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Comparing central truss with concurrent arm brace in high- rise structures (Numerical simulation in sap 2000 software)

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ABSTRACT

The main components of high-rise buildings are brace system with belt truss including arms in center and perimeter coloumns of belt truss in some floors that the most important role of belt truss is appropriate distribution of lateral forces from central core toward perimeter coloumns. So, in comparison with arm restraint system, other components of structure have more contribution in lateral loading. In this paper, linear and non-linear performance of frames in arm system with belt truss was investigated under non-linear static analysis or Push-over load. Investigated variables in this research are two 20-story 7-bay frames consist of two bays of central core. One of them was located in 10th and 20th story of belt truss. Investigated frames were metal which were analyzed in limited components software of sap 2000. Results show that using belt truss (bracing) system with core intermediate arm improve non-linear behavior of structure considerably and existing belts arms in building height causes increasing maximum final resistance of energy absorption tolerance force and structure hardness in all loading stages. Also, in frame with belt truss all members have better and safer performance level than without belt condition.

KEYWORDS
truss system performance, arm system, non-linear static analysis, high rise buildings, sap 2000.

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1. Introduction

By engineering view, when we can call structure as high rise that its height causes lateral forces such as earth quack affects design considerably. Loading in high rise structures is different from mini structures because of most floors, importance and more dynamical effects. Proposing absolute definition for high rise structure is difficult as highness of structure (from appearance view) is a relative issue and depends on region in which structure was built. In region with one-floor buildings, five-floor building can seems high. In Shiraz, the highest structure is Chamran hotel with 33 floors while in New York, Manhattan and Dubai there are structures with 100 to 120 floors. But from structural view, highness definition is easier in this way: structure that in its analysis and design, lateral forces and resulted vibration are more determining than gravity forces are considered as high rise building. Thus, as structure engineer, one of the most important issue that we should mention in designing high rise building is lateral forces and it's fighting system. Two types of systems are common for confronting lateral force in high rise structure of central core system and central core with belt or belt truss that in this paper, performance level of its members are analyzed and compared. For reaching this issue, non-linear analyze should applied on structures that one of common methods, is non-linear static analyze (Push-over). Other researches done in this context are as follow:

Smith et al (1996) proposed performance of structures with outrigger. They suggest spacer outrigger systems in which arming truss and belt truss are located out of the core walls plate, it means in these systems, arm and belt are located in story plan, somewhere far from central core. The aim of this work is decreasing flung areas in comparison with other common arming and belt system.

Xiaoxuan and Shuang (1996) proposed effect of arming beam system with 2D structural model. This model includes one wall studs core, two exterior columns and one series of paired arming beam which connects core wall to the columns. They show that lateral displacement is minimum when system has three arming beam.

Kiyan and Sepahan (2001) investigated using arming and belt truss system in high rise structures reinforced by concrete which are under earth quack and wind loading. They investigated eight 40-story 2D models and five 60-story 3D models and found that in 40-story 2D model, 65% of displacement decreasing will achieved with putting arm in the top and middle of structure and in 60-story 3D model, 18% of displacement decreasing will be achieved by putting arm in the top of structure and 33th story.

Bayati et al (2008) believe that using bracing systems for more than 40-story buildings is insufficient and using belt truss and exterior columns should be avoided because of exterior column shortening and space which is occupied. They suggest Virtual outrigger systems; in this system, ceiling and diaphragm act as belt truss and have less hardness than belt truss. Earth quack in high rise structure affects structure with more intense and larger anchor arm affects structure. Increasing highness and returns of tall buildings causes decreasing in its hardness and stability. For applying stability principles, in addition to control of all structure members, also structure should be considered as a set. Behavior of a high rise structure is similar to a column cantilever with an average weight loss but with considering much shear flexibility or even determinant, behavior of these structures will be different from columns of typical structures which originally has moment behavior. As a result, probable modes of the overall buckling of structure will not only being the moment behavior but also the shear mode or combination of both. Additionally, modes emerge not only in lateral buckling but also in torsional buckling with the transverse bolt of structure. Different principles of designing are proposed and used for confronting lateral loads in high rise structures as follow:

Moment frame system, convergent braces, divergent braces, shear wall or combination of both. If structure highness become more than given given measure, other typical methods are not sufficient for bracing these structures and tabular of box frame system as single cell or multi-cell, outrigger system and truss belt system will be used.

