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OPTIMAL PLACEMENT METHOD OF OUTRIGGER WITH BRB IN A CORE WALL SYSTEM STRUCTURE

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Abstract

The outrigger system has shown to be an effective structural lateral load resisting system in super-tall buildings and provides significant lateral stiffness under seismic loading conditions. The optimal placement of outrigger along with optimal combination of energy dissipation devices have major influence on seismic performance of super-tall buildings. In this paper, the power optimization procedure is performed to determine the optimal number and optimal location of outriggers by controlling Buckling Restrained Braces (BRBs) stiffness installed at perimeter column and outrigger connection zone. A 9-zone Finite Element (FE) model is developed in MATLAB programing and is subjected to a series of nonlinear time history analyses. The number of outrigger and BRB stiffness is considered as design variables, and the inter-story drift response of the model is to be minimized as objective functions. The results indicate that the optimization solution with different BRB grouping has almost the same solution and increasing of BRB stiffness does not significantly affect the optimal placement solution of outriggers. Therefore, this method of optimization solution shown to be an effective and practical optimal solution of optimal placement of outriggers with BRB for improving the seismic performance of outrigger system structure.

Keywords: Outrigger, Energy Dissipation Devices, Power Optimization, Time History Analysis.

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1 INTRODUCTION

The outrigger system has been proved to be an affective lateral load resisting system to improve the seismic performance of high-rise building structures. The outriggers and perimeter columns work together as a further restrain to the core wall to resists the part of overturning moment resulting from the lateral loading [1]. The setting of outriggers will lead to the rapid changes of the story stiffness and causing the abrupt changes of the story shear force, thus resulting in forming the weak stories under strong earthquakes [2]. The conventional outrigger system can be upgraded by attaching energy dissipation devices at the outrigger connection zone to absorb the vibrations caused by winds or earthquakes. Supplemental passive, active, hybrid and semi active damping strategies offer attractive means to protect structures against natural hazards, and are widely accepted by engineering community for improving seismic response of the structures [3].

The optimal placement of outrigger along with supplemental energy dissipation devices have major influence on seismic performance of super-tall buildings and have been the focus of many researchers. A multi-objective genetic algorithm was applied on a mathematical model of outrigger braced structures to achieve the optimal number and placement of outrigger under wind excitation to reduce the top drift and core base moment [4]. Their study concluded that the optimal solution for the minimum top drift of the structure is two outriggers. Finite Element (FE) models were developed to simulate the specimen of the shaking table test to determine the optimal number and optimal locations of outriggers in a 9-zone model based on response spectrum analysis [5]. They further extended their studies by modifying the conventional outrigger into energy dissipation outriggers to determine the most effective combination of energy dissipation outriggers along the structure using time history analysis. Furthermore, a study on optimal quantity and placement of outriggers for a super-tall building based on simple sensitive vector algorithm optimization method reported that the optimal outrigger scheme relates to both the quantity and placement rather than simply proportional to the quantity [6]. The optimal single damped-outrigger elevation shown to be approximately 70% to 80% of the building height, and placing a conventional and damped-outrigger at elevation of 70% and 50% height, respectively, are effective in reducing the structural damages [7]. Additionally, an inter-story drift parameter analysis for optimal location of outrigger in tall building reported that under earthquake load, the optimal elevation of outrigger is slightly lower compare to that of wind load [8]. Optimum outrigger position using the dynamic time history analysis reported that the optimal location of outriggers depends on the type of earthquake records [9]. They also concluded that it is more effective to locate the single outrigger at the upper part of the tall building to reduce the lateral displacement at the top of the building. Most of the optimal placement of outrigger elevations in the past studies rely on a huge number of constraints and analytical model which are leading to maximum computational efforts and analysis cost.

This study reports a simple and practical power optimization approach for optimal placement of outrigger by controlling BRB stiffness attached vertically at perimeter column and outrigger connection zones. A 3D 9-zone FE model is developed in Matlab to simulate the shaking table tests specimen which was carried out at Guangzhou University [10]. The aim of this study is to propose a simple method to evaluate the seismic response of multiple outrigger system to minimize the inter-story drift of the structure. The method presented in this study significantly reduces the computational efforts and analysis cost, and itis an effective method to determine the number and location of outriggers in a tall building structure.

