PACE-2021
International Congress on the
Phenomenological Aspects of Civil Engineering
Research Article 20-23 June 2021

An Analytical Approach to Seismic Response Variation of Hybrid Resistant Structures Comprised of Braced Planed Tube with Belt

Mohaddese Sadeghpour*[1], Afshin Meshkat-Dini[2].
[1] Department-of-Civil Engineering, Shahrood University of Technology, Shahrood, Iran
[2] Department-of- Engineering, Kharazmi University , Tehran, Iran
Corresponding Author E-mail: m.sadrghpour489@gmail.com Corresponding Author ORCID: 0000-0002-6551-1704

Keywords

Tall Building,
Hybrid Resistant Structures,
Belt truss,
Seismic Behavior ,
Outrigger.

Abstract

Recent societal needs have led to the expanding growth of tall buildings with added emphasis on safety, human comfort, and serviceability under wind and earthduake loading as well as environmental and economic impact. In modern tall buildings, lateral loads induced by wind or earthquake are often resisted by a system of coupled shear walls. But when the building increases in height, the stiffness of the structure becomes more important. One of the most efficient approaches to provide both strength and stiffness in a structural frame is to implement hybrid system of peripheral braced frame along with belt truss. This paper aims to investigate the seismic behaviour of steel tall buildings having a compound braced-tube resistant skeleton with belted trusses in higher levels.To this end, two 30-story study models have been designed in 3D. The chosen ensemble of three-component ground motions includes highly powerful near-field records as well as one far-field tremor. Based on the analysis results results in a large decrease in lateral displacement and dynamic drift of the structure and will therefore cause an increase in using the axial capacity of peripheral columns of the structre plan. Therefore, implementing belt truss in addition to lateral resisting system of the structure, is proposed as an efficient scheme in designing high rise buildings.

1.Introduction

In the recent years, there have been many new skyscrapers built which soar into new heights. The most efficient building system for high-rises has been the framed tube system. The tubular concept is credited to Dr. Fazlur Khan. Tubular systems are so efficient that in most cases the amount of structural material used is comparable to that used in conventionally framed buildings half the size. Their development is the result of the continuing quest for structural engineers to design the most economical yet safe and serviceable system. However, the framed tube building suffers from shear lag effects which cause a nonlinear distribution of axial stresses along the face of the building[1-2]. Shear lag is a nonlinear distribution of stresses across the sides of the section, which is commonly found in box girders under lateral load. This effect results in higher stresses at the corner columns than the inner columns of the sides. This reduces the structural efficiency of a tube structure and increases the lateral displacement of the building increases under lateral load[3]. In order to improve the efficiency of a framed tube structure and its use in high-rise building, Combining this system with other lateral resisting systems, such as braced tube. A braced tube overcomes this problem by stiffening the perimeter frames in their own planes. The braces also collect gravity loads from floors and act as inclined columns. The diagonals of a trussed tube connected to columns at each joint effectively eliminate the effects of shear lag throughout the tubular framework. Therefore, the columns can be more widely spaced and the sizes of spandrels and columns can be smaller than those needed for framed tubes, allowing for larger window openings than in the framed tubes[4-5].

One way of limiting drifts is a technique of using a outrigger and belt truss system.An outrigger is a stiff beam that connects the shear walls to exterior columns. When the structure is subjected to lateral forces, the outrigger and the columns resist the rotation of the core and thus significantly reduce the lateral deflection and base moment,which would have arisen in a free core[6-8].

In the current research, nonlinear dynamic behavior of high rise steel structures having peripheral braced frame accompanied by belt trusses in higher levels is studied. To this end, two three dimensional 30-story models are simulated.

2. Specifications of the structural models

As the case study, two 30-story steel structure was designed . The structures floor plan and elevation view are shown in Fig. 1. The plan configuration includes six bays in both of the X and Y axises. Additionally, the height of all stories is constant and equal to 3.5m. The 3D computer models of these four studied structures were created using SAP2000 (Version 14.2.2). The sections, members and connections of all structural models have been designed based on the Iranian national building code (steel structures- part 10) and they have moderated ductility parameter.

