SEISMIC PERFORMANC EVALUATION OF LOW-RISE STEEL BUILDINGS

Virote Boonyapinyo[1,*], Naramet Preethai[1], Jirawat Junruang[2], Sutat Leelataviwat[3]

Jarun Srechai[4], Wongsa Worakulsajja[5]

[1] *Faculty of Engineering, Thammasat School of Engineering, Thammasat University, Rangsit Campus, Pathumthani, Thailand*
[2] *Faculty of Engineering and Architecture, Rajamangala University of Technology Tawan-ok, Uthenthawai Campus, Bangkok, Thailand*
[3] *Faculty of Engineering, King Mongkut's University of Technology Thonburi, Bangkok, Thailand*
[4] *Faculty of Engineering, Burapha University, Chon Buri, Thailand*
[5] *Faculty of Engineering, Rajamangala University of Technology Thanyaburi, Pathumthani, Thailand*

*Corresponding author: bvirote@engr.tu.ac.th

1. INTRODUCTION

Ground shaking from earthquakes can cause buildings and bridges to collapse. DPT.1301/1302-61 (2018) standard in Thailand, require that buildings located in seismic zones must be designed and constructed to meet criteria. Moment-resisting steel frames (MRFs) are recognized for their flexibility, excellent ductility, and energy dissipation capacity. Nonetheless, their flexibility presents difficulties in adhering to drift control regulations, and their rigid beam-column connections can be vulnerable to fractures during seismic events. In high seismic zones, concentrically braced steel frames (CBFs) are commonly used as effective systems for resisting seismic loads. CBFs demonstrate increased lateral stiffness, but the alternating tension and compression loads may restrict the structure's ability to dissipate energy due to the brace buckling. Eccentrically braced steel frames (EBFs) combine the advantages of both CBFs and MRFs, providing the required elastic stiffness to meet drift control criteria during frequent earthquakes and ensuring the necessary ductility to prevent structural failure in rare seismic events. However, there are limited data on selecting a structural steel system to resist small to moderate seismic zones in Thailand.

This study present seismic performance comparisons of steel structures with various structural systems, ductility. The member design calculations are performed using DPT.1301/1302-61 with the seismic demand and overstrength requirements for steel structure adopted from DPT.1304-61 (2018). A nonlinear static (pushover) analysis (SAP2000, 2010; Boonyapinyo and Choopool, 2014; Boonyapinyo and Hinlad, 2021) is performed to evaluate the capacity and ductility associated with each configuration. This study, provides a useful guideline for appropriately selecting the lateral resisting system and ductility when designing earthquake-resistant structural steel buildings in Mueang Chiang Mai, Thailand.

2. ANALYTICAL MODEL

2.1 Case Study for 8-Storey Steel Building

The building model employed in this study is an eight-story steel structure with plan dimensions of 32 m x 26 m (Figure 1.). The story height is 4.5 m for the first floor and 3.5 m for other floors (Figure 2.). In this study, the Allowable Strength Design (ASD) method is used to design steel structures in accordance with the guidelines in EIT 011038-22 (2022). The moment-resistant frames (MRFs) are about major X axis or in Y direction and about minor Y axis or X direction (Figure 1.). The concentrically and eccentrically braced frames (CBFs/EBFs) are positioned along the perimeter in both X and Y directions as illustrated in Figure 1.

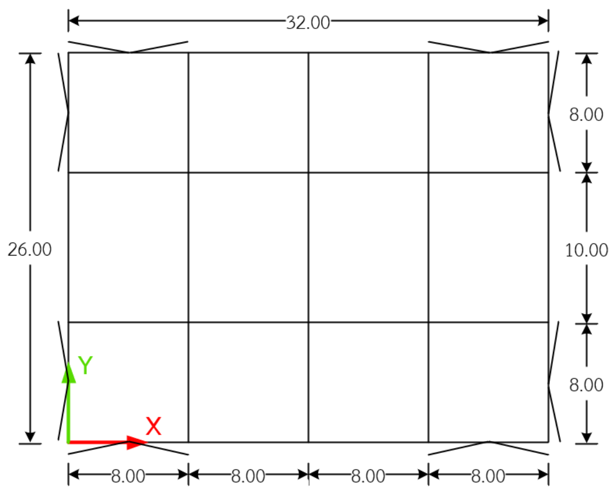


Figure 1. Plan view of 8-storey steel building (unit: m)