2 MODEL DESCRIPTIONS

The structure model used in this study rely on the model structure used for the shaking table tests [10]. The dimension of the model is 1600 mm by 400 mm in each horizontal direction respectively. All materials used in this study is steel of 345 MPa nominal yield strength. The size of core tube is 200 mm by 400 mm and the thickness of steel tube is 8 mm. The size of column is 50mm×50mm with thickness of 5 mm. Each zone has two L-section steel beams of 30 mm by 30 mm and with thickness of 3 mm to connect the column in Y-direction. The outriggers are steel channels with a cross-section of 120 mm by 40 mm and 8 mm thick. An additional mass of 280 kg is added on each story. There are two outriggers with Viscus Damper (VD) attached at zone 4 and 8 representing damped outriggers in the original model of figure 1.

In the original model, the overall height of the structure is 7200 mm in height. However, in this study, the total height of the structure is modified to 8100 mm resulting in a 9-zone model with the height of 900 mm for each zone as shown in figure 2. The outriggers are installed in zone 2 to zone 9 and the BRBs are attached at each outrigger level. The outriggers are installed 150 mm above the floor levels and it is fixed at the core wall and they are attached with BRBs at the column side. There is 100 mm gap between outriggers and column to provide space for the BRBs. The BRBs are attached between outrigger and column with i-end attached to the outrigger at the outrigger level, and the j-end at column with 50 mm height from the floor level. Our aim is to find the optimal number and optimal location of outrigger by controlling BRB stiffness at each outrigger location as will be discussed in the next section.

Figure 1: Original model on a shaking table test [10]

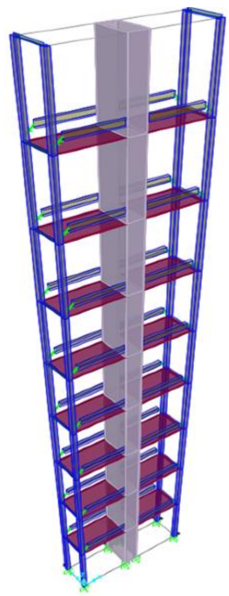


Figure 2: Perspective view of target model

3 OPTIMIZATION PROCEDURES

A 9-zone structural model is developed in Matlab programming and the Power Optimization procedure is applied using time history analysis of 1940 El Centro seismic waves. The number of outriggers and stiffness of BRB is considered as design variable and the objective function to be minimized is the maximum inter-story drift response of the model. The BRBs are attached into outriggers and column at each zone level of 2 to 9 to represent damped outrigger with BRB based on random placement. A simple algorithm is used to solve the optimization problem. This procedure continuously traces the most effective placement of outrigger by increasing the total stiffness of BRB from zero based on figure 3 as follows:

a- Consider N-story structure model and set the yield displacements of the structure and BRB and the incremental stiffness of the BRB (Δk).

b- Consider N candidate models. In this example, the total optimization step number is set to 8, one for each outrigger level with BRB. As for the i-th candidate model, BRB with stiffness Δk is added to the i-th story of the model with optimal outrigger with BRBs obtained in the previous optimization step.

c- Compute the time history responses of the N candidate models in (b) for input ground acceleration and evaluate the maximum response as an objective function.

d- Find the candidate model with the lowest objective function among the N candidate models.

e- Update the stiffness of BRBs and return to (b) until the total stiffness of BRBs reaches the specified value.

