear walls	3.5	1.6	NL	NL	NL	NL	NL
Moderately ductile shear walls	2.0	1.4	NL	NL	NL	60	60
Conventional construction							
Moment-resisting frames	1.5	1.3	NL	NL	20	15	10(5)
Shear walls	1.5	1.3	NL	NL	40	30	30
Two-way slabs without beams	1.3	1.3	20	15	NP	NP	NP

Development of Equivalent Lateral Forces

Lateral earthquake force V shall be determined per Cl 4.1.8.11 (2)

$$V = S(T_a)\, M_v I_E W / (R_d R_o)$$

Minimum lateral earthquake force V_{min} shall be:

a) for walls, coupled walls and wall-frame systems, V shall not be less than

$$S(4.0)\, M_v I_E W / (R_d R_o)$$

Maximum lateral earthquake force V_{max} shall be:

c) for *buildings* located on a site other than Class F and having an SFRS with an R_d equal to or greater than 1.5, V need not be greater than the larger of

$$\frac{2}{3} S(0.2) I_E W / (R_d R_o) \text{ and}$$

$$S(0.5)\, I_E W / (R_d R_o)$$

Building period limitations per Cl 4.1.8.11 (3)(d)(iii)

iii) for shear wall structures, T_a shall not be taken greater than 2.0 times that determined in Clause (c),

For determining weight of the building, W per Cl4.1.8.11(5)

$$W = \sum_{i=1}^{n} W_i$$

For determining the lateral force Fx applied to level x per Cl4.1.8.11(7)

$$F_x = (V - F_t)\, W_x h_x / \left(\sum_{i=1}^{n} W_i h_i \right)$$

For determining the Higher Mode Factor, M_v and Base Overturning Reduction factor, J using interpolation per Table 4.1.8.11

Table 4.1.8.11.
Higher Mode Factor, M_v, and Base Overturning Reduction Factor, J[1][2][3][4]
Forming Part of Sentence 4.1.8.11.(6)

S(0.2)/S(5.0)	M_v for $T_a \le 0.5$	M_v for $T_a = 1.0$	M_v for $T_a = 2.0$	M_v for $T_a \ge 5.0$	J for $T_a \le 0.5$	J for $T_a = 1.0$	J for $T_a = 2.0$	J for $T_a \ge 5.0$
Walls, Wall Frame Systems								
5	1	1	1	1.25[7]	1	0.97	0.85	0.55[8]
20	1	1	1.18	2.30[7]	1	0.80	0.60	0.35[8]
40	1	1.19	1.75	3.70[7]	1	0.63	0.46	0.28[8]
65	1	1.55	2.25	4.65[7]	1	0.51	0.39	0.23[8]
Coupled Walls[6]								
5	1	1	1	1[7]	1	0.97	0.92	0.80[8]
20	1	1	1	1.08[7]	1	0.93	0.85	0.65[8]
40	1	1	1	1.30[7]	1	0.87	0.78	0.53[8]
65	1	1	1.03	1.49[7]	1	0.80	0.70	0.46[8]

For determining the Overturning Moment and level x, Mx applied to level x per Cl4.1.8.11(8)

$$M_x = J_x \sum_{i=x}^{n} F_i \,(h_i - h_x)$$

Dynamic Analysis Procedure requirements per Cl. 4.1.8.12

4.1.8.7. Methods of Analysis

1) Analysis for design earthquake actions shall be carried out in accordance with the Dynamic Analysis Procedure described in Article 4.1.8.12. (see Note A-4.1.8.7.(1)), except that the Equivalent Static Force Procedure described in Article 4.1.8.11. may be used for structures that meet any of the following criteria:

a) in cases where $I_E F_a S_a(0.2)$ is less than 0.35, ← **Dynamic analysis required**

b) regular structures that are less than 60 m in height and have a fundamental lateral period, T_a, less than 2 s in each of two orthogonal directions as defined in Article 4.1.8.8., or

c) structures with structural irregularity, of Type 1, 2, 3, 4, 5, 6 or 8 as defined in Table 4.1.8.6., that are less than 20 m in height and have a fundamental lateral period, T_a, less than 0.5 s in each of two orthogonal directions as defined in Article 4.1.8.8.