In this paper, mentioned high rise structures became spectral and designed as central system of dynamic analysis. Then, structure was analyzed by Push Over analysis. Results show that using (outrigger) truss belt system with intermediate arming core improved non-linear behavior of structure and existing outrigger belts causes increasing maximum final resistance of energy absorption tolerance force and structure hardness during all stages of loading. Also, in frame with truss belt, all members had better and safer performance level than without belt condition.

2. Principles and methods of designing based on performance

In current designing methods, design criterion is expressed in terms of force or resistance but generally, behavioral models and failure criteria of structural members were mostly defined in terms of displacement or strain. There is a linear relationship between force and displacement or tension and strain in the linear elastic range and force or resistance criterion could be applied easily. But when members enter into the non-linear range, there will be no constant relationship between force- displacement and stress- strain and as a result, force and resistance criteria cannot show behavior and failure of members. In current regulations, it is tried to concern these points by doing a series of secondary control apart from designing method such as controlling lateral displacement. So, designing methods based on resistance and force are appropriate just for small earthquakes which expects to remain within non-linear range but for severe earthquakes in which structure undergoes inelastic deformations and requires ductile behavior, these methods are not suitable. Even some researchers do not know displacement criterion appropriate and believe that design should done based on energy criterion , it means that the energy exerted on the structure in earthquake being less energy absorbed by the structure. In recent years, because of above reasons, approach toward design methods based on performance is increasing. In design methods based on performance, different operational levels are determined for building. These operational levels are defined based on destruction and collapse exerted on structural non-structural systems of building qualitatively and quantitavely. In addition to the different operational levels for building, also different levels are stated for given level of seismic hazard. In next sections, levels of structural and non-structural operation and determination of operation levels of whole building are expressed in detail. Two key factors in design based on operation, are capacity and need and building operation is evaluated and determined through the relationship between capacity and need. Earthquake with selected level of risk, determines need for structure. Expressing the need for building is done based on design parameters such as forces and deformations. The whole capacity of structure is determined by different methods and with considering all hidden capacities in structure such as non-linear deformations of member and according to the similar parameters of need is defined. The basic principles governing the design methods could be defined as "structure should have tolerance capacity for imposed need by considered earthquake as its performance being compatible with design goals. Compared to the force criterion in the current regulations as follows:

Allowable stresses> imopsed tensions or final resistance> imposed final force, design methods criterion are defined based on performance according to the basic principles governing on it:

Capacity> need.

Different methods of design based on performance all based on unit concept and in all of them, basic criteria of design according to the performance is ruling. The only difference of these various methods in the way of determining need and capacity. Some of these methods are capacity spectrum method, displacement coefficient method and methods based on energy.

Among mentioned methods, capacity spectrum and displacement coefficient methods are formally described in famous references such as ATC and FEMA and have more validity among engineers and researchers. Capacity spectrum in ATC40 instruction and displacement coefficient method in instructions FEMA (273 and 356) and considered as basis. Generally these methods are determined after specifying capacity and need of structural point named performance point or displacement that in fact shows the intersection of structural capacity with imposed requirement of considered earthquake. Then, for controlling performance adjustment of structure with the selected performance goals, responses of structural responses corresponding to the yield point are controlled by moving target acceptance criteria corresponding to the performance purpose. One of the best methods for determining the structural capacity of analysis is using Pushover analysis with using increasing nonlinear static analysis step for step, shows structure capacity curve with base shear-displacement roof. Pushover method is applied as a basis for determining structure capacity in capacity spectrum, displacement coefficients methods and co on. Capacity determination is determined depending on mentioned performance and reduction factors associated with damping. In total, regardless of the method used, different steps of seismic design trend could be summarized as follow:

- Investigating different performance levels of building
- Investigating different levels of seismic risk
- Determining performance goals as optimal performance of buildings for given seismic risk levels.
- Determining structure capacity and imposed need from earthquake.
- Investigating relationship between need and capacity and controlling acceptance criteria for mentioned performance goal (capacity spectrum method was chosen in ATC40 instruction as a basis).

