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COMPARATIVE STUDY ON PERFORMANCE OF RC BUILDING WITH OUTRIGGER SYSTEM INCORPORATING BUCKLING RESTRAINED BRACINGS

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Abstract - *In cities due to limited resources of land available for construction there has been increasing demand for high rise buildings construction. But with increase in height and floors the lateral forces starts dominating the structural system in form of earthquake and wind. To reduce the effect of lateral loads, lateral load resisting systems are established .One such system is Outrigger systems built which counters the effect on the core of structure and increases stiffness. In the present case the outrigger with Buckling Restrained Braces are used for resisting the lateral loads on the RC building. Study performance of a RC building with outrigger belt truss systems and Buckling Restrained Braces. Comparison of BRB configuration in outrigger and belt truss is to be carried out with various parameter. The analysis is done to study the behavior of structure and its interaction using commercial software ETABS. The response of RC building with BRB configurations under seismic motion is compared in terms of various parameters like Time Period, Inter Storey drift ratio and Storey displacements.*

Key Words: RC Building, ETABS, BRB, Outrigger, Belt Truss, Storey Displacement, Drift Ratio, Seismic Analysis

1. INTRODUCTION

In evolution there is expansion of cities in all directions and all aspects of development. With an urban population density of km's multiple community problems arises. This burdens for the creation of medium-high rise buildings. As the building height increases, high lateral earthquake and wind loads starts highly dominating the building. To resist the building should have a good lateral load resisting capacity as Wind and earthquakes create large forces in the form of overturning moment and shears, which must be resisted by a lateral force resisting system.

Controlling the lateral response of tall RC buildings to be studied. There are many methods to incorporate lateral load resisting ability into a structure. One of these methods is an outrigger system. Outrigger structure system consists of a core mainly of bracings or shear walls located centrally in the building along with horizontal trusses, girders or walls.

1.1 Core and Outrigger System

A structural system which is extension of the core elements and perimeter columns. Belt Truss is the element provided in the outrigger system to increase the stiffness. The lateral force and Over turning moments are resisted by outrigger.

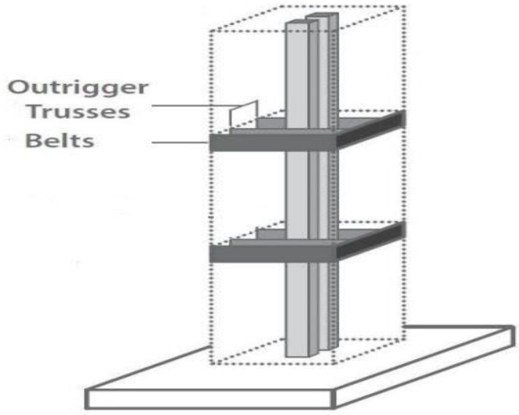

Figure 1 Core Wall and Outrigger Belt truss (credit: CTBUH)

These outriggers can be made up of either concrete, steel or a composite material. There are two types of outriggers, namely *conventional outriggers* and *virtual outriggers.* Conventional outriggers are found to be better than virtual outriggers [4]. At present the conventional outrigger are studied.

The traditional outrigger mitigates building seismic responses by growing the system stiffness. Though, the increase in stiffness may also cause amplification of acceleration response. The elastic design concept of outrigger may result in large force demands on the outrigger members, increasing both complexity and costs in engineering practices [5].

The conception of a damped-outrigger effects in increase the damping of structure, instead of increasing the stiffness of structure significantly, by damping devices at the outrigger truss. For same work the outrigger truss member, incorporating buckling-restrained brace (BRB) can be applied to limit the maximum forces generated in columns, at connections and in core walls in recent design practices.

Use of BRB in the buildings made the connections to the core wall and outrigger columns less challenging, this led to outrigger columns sizing smaller [10].

1.2 Buckling Restrained Braces

In a severe earthquake, the braces are subjected to extreme loading with repeated cycle of stress, which exceed the elastic limits of the brace. BRBs as energy dissipating elasto-plastic dampers prevents the damages of the main frame [10].

Required cross section area of BRB when compared to ordinary braces is deduced from the formula of calculating elastic bearing capacity where it is shown that the area of the ordinary braces must be 1.215 times that of BRB for ensuring the same performance [3].

For Seismic prone areas composite building with BRB frame is more effective [6]. Buckling restrained braces have full balanced hysteresis loops with compression and tension yielding behaviour shown in fig. 2. Buckling Restrained Braces perform control over displacement [1].