Appendix E: NBCC 2015 Equivalent Lateral Force Procedure Results

Project: **L_SW_D**
Number : **Model 1**
Direction: **X direction**

Location: Montreal

Total Number of Floors, N_{TL} = **12**

Climatic Data and Structural Parameters

q	$S_a(0.2)$	$S_a(0.5)$	$S_a(1.0)$	$S_a(2.0)$	PGA	F_a	F_v	M_v	J
0.42	0.594	0.373	0.194	0.092	0.303	1.2	1.3	1.043	0.809

Site Classification
- ○ Hard rock
- ○ Rock
- ○ Very dense soil and soft rock
- ◉ Stiff soil
- ○ Soft soil
- ○ Other soils

D

Importance Factor
- ○ Low
- ◉ Normal
- ○ High
- ○ Post-disaster

1.0

Type of SFRS

Concrete _ Ductile shear walls

R_d = 3.5 R_o = 1.6

$T_{a,\ etabs}$ = 1.217 s T_a = 1.217 s

$T_{a,\ code}$ = 0.869 s $I_EF_aS_a(0.2)$ = -0.69

V/W = 0.0410 V = 4452 kN F_t = 379 KN

Dynamic Analysis Procedure Required!

Floor	h_i (m)	h_x (m)	DL (kPa)	A_{trib} (m^2)	W_x (kN)	W_x*h_x	F_x (kN)	M_x (kN.m)
ROOF	3.65	45.00	5.46	853.00	4660	209689	710	2590
12	3.65	41.35	10.93	853.00	9320	385361	607	7397
11	3.65	37.70	10.93	853.00	9320	351345	554	14225
10	3.65	34.05	10.93	853.00	9320	317329	500	22878
9	3.65	30.40	10.93	853.00	9320	283313	446	33160
8	3.65	26.75	10.93	853.00	9320	249297	393	43637
7	3.65	23.10	10.93	853.00	9320	215280	339	54739
6	3.65	19.45	10.93	853.00	9320	181264	286	66131
5	3.65	15.80	10.93	853.00	9320	147248	232	77558
4	3.65	12.15	10.93	853.00	9320	113232	178	88783
3	3.65	8.50	10.93	853.00	9320	79216	125	99591
2	4.85	4.85	12.54	853.00	10693	51861	82	112997
	0	0		**Sum =**	108548	2584435	4452	112997

Project: **H_SW_D**
Number : **Model 2**
Direction: **X direction**

Location: Montreal

Total Number of Floors, N_{TL} = **40**

Climatic Data and Structural Parameters

q	$S_a(0.2)$	$S_a(0.5)$	$S_a(1.0)$	$S_a(2.0)$	PGA	F_a	F_v	M_v	J
0.42	0.594	0.373	0.194	0.092	0.303	1.2	1.3	1.600	0.500

Site Classification
- ◯ Hard rock
- ◯ Rock
- ◯ Very dense soil and soft rock
- ◉ Stiff soil
- ◯ Soft soil
- ◯ Other soils

D

Importance Factor
- ◯ Low
- ◉ Normal
- ◯ High
- ◯ Post-disaster

1.0

Type of SFRS

Concrete _ Ductile shear walls

R_d = 3.5 R_o = 1.6

$T_{a,\ etabs}$ = 8.826 s T_a = 4.226 s

$T_{a,\ code}$ = 2.113 s $I_E F_a S_a(0.2)$ = 0.69

V/W = 0.0172 V = 6342 kN F_t = 1586 KN

Dynamic Analysis Procedure Required!