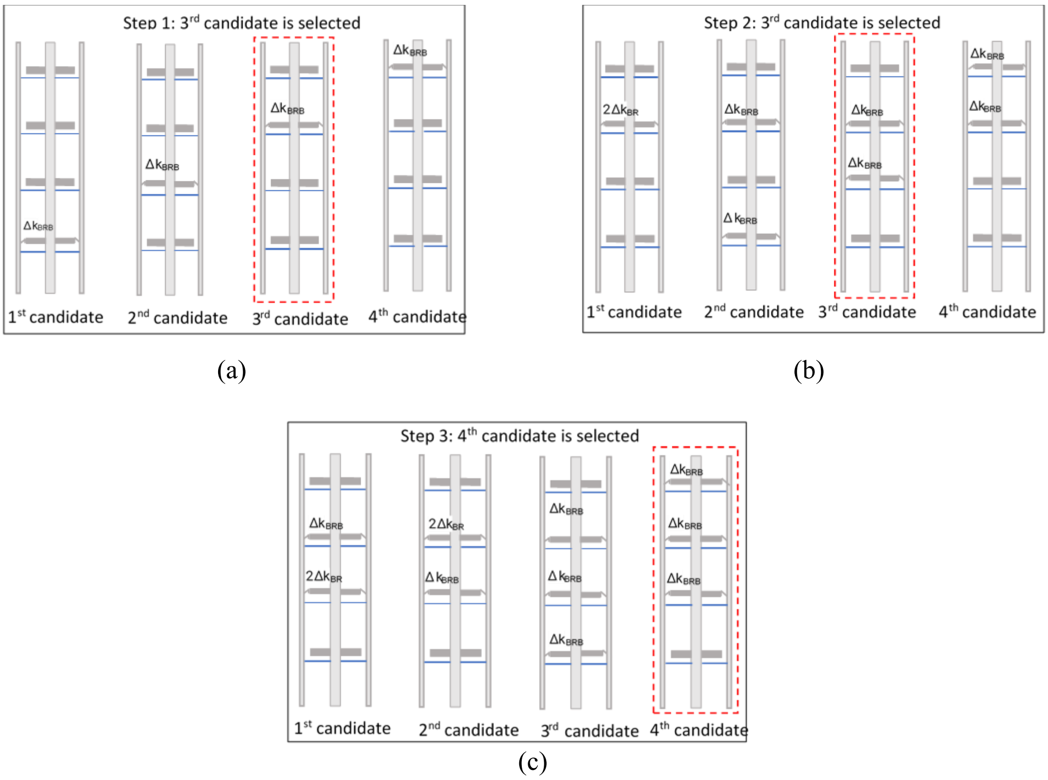


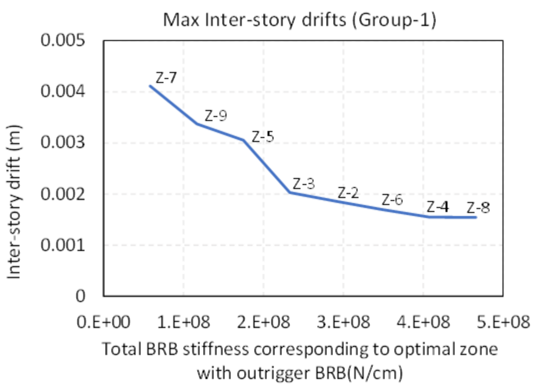
Figure 3: Schematic model of outrigger BRB placement using power optimization method: (a) 1st step, (b) 2nd step, and (c) 3rd step

This method of optimization requires only N-candidate numbers at each optimization step which is equal to the number of stories. Figure 3 above compares only four candidate number corresponding to the smallest maximum inter-story drifts; however, there are 8 candidate solutions which are equal to the total number of stories in which the outriggers are to be installed. During the optimization procedure, the outrigger is installed at each designated zone first, then, the BRBs are installed at each outrigger level, and the optimal story with the smallest maximum story responses is selected based on procedure (b). Then, the obtained optimal story is considered constant and the second BRB is installed to the outrigger in the story with the smallest maximum story responses. This procedure is continued until the nth optimal story is obtained.

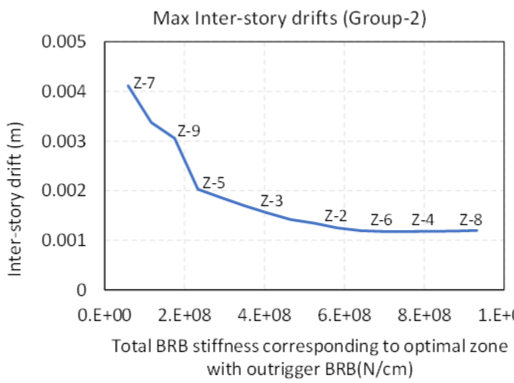
The optimization procedure is examined with 6 different BRB stiffnesses or grouping. First, one BRB is installed at each outrigger level and the time history analysis is performed. In order to validate the accuracy of proposed method and the effect of BRB stiffness, the number of BRB is increased from 1 to 2, 3, 4, 5, and 10 BRBs referred to BRB groups of 1 to 6 at each outrigger level and the analysis is performed for each case separately. The maximum inter-story drift response of the model is obtained at each optimization step. This method of optimization does not require complicated analytical procedure and significantly reduces the computational efforts of analysis cost and time.

