11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
E. Oñate, J. Oliver and A. Huerta (Eds)

THE CORRELATION BETWEEN COMPLICATED LATERAL LOAD RESISTING SYSTEM OF THE SHANGHAI TOWER

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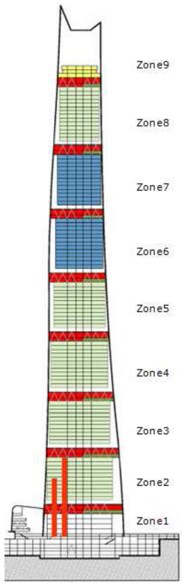
Key Words: *Shanghai Tower, Outrigger System, Displacements Coordination, ANSYS.*

Abstract. The Shanghai Tower with a total height of 632m adopts the steel-concrete hybrid mega frame - core tube - outrigger structural system. In order to understand the effects of outrigger structural system in mega frame and core tube, numerical simulation have been done in this paper to analysis the structural aseismicity by the ANSYS program. Appraise to the performance of Shanghai Tower was obtained with bringing down the stiffness of the outrigger structural system. The research results show that the core-tube is the first line of seismic resistance, and the mega-column is the second line of seismic resistance. Outrigger is playing the displacements coordination between lateral load resisting members.

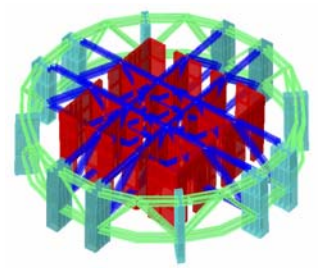
1 INTRODUCTION

The Shanghai Tower adopts the steel-concrete hybrid mega frame-core tube-outrigger structural system. There are going to be two main parts above ground of the complex, which are one 632m tower and one 38m podium, with 5-storey basement. The tower is divided into eight main zones vertically, with a tower crown on the top. The circular base plan of the super tower is 83.6m in diameter and gradually reduces to 42m in diameter on the 8th zone. The Fig.1 shows the horizontal plan and typical elevation of structure[1].

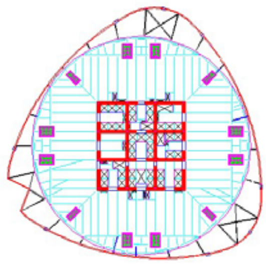
The lateral load resisting system is comprised of an interior reinforced concrete core, exterior composite super columns and steel outrigger and belt trusses. The exterior mega frame consists of four paired concrete super-columns and four diagonal super-columns, which are both reinforced with shaped steel elements, and eight 2-storey-height belt trusses at each strengthened/refuge storey. The core wall is concrete embedded with steel plate below floor 14. The maximum overall dimensions of the core wall at base plan are 30m×30m. The six outrigger systems located in the strengthened storey of zone 2 and zone 4 to zone 8 are designed to connect the mega frame and core wall, which make them work together to resist the wind load and seismic force efficiently. Seismic intensity is 7 degrees, earthquake intensity class B. The Shanghai Tower Building is a high-rise building with irregular plan and facade, the structure system is complex[2].



