Earthquake Analysis by Providing Outriggers with Belt Truss System to Buildings

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Abstract— The detailed study is to understand structural behavior of the high rise building with lateral load resisting system under seismic loading is essential for appropriate design and their better performance. In high rise buildings the lateral loads are major concern like earthquake or wind. These are resisted by introducing a system of coupled shear walls and bracings in the structure. But in very tall buildings this lateral stiffness is not enough to resist the lateral loads and hence the introduction of the outrigger beams between the shear walls and external columns is the only solution to provide sufficient lateral stiffness to the structure. The outrigger is commonly used as one of the structural system to effectively control the excessive drift due to lateral load, so that, during small or medium lateral load due to either wind or earthquake load, the risk of structural and non-structural damage can be minimized. For high-rise buildings, particularly in seismic active zone or wind load dominant zone, this system can be chosen as an appropriate structure. The objective of this thesis is to study the outrigger location optimization and the efficiency of each outrigger which is used in the structure. In 60−storey three dimensional models of outrigger with belt truss system is subjected to earthquake load are analyzed and find the natural time period, frequency, base shear, storey drift, lateral displacement reduction related to the outrigger and belt truss system location. The modular analysis for outrigger with belt truss system has been carried out as the thesis.

Key words: Outriggers, Belt Truss, Frequency, Base Shear, Displacement, Mode Shapes

I. Introduction

Human race had always fascinated for height and throughout our history, we have constantly sought to reach for the stars, from the ancient pyramids to today's modern skyscraper. Today, there has been a demonstrated competitiveness that exists in human race to proclaim to have the tallest structure in the world. In late 19th century the tall structures were emerged in the U.S.A. They constituted so-called "American Building Type," meaning is that most important tall buildings were built in the U.S.A. However, now a day's there is a worldwide architectural phenomenon in the development of tall buildings which has evolved rapidly in recent years.

As the population increases in the metropolitan cities the availability of land for shelter is diminishing. Hence to overcome these problems multistorey's buildings are most prominent and efficient solution. In development of tall buildings we have to take an account of various aspects such as requirements, technology, and construction regularities and so on. For designer as the building height increases the challenges will also increases and self-weight of the building, live load acting, and earthquake loads and along with wind forces are significant factors that will affect the design.

For multistory building we have to ensure safe working environment against the dynamic actions. An earthquake is an unexpected moment of the earth's crust which originates below the ground surface. When an earthquake occurs the structures moves vertically and horizontally caused by the ground motion induced by earthquake.

A structure is to be designed to resist the lateral forces which occur to it. In order to achieve this lateral resisting system should be introduced to the structures such as moment resisting frames, unfilled frames, shear walls, framed tubes, trussed tubes, super frames, tube in tube, bundle tubes, outriggers etc.

II. Outrigger

The outrigger and belt truss system acts very important role to resist the lateral loads in the structure. In the structure the external columns are tied to the central core wall with stiffened outriggers and belt truss at one or different levels. This system is rigidly fixed to the core and simply connected to the exterior columns. When central core tries to bend, the belt trusses act as lever arms which directly transfer axial stresses into the perimeter columns, so that the columns act as struts to resist the lateral deflection of the core. Hence the core fully develops the horizontal shear and the belt trusses transfer the vertical shear from the core to the outrigger frame. Thus, the structure is made to act as a single unit similar to cantilever tube.

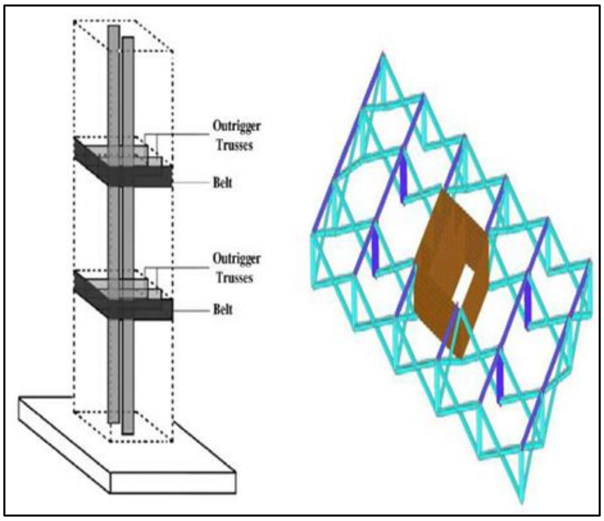

Fig. 1.1: Structure with outriggers and Fig 1.2: 3D view of Outrigger and belt truss belt truss

Outriggers are stiff elements connected to a structure core or to outer columns. Outriggers improve the stiffness against overturning by developing a tension-compression couple in perimeter columns when a central core tries to bend, generating restoring moment acting on the core at the outrigger level.

