Static Elastoplastic Analysis of Turbine House under Different Lateral Loading Modes in Conventional Island of Nuclear Power Plant

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Abstract: Nuclear island in nuclear power plant requires that under the extreme safety shutdown earthquake action, the collapse of the turbine house of conventional island shall not affect the safety of nuclear island, so as to ensure the functional integrity of nuclear island. At present, the way to meet this requirement is to carry out elastoplastic analysis on the turbine house of the regular island under the action of the ultimate safe earthquake to ensure that it does not collapse and its deformation meets the deformation requirements of the standard rare earthquake. Structure elastic-plastic analysis method with static analysis and dynamic elastic-plastic time history analysis, in this paper, the turbine room nappe analyzed, and compared the five kinds of lateral load loading mode of static elastoplastic analysis results, the seismic performance of the structure, puts forward the layer shear lateral loading mode suitable for turbine room structure static elastoplastic analysis.

Keywords: Regular island steam engine room; Seismic performance design of structure; PUSHOVER analysis; Five lateral loads.

1. Preface
The structure of the main plant building on the regular island of AP1000 NPP is non-nuclear, and its seismic design can be according to the standard of seismic fortification of ordinary buildings, that is, it is in elastic state under small earthquakes and in elastoplastic state under rare earthquakes and does not collapse. However, the nuclear island requires that under the action of extreme safety shutdown seismic vibration (SL-2), the collapse of the turbine house on the conventional island should not affect the seismic class I plant. The exceedance probability of SL-2 year is 0.1‰, and the exceedance probability of rare earthquake year is 0.4‰~0.6‰. It can be seen that the seismic requirements of nuclear island for turbine house of regular island are higher than the standard of conventional force-off.

Through nonlinear analysis and performance design method, this paper studies the collapse-resistance performance of the main plant structure on the regular island under the horizontal earthquake action of the plant site SL-2. The methods of structural elastoplastic analysis include static elastoplastic analysis and dynamic time-history analysis. In this paper, the static elastoplastic pushover analysis is carried out for the regular island turbine house. PUSHOVER analysis to define the assumption of...
horizontal seismic force to a lateral load, different static load models will have the ability of different spectral curve, if the curve is too high or too low to estimate the seismic capacity of the structure, then the result is not reasonable, this article will compare five lateral load loading mode of static elastoplastic analysis results, The seismic performance of the structure under various loading modes is obtained, and the loading modes suitable for the static elasto-plastic analysis of the structure of the regular island turbine house are put forward.

2. Main design parameters
The main structure is cast-in-place reinforced concrete structure, which is composed of TA axis rack column, steam engine room contact platform frame and deaeration frame in turn. The longitudinal frame is the frame. The main structure is divided into intermediate layer, running layer, deaerator layer and roof, and the roof structure is trapezoidal steel roof structure. The main factory building of the regular island is a cast-in-place reinforced concrete frame structure with plane dimensions of 125m longitudinal length and 55m transverse width. The bottom elevation of the steel roof truss is 36.70m, the highest point of the steel roof truss is 42.50m, the elevation of the platform of the middle floor is 7.5m, and the elevation of the operating floor is 16m, as shown in Fig. 1. The connection between the steel roof truss and the concrete frame member is hinged, the steel roof truss internal inclined brace is hinged, and the others are just connected.

![Three-dimensional model of structure](image)

Fig. 1 Three-dimensional model of structure

3. Elastoplastic analysis results under different loading modes
Midas is used to investigate the seismic response of the original structure under various loading modes, including the seismic performance of the structure, the bearing ratio of various components, weak layers, etc. The order of each structural component entering the elastoplastic stage and the distribution of damage degree under each loading mode are studied.

The seismic capacity of frame structure in the elastoplastic stage is reflected in the deformation bearing capacity, including two aspects:

A) Whether the deformation of structural members is within its tolerable range, mainly refers to the plastic deformation of the cross section of frame members (beams, columns and supports).

B) Whether the interlayer displacement Angle is within the range specified in the specification. Output the displacement time history of the opposite corner of each layer, and then calculate the time history of the displacement Angle between layers, and take the maximum value.