A detailed description of sections are provided in Fig. 2. Seismic loading of the structure was based on Iranian code 2800(fourth version). The building was assumed to be located in a high seismic hazard region (peak ground acceleration of 0.3 g) with the soil class 2. The applied dead load is 5kpa for all floors. Yet, the live load was set 2 kpa for the floors and 1.5 kpa on the roof. Table 1 shows the modal vibration periods associated with all four studied models related to the X direction.

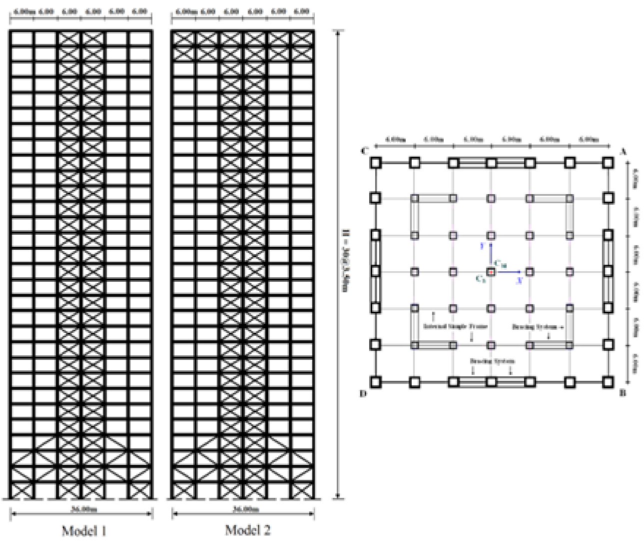

Figure 1. The structures floor plan and elevation view

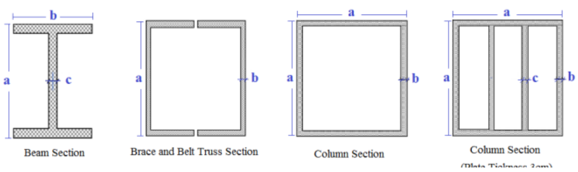

Figure 2. Section property of 30-storey models

Table 1. Modal vibration periods of structural models

Lateral Resistant System	T1 (sec) First Lateral Mode	T2 (sec) Second Lateral Mode	T3 (sec) Initial Torsional Mode
Model 1	3.905	2.503	0.961
Model 2	3.248	2.066	0.834

3. Characteristics of near-fault ground motions

Ground motion records from the sites near the fault rupture can be distinguished from far-fault records by an intense velocity pulse. Capable of severe structural damage, this long period pulse causes most of the energy released from the ruptured fault to apply to the structure within a short time at the beginning of the earthquake[9-10]. This phenomenon can be particularly attributed to the directivity effect or fling step. Oriented in the fault-normal component of the ground motion, directivity effect occurs where the rupture propagates towards a site with a speed close to the shear wave velocity and the site is aligned with the fault rupture. Fling step is generated by a significant permanent displacement resulting from the tectonic ground movement in both fault-normal and fault-parallel components[11].

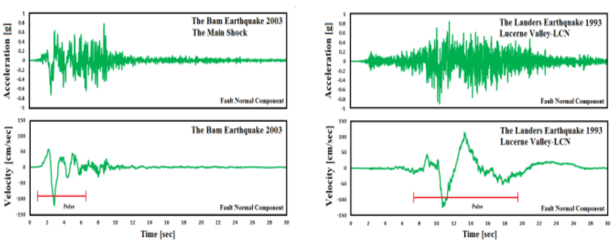

Figure 3. The acceleration and velocity time histories of (a) Bam(TR) (b) LCN(TR)

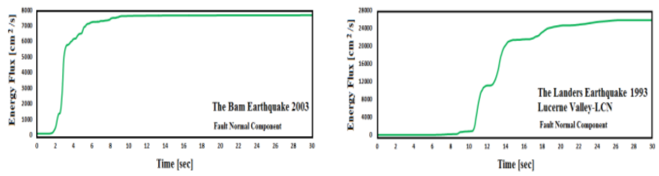

Figure 4. The Energy Flux of (a)Bam (b)LCN

4. The selected earthquake records

The strong ground vibrations that have been used in this research include a number of far-fault and near-fault ground motions from different tectonic tremors. The selected earthquake records have been applied with ground accelerations recorded in three orthogonal directions, i.e. two horizontal and one vertical components. The examined near-fault ground motions, which have been recorded at a distance less than 20 Km from the fault rupture plate, may be characterized by intense velocity pulses of relatively long period. This factor causes that to distinguish them from typical far-field ground motions. It is notified that the near-fault records which contain forward directivity effects were selected from the strong motion database of the Pacific Earthquake Engineering Research Center[12].