4 RESULTS

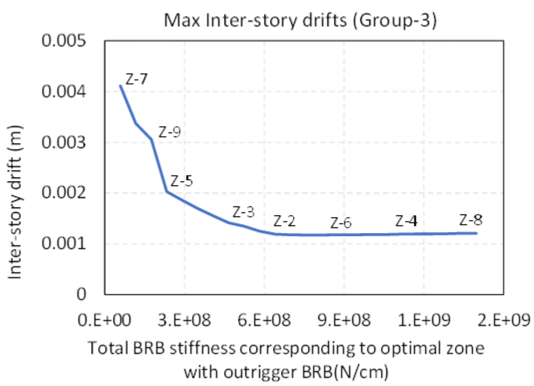
The results of optimization solution are presented in figure 4. Our aims are to obtain the optimal placement of outrigger by controlling BRB stiffness. From the results of analysis and figure 4, it can be seen that the method proposed in this study can identify the optimal placement and the optimal number of outriggers with BRBs. This method of optimization can also predict and identify the outrigger placement with minor or no effects on the performance of the structure. As discussed earlier, this method of optimization requires total of 8 optimization steps which is equal to the total number of outrigger placement in the model. The first four optimization steps corresponding to zones 7, 9, 5 and 3 shows the optimal placement of outrigger in the model.



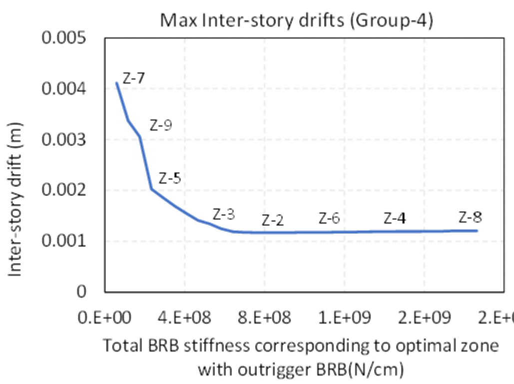
(a)



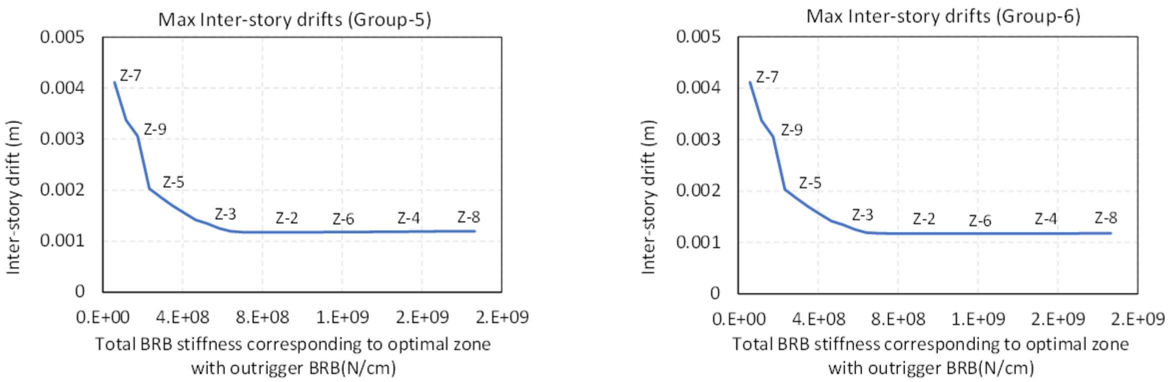
(b)



(c)



(d)



(e) (f)

Figure 4: Effect of BRB stiffness on optimal placement of outrigger BRB: (a) 1 BRB, (b) 2 BRBs, (c) 3 BRBs, (d) 4 BRBs, (e) 5 BRB, (f) 10 BRBs

However, the last four optimization steps corresponding to zones 2, 6, 4 and 8 have minor or no effects on the performance of the structure. Figure 4 (a) and (b) shows that when smaller stiffness is used, the optimal placement with minor effect on the performance of the structure is predicted and the story response of the model is slightly different compare to larger BRB stiffness. However, with larger BRB stiffness, the inter-story drift response of the model remains unchanged with outrigger at zones 2, 6, 4 and 8, indicating that the outrigger placement at these zones does not have any effects on performance of the structure. Figure 5 compares the response of the model with different groups of BRBs.