The performance design is explained in detail in Code for Seismic Design of Building Structures. The contents of structural performance evaluation are based on the whole level and the component level. In Appendix M of the Code for Building Seismic Design, the displacement Angle between floors is used
to control the overall performance of the structure. There are four levels of performance goals. It can be seen from Table M.1.1-2 that the performance design objective does not allow the interstorey displacement Angle of the structure to be greater than 90% of the plasticity limit. However, differences in ductility of different structural forms are not taken into account in this provision. A better way to consider ductility is to include the plasticity limit in the definition of the limit value, namely:

1) When the displacement Angle between layers of the structure is approximately equal to $\Delta e$, the structure is basically intact, which is the performance objective 1, where $\Delta e$ is the elastic displacement Angle limit;

2) Under the action of large earthquakes, the structure is slightly damaged when the displacement Angle between layers is between, which is performance objective 2;

3) Under the action of large earthquakes, the structure suffers moderate damage when the displacement Angle between layers is between, which is performance objective 3;

4) When the displacement Angle between layers of the structure under the action of large earthquake is between, the structure is seriously damaged, which is performance objective 4;

This definition approach is used in this article.

The acceleration loading mode assumes that the lateral horizontal seismic force applied is proportional to the mass assigned to the nodes, and uniform acceleration in any direction can be specified. The following is the calculation result of longitudinal loading according to acceleration.

![Fig. 2 The plastic hinge of TE column frame when the performance point is reached](image)

![Fig. 3 Base shear-Displacement curve](image)

![Fig. 4 Story-drift curve](image)

From the elasto-plastic deformation results of the frame and the damage diagram of the element, it can be seen that:
1) There are performance points in the structure. The maximum displacement of column top at the performance point is 143.3mm, and the maximum inter-storey displacement Angle is 0.0056.

2) The damage degree of the component is not high, and no component damage has reached a more serious damage stage.

3) The position of plastic hinges mainly appears on the frame beam, and there are several plastic hinges at the bottom of the TE column and the frame column of the contact platform.

4) The number of hinge in frame beam is 448, accounting for 65% of the total, among which 447 hinge are in the state of B (+), and 1 hinge is in the state of IO (-); The number of hinge appearing in frame column is 25, accounting for 5% of the total, and the state is B (+).

5) The damage is mainly concentrated in Ta, Te and TF columns. The reason is that E and F are above the platform floor, there is no floor slab, and the column section is reduced, so the overall horizontal stiffness of the structure is weaker than that of the lower part.

6) The structure is mainly part of the frame beam members into the yield stage, the lateral resistance of the whole structure does not significantly decrease, according to the above provisions of seismic performance, the seismic performance of the structure can reach the fourth level, corresponding to performance objective 3.

Structural seismic performance evaluation of longitudinal framework: based on the analysis of macro results and component damage, the longitudinal frame structure in the 0.3 G calibration RG1.60 spectrum under the action of earthquake, component damage degree is low, can reach the fourth level, can satisfy the requirement of the performance goal 3, the rules and regulations of deformation meet the plastic displacement limit value, and therefore the conclusion is that the structure of the longitudinal frame can meet the specification requirements.

4. Conclusion

In this paper, the nuclear power plant ci turbine room for a variety of lateral loading mode PUSHOVER static elastoplastic analysis, a variety of methods can understand the structure under seismic condition limit security deformation and stress distribution of each bar and structure was observed by elasticity to the elastic-plastic transition, find weak parts of the structure, have the ability to structure the spectral curve.

By ci turbine room structure of five kinds of lateral loading ways of the static elastoplastic analysis and comparison of various load model calculation result is large, to achieve the performance of the target is not the same, produce the position of the hinge, especially the state of the frame column on the hinge is large, and different loading modes affect the structural seismic performance of judging correctly or not.

According to the static elasto-plastic analysis, the results under different loading modes differ greatly. Compared with the results of elastic analysis, the lateral loading mode of the layer shear force is more ideal for the conventional island turbine house, and the loading mode of the layer shear force can be selected.

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