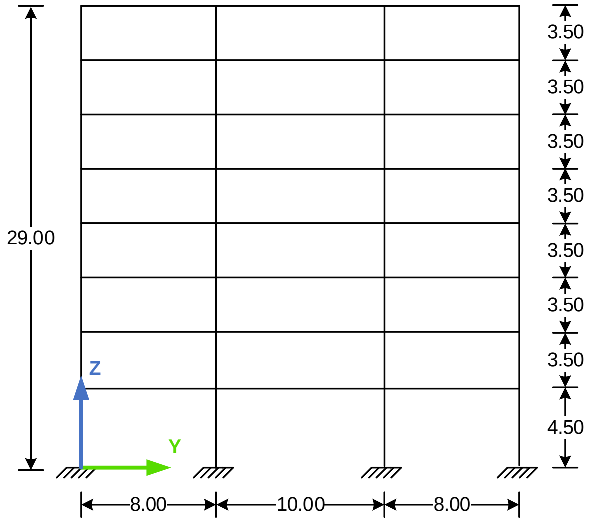


Figure 2. Elevation view of 8-storey steel building (unit: m)

2.2. Seismic Demand Calculations

The seismic load is determined in accordance with the guidelines in DPT.1301/1302-61. For Muang Chiangmai Soil type “D” is considered and S_{DS} = 0.84, S_{D1} = 0.37, S_a for 8-storey buildings = 0.426. The importance factor is assumed as I = 1.0. For steel structure, damping ratio = 2.5% is considered for the design spectrum. The elastic design spectra for Muang Chiang Mai and Bangkok, Thailand are shown in Figure 3.

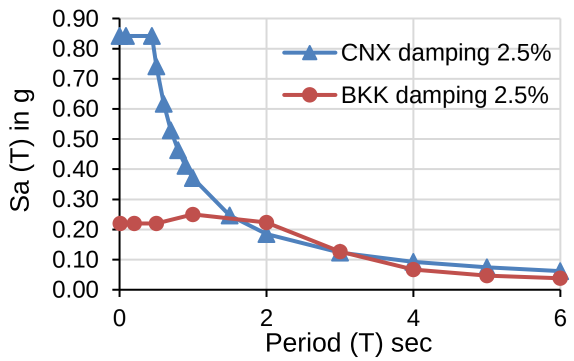


Figure 3. Elastic design spectra for Muang Chiang Mai and Bangkok, Thailand (DPT.1301/1302-61)

3. RESULTS

3.1 Moment Resisting Frame, MRFs

The pushover curve of 8-storey buildings located in Muang Chiang Mai (CNX) with 3 different ductility, including: 1. Gravity load design frame (GLD), 2. Intermediate moment resisting frame (IMRF/CNX), and 3. Special moment resisting frame (SMRFs/CNX) are shown in Figure 4. The results shown that, base shear of IMRFs/ CNX and SMRFs/ CNX equal to 350 and 292 tons, respectively and roof displacement of the building equal to 102 and 115 centimetres, respectively.

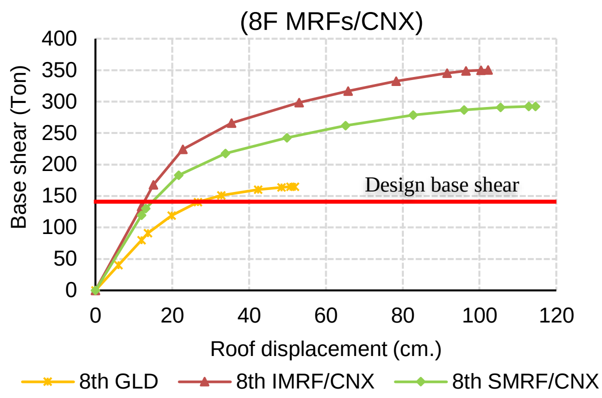
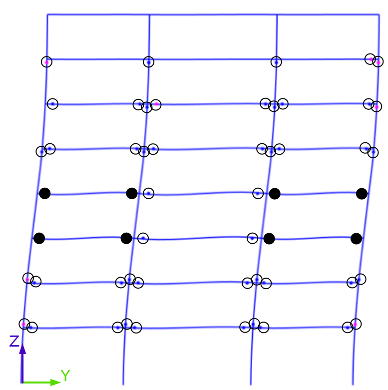


Figure 4. Pushover curve of 8F MRFs/CNX.