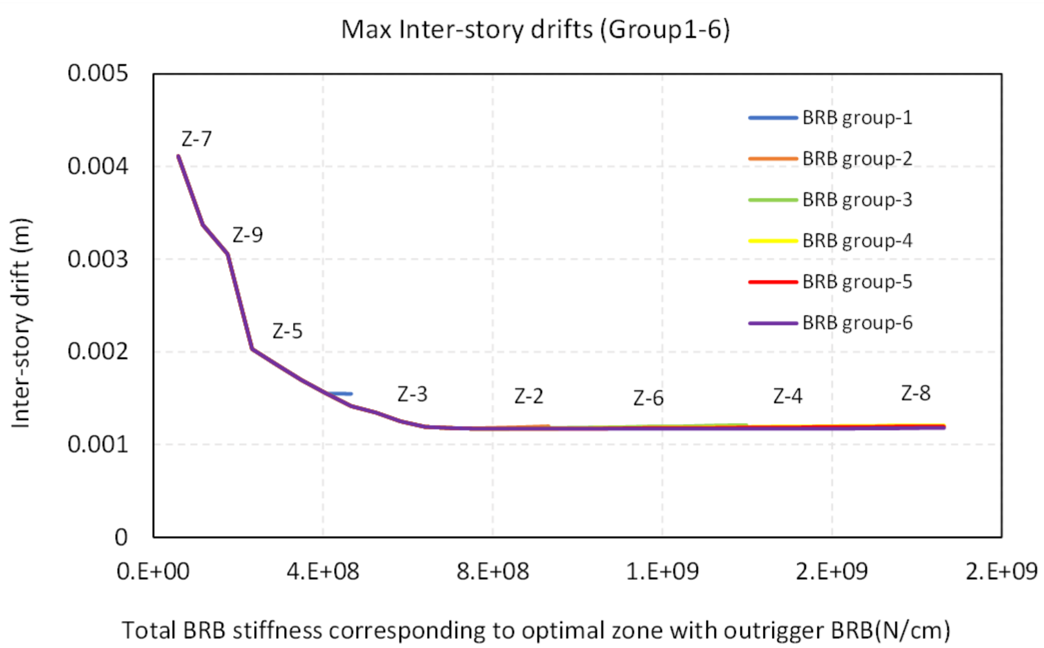


Figure 5: Comparison of optimal placement of outriggers with different BRB grouping

Figure 5 indicates that the optimization solution with different BRB grouping has almost the same solution and changing of BRB stiffness does not significantly affect the optimal placement solution of outriggers. Therefore, this method of optimization solution shown to be an effective and practical optimal solution of optimal placement of outriggers with BRB for improving the seismic performance of outrigger system structure.

Optimal location of outrigger	Number of BRB at each outrigger end in each optimal step					
	Group-1	Group-2	Group-3	Group-4	Group-5	Group-6
Zone-7	1	2	3	4	4	1
Zone-9	1	2	3	4	5	5
Zone-5	1	2	3	4	5	10
Zone-3	1	2	3	4	2	2
Zone-2	1	2	3	4	1	1
Zone-6	1	2	3	4	5	10
Zone-4	1	2	3	4	5	2
Zone-8	1	2	3	4	5	1
Total	8	16	24	32	32	32

Table 1: Maximum number of BRBs at each outrigger end in each optimal step of optimization solution

Table 1 compares the maximum number of BRBs at each outrigger end corresponding to optimal step of optimization with different BRB grouping. According to the table, the order of optimal placement of outrigger under different grouping of BRBs remains the same. When smaller stiffness of BRBs (group 1 to 4) are installed at the outrigger end, the BRBs are distributed equally within the outrigger connection zone, however, with larger BRB stiffness (group 5 and 6), the BRBs are distributed unevenly within the outrigger connection zone. In both cases, the inter-story drift response of the model does not change significantly. From figures 4 and 5, and the distribution of BRBs of table 1, it can be judged that the BRB stiffness does not affect the optimal placement of outrigger and that of the performance of the structure.

5 CONCLUSION

A simple and practical approaches of optimal placement of outrigger by controlling BRB stiffness was proposed to improve the seismic performance of outrigger system structure. The number of outriggers and BRB stiffness was considered as design variables, and the smallest maximum inter-story drift response of the model was considered as objective function. Time history analysis was performed using 1940 El Centro seismic waves in Matlab programing. According to optimization solutions, four outriggers at zones (3-5-7-9) at the height of 0.2407H, 0.463H, 0.685H and 0.9074H of a structure with 9-zones are the optimal solutions for the minimum inter-story drift requirements. This solution is only a local solution since the outrigger location is fixed at 150mm height above the floor levels of zones 2-9, and not all possible zone combinations and scenarios are considered for the optimization solution. In order to achieve the global solution for the optimal number and optimal placement of outrigger, the possibility of outrigger at different height within the zone of the structure along with all possible combination shall be studied, which will be investigated in the future study.

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