(a) Vertical zoning



(b) Strengthened storey



(c) Standard floor

Figure 1: Structure diagram

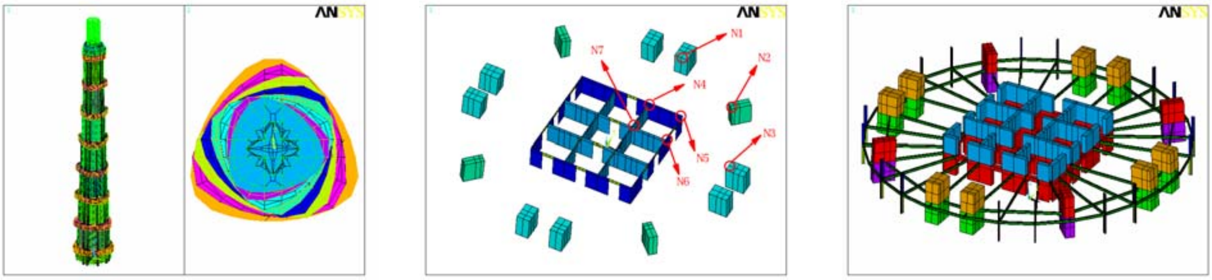
The structural complexity makes the transmission path between lateral load resisting members unclear. As a bridge between core-tube and mega-column, outrigger plays an important role in guaranteeing the structural performance [3-6]. Therefore, the purpose of this article is studying the effects of outrigger structural system between mega frame and core tube.

2 FINITE ELEMENT MODEL

The super tower with 124 storeys above the ground and the top steel truss are built by ANSYS program. Three different types of elements are employed in this program. Beam188 is used to simulate the frame column, transfer truss, frame beam and transfer beam. Shell43 is used to simulate the floor. Mega-column and corner column are made by Solid43.

The physical characteristics of structural element are equivalently transformed by the reinforcement ratio and contain steel ratio. The finite element model is consisting of 19973 beam elements, 45418 shell elements and 14376 solid elements. The total model mass is 674840t. Basement roof structure is counted as the upper end of the fixing. The Fig.2 shows the three-dimensional structural model.

For studying the outrigger structural system effects on mega frame and core tube, and its effects on aseismatic performance of the overall structure, the two models were set up. The one is built according to the design modeling, called “Prototype Structural Model” (PS model). The other is modifying the stiffness of outrigger structural system, called “Deteriorating Structural Model” (DS model), which has decreased 100 times.



(a)Perspective and Plan (b)Typical node (c)Typical element

Figure 2: Analytical model

3 DYNAMIC PROPERTIES

Two different models have been analysed by ANSYS software. The 1st to 10th natural vibration periods are listed in the table 1. The first and second modes are the horizontal vibration modal. The third mode is the torsion vibration modal. The table2 shows the effective mass in different directions. The first second modes of model in X-direction are shown in Fig.3.

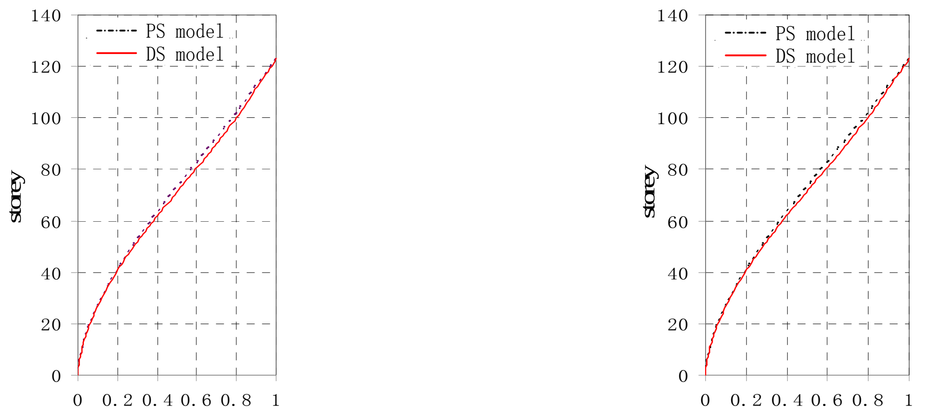
Form the table1 and table2, we can found that the decreased of outrigger structural system is making the period longer and reducing the stiffness of structure. Especially, the first period is increased form 9.29s to 11.12s. On the contrary, the effective mass of model is decreased form 92.47% to 85.581% in X- direction. This illustrates higher modes should be considered when the stiffness of outrigger structural system is decreased. Moreover, there is litter effect on the mode shape of vibration.