3. Performance levels:

Performance level represents the extreme conditions relating to the amount of collapse imposed on structure which is deemed acceptable for a given building and under a given earthquake. These extreme conditions through physical destructions in structure is described as danger to the occupants of the building and the serviceability of structures after the earthquake. Performance levels for structural and non-structural systems are as follow:

4. Performance levels of structural components

Performance levels of structural levels include four levels of the main performance and two levels of middle performance. The main performance levels are: uninterrupted usability, life safety, collapse prevetion, not included.

Middle performance levels are: limited collapse, limited life safety.

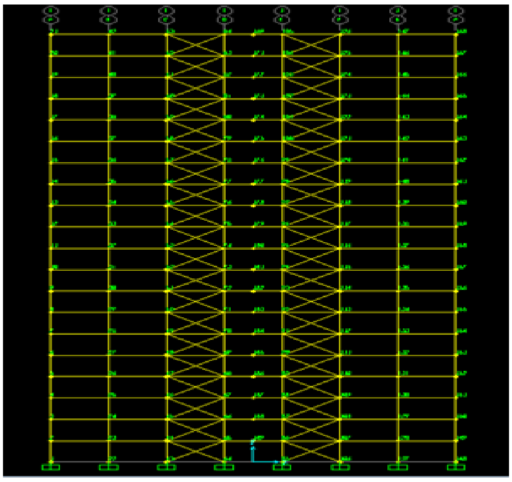
- Performance level of immediate occupancy (IO)
- Performance level of limited collapse
- Performance level of life safety (LS)
- Performance level of limited life safety.
- Performance level of collapse prevetion (CP)
- Not included performance level

5. Numerical model of Sap2000

As an appropriate tool for analysis, current softwares in the field of structural analysis can be used. The appropriate tool is a software in which the characteristics of nonlinear materials could be defined reliably to do static and dynamic analyzes. In this regard, one of the most important softwares is introduced. This software is used as powerful software in the field of transport, industry, public places and sports and so on for analyze and design since 30 years ago. Features such as object-based three-dimensional graphical environment and various options of analyze and design in this software make it as the most comprehensive structural software in this market. Advanced analytical techniques of this software make step by step analyze of great deformations, P-Delta, characteristic analysis and Ritz, Cable analysis, analysis of tension or pressure only, buckling analysis, analysis of explosive, fast nonlinear analysis for dampers, seismic separators and support plasticity and energy methods for drift control possible. SAP2000 is a response to the all analyze and design of structures need for everyone in each project such as simple 2-D static analysis or great 3-D complex non-linear dynamic analysis which is modeled in 2 frames software with a central core and the other one has central core with including belts truss.

6. Introducing modeled frames

In this article, 2 frames with 20 floors and 7 bays were investigated according to the below figures that in these frames, length of all bays were 5 meters and height of 3 meters. In frame 1, in bays 3 and 5, braces arms has been located. In this frame, beam-column connections are as clamped (rigid) and braces connections to the columns are as joint. Above frame is dual. In frame 2, like frame1, arm braces are located in bays 3 and 5 and in floor 10 and 20, belts truss are located as below. In this frame, like frame1, connections of beam to the column are clamped and braces connection to the column are as joint.