Floor	h_i (m)	h_x (m)	DL (kPa)	A_{trib} (m^2)	W_x (kN)	$W_x{*}h_x$	F_x (kN)	M_x (kN.m)
ROOF	3.65	147.20	5.46	853.00	4660	685915	1704	6218
40	3.65	143.55	10.93	853.00	9320	1337814	230	13275
39	3.65	139.90	10.93	853.00	9320	1303798	224	21151
38	3.65	136.25	10.93	853.00	9320	1269782	218	29824
37	3.65	132.60	10.93	853.00	9320	1235766	213	39272
36	3.65	128.95	10.93	853.00	9320	1201750	207	49475
35	3.65	125.30	10.93	853.00	9320	1167733	201	60411
34	3.65	121.65	10.93	853.00	9320	1133717	195	72058
33	3.65	118.00	10.93	853.00	9320	1099701	189	84395
32	3.65	114.35	10.93	853.00	9320	1065685	183	97402
31	3.65	110.70	10.93	853.00	9320	1031669	177	111055
30	3.65	107.05	10.93	853.00	9320	997652	172	125335
29	3.65	103.40	10.93	853.00	9320	963636	166	140220
28	3.65	99.75	10.93	853.00	9320	929620	160	155689
27	3.65	96.10	10.93	853.00	9320	895604	154	171719

26	3.65	92.45	10.93	853.00	9320	861588	148	188290
25	3.65	88.80	10.93	853.00	9320	827572	142	205381
24	3.65	85.15	10.93	853.00	9320	793555	136	214361
23	3.65	81.50	10.93	853.00	9320	759539	131	226748
22	3.65	77.85	10.93	853.00	9320	725523	125	238808
21	3.65	74.20	10.93	853.00	9320	691507	119	250493
20	3.65	70.55	10.93	853.00	9320	657491	113	261757
19	3.65	66.90	10.93	853.00	9320	623475	107	272556
18	3.65	63.25	10.93	853.00	9320	589458	101	282849
17	3.65	59.60	10.93	853.00	9320	555442	96	292594
16	3.65	55.95	10.93	853.00	9320	521426	90	301754
15	3.65	52.30	10.93	853.00	9320	487410	84	310291
14	3.65	48.65	10.93	853.00	9320	453394	78	318171
13	3.65	45.00	10.93	853.00	9320	419378	72	325359
12	3.65	41.35	10.93	853.00	9320	385361	66	331825
11	3.65	37.70	10.93	853.00	9320	351345	60	337539
10	3.65	34.05	10.93	853.00	9320	317329	55	342472
9	3.65	30.40	10.93	853.00	9320	283313	49	346599
8	3.65	26.75	10.93	853.00	9320	249297	43	349895
7	3.65	23.10	10.93	853.00	9320	215280	37	352337
6	3.65	19.45	10.93	853.00	9320	181264	31	353904
5	3.65	15.80	10.93	853.00	9320	147248	25	354577
4	3.65	12.15	10.93	853.00	9320	113232	19	354339
3	3.65	8.50	10.93	853.00	9320	79216	14	353174
2	4.85	4.85	12.54	853.00	10693	51861	9	350169
	0	0		**Sum =**	369494	27661345	6342	350169

Project: **L_SW_C**
Number : **Model 3**
Direction: **X direction**

Location: Montreal

Total Number of Floors, N_{TL} = **12**

Climatic Data and Structural Parameters

q	$S_a(0.2)$	$S_a(0.5)$	$S_a(1.0)$	$S_a(2.0)$	PGA	F_a	F_v	M_v	J
0.42	0.594	0.373	0.194	0.092	0.303	1.2	1.3	1.043	0.809

Site Classification

- ○ Hard rock
- ○ Rock
- ○ Very dense soil and soft rock
- ◉ Stiff soil
- ○ Soft soil
- ○ Other soils

D

Importance Factor

- ○ Low
- ◉ Normal
- ○ High
- ○ Post-disaster

1.0

Type of SFRS

Concrete _ Conventional shear walls

R_d = 1.5 R_o = 1.3

$T_{a,\ etabs}$ = 1.217 s T_a = 1.217 s

$T_{a,\ code}$ = 0.869 s $I_E F_a S_a(0.2)$ = 0.69

V/W = 0.1178 V = 12993 kN F_t = 1107 KN

Dynamic Analysis Procedure Required!