Table 2. The selected earthquake records

Ground Motion	Component	Duration (sec)	PGA (g)	PGV (cm/s)	PGD (cm)	Magnitude Mw
Tabas 1978	LN		0.836	97.7	39.9	
Tabas City - 3.0km	TR	30	0.851	121.3	94.5	7.4
	UP		0.688	45.5	17	
Bam 2003	LN		0.635	59.6	20.7	
Bam City - 1.0km	TR	30	0.793	123.7	37.4	6.6
	UP		0.999	37.66	10.11	
Landers 1993	LN		0.981	39.37	23.76	
LCN - 1.0km	TR	30	0.901	124.61	110.29	7.2
	UP		1.023	57.69	30.57	
Imperial Valley 1979	LN		0.41	64.71	27.18	
E06 - 1.0km	TR	30	0.439	110.93	70.07	6.5
	UP		1.655	55.89	27.88	
Northridge 1994	LN		0.308	23.2	10.8	
Alreta (ARL)- 9.2km	TR	30	0.344	40/6	18	6.7
	UP		0.552	18.4	8.8	
Northridge 1994	LN		0.19	20.2	4.24	
Moorpark (MRP) - 28.0km	TR	30	0.29	20.7	4.79	6.7
	UP		0.16	7.9	0.9	

5.Discussion of the Results

The behavior of a structure under the earthquake load is different from earthquake to earthquake. Using only belt truss improved the performance of the building by reducing dynamic response such as lateral displacement and inter storey drift under the earthquake load.

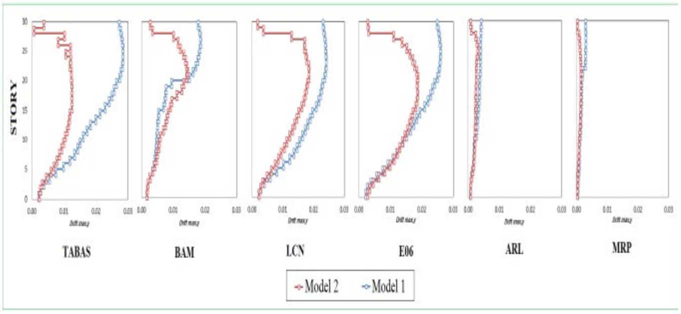

Figure 5 . Stories maximum seismic drift

By studying axial force of columns in one of selected frames, it received that structures containing belt truss components experience greater axial force due to great stiffness and energy absorption in comparison with structures with out belt truss.

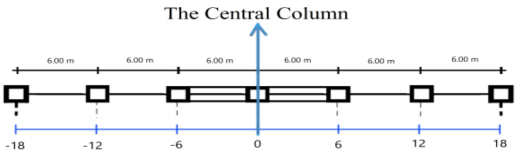

Figure 6 . Selected frame

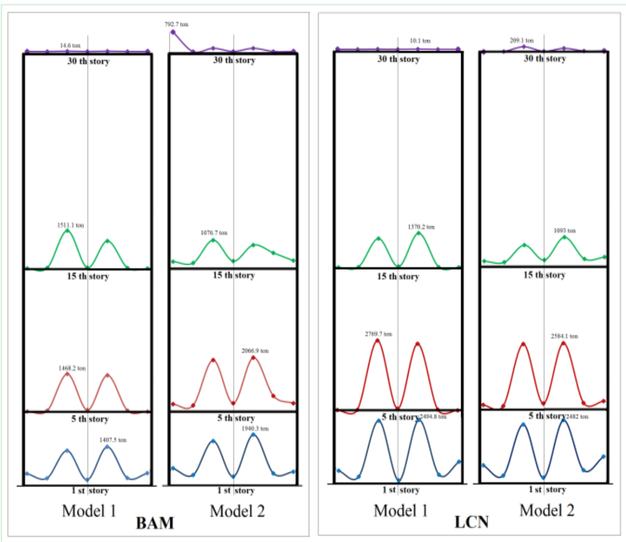

Figure 7. Dynamic axial forces in columns of selected frame

In order to evaluate the behavior of structures during an earthquake, it is appropriate that it be studied time history of roof displacement. It is observed that adding belt truss reduced maximum time history of roof displacement. As well as residual displacement significant reduction in comparison with structures with out belt truss.