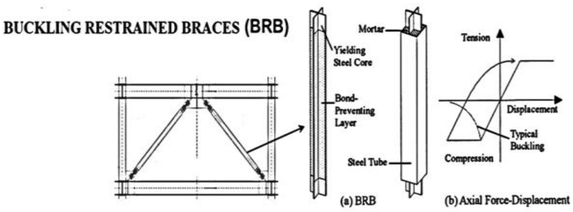

Figure 2 Buckling Restrained Braces

2. Objective of study

•To study the effect on performance of RC structure having outrigger system with BRB, using different bracing configuration system.
•To Analyze the inter storey drift ratio, storey displacement, storey drift and time period using BRB outriggers.
•Put forward the various configurations which have better performance.
•Analyzing models using equivalent static method and response spectrum method as per IS 1893 and understanding the behavior of BRB outriggers under effects of seismic load.

3. Parameters and Models Considered for Analysis

Data for the models used in ETABS is as given below:

3.1 Geometrical Data

1. Building Dimensions: 38m along x & 38 m along y directions
2. Typical Storey height: 4 m (Total Height= 148m)
3. No. of Storey: G+36
4. Beam size: 0.45 m x 0.75 m
5. Column size: 1.5 m x 1.5 m (G.F-12 floor)
1.35 m x 1.35 m (12-24 floor)
1.2 m x 1.2 m (24-36 floor)
6. Slab thickness: 0.150 m
7. Shear Wall thickness: 0.750 m (G.F-12 floor)
0.675 m (12-24 floor)
0.6 m (24-36 floor)
8. Outrigger system:

Outrigger BRB Braces Elements
StarSeismic BRB Elements (Fy250)
Belt Truss
ISMB 600 (Fy250) *Cross Braces arrangement in Periphery Columns.

3.2 Earthquake Data

1. Seismic zone: Zone 5 (Table 3 of IS1893 – 2016(part1))
2. Seismic Zone factor: 0.36 (Table 3 of per IS 1893:2016(part1))
3. Importance Factor: 1.5 (Table 8 of per IS 1893:2016(part1))
4. Response Reduction Factor: 5 (Table 9 of per IS 1893:2016(part1))
5. Type of Soil: Medium Type 2 (Table 4 of per IS 1893:2016(part1)).

3.3 Material data:

1. Grade of concrete =M40 for beams and slabs, M50 for columns and shear wall
2. Grade of rebar steel =Fe500
3. Density of Reinforced Concrete =25 kN/m^3
4. Grade of steel =Fe250.

3.4 Loading Data:

1. Dead load: It is defined automatically software
2. Live load: Live load is taken as 3kN/m^2 on each floor
3. Floor Finish: 2kN/m^2
4. Earthquake load in X and Y directions
5. Wall load on all beams= 10 kN/m
6. 5% Damping Ratio
7. Time period = 2.16 sec.

3.5 Models and Analysis

General guideline for optimum performance of a structure with “n” outrigger levels, states outriggers should be placed at the 1/ (n+1) up to the n/ (n+1) height locations (Smith & Coull 2007). Most potential locations of the outriggers are the mechanical floors to get more rentable space. As this mechanical floors are every 12-15 storey the number of outrigger are limited to two. Single Outrigger: 36/ (1+1) =18 and up to 18 floor and for Dual Outrigger: 36/ (1+2) =12 up to 24 floor.
Various models with various configurations made are as follows:
M1: Bare frame

M2: Frame with Core Wall [Base Model]
M3: Single outrigger (18-20 storey) BRB Braces X
M4: Single outrigger (18-19 storey) BRB Braces V
M5: Single outrigger (17-21 storey) BRB Braces K
M6: Single outrigger (18-19 storey) BRB Braces Diagonal
M7: Dual outrigger (12-14 and 24-26 storey) BRB Braces X
M8: Dual outrigger (12-13 and 24-25 storey) BRB Braces V
M9: Dual outrigger (11-15 and 23-27 storey) BRB Braces K
M10: Dual outrigger (12-13 and 24-25 storey) BRB Braces Diagonal
M11: Core wall with only Single Belt Truss X Braces (18-19 storey)
M12: Single outrigger (18-19 storey) BRB Braces Diagonal with Belt truss X Braces
M13: Single outrigger (18-19 storey) BRB Braces V with Belt Truss X Braces
M14: Core wall with only Dual Belt Truss X Braces (12-13 and 24-25 storey)
M15: Dual outrigger (12-13 and 24-25 storey) BRB Braces Diagonal with Belt truss X Braces
M16: Dual outrigger (12-13 and 24-25 storey) BRB Braces V with Belt Truss X Braces.

Seismic Lateral force in form of ESM and RSA are applied. Models are assigned loads. Analysis is performed in ETABS. Fixed support at base.

For Analysis, Buckling-restrained braced frames (BRBF) are designed using an equivalent lateral force method. Like concentrically braced frame types reduced seismic load is applied to a linear elastic model to determine the BRB frame's required strength and stiffness.

