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Research Article

Study on Seismic Performance of Unit Thermal Power Main Plant Steel-Concrete Structure for 1000 MW in High Intensive Seismic Region

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Abstract: Build 1000 MW unit thermal power main plant by using steel structure system in high intensive seismic region at home and abroad. As steel structure system little lateral stiffness, need more project cost and maintenance cost. In order to find new structure system which is applicable to seismic performance of large capacity unit Thermal Power Main Plant in high intensive region, reasonable equipment layout, project cost and the maintenance cost lower than the steel structure, taking a 1000 MW unit thermal power main plant bridge as the research object, steel reinforced concrete frame-dispersed shear wall structure system is tested. (1/7 scale) model of three substructure of primary structure with pseudo-dynamic test and pseudo-static test is tested in seven working condition. The results show that the structure system can meet the needs of design in zone with the seismic fortification intensity 8, have better deformation property, the many defensive line of horizontal force resistant and can be used in the main power house of large capacity unit Thermal Power Plant.

Keywords: High intensive region, main power house, seismic behavior, steel reinforced concrete frame-dispersed shear wall

INTRODUCTION

In modern society, foundation engineering facilities that maintain the function of modern urban and regional economy are defined as lifeline engineering. Thermal Power Plant is the core of the thermal power project, an important part of the large and complex lifeline system and the safety of its structure directly affect the production and construction of the country and the people's living order (Franklin, 1981; Shahrooz *et al*., 2001). But the structure of main plant have a wide range of equipments and complex operating parameters, resulting in the overall layout of the irregular, poor performance space, the uneven distribution of mass and stiffness and poor seismic performance of the structural system.

The main plants were mainly used reinforced concrete frame bent structure in small units in the past, such as the 300 and 600 MW units. As the development of the power industry and unit capacity increasing, structural height, span, load will also increase, structural dynamic properties is more complex, structures withstand earthquakes is greater. Traditional reinforced concrete structure of main plant are not suitable for main plant of large capacity units in high intensive region, part of axial compression ratio at the ground floor columns is too large, the structure layer displacement and vertex displacement under earthquake is too large (Zhiqin *et al*., 2010; Xiaojuan *et al*., 2010; Guoliang, 2008). Currently, the steel structure in the form of steel support-steel frame is commonly used at home and abroad by setting much of support in order to ensure the anti-side shift stiffness of steel structure for main plant of large capacity units (1000 MW) in high intensive region (seismic intensity of 8, 9º). However, a large number of supports in steel structure which increase the lateral stiffness have a greater effect on process layout, run maintenance space, project cost, steel anti-corrosion coating maintenance and cost of operation and maintenance.

Main plant is structural system of short load path, which is suitable for the technological systems and equipment layouts, meet the requirements of the safe operation, maintenance and construction installation and control project cost (Zhiqin, 2012). It is an important criterion to measure whether the structural system of the main plant is reasonable or not. Under complexity and problems of the main plant structure in high intensive region and the main plant in low intensive region still using reinforced concrete structure (Shansuo, 2000; Chungche and Chiaming, 2002), reasonably effective structural system of the main plant of thermal power plants in high intensive region is necessary. This study propose large capacity thermal

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power main plant in high intensive region with steel reinforced concrete frame-dispersed shear wall structure on the base of 1000 MW unit power plant and popularization and application of this structure system and a basal research for the establishment of associated design procedures.

TEST RESEARCH

Design and make of model: The prototype of the steel reinforced concrete frame-dispersed shear wall structure system is a the main power house of thermal power plant, as technological layout and piping layout of the main house are approximately same whether using any structure system, the layout is shown in Fig. 1. This structure system is designed for 1000 MW unit, 8º of seismic design area and the second class site. The structure is design for 9º. Anti-seismic grade of steel reinforced concrete frame-dispersed shear wall is second grade. According to experiment purpose and the field test environment, three substructure is selected for testing, 1/7 scale model is carried out. Twenty percent for full load is loaded vertical weight. Dynamic Similitude Law of model and prototype is shown in Table 1 according to counterweight lacking.