Table 1: Natural periods

Mode No.	Period(s)		Mode No.	Period(s)	
	PS	DS		PS	DS
1	9.29	11.12	6	2.22	2.42
2	9.21	10.96	7	1.61	1.82
3	4.70	5.10	8	1.58	1.78
4	3.41	3.92	9	1.38	1.76
5	3.34	3.83	10	1.01	1.70

Table 2: Effective mass

Model		X	Y	Z
PS	mass (t)	623995	625047	443274
	Factors (%)	92.47	92.62	65.69
DS	mass (t)	577085	573655	14792
	Factors (%)	85.51	85.01	2.19



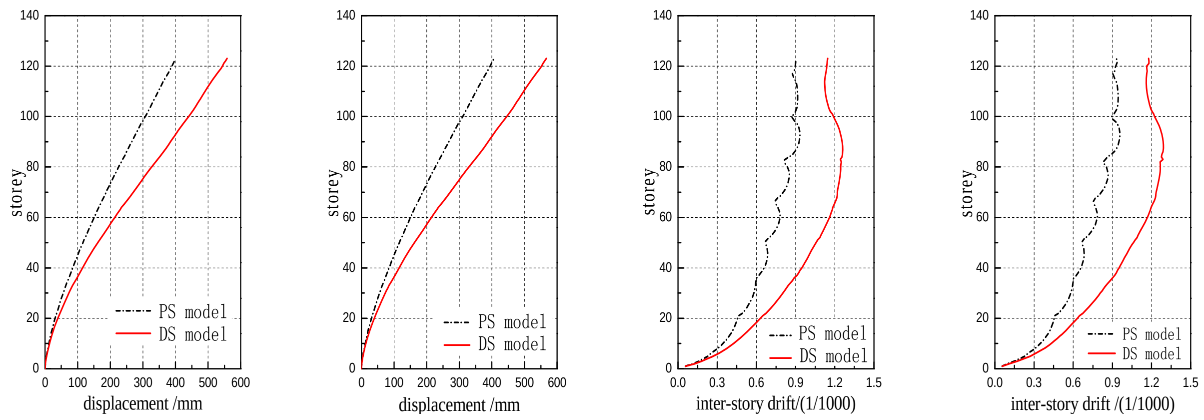
(a) the first mode shape (b) the second mode shape

Figure 3: The first and second horizontal modes shape in X direction

4 RESPONSE SPECTRUM ANALYSIS

According to the code for seismic design of buildings in Shanghai, China[7,8], seismic accelerate response spectrum analysis is performed by means of mode superposition method with 40 modals. The modal damping ratios is 4%[9,10], and the CQC method is adopted to the combination. Two different working condition, single X-direction only and bi-direction (X-main direction) response spectrum, have been analysed.

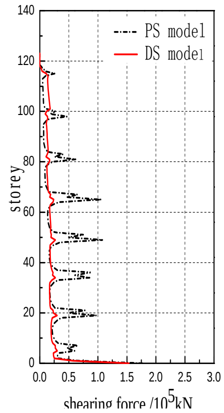
The figure 4 shows the top maximum displacement and inter-story drift under response spectrum. The structural deformation features of both models are typical flexural. Comparing with the PS model, the maximum displacement of DS model has increased about 40% in both working conditions. The elastic maximum inter-story drift, which was created at layer 94, has also increased about 35% in both working conditions. But elastic maximum inter-story drifts are smoothed in strengthened/refuge storey in DS model.