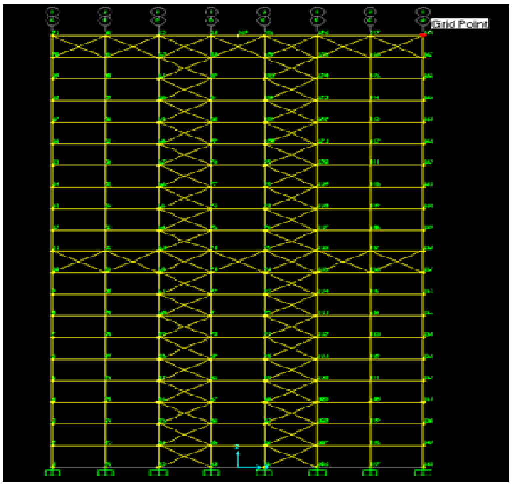


Figure2: frame with central core with belt truss

Figure1: frame with central core

7. Modeling trend

Loading compounds were used according to the National Building Regulations of loading, sixth issue and also, in modeling steel frames, modeling frame is possible easily because of homogeneity of materials and adequacy of available information about steel materials. For steel materials, specifications of consumption steel exist in the market were used in accordance with the following table:

Table1: elastic and plastic specifications of steel materials

Yield stress	2400 Kg/cm2
The ultimate stress	3600 Kg/cm2

Plastic strain	0. 19
Poisson's ratio	0. 3
Modulus of elasticity	$2100000 Kg/cm^2$

The standard plan spectrum used for frame analysis of studied frames is soil type II relatively low risk.

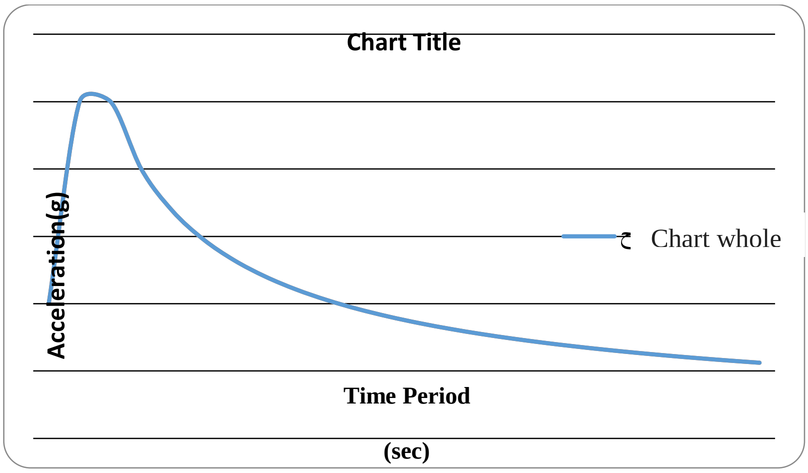


Figure2: plan spectrum for soil type II

8. Method for determining performance levels of frames members

One of the SAP2000 outputs, is determining area of members performance level for which, we defined plastic joints. The way of presenting performance level of members is colored for member joint. Figure 3 shows sample output.

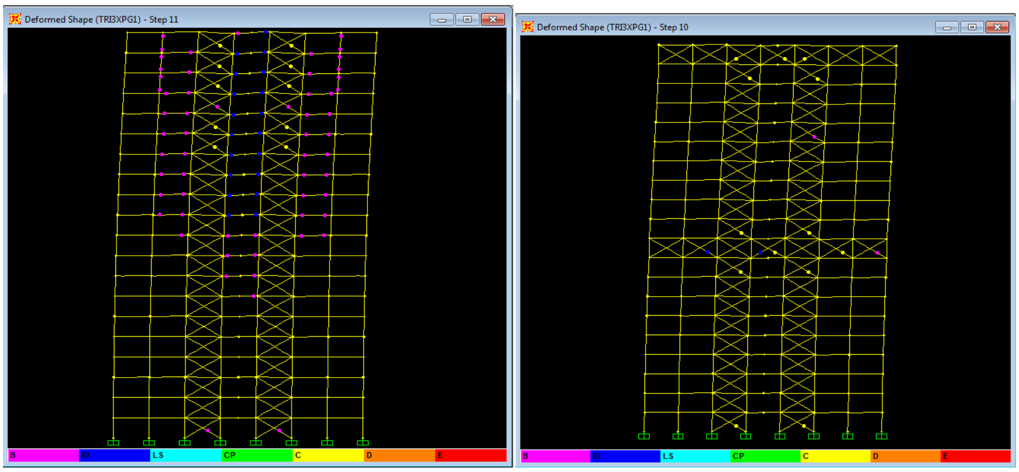


Figure3: comparing joints color of the main members of two types of frames under triangular lateral load in positive direction

After determining joints color for all members in all loading modes (triangular and rectangular) and directions (positive and negative) performance level of all members was achieved and finally, was shown as percentage charts for members and whole structure.