According to the characteristics of prototype structure, the similarity coefficient of model structure and prototype structure and test site etc. Size of each member and sectional reinforcement are designed and calculated. According to the principle of the same shear ratio of prototype structure and model structure, the area of test model shear wall are determined according study seismic behavior and failure mechanism in the earthquake with providing the basis for the

to area ratio of prototype structure shear wall and frame. The beam and column of model structure concrete strength grade is C45, poured concrete slab is C30; section steel of SCR column is Q235. Plane Arrangement Chart of model structure are shown Fig. 2, reinforcement of column are shown in Fig. 3, west elevation are shown in Fig. 4, west elevation of counterweight 20% structure are shown in Fig. 5.

Test parameters and loading system: The model of main power house steel reinforced concrete frame-dispersed shear wall is tested by using equivalent single particle loading method in structure and seismic laboratory, three actors are arranged in elevation 2.400, 4.800, 7.200 m, respectively test loading device are shown in Fig. 6. Vertical load is finished before loading horizontal load, horizontal load is applied by actor in corresponding position of model and the mass matrix of model structure is obtained in the position of actor:

$$\begin{bmatrix} M_1 & & \\ & M_2 & \\ & & M_3 \end{bmatrix} = \begin{bmatrix} 5420 & & \\ & 19310 & \\ & & 22860 \end{bmatrix} \text{kg}$$

The test is for three times cyclic loading, obtain the initial stiffness matrix:

$$\begin{bmatrix} k_{11} & k_{12} & k_{13} \\ k_{21} & k_{22} & k_{23} \\ k_{31} & k_{32} & k_{33} \end{bmatrix} = \begin{bmatrix} 12.9 & 29.5 & 76.5 \\ 29.5 & 33.6 & 80.4 \\ 76.5 & 80.4 & 103.9 \end{bmatrix} \text{kN/mm}$$

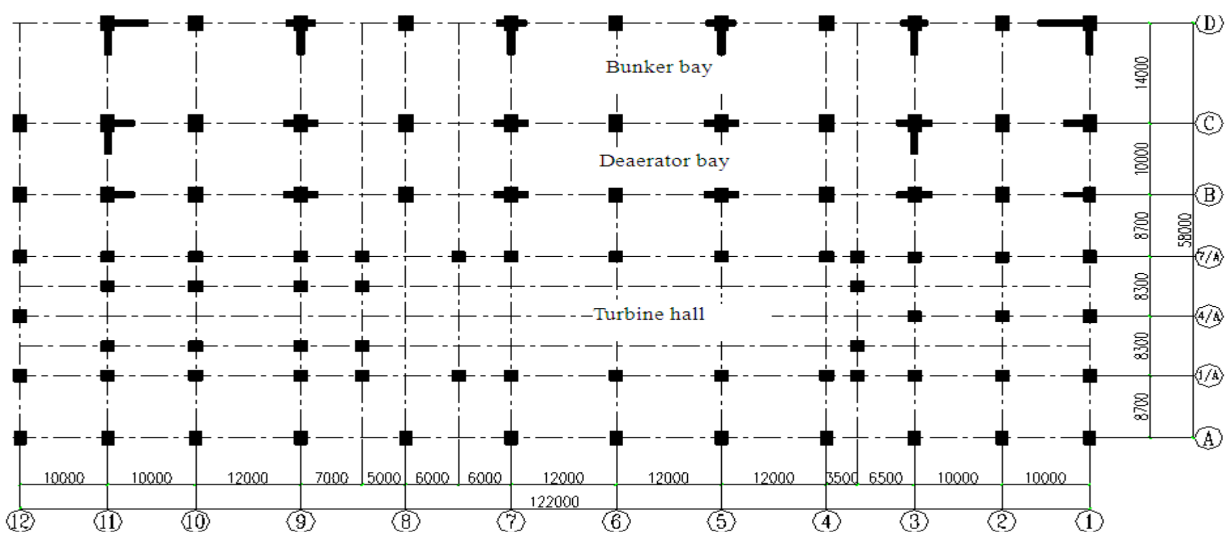

Fig. 1: Plane arrangement chart of steel reinforced concrete frame-dispersed shear wall