From Figure 4, base shear capacity of IMRFs/ CNX is 350 tons. This value is higher than the design base shear of 148 tons specified by the DPT.1301/1302-61 standard. An overstrength ratio is the ratio between the actual base shear capacity of a structure and the design base shear. Then, the overstrength ratio of IMRFs/ CNX equal to 350/148= 2.36.

From Figure 4, the Initial stiffness of SMRFs is like IMRFs but the ductility of SMRFs is moderately higher than IMRFs. However, the base shear capacity of IMRFs is moderately higher than SMRFs because design base shear of IMRFs with R = 4.5 is higher than that of SMRFs with R = 8. GLD steel building is in the inelastic range and can withstand a design earthquake in the life safety due to the overstrength factor.



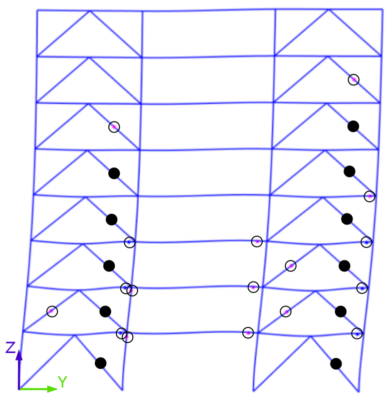
(○ yielding, ● Plastic hinge)

Figure 5. Pushover curve of 8F CBFs/CNX

For IMRFs, the plastic hinge mechanisms of 8-storey buildings located in Muang Chiang Mai (CNX) is shown in Figure 5. Yielding or plastic hinges were presented in all beams except those on the 7th and 8th floors. This was a result of the predominance of gravity load conditions in the design of beams on the upper floor. As the pushover analysis considered distributed gravity loads, and the same steel frame section was used at both the top and bottom of the beams, Yielding or plastic hinges were only observed at the ends of the beams in the 1st to 6th floors. From sequence of hinge mechanism, it becomes evident that plastic hinges initially appeared in all beams and subsequently at the base of the columns. Yielding was detected in columns at many locations other than the 1st and 2nd floors using the larger columns.

3.2 Concentric Braced Frame, CBFs

Concentrically braced frames are usually more economical to construct than moment resisting frames and eccentrically braced frames. The pushover curve of 8-storey buildings located in Muang Chiang Mai (CNX) with 2 ductility including: 1) Gravity load design frame (GLD) and 2) Special concentric braced frame (SCBFs/CNX) are shown in Figure 4. The results shown that base shear of SCBFs/CNX equal to 355 tons and roof displacement of the building equal to 18 centimetres. The CBFs have greater seismic strength than the GLD building but exhibit relatively low roof displacement. The model SCBFs/CNX is designed for a larger seismic demand than model SCBFs/BKK thus resulting in larger strength and stiffness. The behavior of CBFs demonstrate enhanced lateral rigidity. However, the inelastic response of braces makes them susceptible to alternating tensile and compressive forces, potentially restricting the structure's ability to dissipate energy because of brace buckling as shown in Figure 6.



(○ yielding, ● Plastic hinge)

Figure 6. Pattern of plastic hinge formation of SCBFs/CNX.

3.3 Effects of Masonry Infill Wall on Stiffness and Strength

The pushover curve of 8-storey buildings located in Muang Chiang Mai (CNX) with intermediate moment resisting frame (IMRFs) is shown in Figure 7. The results shown that base shear of IMRFs/CNX with and without infill-wall equal to 718 and 350 tons, roof displacement of the building equal to 34 and 102 centimeters, respectively. The capacity curve of model including infill-wall for IMRFs/CNX can increase the maximum capacity to 205%.