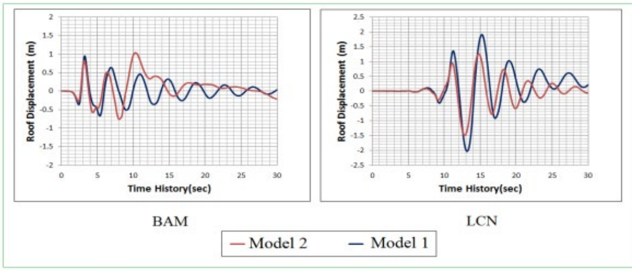

Figure 8. Time history of roof displacement

6.Conclusions

Assessing study results reveal that applying belted trusses in tall braced-tube skeletons would lead in a remarkable increase in stiffness and a growth in the capability to absorb the earthquake's kinetic energy. This issue also results in a large decrease in lateral displacement and dynamic drift of the structure and will therefore cause an increase in using the axial capacity of peripheral columns of the structure plan. Thus it becomes possible to introduce the application of resistant structures with belted trusses in structural skeletons of high-rise buildings, especially in areas with high seismicity as a suitable and efficient alternative plan compared to other structural systems.

Nomenclature

X : The length of the specimen in horizontal direction
Y : The length of the specimen in vertical direction

Declaration of Conflict of Interests

The authors declare that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1.] Cook, J.A., *Structural steel framing options for mid-and high rise buildings* (Doctoral dissertation, Massachusetts Institute of Technology)(2006).
[2.] Hafner I, Vlašić A, Kišiček T, Renić T. Parametric Analysis of the Shear Lag Effect in Tube Structural Systems of Tall Buildings. Applied Sciences. 2021 Jan;11(1):278.
[3.] Rahgozar P. Free vibration of tall buildings using energy method and Hamilton's principle. Civil Engineering Journal. 2020 May 1;6(5):945-53.
[4.] Wang M, Nagarajaiah S, Sun FF. Dynamic characteristics and responses of damped outrigger tall buildings using negative stiffness. Journal of Structural Engineering. 2020 Dec 1;146(12):04020273.
[5.] Alhaddad W, Halabi Y, Xu H, Lei H. Outrigger and Belt-Truss System Design for High-Rise Buildings: A Comprehensive Review Part II—Guideline for Optimum Topology and Size Design. Advances in Civil Engineering. 2020 Feb 21;2020.
[6.] Tavakoli R, Kamgar R, Rahgozar R. Optimal location of energy dissipation outrigger in high-rise building considering nonlinear soil-structure interaction effects. Periodica Polytechnica Civil Engineering. 2020 Jun 18;64(3):887-903.
[7.] Lin PC, Takeuchi T, Matsui R. Seismic performance evaluation of single damped-outrigger system incorporating buckling-restrained braces. Earthquake Engineering & Structural Dynamics. 2018 Oct 10;47(12):2343-65.
[8.] Chen Y, Zhang Z. Analysis of outrigger numbers and locations in outrigger braced structures using a multiobjective genetic algorithm. The Structural Design of Tall and Special Buildings. 2018 Jan;27(1):e1408.

[9.] Alavi, B., and Krawinkler, H. “Behavior of moment-resisting frame structures subjected to near-fault ground motions.” Earthquake Eng. Struct. Dyn., (2004) 33(6),pp. 687–706.
[10.] Mortezaei A, Ronagh HR. Effectiveness of modified pushover analysis procedure for the estimation of seismic demands of buildings subjected to near-fault ground motions having fling step. Natural Hazards and Earth System Sciences. 2013 Jun 19;13(6):1579-93.
[11.] Baker JW. Quantitative classification of near-fault ground motions using wavelet analysis. Bulletin of the Seismological Society of America. 2007 Oct 1;97(5):1486-501.
[12.] PEER Ground Motion Database, http://peer.berkeley.edu/.