Table 1: Similarity coefficient of the main physical parameters

Physical quantity	Elastic modulus	Vertical stress	Line length	Linear displacement	Seismic action	Quality	Stiffness	Frequency	Velocity	Acceleration
Similarity coefficient	1	1/5	1/7	1/7	1/49	1/245	1/7	$\sqrt{35}$	$\sqrt{5/7}$	5

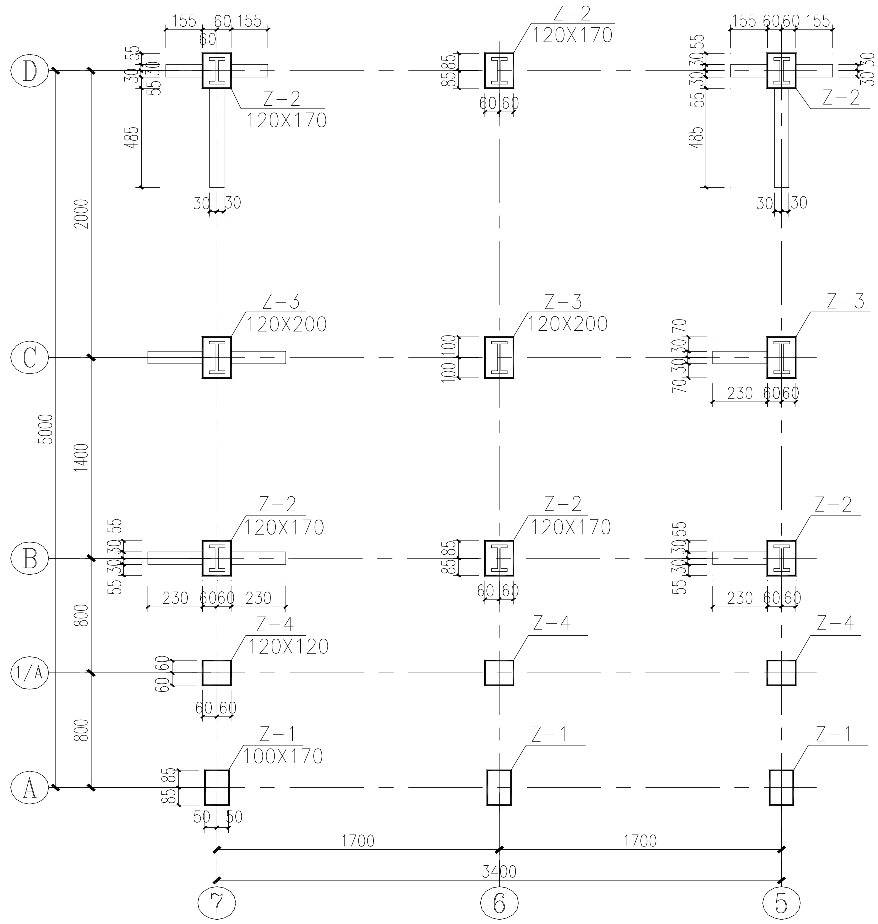

Fig. 2: Plane arrangement chart of model structure

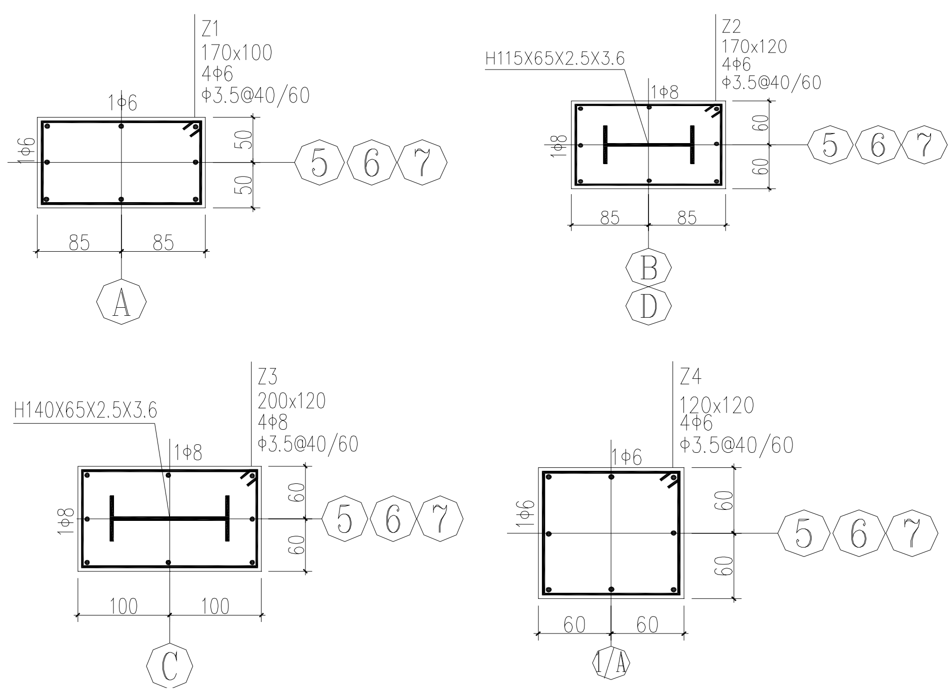

Fig. 3: Reinforcement of column

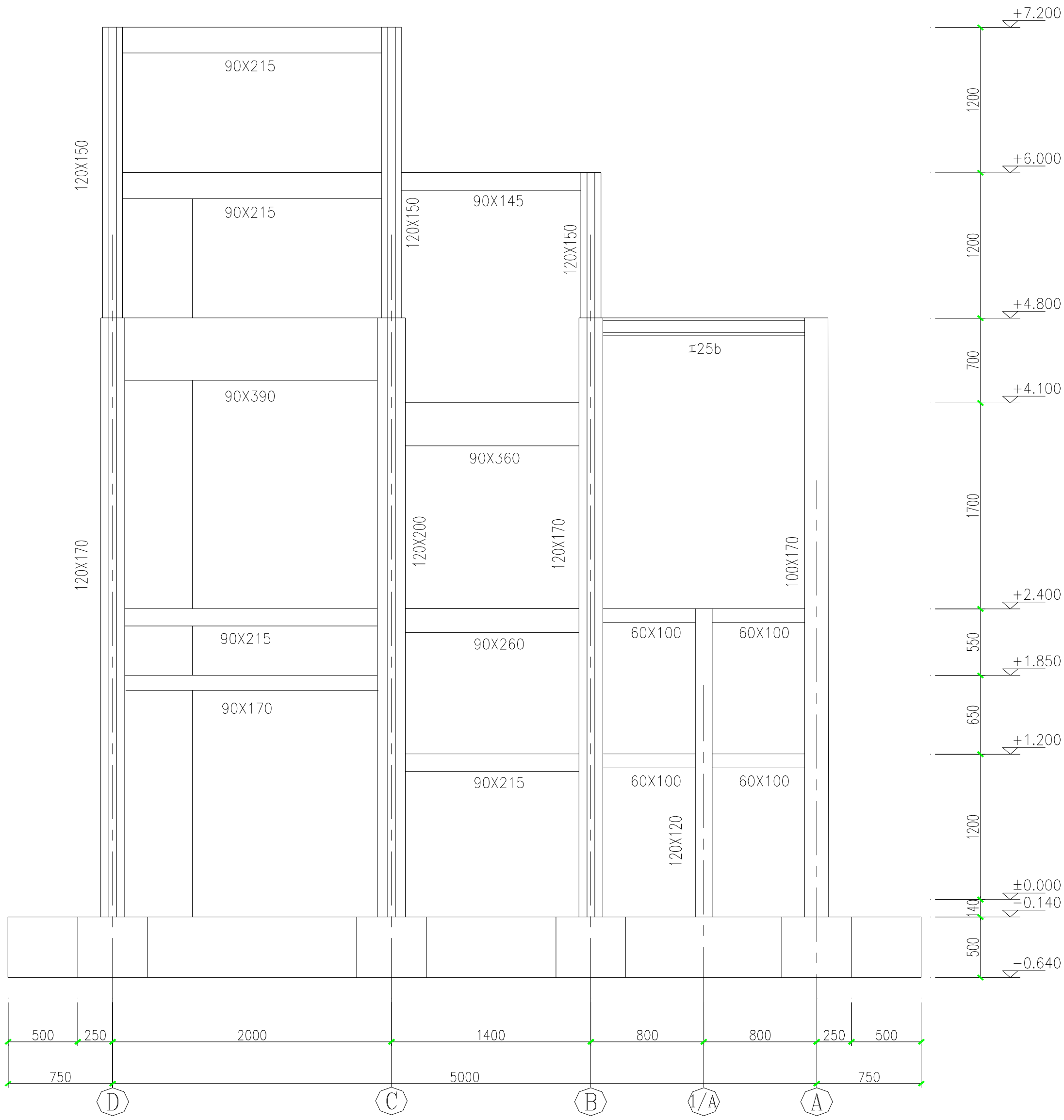

Fig. 4: West elevation of model structure

Fig. 5: West elevation of model structure 20% counterweight

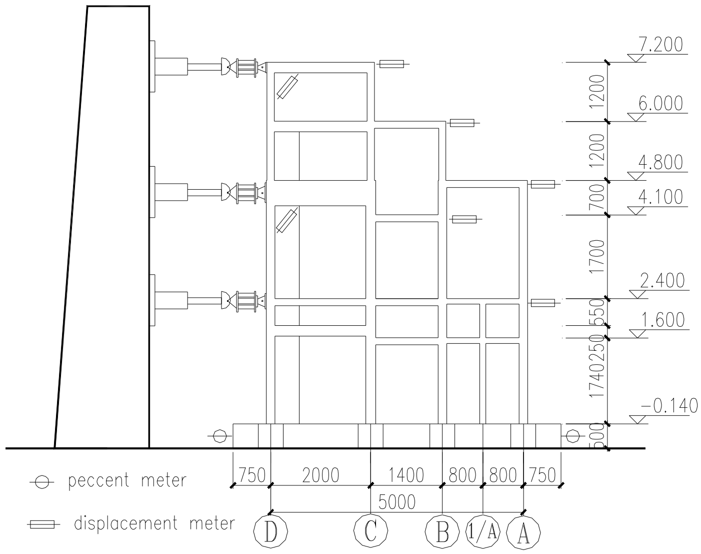

Fig. 6: Loading device and test point arrangement of model test

(a) 500 gal cracks of bottom shear wall (b) 2000 gal cracks of bottom shear wall (c) damage of bottom shear wall

Fig. 7: Cracks of bottom shear wall

Table 2: Crack development of model structure