Floor	h_i (m)	h_x (m)	DL (kPa)	A_{trib} (m^2)	W_x (kN)	W_x*h_x	F_x (kN)	M_x (kN.m)
ROOF	3.65	45.00	7.53	853.00	6426	289150	2397	8749
12	3.65	41.35	10.93	853.00	9320	385361	1719	23774
11	3.65	37.70	10.93	853.00	9320	351345	1568	44521
10	3.65	34.05	10.93	853.00	9320	317329	1416	70436
9	3.65	30.40	10.93	853.00	9320	283313	1264	100964
8	3.65	26.75	10.93	853.00	9320	249297	1112	131809
7	3.65	23.10	10.93	853.00	9320	215280	961	164364
6	3.65	19.45	10.93	853.00	9320	181264	809	197667
5	3.65	15.80	10.93	853.00	9320	147248	657	230993
4	3.65	12.15	10.93	853.00	9320	113232	505	263677
3	3.65	8.50	10.93	853.00	9320	79216	353	295107
2	4.85	4.85	12.54	853.00	10693	51861	231	334052
	0	0		**Sum =**	110313	2663896	12993	334052

Project: **H_SW_C**
Number : **Model 4**
Direction: **X direction**

Location: Montreal

Total Number of Floors, N_{TL} = **40**

Climatic Data and Structural Parameters

q	$S_a(0.2)$	$S_a(0.5)$	$S_a(1.0)$	$S_a(2.0)$	PGA	F_a	F_v	M_v	J
0.42	0.594	0.373	0.194	0.092	0.303	1.2	1.3	1.600	0.500

Site Classification
- ○ Hard rock
- ○ Rock
- ○ Very dense soil and soft rock
- ◉ Stiff soil
- ○ Soft soil
- ○ Other soils

D

Importance Factor
- ○ Low
- ◉ Normal
- ○ High
- ○ Post-disaster

1.0

Type of SFRS

Concrete _ Conventional shear walls

R_d = 1.5 R_o = 1.3

$T_{a,\ etabs}$ = 8.826 s T_a = 4.226 s

$T_{a,\ code}$ = 2.113 s $I_E F_a S_a(0.2)$ = 0.69

Dynamic Analysis Procedure Required!

V/W = 0.0493   V = 18213 kN F_t = 4553 KN

Floor	h_i (m)	h_x (m)	DL (kPa)	A_{trib} (m^2)	W_x (kN)	W_x*h_x	F_x (kN)	M_x (kN.m)
ROOF	3.65	147.20	5.46	853.00	4660	685915	4892	17856
40	3.65	143.55	10.93	853.00	9320	1337814	661	38124
39	3.65	139.90	10.93	853.00	9320	1303798	644	60741
38	3.65	136.25	10.93	853.00	9320	1269782	627	85648
37	3.65	132.60	10.93	853.00	9320	1235766	610	112782
36	3.65	128.95	10.93	853.00	9320	1201750	593	142082
35	3.65	125.30	10.93	853.00	9320	1167733	577	173487
34	3.65	121.65	10.93	853.00	9320	1133717	560	206935
33	3.65	118.00	10.93	853.00	9320	1099701	543	242366
32	3.65	114.35	10.93	853.00	9320	1065685	526	279717
31	3.65	110.70	10.93	853.00	9320	1031669	509	318928
30	3.65	107.05	10.93	853.00	9320	997652	493	359938
29	3.65	103.40	10.93	853.00	9320	963636	476	402684