A. The Concept of Outrigger

In the ancient times the sailing ships are using outriggers to resist the wind force in their sails. Like the ship, the tall building core can be related to the mast of the ship, the outrigger acting like the spreaders and the exterior columns like the stays or shroud of the ship.

B. Types of Outrigger Truss System

Based on connectivity of core to exterior columns, the outrigger truss system may be divided in two ways.

1) conventional outrigger concept
2) virtual outrigger concept

1) Conventional Outrigger Concept

The concept of the conventional outrigger is the outrigger trusses are directly connected to the shear walls or braced frames at the core of the structures. The columns are located outboard of the core. Normally the columns are located at the outer edges of the building.

2) Virtual Outrigger Concept

In the "virtual" outrigger concept, the transfer of overturning moment from the core to elements outboard of the core is achieved without a direct connection between the outrigger trusses and the core. The fundamental concept to use floor diaphragms, which are very stiff and strong in their own plane.

3) Belt Trusses as Virtual Outriggers

The basic principle is the same as when belt trusses are used as virtual outriggers. Some of the moment in the core is transformed into a horizontal couple and transferred to the truss chords in the floors at the top and the bottom of the diaphragm and finally converted into vertical forces at the exterior columns.

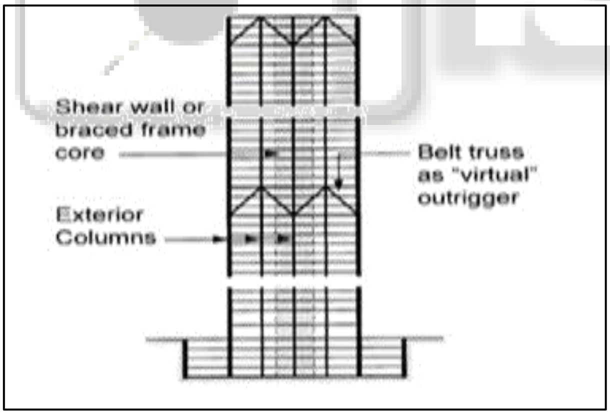

Fig. 1.4: Structure with belt trusses as "virtual" outriggers

III. METHODOLOGY

During earthquake most of the buildings were get damaged but multistories buildings will suffers more than others due to their structural configuration and lack of stiffness against lateral loads. Hence to overcome this stiffness problem we provide outrigger, shear wall, tube in tube, bracings, tubular structure etc.

The behavior of the building also depends upon types of soils also. There are three types of soils are there I, II, III. Soil I and II means hard soil and medium soil respectively. The foundation system should be good because it should carry the whole building mass of the structure to the foundation

A. Objective

Analysis of the 3D models of the 60 storey building located in zone IV and V for medium and hard soil has been performed and overall seismic evaluation of the structures were carried out using the performance parameters like Base shear, Displacement, and storey drift in each storey obtained from the dynamic analysis using the software ETABS.

B. Need for Present Study

- Several studies were carried out on structure by taking shear wall, bracing systems as a lateral load resisting for dynamic analysis
- In several studies outrigger system were only used as a lateral resisting system.
- Based on literature review there is a scope to provide outrigger struts and belt trusses.

C. Scope of the Study

In the present study, 60 story building was considered with the plan area of 42m x 42m in both x and y direction of 7 no. of bays. The typical floor height is considered as 3m throughout the structure and total height of the structure is 180m. The beams, columns, shear walls were assumed as concrete structure and outrigger as steel structure.

1) Constant Parameters

Plan	42m x 42m
Column to column spacing in x & y direction	6m
Support condition	Fixed
Column sizes	
a) 1-8 floors	1150mm x 1150mm
b) 9 floor	1100mm x 1100mm
c) 10-13 floor	1000mm x 1000mm
d) 14-25 floor	950mm x 950mm
e) 26-60 floor	850mm x 850mm
Beam sizes	300mm x 700mm
Slab thickness	150mm
Shear wall	350mm
Outrigger sizes	250 x 250mm
Grade of concrete	M50
Grade of steel	Fe 415

D. Method of Analysis

In the present study the method of analysis is adopted are equivalent static method and Response spectrum method. For the simpler structure we often consider only equivalent static method but in case of multistories structure we consider at dynamic analysis.