For common building types, this system tends to be governed by strength. For BRBF with braces proportioned according to this method, the difference between the elastic and inelastic deformation modes is much less dramatic than for SCBF. Because of this, an inelastic (nonlinear) analysis typically is not required, although such an analysis can give a much better estimation of brace ductility demands [2].

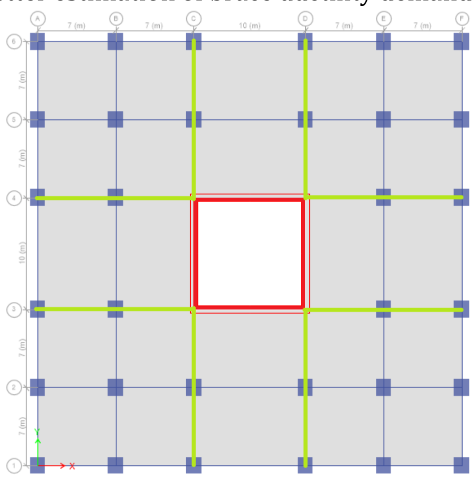

Figure 3 Plan view of building (Green line for outrigger location)

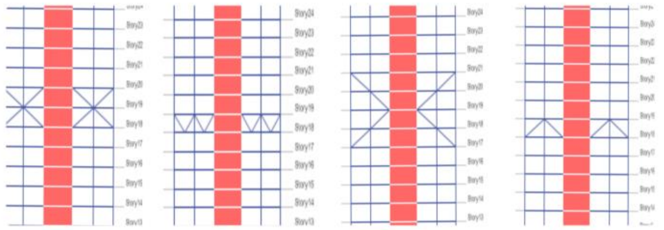

Figure 4 Configuration of Cross X, Chevron V, K shape and Diagonal BRB outrigger frames

The BRBs are modeled by a truss element resist all the storey shear of a storey. Buckling-restrained braced frames (BRBF) are designed using an equivalent lateral force method.

BRB are characterized by a cross-section with an equivalent area $A_{y,core}$ area of core equal to

$A_{y,core} \geq P_u/0.9f_y$

F_y = yielding stress of the BRB's core
α = angle of inclination of the brace with respect to the longitudinal beam axis
P_u = Axial Force

Stiffness of BRB: $K_{br} = \frac{P}{\Delta}$

P = axial force in brace and Δ is displacement of the brace
Preliminary area of yield core obtained from above equations is given in table below.
Diagonal braces Area (in^2) used for all outrigger BRB frames with X, Diagonal and K configurations. While the V Braces (in^2) used for only V brace frame outrigger BRB configurations.

Table 1 Cross Sectional Core Area for BRB

Outrigger With Level	Storey level BRB Frames (Slab Level)	Area for yield core Diagonal Braces (in^2)	Area for yielding core V Braces (in^2)
Single	19	29	19.5
Dual Lower	13	32	21
Dual Upper	25	23.5	15.5

This yielding core cross sections are selected from StarSeismic.pro elements.

4. RESULTS

4.1 Lateral Displacement and Inter Storey Drift Ratio

Discussions for results obtained:

1. For single outrigger model M5 has highest reduction in displacement and Inter Storey Drift Ratio compared to other models.

2. For Dual outrigger model M9 model gives the most reduction.

3. For belt truss used models category the reduction in maximum storey displacement and Inter Storey Drift ratio is of model M16.

4. Overall model M7 and M9 outperformed other models with different configurations.

Table 2 Percentage Reduction of Maximum Lateral Displacement in All the Models

Model	Max Displacement RS(mm)	Reduction in Displacement RS % w.r.t M2
M2	370.015	*
M3	252.488	31.76%
M4	260.438	29.61%
M5	241.535	34.72%
M6	272.676	26.31%
M7	209.395	43.41%
M8	243.823	34.10%
M9	208.155	43.74%
M10	248.955	32.72%
M11	284.661	23.07%
M12	252.534	31.75%
M13	249.766	32.50%
M14	261.814	29.24%
M15	218.144	41.04%
M16	215.846	41.67%

Table 3 Percentage Reduction of Maximum Inter storey Drift Ratio in all the Models

Model	Max. Inter Storey Drift RS	Reduction in Drift Ratio RS % w.r.t M2
M2	0.003237	*
M3	0.002238	30.86%
M4	0.00232	28.33%
M5	0.002158	33.33%
M6	0.002402	25.80%
M7	0.001874	42.11%
M8	0.002143	33.80%
M9	0.001866	42.35%
M10	0.002191	32.31%
M11	0.002493	22.98%
M12	0.002257	30.27%
M13	0.002231	31.08%
M14	0.00228	29.56%
M15	0.001954	39.64%
M16	0.001927	40.47%