28	3.65	99.75	10.93	853.00	9320	929620	459	447106
27	3.65	96.10	10.93	853.00	9320	895604	442	493142
26	3.65	92.45	10.93	853.00	9320	861588	425	540731
25	3.65	88.80	10.93	853.00	9320	827572	409	589812
24	3.65	85.15	10.93	853.00	9320	793555	392	615601
23	3.65	81.50	10.93	853.00	9320	759539	375	651175
22	3.65	77.85	10.93	853.00	9320	725523	358	685808
21	3.65	74.20	10.93	853.00	9320	691507	341	719364
20	3.65	70.55	10.93	853.00	9320	657491	325	751712
19	3.65	66.90	10.93	853.00	9320	623475	308	782726
18	3.65	63.25	10.93	853.00	9320	589458	291	812284
17	3.65	59.60	10.93	853.00	9320	555442	274	840271
16	3.65	55.95	10.93	853.00	9320	521426	257	866576
15	3.65	52.30	10.93	853.00	9320	487410	241	891093
14	3.65	48.65	10.93	853.00	9320	453394	224	913721
13	3.65	45.00	10.93	853.00	9320	419378	207	934365
12	3.65	41.35	10.93	853.00	9320	385361	190	952934
11	3.65	37.70	10.93	853.00	9320	351345	174	969343
10	3.65	34.05	10.93	853.00	9320	317329	157	983511
9	3.65	30.40	10.93	853.00	9320	283313	140	995362
8	3.65	26.75	10.93	853.00	9320	249297	123	1004827
7	3.65	23.10	10.93	853.00	9320	215280	106	1011839
6	3.65	19.45	10.93	853.00	9320	181264	90	1016340
5	3.65	15.80	10.93	853.00	9320	147248	73	1018273
4	3.65	12.15	10.93	853.00	9320	113232	56	1017589
3	3.65	8.50	10.93	853.00	9320	79216	39	1014243
2	4.85	4.85	12.54	853.00	10693	51861	26	1005614
	0	0		**Sum =**	369494	27661345	18213	1005614

Project: **L_MF_D**
Number : **Model 5**
Direction: **X direction**

Location: Montreal

Total Number of Floors, N_{TL} = **12**

Climatic Data and Structural Parameters

q	$S_a(0.2)$	$S_a(0.5)$	$S_a(1.0)$	$S_a(2.0)$	PGA	F_a	F_v	M_v	J
0.42	0.594	0.373	0.194	0.092	0.303	1.2	1.3	1.000	0.910

Site Classification

- ○ Hard rock
- ○ Rock
- ○ Very dense soil and soft rock
- ◉ Stiff soil
- ○ Soft soil
- ○ Other soils

D

Importance Factor

- ○ Low
- ◉ Normal
- ○ High
- ○ Post-disaster

1.0

Type of SFRS

Concrete _ Ductile moment-resisting frames

R_d = 4 R_o = 1.7

$T_{a,\ etabs}$ = 1.854 s T_a = 1.854 s

$T_{a,\ code}$ = 1.303 s $I_E F_a S_a(0.2)$ = 0.69 **Dynamic Analysis Procedure Required!**

V/W = 0.0205 V = 2489 kN F_t = 323 KN

Floor	h_i (m)	h_x (m)	DL (kPa)	A_{trib} (m^2)	W_x (kN)	W_x*h_x	F_x (kN)	M_x (kN.m)
ROOF	3.65	45.00	6.56	853.00	5592	251627	510	1861
12	3.65	41.35	12.31	853.00	10497	434039	322	4896
11	3.65	37.70	12.31	853.00	10497	395726	294	9004
10	3.65	34.05	12.31	853.00	10497	357413	265	14079
9	3.65	30.40	12.31	853.00	10497	319100	237	20019
8	3.65	26.75	12.31	853.00	10497	280787	208	26370
7	3.65	23.10	12.31	853.00	10497	242474	180	33215
6	3.65	19.45	12.31	853.00	10497	204161	151	40412
5	3.65	15.80	12.31	853.00	10497	165848	123	47843
4	3.65	12.15	12.31	853.00	10497	127535	95	55394
3	3.65	8.50	12.31	853.00	10497	89222	66	62956
2	4.85	4.85	12.54	853.00	10693	51861	38	72837
	0	0		**Sum =**	121252	2919790	2489	72837