Condition	The maximum thrust Step	The displacement of the top floor (mm)	Shear of basement (kN)	The maximum pull Step	Displacement of the top floor (mm)	Shear of basement (kN)
500 gal	681	5.1	108.8	605	-5.0	-101.5
Phenomenon description	Several micro cracks appeared only in the SRC column of west-side beam bottom; positive loading is max, several micro cracks appeared in lateral shear wall of D column elevation 1.85, negative loading is max, several micro cracks appeared in the bottom of shear wall (Fig. 7). No cracks appeared in the others, the whole stiffness of structure does not decrease.					
1000	689	14.4	185.1	609	-10.2	-193.3
Phenomenon description	The cracks appear in the bottom and the top of shear wall D column and the west side of column; some cracks appeared in the top of B column and the top of platform column, horizontal fracture of 100 mm long appeared in the bottom of B column elevation 1.2 m, horizontal cracks appeared in the bottom of shear wall D column elevation 4.8 m. The ratio of horizontal shear of SCR structure increased in the earthquake. Loading and displacement is also similar in increasing speed, structure and element does not yield. Stiffness of structure begins to decrease in the condition.					
2000	548	24.8	332	624	-31.7	-362.3
Phenomenon description	More cracks appeared in each element, some cracks of element have been transfixion, some cracks appeared in the D column, but some cracks have extended (Fig. 7). It is well that shear wall is the first defense line.					
3000	549	43.5	442.2	637	-48.7	-455.4
Phenomenon description	A lot of cracks appeared in each element. More crossing cracks appeared in the shear wall of bottom floor. Crossing cracks appeared in the node of C column. Crossing crack extend to mid-span in the cross of shear wall and beam; crossing cracks appeared in the C6 column elevation 4.1-4.8. Stiffness decrease, more cracks appeared in the condition.					