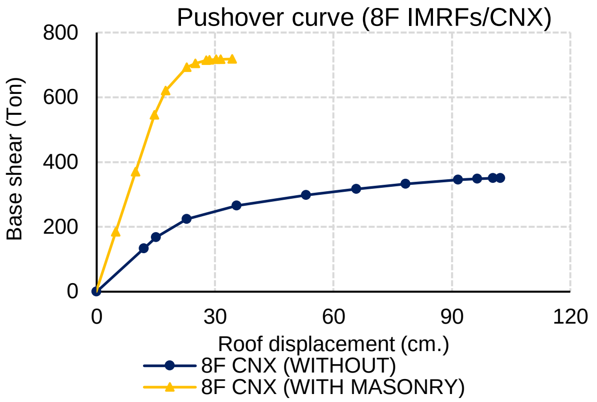


Figure 7. Pushover curve of 8F IMRFs/CNX

4. CONCLUSIONS

This research focuses on assessing the seismic performance of 8-storey steel buildings with various structural systems and structural ductility, both with and without infill walls. These buildings were designed according to DPT.1301/1302-61. The seismic performance of all the buildings in this study can be summarized as follows:

- Base shear overstrength of the intermediate moment resisting frame (IMRFs) at Mueang Chiang Mai is 2.36. The over-strength factor is influenced by four main factors: 1) Material overstrength, 2) Section overstrength, 3) Structural systems overstrength, and 4) Seismic code requirements.
- The SMRFs exhibit the highest level of ductility but the lowest stiffness and strength. The special concentric braced frames (SCBFs) exhibit the highest stiffness and strength.
- The ability to absorb energy during an earthquake depends on the building's ductility level. Increasing the ductility level of a building improves its dissipate energy capacity.
- An 8-storey IMRFs with infill-walls can increase the maximum capacity by up to 205%. The infill walls enhance the structure's stiffness and ultimate strength. However, they have the opposite effect on ductility and energy absorption, decreasing these properties.

5. ACKNOWLEDGEMENTS

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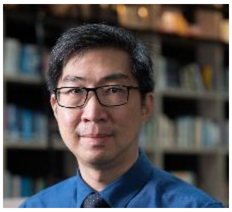
7. AUTHOR BIOGRAPHIES

Virote Boonyapinyo is currently a professor in Civil Engineering, Faculty of Engineering, Thammasat School of Engineering, Thammasat University. He obtained B.Eng and M.Eng from Chulalongkorn University and D.Eng in Structural Engineering from the Yokohama National University, Japan. His research interests include Wind Tunnel Test of High-Rise Buildings and Long-Span Bridges, Earthquake-Resistant Analysis and Design of Bridges and Buildings, Analysis and Design of Steel Structures. He is also a chairman of the subcommittee on the Effects of Earthquakes and Wind Loads, and advisor for the subcommittee on Steel Structures, Engineering Institute of Thailand under H.M. the King's Patronage.

Naramet Preethai is currently working in his own company. He obtained a B.Eng and M.Eng in Civil Engineering from Thammasat University, Thailand. His research interests include Earthquake-Resistant Analysis and Design of Buildings, Analysis and Design of Steel Structures.

Jirawat Junruangg is currently a lecturer at the Faculty of Engineering and Architecture at Rajamangala University of Technology Tawan-ok. He obtained a B.Eng in Civil Engineering from King Mongkut's University of Technology North Bangkok, as well as M.Eng and D.Eng in Structural Engineering from Thammasat University, Thailand. His research interests include wind tunnel testing of high-rise buildings and long-span bridges, simulating airflow over structures using Computational Fluid Dynamics, and earthquake-resistant analysis and building design.



Sutat Leelataviwat is currently an associate professor in Civil Engineering and an assistant director for research and technology at the Institute for Scientific and Technological Research and Services (ISTRS) at the King Mongkut's University of Technology Thonburi. He obtained Ph.D. in Structural Engineering from the University of Michigan at Ann Arbor, USA. His research interests include seismic design and behavior of RC and steel structures, seismic retrofitting of structures, and energy-based seismic design methods. He is also a member of the committee on the Effects of Earthquakes and Wind Loads and advisor for the committee on Steel Structures, Engineering Institute of Thailand.

Jarun Srechai is currently an assistant professor in Civil Engineering at Burapha University. He obtained Ph.D. in Civil Engineering from Chulalongkorn University, Thailand. His research focused on seismic design and evaluation of RC structures. He is also a committee member of the Effects of Earthquakes and Wind Loads Engineering Institute of Thailand.

Wongsa Wararuksajja is currently an assistant professor in Civil Engineering at Rajamangala University of Technology Thanyaburi. He graduated with a Ph.D. in Structural Engineering from King Mongkut's University of Technology Thonburi, Thailand. His research interests are seismic design and behavior of infilled RC frame.