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ELASTO-PLASTIC ANALYSIS OF LARGE SPAN RETICULATED SHELL STRUCTURE UNDER MULTI-SUPPORT EXCITATIONS

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Abstract. It established Multi-Support excitations time history analysis model Based on large quality method. It took large span reticulated shell for example, chose EL-centro wave to carry on the spectrum analysis and time history analysis with direct integral method, studied the deformation capacity and destruction features of structure under rare earthquake of magnitude of 8, and put forward the seismic performance's related measures and suggestions in elasto-plastic analysis of the large span reticulated shell under multi-support excitations for the actual engineering reference in design.

Introduction

With light weight, good structure stiffness, covering larger space, and many kinds of novel building modeling, large span reticulated shell got more and more applications. With the development of the calculation theory and application of new material, the span of large span reticulated structures was more and more big, the thickness of component was thinner and thinner, geometry nonlinear of structure improved, and its dynamic characteristics improved significantly, the general elasticity theory analysis had been difficult to meet the demands, therefore, the large span shell structure's dynamic properties under earthquake effect has become research focus for many scholars and designer. According to the guiding ideology of structural seismic design, the reasonable seismic design should make a part element of structure into yield and material into plastic under rare earthquake. Elasto-plastic analysis was one of the important ways to solve the ductility analysis of structure under rare earthquake; therefore, it is very important to study the dynamic elastic-plastic analysis of large span shell structure.

It took the single large span reticulated shell as the research object, analyzed the dynamic properties of this type of structure under earthquake effect, and discussed the seismic performance problems of large span shell structure, which were doing a beneficial supplement for dynamic elasto-plastic analysis theory of structure.

Elasto-plastic analysis principle and method.
The dynamic equation of more freedom structure system under earthquake was:

$$[M]\{\ddot{x}(t)\}+[C]\{\dot{x}(t)\}+[K]\{x(t)\}=f(t) \tag{1.1}$$

In which, $[M]$ is mass matrix, $[C]$ is proportion damping matrix, $[K]$ is stiffness matrix, $\{\ddot{x}(t)\}$ 、 $\{\dot{x}(t)\}$ 、 $\{x(t)\}$ are acceleration vector, velocity vector and displacement vector respectively within the time step Δt , $f(t)$ is ground motion vector. Incremental relationship among displacement, velocity and acceleration vector within the time step Δt can be expressed as:

$$[M]\{\ddot{x}(t+\Delta t)\}+[C]\{\dot{x}(t+\Delta t)\}+[K]\{x(t+\Delta t)\}=f(t+\Delta t) \tag{1.2}$$

Given the time in tiny acceleration $\{\ddot{x}(t)\}$, speed $\{\dot{x}(t)\}$, and displacement $\{x(t)\}$ are linear variation the increment form of dynamic equation got by type (1) and (2) subtracting was:

$$[M]\{\triangle\ddot{x}(t)\}+[C]\{\triangle\dot{x}(t)\}+[K]\{\triangle x(t)\}=\Delta f(t) \tag{1.3}$$

In time to take some assumptions, incremental gradually integral to, it concluded the vibration response's whole process of structure under the effects of earthquake. Time-history analysis method was that it divided simple harmonic force role into a series of small time period, using type (1.3) to solve the approximate solution of the moment at 0, Δt , $2\Delta t \cdots\cdots$.Due to the high accuracy of calculation, good stability$Wilson-\theta$ method was widely used in time-history analysis. Through direct integral equation of motion, it gets the displacement, velocity and acceleration of computing system and earthquake shear curve of structural components. The results also can analyze the weak layer of the structure and the position of component plastic hinge. Therefore, this method is more accurate and complete to reflect the deformation characteristics of structure under strong earthquake, it is an important measures to improve the seismic capacity and the level of seismic design. Analysis procedure is as follows:
(1) Establishing the integral structure model;
(2) Defining of material constitutive model, assigning the corresponding unit types and material type of the components, determining the parameters of the dynamic response of structures;
(3) Defining boundary conditions of structure model;
(4) Applying the vertical load (dead load, live load)and the level wind load;
(5) Defining and distributing plastic hinge characteristics value on structure component;
(6) Inputting appropriate seismic waves for this field;
(7) Elasto-plastic analysis, analyzing the plastic hinge distribution lateral displacement and relative storey displacement of the structure, comprehensive evaluation structural anti-seismic ability.