Table 3: Inter-story displacement angle of model structure

	500 gal		1000 gal		2000 gal		3000 gal	
Elevation (m)	Positive	Negative	Positive	Negative	Positive	Negative	Positive	Negative
1.85	1/2444	-1/3333	1/802	-1/1255	1/224	-1/295	1/110	-1/200
2.40 (operation floor)	1/1549	-1/1637	1/357	-1/458	1/125	-1/165	1/90	-1/250
4.10	1/1298	-1/1304	1/496	-1/484	1/226	-1/262	1/140	-1/180
4.80 (the top of coal scuttle)	1/1068	-1/1044	1/333	-1/391	1/156	-1/191	1/125	-1/191
6.00	1/3539	-1/6000	1/873	-1/2170	1/444	-1/889	1/620	-1/800
7.20	1/845	-1/1176	1/517	-1/658	1/237	-1/278	1/462	-1/254

Table 4: Stiffness of model structure

Loading condition	Fundamental period (s)	Shear of basement (kN)	Displacement of top Δ(mm)	Structure of stiffness K (kN/mm)	The relative loading P/P_{max}	The relative stiffness K/K_0
100 gal	0.2329	21.680	0.995	21.784	0.038	1.000
250 gal	0.2397	52.002	2.496	20.834	0.092	0.956
500 gal	0.2465	104.807	5.005	20.940	0.185	0.961
1000 gal	0.2583	189.822	9.691	19.587	0.334	0.899
1500 gal	0.2754	261.263	16.532	15.803	0.460	0.725
2000 gal	0.3196	347.778	28.271	12.302	0.612	0.565
3000 gal	0.3706	448.619	45.892	9.776	0.790	0.449
The ultimate load	-	567.918	107.759	5.270	1.000	0.242

According to the mass matrix and the Initial Stiffness Matrix, obtain fundamental mode of Structural Vibration by matrix iteration method:

$$U_R = \{1\ 0.7920.364\}^t$$

According to basic vibration mode and mass matrix of test model, obtain loading position elevation for 7.200, 4.800, 2.400:

$$F_1: F_2: F_3 = 0.36:1:0.55$$

Seismic test of structure model is divided into two stages, the first stage is pseudo-dynamic test and the second stage is pseudo-static test. Pseudo-dynamic test is by inputting different peak value Acceleration of EL-Centro earthquake wave gradually. Then pseudo-static test is executed to structure failure, the loading position is same in the two stage, loading system of pseudo-dynamic test is 100, 250, 500, 1000, 1500, 2000 and 3000 gal, respectively seven working condition.

Test result: Input different peak acceleration EL-Centro seismic wave to model structure, observe and record crack development of model structure (Table 2). According to loading and extreme value of displacement recreation, Inter-story displacement angle of each floor is obtained. According to base shear and corresponding displacement of model structure in different condition, stiffness of structure is obtained (Table 2).
According to Table 2 to 4:

- Fine cracks of some individual element appeared in 500 gal condition of model structure and stiffness does not decrease, the structure is in the elastic stage, this show that the prototype structure satisfies the seismic requirement of no damage in small earthquake of the 8º zone. Cracks of shear wall and column increases obviously, but stiffness of decreasing is not obvious, this show that the prototype structure can satisfy the repairable under moderate earthquake in the 8° zone. Cracks of more elements appeared in 2000 gal condition and stiffness decreasing obviously, but the structure is not collapse, this show that the prototype structure satisfies the request of No Collapsing with Strong Earthquake in 8º zone.
- The max elastic inter-story displacement angle of model structure is 1/1044 at the elevation 4.8 m in the 500 gal condition, the max Elastic-Plastic inter-story displacement angle is 1/125 at the elevation 2.4 in 2000 gal condition, the max inter-story displacement angle is 1/90 at the top of operate floor.
- According to Table 2 cracks progress of model structure, show that dispersed shear wall of RC is the first defense line of resist earthquake, delay appearance and development of cracks and delay the cracks of column, this structure forms three defense lines, the first line is shear wall, the second line is the frame of shear wall, the third line is the frame of no shear wall.