Project: **H_MF_D**
Number : **Model 6**
Direction: **X direction**

Location: Montreal

Total Number of Floors, N_{TL} = **40**

Climatic Data and Structural Parameters

q	$S_a(0.2)$	$S_a(0.5)$	$S_a(1.0)$	$S_a(2.0)$	PGA	F_a	F_v	M_v	J
0.42	0.594	0.373	0.194	0.092	0.303	1.2	1.3	1.000	0.900

Site Classification
- ○ Hard rock
- ○ Rock
- ○ Very dense soil and soft rock
- ◉ Stiff soil
- ○ Soft soil
- ○ Other soils

D

Importance Factor
- ○ Low
- ◉ Normal
- ○ High
- ○ Post-disaster

1.0

Type of SFRS

Concrete _ Ductile moment-resisting frames

R_d = 4 R_o = 1.7

$T_{a,\,etabs}$ =	7.382 s	T_a =	4.754 s		
$T_{a,\,code}$ =	3.170 s	$I_E F_a S_a(0.2)$ =	0.69	**Dynamic Analysis Procedure Required!**	
V/W =	0.0177	V =	7336 kN	F_t =	1834 KN

Floor	h_i (m)	h_x (m)	DL (kPa)	A_{trib} (m^2)	W_x (kN)	W_x*h_x	F_x (kN)	M_x (kN.m)
ROOF	3.65	147.20	6.56	853.00	5592	823098	1979	7224
40	3.65	143.55	12.31	853.00	10497	1506801	266	15417
39	3.65	139.90	12.31	853.00	10497	1468488	259	24555
38	3.65	136.25	12.31	853.00	10497	1430175	252	34615
37	3.65	132.60	12.31	853.00	10497	1391862	245	45569
36	3.65	128.95	12.31	853.00	10497	1353549	239	57396
35	3.65	125.30	12.31	853.00	10497	1315237	232	70068
34	3.65	121.65	12.31	853.00	10497	1276924	225	83563
33	3.65	118.00	12.31	853.00	10497	1238611	218	97855
32	3.65	114.35	12.31	853.00	10497	1200298	212	112919
31	3.65	110.70	12.31	853.00	10497	1161985	205	128731
30	3.65	107.05	12.31	853.00	10497	1123672	198	145267
29	3.65	103.40	12.31	853.00	10497	1085359	191	162501
28	3.65	99.75	12.31	853.00	10497	1047046	185	180409
27	3.65	96.10	12.31	853.00	10497	1008733	178	198966