Time-history analysis model and method under multi-support excitations

During an earthquake, the energy released from the seismic source in the form of a wave of energy to the surface and caused ground vibration, as with the structure of the large span, because each fulcrum 's distance and the wave length of seismic waves in the same order of magnitude, making the fulcrum of seismic waves reach in different time; Since of the inhomogeneity of the earth medium, resulting in dispersion loss of each fulcrum in seismic motion; there are many different reasons in each fulcrum such as local site soil layer different, causes different types of the fulcrum of ground motion, therefore we should fully take seismic time effect and space effect into consideration in the large span of complex structure seismic design .

The accuracy of the input load is an accurate analysis of the elastic-plastic performance of the large-span space shell structure is very necessary, multi-point excitation is to consider this feature of spatial variation in the input of seismic ground motion. The common law model of Multi-support excitation time-history analysis has a large mass method, a large stiffness method, the direct input displacement method and the relative displacement method. Taking into account the input of ground motion displacement time histories in the bearing more convenient and appropriate, this multi-support excitation time-history analysis using a large mass method.

Large mass method is introduced a large mass M in the structural fulcrum, getting the acceleration $\ddot{x}_0(t) = \ddot{x}(t)$, in supporting points, namely that the response time-dependent of the acceleration in the supporting points remain consistent with the response time-dependent of the acceleration of multi-point excitation inputted. Therefore, through endowing with a large mass, it achieves the seismic motion of the large mass excitation structure that can be realized directly loading of the multi-support excitation and boundary conditions introduced of the structure, so as to achieve the excitation of the multi-point seismic motion of the entire structure in figure 1.

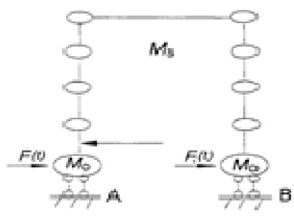

Fig.1 Large mass method

The selection of seismic wave

The choice of seismic waves affects the results of calculation largely, according to the different seismic waves, the results of the analysis may have significant differences. Therefore, the condition of seismic wave should be the same as the actual conditions in engineering at these aspects of the characteristic of spectrum, the effective peak and the time of duration. The characteristic of spectrum is determined by the site classification and the earthquake grumpily; The value of effective peak should be dereference according to the standard , making each record in compliance with the characteristic spectral lines in statistical significance; The time of duration is generally 5 ~10 times for basic cycle of structure.

When the analysis of time-histories response to the structure effected by the earthquake, The seismic wave can generally be divided into the following three types: (1) the real seismic records of the site to be built; (2)the records of the typical strong earthquake; (3)the time-histories curve of acceleration which is simulative artificially. Because of the randomness of earthquake, the seismic waves generated at the same site will have great differences with the actual record of the past in many factors. Therefore, the actual records of strong earthquake at proposed site cannot fully reflect the actual earthquake condition in the future. The code for seismic design of building provides: When the time history method is adopted, it should choose not less than two groups of practical records of strong earthquake and a set of acceleration versus time data which is simulated artificially according to the types of construction sites and the group of design earthquake.

Example analysis

One engineering project as follows: A single-layer of long-span spatial reticulated shell structure, its span is 40 meters and vector height is 8 meters. All the bars are Q235 steel pipe with it's cross-section is 114.3mm×4.5mm,as shown in figure 2.The dead load of roof is $1.5\,KN/m^2$,live load is $1.5\,KN/m^2$,transform them into joint load then exert on each joint. This project selected EL-Centro wave, take account of the influence of the traveling wave effect , as well as the level of bi-directional ground motion excitation in x and y directions, the characteristic period Tg = 0.35s, 8 degrees (0.2g),rare earthquake(strong earthquake) effects, the vibration duration 12s.