9. Comparing performance level of frame members and whole structure

A) Comparing performance level of columns

As it is clear in figure4, performance level of columns which are the most important members of our in structures and we expect that in the last stage, columns decline and totally, they play the main role in structure resistance, they have better performance in frame with truss belt than frame without truss belt. In frame with truss belt, 100% of columns are in immediate occupancy area (IO) that in frame without truss belt, 96% of columns are in in immediate occupancy (IO) area.

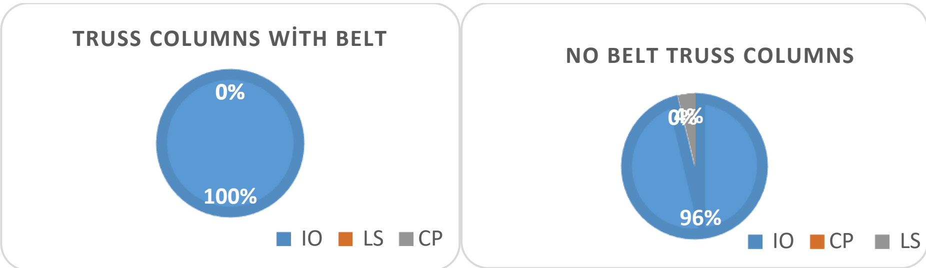


Figure 4: performance level of columns in frame without truss belt (right), performance level percentage of columns in frame with truss belt (left)

B) Comparing performance level of beams

In beams which are the most important members of structure after column, 100% of beams in frame with truss belt have performance level of uninterrupted usage that in frame of truss belt, 93% of beams have immediate occupancy performance in this level and the other 7%, are in life safety area.

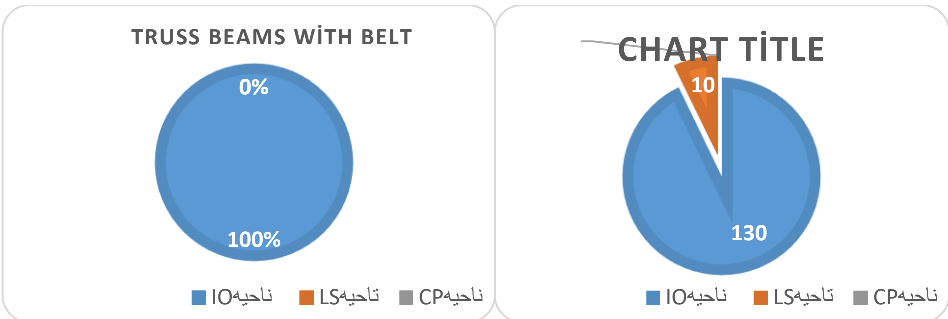


Figure5: Percentage of beams performance level in frame without the belt truss (right), Percentage of beams performance level in frame with the belt truss.

C) Comparing performance level of braces

In braces, in frame with truss belt, 56% of braces are in uninterrupted usage area, 28% of them are in performance level of lateral life safety area and the other 16% are in performance level of collapse prevetion (CP). As you know, we expect designed structures that first, braces and after that beams and finally columns undergoes rupture. Braces in frame with truss belt, 35% of these members are in immediate occupancy area (IO), 35% of these members are in life safety (LS) area and the other 30% are in collapse prevetion (CP) area. In figure 6 and 7, comparison of members percentage of these two types of frames are shown.