Seismic codes will vary from region to region or country to country. In our country Indian standard criterion for earthquake resistant design of structures IS 1893 (part 1): 2002 is the main code that provides outline for calculating seismic design forces. Design force are depends on the seismic coefficient and mass of the structures and latter in turn depends on properties like seismic zone in which the structure is located. The code recommends the following method of analysis

1) Equivalent static analysis method
2) Dynamic analysis method
   a) Response spectrum analysis

b) Time history analysis

1) Equivalent Static Method

The equivalent static method is a technique to substitute the effect of dynamic loading of an expected earthquake by a static force distribution laterally on a structure for a design purpose. The total applied seismic force is generally evaluated in two horizontal directions parallel to the main axes of the building. It is assumed that building responds in its fundamental lateral mode. For this to be true the building must be fairly symmetric to avoid torsional moment underground motions.

2) Response Spectrum Analysis

The response spectrum represents an interaction between ground acceleration and the structural system, by an envelope of several different ground motion records. The resulting plot can be used to select response of any linear single degree of freedom oscillator which gives its natural frequency of oscillation.

E. Model Details

1) Case 1: RC bare frame having shear wall in hard and medium soil for zone IV and V
2) Case 2: RC bare frame having shear wall with outrigger struts and belt trusses in medium soil at zone IV (OB-M-IV)
   - Outrigger struts and belt trusses at multi storeys (OB-M-IV) in 15-30-45
   - Outrigger struts and belt trusses at multi storeys (OB-M-IV) in 30-45-60
   - Outrigger struts and belt trusses at double storeys (OB-M-IV) in 15-30
   - Outrigger struts and belt trusses at double storeys (OB-M-IV) in 15-45
   - Outrigger struts and belt trusses at double storeys (OB-M-IV) in 30-45
   - Outrigger struts and belt trusses at double storeys (OB-M-IV) in 30-60
   - Outrigger struts and belt trusses at double storeys (OB-M-IV) in 45-60
   - Outrigger struts and belt trusses at single storey (OB-M-IV) in 15
   - Outrigger struts and belt trusses at single storey (OB-M-IV) in 30
   - Outrigger struts and belt trusses at single storey (OB-M-IV) in 45
   - Outrigger struts and belt trusses at single storey (OB-M-IV) in 60
3) Case 3: RC bare frame having shear wall with outrigger struts and belt trusses in hard soil at zone IV (OB-H-IV)
   - Outrigger struts and belt trusses at multi storeys (OB-H-IV) in 15-30-45
   - Outrigger struts and belt trusses at multi storeys (OB-H-IV) in 30-45-60
   - Outrigger struts and belt trusses at double storeys (OB-H-IV) in 15-30
   - Outrigger struts and belt trusses at double storeys (OB-H-IV) in 15-45
   - Outrigger struts and belt trusses at double storeys (OB-H-IV) in 30-45
   - Outrigger struts and belt trusses at double storeys (OB-H-IV) in 30-60
   - Outrigger struts and belt trusses at double storeys (OB-H-IV) in 45-60
   - Outrigger struts and belt trusses at single storey (OB-H-IV) in 15
   - Outrigger struts and belt trusses at single storey (OB-H-IV) in 30
   - Outrigger struts and belt trusses at single storey (OB-H-IV) in 45
   - Outrigger struts and belt trusses at single storey (OB-H-IV) in 60
4) Case 4: RC bare frame having shear wall with outrigger struts and belt trusses in medium soil at zone V (OB-M-V)
   - Outrigger struts and belt trusses at multi storeys (OB-M-V) in 15-30-45
   - Outrigger struts and belt trusses at multi storeys (OB-M-V) in 30-45-60
   - Outrigger struts and belt trusses at double storeys (OB-M-V) in 15-30
   - Outrigger struts and belt trusses at double storeys(OB-M-V) in 15-45
   - Outrigger struts and belt trusses at double storeys (OB-M-V) in 30-45
   - Outrigger struts and belt trusses at double storeys (OB-M-V) in 30-60
   - Outrigger struts and belt trusses at double storeys (OB-M-V) in 45-60
   - Outrigger struts and belt trusses at single storey (OB-M-V) in 15
   - Outrigger struts and belt trusses at single storey (OB-M-V) in 30
   - Outrigger struts and belt trusses at single storey (OB-M-V) in 45
   - Outrigger struts and belt trusses at single storey (OB-M-V) in 60
5) Case 5: RC bare frame having shear wall with outrigger struts and belt trusses in hard soil at zone V (OB-H-V)
   - Outrigger struts and belt trusses at multi storeys (OB-H-V) in 15-30-45
   - Outrigger struts and belt trusses at multi storeys (OB-H-V) in 30-45-60
   - Outrigger struts and belt trusses at double storeys (OB-H-V) in 15-30
   - Outrigger struts and belt trusses at double storeys (OB-H-V) in 15-45
   - Outrigger struts and belt trusses at double storey (OB-H-V) in 30-45
   - Outrigger struts and belt trusses at double storey (OB-H-V) in 30-60
   - Outrigger struts and belt trusses at double storey (OB-H-V) in 45-60
   - Outrigger struts and belt trusses at single storey (OB-H-V) in 15
   - Outrigger struts and belt trusses at single storey (OB-H-V) in 30
   - Outrigger struts and belt trusses at single storey (OB-H-V) in 45