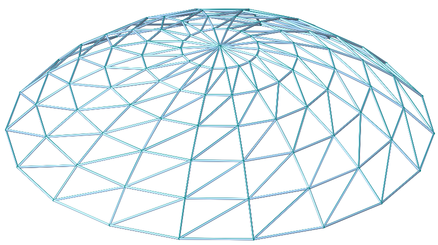

Fig.2 Large span reticulated shell structure

Using the direct integral method, it carries response spectrum analysis and nonlinear time history analysis on structural based on the finite element analysis software MIDAS, the top horizontal displacement are shown in figure 3, vertical displacement are shown in figure 4, the plastic hinge of reticulated shell structure distribution are shown in figure 5 .It made statistical comparison about the structure response spectrum analysis and time-history analysis results on the control of internal forces. According to the results it can see basically that all the components came into a plastic state in the earthquake, but most of them were in the first stage, the individual rods came to fourth stage, parts were in the second or third stage, the maximum vertical displacement was less than the span of the 1/300, and met the design requirements. According to the statistical results of internal forces of rod, the results of history analysis of calculation and the response spectrum calculation changed the similar rules, but different amplitude. The former amplitude change greatly. So, it can judge that this design is reasonable. It can be withstand loads of magnitude 8 earthquakes, and only need to optimize the individual rods.

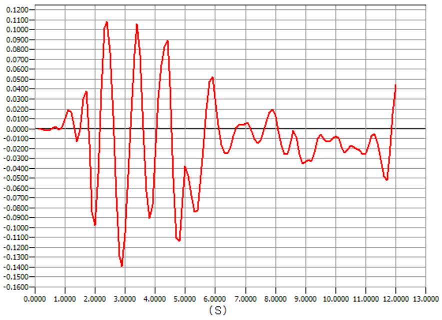

Fig.3 Horizontal displacement graph of vertex

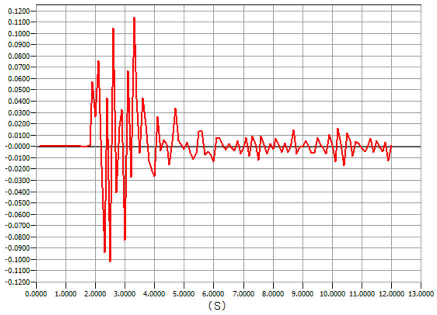

Fig.4 Vertical displacement graph of vertex

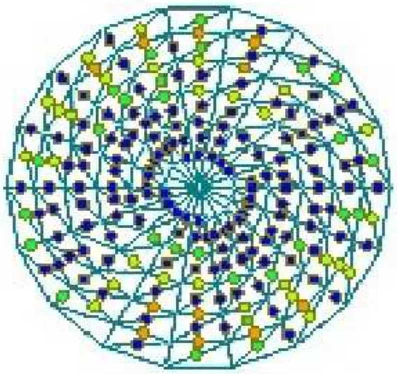

Fig.5 Plastic hinge distribution of shell structure

Conclusions

（1）The structure at regions of magnitude 8 (0.2g) can meet the China seismic design code of three stage design standards.

（2）From the elasto-plastic hinge distribution of large span spatial reticulated shell structure, we can judge where the weak parts of the structure are. For large span reticulated shell structure, the elasto-plastic ultimate capacity depends on the circumferential and longitudinal rods deformation and strength.

（3）The results of time history analysis and the response spectrum analysis change similar rules but different amplitude. To save the project cost, it is very meaningful to use dynamic elasto-plastic analysis and design for large span spatial reticulated shell structures.

（4）Dynamic elasto-plastic analysis method can make the reasonable appraisal of the structure seismic performance according to the seismic code. For the realization of performance based on seismic design, It provides us a good method of calculation.

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