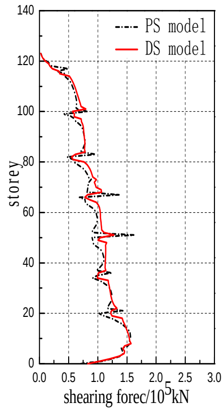
(a) single direction (b) bi-direction (c) single direction (d) bi-direction

Figure 4: Max-displacements and Inter-story drift under response spectrum analysis

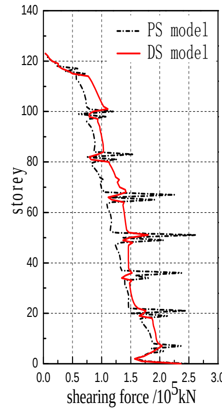
The figure 5 shows the distribution and quantity of seismic force between lateral load resisting members. In both working conditions, the lager of seismic force is taken on by the core-tube, which is the first line of seismic resistance. And the mega-column is the second line of seismic resistance. Comparing with the PS model, the forced condition is slightly increased in DS model, but there is significantly decreased in each strengthened/refuge storey in DS model. One possible explanation for this is that the force of outriggers is reduced with the decreased stiffness. As a bridge between core-tube and mega-column, outrigger structural system plays a significant effect on distribution of seismic force between lateral load resisting members.



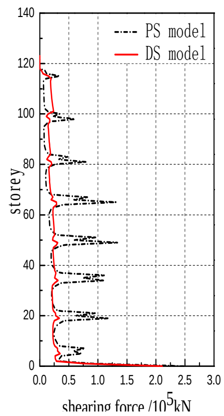
(1)Mege-column in single direction



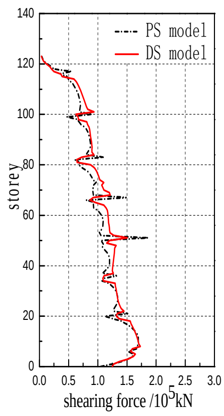
(3)Core-tube in single direction



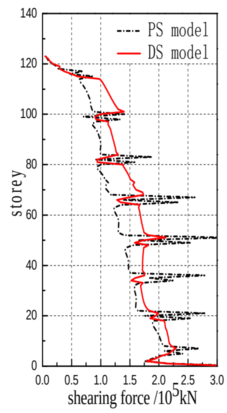
(5)Storey in single direction



(2)Mege-column in bi-direction



(4)Core-tube in bi-direction



(6)Storey in bi-direction

Figure 5: Distribution of storey shearing force under response spectrum analysis

5 ELASTOPLASTICITY TIME-HISTORY ANALYSIS

For Shanghai tower, Shanghai artificial wave-3 (SHW3, Fig.6) is used to conduct the elastoplasticity time-history analysis. The wave scaled to 200cm/s^2 peak ground acceleration. The displacement responses to earthquake loading in single X-direction.

Figure 7 shows the top maximum displacement and inter-story drift. Comparing with the PS model, the maximum displacement of DS model is increased about 42%. The maximum inter-story drifts, which are created at layer 108, are also increased about 22%. But maximum inter-story drifts are smoothed in strengthened/refuge storey in DS model, which resembles the spectrum analysis.