– Outrigger struts and belt trusses at single storey (OB-H-V) in 60

IV. RESULT AND DISCUSSION

A. Introduction

This chapter presents the results of seismic analysis carried out on a 60th storey bare frame in which outriggers and outrigger with belt truss system were introduced as a lateral load resisting systems. The results of natural time period, frequency, base shear, displacement and storey drift are discussed.

B. Discussion – Natural Time Period

– Providing the outrigger with belt truss to the structure the stiffness of the structure will increases resulting the reduction of natural time period compared to the bare frame.
– In single outrigger with belt truss system the 15th, 30th and 45th stories there will be a reduction of natural time period.
– Providing outrigger with belt truss system at 15th storey will increase the lateral stiffness of the structure and hence it is effective in resisting the lateral force compare to the other stories as observed in graph 4.1, 4.4.
– In double and multi outrigger with belt truss system the lateral stiffness will be more and it is observed in the graph 4.2, 4.3, 4.5, 4.6.
– For single, double, multi storeys the provision of outrigger with belt truss system at 15, 15-30, 15-30-45 storeys will increase the lateral stiffness of the structure.

C. Frequency

D. Base Shear

1) Discussion – Base Shear

– By analyzing the above graph it is observed that by introduction of outrigger system there will be an increase in base shear.
– The base shear is increased when outrigger is provided it occurs due to increase in stiffness and mass.
– The base shear will be less for the outrigger system compare to the outrigger with belt truss system.

E. Displacement

1) Discussion - Displacement

– The maximum displacement of the structure is reduced by the introduction of outrigger
– Providing the outrigger with belt truss to the structure the stiffness of the structure will increases resulting the reduction of displacement compare to the bare frame.
– Providing outrigger with belt truss system at 15th storey will decrease the displacement of the structure and hence it is effective in resisting the lateral force compare to the other stories as observed in above graph
– In double and multi outrigger with belt truss system at 15-30, 15-30-45 storey the displacement will be minimum compare to the single outrigger and outrigger with belt truss system, it is observed in the graph
– For single, double, multi storeys the provision of outrigger with belt truss system at 15, 15-30, 15-30-45 storeys will decrease the displacement of the structure.
– It was found that a gap of 15 storeys in introducing outrigger and outrigger with belt truss system worked out effective in reducing the displacement.

V. CONCLUSION

– As per the study made the following conclusion have been arrived at
– The introduction of outrigger and outrigger with belt truss there is a significant contribution to the stiffness of the structure.
– For single, double, multi storeys the provision of and outrigger with belt truss system at 15, 15-30, 15-30-45 storeys will increase the lateral stiffness of the structure and resulting the reduction of natural time period.
– The base shear will be more for the outrigger with belt truss system.
– Providing a outrigger and outrigger with belt truss system at 15, 15-30, 15-30-45 storey will decrease the displacement of the structure and hence it is effective in resisting the lateral force compare to the other stories.
– In double and multi outrigger and outrigger with belt truss system the natural time period, displacement, storey drift will be minimum compare to the single outrigger and outrigger with belt truss system.
– It was found that a gap of 15 storeys in introducing outrigger and outrigger with belt truss systems worked out of effectively in resisting the lateral forces induced in the structure.

VI. SCOPE OF FUTURE STUDY

1) Future studies are needed in both analytical and experimental area. Some of the following studies suggested are by considering structures with mass irregularity and vertical irregularity.
2) Instead of steel outriggers concrete outriggers can be considered.
3) Provision of diagonal outriggers can also be considered.

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