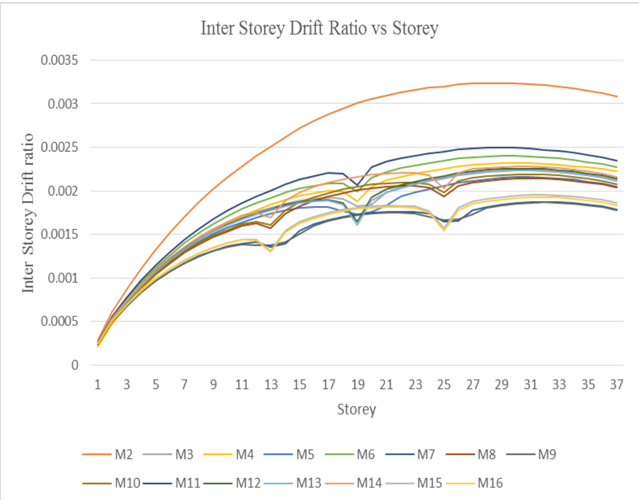

Figure 5 Inter storey drift ratio vs. Storey

4.2 Fundamental Time Period

Maximum reduction in the time period occurred in M9.

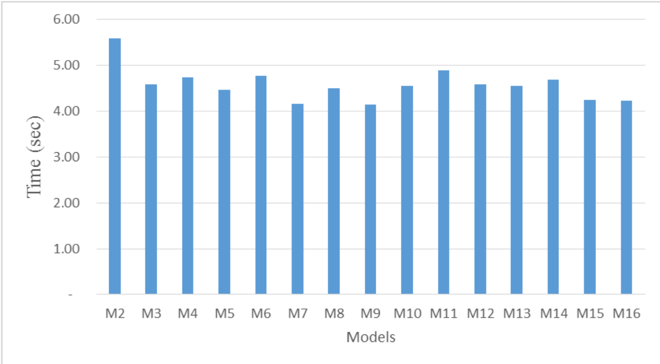

Figure 6 Fundamental Natural Time period of models

4.3 Quantity of steel used in models

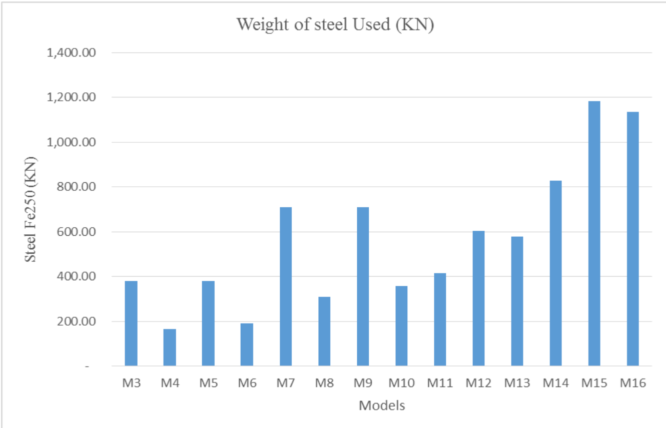

Figure 7 Quantity of steel used in models

1. M4 gives better performance with similar weight with M6.
2. Model M15 consumes highest amount of steel and M4 lowest steel.

5. CONCLUSIONS

In this study, different options of configuration and location of BRBs in outrigger are investigated for G+36 floor model case building. For Maximum Lateral Displacement, inter storey drift ratio, time period and Weight of steel:

1. From current analysis for displacements is that K Braces configuration type (M9) and X Braces configuration type (M7) which are configured on multiple floor perform better than other configuration models even with low amount of BRB design requirements.
2. Their percentage reduction is better than Single and Dual BRB outrigger models with belt truss.
3. Maximum reduction in lateral displacement is 43.74% while inter storey drift ratio is 42.35%.
4. Lowest Fundamental Natural Time period is of Model M9.

5. BRB V braces configuration outriggers perform well in comparison to BRB Diagonal even though weight of steel used is less in BRB V Braces.

Overall:

1. Direct connection with the core wall and the perimeter columns gives better results.
2. All BRBs options studied are capable for reduction in lateral displacement and inter storey drift ratio.
3. BRB members used in outrigger system improves the performance of building.
4. The BRB outrigger structural system in RC building shows to increases stiffness and stability against seismic loads.
5. Increase in performance of building structure can be seen with increase in number from single to dual outrigger system levels.
6. Outrigger Structural system incorporated BRB gives noticeable reduction in Lateral Displacement and Inter Storey Drift ratio of the structure against Lateral Loading.

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