26	3.65	92.45	12.31	853.00	10497	970420	171	218148
25	3.65	88.80	12.31	853.00	10497	932107	164	237930
24	3.65	85.15	12.31	853.00	10497	893794	158	256292
23	3.65	81.50	12.31	853.00	10497	855481	151	275885
22	3.65	77.85	12.31	853.00	10497	817168	144	295822
21	3.65	74.20	12.31	853.00	10497	778855	137	316073
20	3.65	70.55	12.31	853.00	10497	740542	131	336608
19	3.65	66.90	12.31	853.00	10497	702229	124	357397
18	3.65	63.25	12.31	853.00	10497	663916	117	378411
17	3.65	59.60	12.31	853.00	10497	625603	110	399619
16	3.65	55.95	12.31	853.00	10497	587290	104	420995
15	3.65	52.30	12.31	853.00	10497	548977	97	442509
14	3.65	48.65	12.31	853.00	10497	510664	90	464134
13	3.65	45.00	12.31	853.00	10497	472352	83	485842
12	3.65	41.35	12.31	853.00	10497	434039	77	507606
11	3.65	37.70	12.31	853.00	10497	395726	70	529400
10	3.65	34.05	12.31	853.00	10497	357413	63	551197
9	3.65	30.40	12.31	853.00	10497	319100	56	572972
8	3.65	26.75	12.31	853.00	10497	280787	50	594699
7	3.65	23.10	12.31	853.00	10497	242474	43	616354
6	3.65	19.45	12.31	853.00	10497	204161	36	637911
5	3.65	15.80	12.31	853.00	10497	165848	29	659347
4	3.65	12.15	12.31	853.00	10497	127535	22	680637
3	3.65	8.50	12.31	853.00	10497	89222	16	701759
2	4.85	4.85	12.54	853.00	10693	51861	9	729523
	0	0		**Sum =**	415159	31199400	7336	729523

Project: **L_MF_C** Location: Montreal

Number : **Model 7**

Direction: **X direction** Total Number of Floors, N_{TL} = **12**

Climatic Data and Structural Parameters

q	$S_a(0.2)$	$S_a(0.5)$	$S_a(1.0)$	$S_a(2.0)$	PGA	F_a	F_v	M_v	J
0.42	0.594	0.373	0.194	0.092	0.303	1.2	1.3	1.000	0.910

Site Classification

- ○ Hard rock
- ○ Rock
- ○ Very dense soil and soft rock
- ◉ Stiff soil
- ○ Soft soil
- ○ Other soils

D

Importance Factor

- ○ Low
- ◉ Normal
- ○ High
- ○ Post-disaster

1.0

Type of SFRS

Concrete _ Conventional moment-resisting frames

R_d = 1.5 R_o = 1.3

$T_{a,\ etabs}$ = 1.854 s T_a = 1.854 s

$T_{a,\ code}$ = 1.303 s $I_E F_a S_a(0.2)$ = 0.69 **Dynamic Analysis Procedure Required!**

V/W = 0.0716 V = 8680 kN F_t = 1127 KN

Floor	h_i (m)	h_x (m)	DL (kPa)	A_{trib} (m^2)	W_x (kN)	W_x*h_x	F_x (kN)	M_x (kN.m)
ROOF	3.65	45.00	6.56	853.00	5592	251627	1778	6488
12	3.65	41.35	12.31	853.00	10497	434039	1123	17075
11	3.65	37.70	12.31	853.00	10497	395726	1024	31398
10	3.65	34.05	12.31	853.00	10497	357413	925	49097
9	3.65	30.40	12.31	853.00	10497	319100	826	69809
8	3.65	26.75	12.31	853.00	10497	280787	726	91957
7	3.65	23.10	12.31	853.00	10497	242474	627	115826
6	3.65	19.45	12.31	853.00	10497	204161	528	140924
5	3.65	15.80	12.31	853.00	10497	165848	429	166837
4	3.65	12.15	12.31	853.00	10497	127535	330	193169
3	3.65	8.50	12.31	853.00	10497	89222	231	219540
2	4.85	4.85	12.54	853.00	10693	51861	134	253996
	0	0		**Sum =**	121252	2919790	8680	253996

Project: **H_MF_C**
Number : **Model 8**
Direction: **X direction**

Location: Montreal

Total Number of Floors, N_{TL} = **40**

Climatic Data and Structural Parameters

q	$S_a(0.2)$	$S_a(0.5)$	$S_a(1.0)$	$S_a(2.0)$	PGA	F_a	F_v	M_v	J
0.42	0.594	0.373	0.194	0.092	0.303	1.2	1.3	1.000	0.900

Site Classification

- ○ Hard rock
- ○ Rock
- ○ Very dense soil and soft rock
- ◉ Stiff soil
- ○ Soft soil
- ○ Other soils