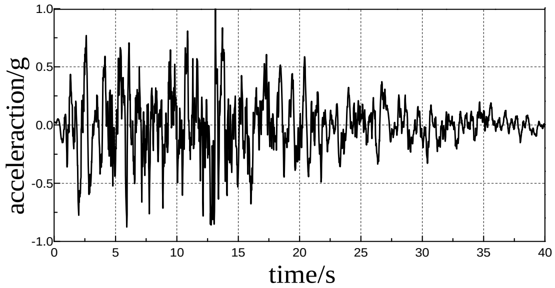


Figure 6: Seismic wave of SHW3

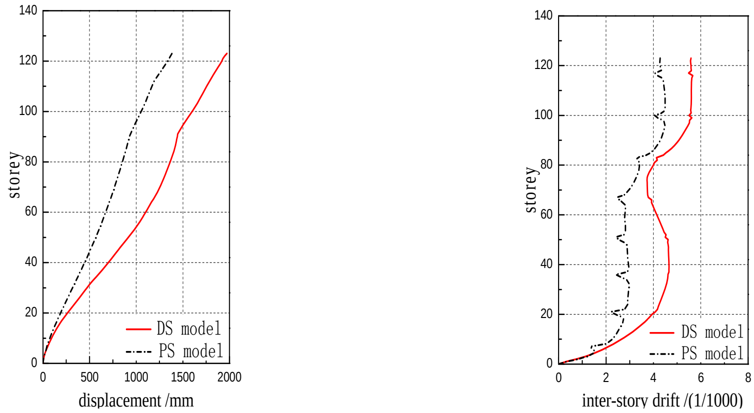
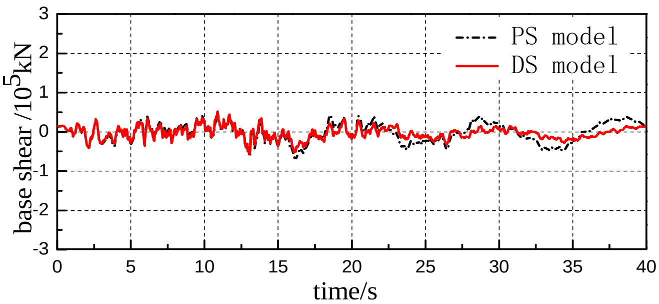
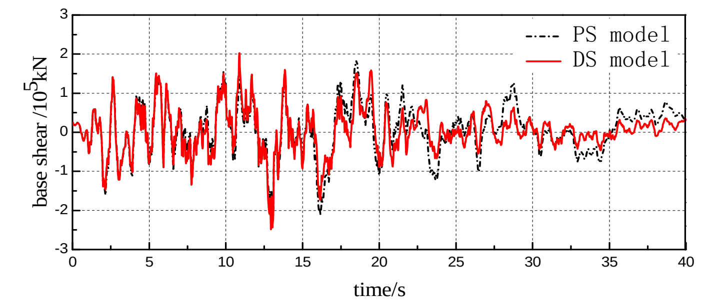


Figure 7: Displacements and inter-story drift ratios under time-history analysis

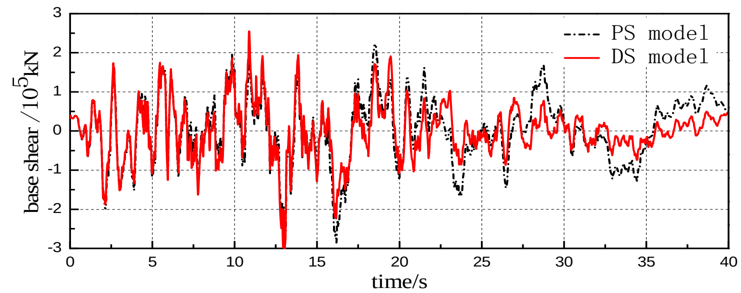
Figure 8 shows the base shear time-history results of mege-column, core-tube and structure in both models. Before reaching time history peak, the response of elastoplasticity time history are similar in both models. But after the time history peak, the response of the DP model is less than that of PS model.



（a）mega-column



（b） corn-tube



（c） model

Figure 8: Base shear under time-history analysis

6 CONCLUSIONS

- The decreased stiffness of outrigger structural system is making the structural period longer, reducing the stiffness of structure and the effective mass. There is a litter effect on the mode of vibration.
- From the results of spectrum and time-history analysis, the maximum displacement and inter-story drifts of DS model has significantly increased than that of the PS model. The inter-story drifts are smoothed in strengthened/refuge storey in DS model.
- Comparing with the PS model, the forced condition is slightly increased in DS model, but there is significantly decreased in each strengthened/refuge storey in DS model.
- The core-tube is the first line of seismic resistance, and the mega-column is the second line of seismic resistance. Outrigger is playing the displacements coordination between lateral load resisting members

AKCNOWLEDGEMENT

The authors acknowledge with thanks the support from (a) National Key Technology R&D Program (grant No. 2012BAJ13B02); (b) the National Natural Science Foundation of China (grant No. 51078274) .

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