ANALYSIS RESULT OF TEST

Fortification objects of structure seismic: The fortification objects of structure seismic are the no damage in small earthquake, repairable under moderate earthquake, no collapsing with strong earthquake. According to the results of pseudo-dynamic test, the structure is in elastic stage at 500 gal earth quake; satisfy the no damage in small earthquake in 70 gal, no collapsing with strong earthquake in 400 gal.

Deformation performance of structure:

- The max inter-story displacement angle is 1/1044 in the top of coal scuttle according to Table 3 500 gal. This show that the floor of coal scuttles is the weak story when the structure is in the elastic stage. The limit value of the inter-story

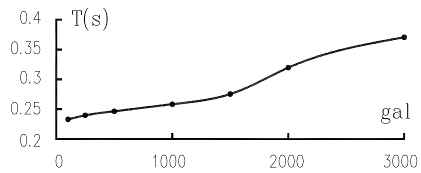

Fig. 8: Periodic variation of the model structure

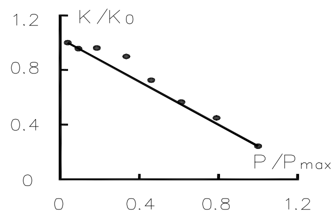

Fig. 9: Stiffness degradation of model structure

displacement angle of 1000 MW unit main power house is 1/750, according to Seismic Design Code of Buildings.

- The max inter-story displacement angle is 1/125 in the operation story elevation 2.4 m according to 2000 gal, the max value is 1/90 at 3000 gal and the place is the same. This shows that the operation story is weak story. The limit value of angle is 1/80 according to Seismic Design Code of Buildings in elastic-plastic stage.

The law of structure stiffness degradation: According to Table 4 as the earthquake increasing the stiffness of structure reduces gradually. The model is in elastic stage when the peak value of seismic is less than 250 gal. The cracks of the model structure appeared when the peak value is 500 gal. The cracks of the bottom shear wall and the coal scuttle beam is serious at 1000 gal, the stiff of structure is 0.99 times of the initial stiffness. The shear wall and operation beam are damaged at 2000 gal, the stiffness of structure is 0.565 times of initial stiffness. When the loading is to ultimate value the stiffness of structure is 0.242 times of initial stiffness.

The change law of fundamental period of model structure obtained in different stage according to Table 4 and Fig. 8. The period of structure model rises as the earthquake, the period is 0.3706s at 3000 gal. According to similarity coefficient of model structure and prototype structure the fundamental period of prototype structure is 2.1925s ($t = 0.3706S\times\sqrt{35} = 2.1925s$). According to Tab. 4 the relationship of structure relative stiffness and relative loading are shown Fig. 9, the linear formula are obtained. $K/K_0 = -0.085P/P_{max} + 1.0779$.

CONCLUSION

- The structure system of Steel reinforced concrete Thermal Power Main Plant is put forward can contend seismic design of 8º and satisfy the Three-Level performance objectivity.
- The stiffness of structure decrease is not obvious, the structure is in the elastic stage at frequent earthquake and the seismic deformation satisfies the limit value of elastic inter-story displacement angle of seismic design code. Under Rare Earthquake the stiffness of structure decrease obviously, the structure is in the elastic-plastic stage, the seismic deformation satisfies the limit value of elastic-plastic inter-story displacement angle of seismic design code.
- The structure system realize the need of many defend lines and can be used in high intensity seismic region. The result of research show that the structure system of Steel reinforced concrete Thermal Power Main Plan has better seismic performance can be extended at high intensity seismic region.

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