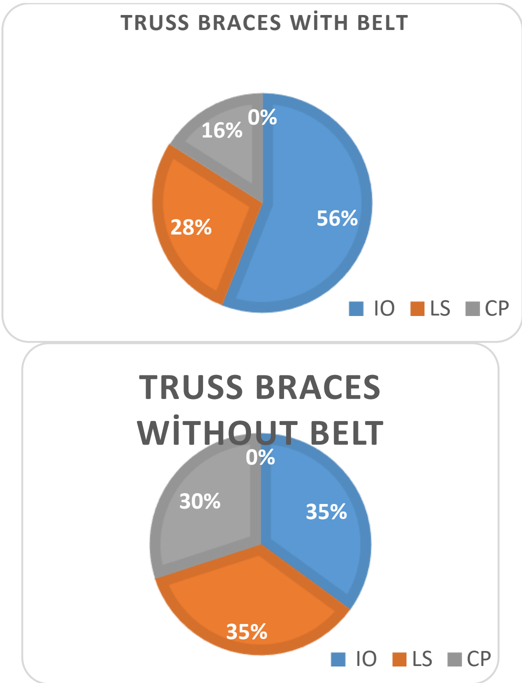


Figure6: level percent of braces performance in frame without truss belt (right), level percent of braces performance in frame with truss belt

D) Comparing performance level of all structure members

As seen in below figure, 94% of all frame members with belt are in immediate occupancy ice area (IO) that in frame without belt, this amount is 88%. In frame with truss belt, 4% of all frame members are in life safety (LS) area that in frame without belt this amount is 9%. Finally, in frame with truss belt, 2% of all members are in performance area of collapse prevetion (CP) that this number in frame without belt is 3%.

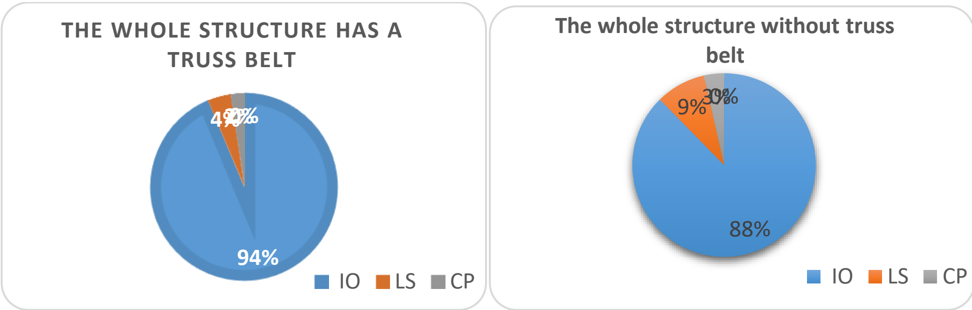


Figure7: level of performance of whole structure in frame without truss belt (right), level of performance of whole structure in frame with truss belt (left)

10. Conclusion

In high buildings in which linear design is not economical, limited conditions and nonlinear behavior of system could be used. Considering results of this research, it was determined that using belt (arm) truss) with middle arm core has significant improvement in non-linear behavior of structure. Considering Push-over curve resulted from non-linear static analyze of investigated frames, it was determined that existence of belts arm at the height of the building causes significant increase in final resistance of the maximum tolerance of energy absorption and structure ductility in all loading stages.

One of the most important investigated issues in this research is comparing performance level of all members in (arm) central core mode with belt truss and without belt truss that results show that in frame with belt truss, all members has better and safer performance levels than in mode without belt.

For earthquake, building design regulation (2800) was developed based on performance level of life safety (LS). After linear dynamic design of these two structures which were based on this regulation and with more accurate non-linear- static analysis we understand that number of members passed the performance level of life safety and reached collapse prevetion (CP) and this problem shows that we hope seismic rules are met with design in linear boundaries based on regulations but after deeper analysis, we observe that seismic rules are not met.

Another benefit of this plan which is more usable for contractors and design engineers is economical efficiency of the system. Results show that existence of belts truss causes significant decrease in the cross section of different parts of the building comparing with usual bracing system. Due to the increasing costs of building industry particularly in steel buildings, importance of usage this system in high buildings being recognized more than before.

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