D

Importance Factor

- ○ Low
- ◉ Normal
- ○ High
- ○ Post-disaster

1.0

Type of SFRS

Concrete _ Conventional moment-resisting frames

R_d = 1.5 R_o = 1.3

$T_{a,\ etabs}$ = 7.382 s T_a = 4.754 s

$T_{a,\ code}$ = 3.170 s $I_E F_a S_a(0.2)$ = 0.69 **Dynamic Analysis Procedure Required!**

V/W = 0.0616 V = 25581 kN F_t = 6395 KN

Floor	h_i (m)	h_x (m)	DL (kPa)	A_{trib} (m^2)	W_x (kN)	$W_x{*}h_x$	F_x (kN)	M_x (kN.m)
ROOF	3.65	147.20	6.56	853.00	5592	823098	6901	25190
40	3.65	143.55	12.31	853.00	10497	1506801	927	53762
39	3.65	139.90	12.31	853.00	10497	1468488	903	85629
38	3.65	136.25	12.31	853.00	10497	1430175	879	120707
37	3.65	132.60	12.31	853.00	10497	1391862	856	158909
36	3.65	128.95	12.31	853.00	10497	1353549	832	200149
35	3.65	125.30	12.31	853.00	10497	1315237	809	244341
34	3.65	121.65	12.31	853.00	10497	1276924	785	291399
33	3.65	118.00	12.31	853.00	10497	1238611	762	341237
32	3.65	114.35	12.31	853.00	10497	1200298	738	393769
31	3.65	110.70	12.31	853.00	10497	1161985	715	448909
30	3.65	107.05	12.31	853.00	10497	1123672	691	506571
29	3.65	103.40	12.31	853.00	10497	1085359	667	566670
28	3.65	99.75	12.31	853.00	10497	1047046	644	629118
27	3.65	96.10	12.31	853.00	10497	1008733	620	693830

26	3.65	92.45	12.31	853.00	10497	970420	597	760721
25	3.65	88.80	12.31	853.00	10497	932107	573	829704
24	3.65	85.15	12.31	853.00	10497	893794	550	893738
23	3.65	81.50	12.31	853.00	10497	855481	526	962060
22	3.65	77.85	12.31	853.00	10497	817168	503	1031585
21	3.65	74.20	12.31	853.00	10497	778855	479	1102204
20	3.65	70.55	12.31	853.00	10497	740542	455	1173814
19	3.65	66.90	12.31	853.00	10497	702229	432	1246308
18	3.65	63.25	12.31	853.00	10497	663916	408	1319586
17	3.65	59.60	12.31	853.00	10497	625603	385	1393545
16	3.65	55.95	12.31	853.00	10497	587290	361	1468085
15	3.65	52.30	12.31	853.00	10497	548977	338	1543108
14	3.65	48.65	12.31	853.00	10497	510664	314	1618518
13	3.65	45.00	12.31	853.00	10497	472352	290	1694218
12	3.65	41.35	12.31	853.00	10497	434039	267	1770113
11	3.65	37.70	12.31	853.00	10497	395726	243	1846112
10	3.65	34.05	12.31	853.00	10497	357413	220	1922124
9	3.65	30.40	12.31	853.00	10497	319100	196	1998057
8	3.65	26.75	12.31	853.00	10497	280787	173	2073823
7	3.65	23.10	12.31	853.00	10497	242474	149	2149337
6	3.65	19.45	12.31	853.00	10497	204161	126	2224510
5	3.65	15.80	12.31	853.00	10497	165848	102	2299261
4	3.65	12.15	12.31	853.00	10497	127535	78	2373504
3	3.65	8.50	12.31	853.00	10497	89222	55	2447161
2	4.85	4.85	12.54	853.00	10693	51861	32	2543979
	0	0		**Sum =**	415159	31199400	25581	2543979

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