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SEISMIC EVALUATION OF LCS METHOD RC STRUCTURAL ENCLOSURES

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----------ABSTRACT----------
For a structural enclosure, seismic testing consumes a lot of resources. The accuracy of obtaining seismic performance through theoretical calculation in the design stage has become the focus of attention. However, the choiceof theoretical calculation methods affects the accuracy and timeliness of the structural enclosure's seismic performanceanalysis. This paper uses the principles of structural seismic analysis to determine the applicability of each theoreticalcalculation method, including elastic static method, response spectrum method, bottom shear method, nonlinear static method, time history analysis method, energy design method, and random vibration method, to solve the rationality of the selection of seismic performance calculation methods for structural enclosure. The main objective of this paper is to perform a literature review on works done on seismic analysis of RC structural enclosures.----------

I. INTRODUCTION

An earthquake is a sudden and transient motion of the earth's surface. According to geologists, the earth has suffered earthquakes for hundreds of millions of years, even before humans came into existence. In terms of the geological time scale, it is only recently (the middle of seventeenth century) that an earthquake has been viewed as a natural phenomenon driven by the processes of the earth as a planet. Thus, subsequent work especially in nineteenth century, led to tremendous progress on the instrumental side for the measurement of earthquake data. Seismological data from many earthquakes were collected and analysed to map and understand the phenomena of earthquakes. These data were even used to resolve the earth's internal structure to a remarkable degree, which in turn, helped towards the development of different theories to explain the causes of earthquakes. While the body of knowledge derived from the study of collected seismological data has helped in the rational design of structures to withstand earthquakes, it has also revealed the uncertain nature of future earthquakes for which such structures are to be designed. Therefore, probabilistic concepts in dealing with earthquakes and earthquake resistant designs have also emerged. Both seismologists and earthquake engineers use the seismological data for the understanding of an earthquake and its effects, but their aims are different. Seismologists focus their attention on the global issues of earthquakes and are more concerned with the geological aspects, including the prediction of earthquakes. Earthquake engineers, on the other hand, are concerned mainly with the local effects of earthquakes, which are capable of causing significant damage to structures. They transform seismological data into a form which is more appropriate for the prediction of damage to structures or, alternatively, the safe design of structures. However, there are many topics in seismology that are of immediate engineering interest, especially in the better understanding of seismological data and its use for seismic design of structures.

Seismic analysis is a subset of structural analysis and is the calculation of the response of a building (or nonbuilding) structure to earthquakes. It is part of the process of structural design or earthquake engineering in regions where earthquakes are prevalent. Earthquake has great threat and can cause damage for the enclosure system. Structural enclosures with poor seismic performance are easy to be damaged under the earthquake, which leads to the failure of the whole system. Therefore, the seismic performance of the enclosures must be considered to avoid the effects caused by an earthquake.

At present, the methods for analysing the seismic performance of structures mainly include theoretical calculation methods, experimental analysis methods and seismic damage statistics methods. However, as the requirements for the seismic performance of the structural enclosures is important, the theoretical calculation method is required to analyse the seismic performance of enclosures in the product design stage, and the selection of different theoretical calculation methods affects the accuracy of seismic performance analysis of enclosures. This paper summarizes and analyses the research progress of structural seismic analysis theory, analyses its applicability from the principle of seismic analysis and provides a theoretical basis for the selection of seismic theory and methods required for the seismic analysis of the structural enclosures.

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II.SEISMIC REQUIREMENTS FOR STRUCTURAL ENCLOSURES

Seismic loading is one of the basic concepts of earthquake engineering which means application of a seismic oscillation to a structure. It happens at contact surfaces of a structure either with the ground or with adjacent structures. Seismic loading depends, primarily on seismic hazard, geotechnical parameters of the site, and structure's natural frequency etc. There are horizontal and vertical components of earthquake ground motions, but the horizontal component of earthquake ground motion is the main cause of the damages caused. Therefore, only horizontal earthquake ground motion is considered in the seismic analysis.

Inertial forces arise from the move. It is sufficient to determine these forces and apply them on the structure. Thus, the dynamic load is transformed into a static load. It is difficult to predict the precise movement of subsoil and therefore it is difficult to determine the seismic forces precisely. But it is possible to apply formulas of a technical standard or employ the frequency spectrum of a real earthquake for the purpose of analysis.

A. Symbols and Notations

A_p: Dynamic Response Amplification factor

F_a: Amplification factor of site response acceleration spectrum

F_{ph}: Earthquake load (Horizontal direction)

F_{pv}: Earthquake load (Vertical direction)

$\frac{H_x}{H_n}$: Ratio of building height where equipment is placed to building height

I_p: Seismic Importance factor

N_a: Near seismic source factor

R_{pa}: Allowance seismic response reduction factor

R_p: Seismic response reduction factor

S_{ds}: Design horizontal response acceleration at short periods S_s: Structural response acceleration parameter at short periodsW_p: System weight

B. Structural Classification

A rigid structure is one that has a primary natural frequency of at least 17 Hz, according to 2005 ASCE7 Section 11.2 of the code. A structure is categorised in accordance with this definition as:Flexible Structure: Natural frequency < 17 Hz

Rigid Structure: Natural frequency ≥ 17 Hz

C. Seismic Forces

The total design horizontal force Fph, is independent of building structural properties and shall be determined based on IBC (International Building Code) 2009 and NEHRP (National Earthquake Hazard Reduction Program) in accordance with the appropriate formula stated in ASCE 7 section 13.3 as,

$$F_{ph} = 0.4\, S_{ds} \frac{A_p \times I_p}{R_{pa}} [1+2\frac{Hx}{H_n}]\, W_p$$

The total design vertical force F_{pv}, in addition to system weight is determined from ASCE 7 section 12.4.2.2, earthquake usually produce much higher vertical seismic forces which must be considered at 67 % of the designed horizontal force which is represented as,

$$F_{pv} = \frac{2}{3} F_{ph}$$

Load combinations for the analysis are defined in IBC 2009 section 1605 which represents the worst case basic loads for strength design according to the following formulas:

Horizontal load: Apply the value of Fph along the horizontal direction.

Vertical load: Apply along the vertical direction according to the following values,

$1.2\ W_p + F_{pv}$ for downward (direction same as gravity)

$0.9\ W_p - F_{pv}$ for uplift (direction opposite to gravity)

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D. Determining Parameters A_p , R_p , I_p , $\frac{H_x}{H_n}$ and S_{ds}

a. Dynamic Response Amplification Factor, A_p

This factor depends on structural rigidity and material ductility. ASCE 7 Chapter 13, Table 13.5 – 1 classifies material into the following three deformability categories: low, limited and high. Although the structure framing could be classified as high deformability element, a conservative approach of limited deformability classification is taken due to the connection in framing. According to this classification, in reference to ASCE7 Table 13.5 – 1 this factor assumes the following values: 1.0 for rigid structure and 2.5 for a flexible structure.

b. Seismic Response Reduction Factor, R_p

This factor does not depend on structural rigidity but does depend on material ductility. With a material classification of limited deformability, in reference to ASCE 7 Table 13.5 – 1 this factor assumes the value of2.5.

c. Seismic Importance Factor, I_p

This factor is assigned the values of either 1.0 or 1.5 the value is based on according to the harm potential a failure has to human life and environment. A value of 1.5 is assigned to components carrying Hazardous Potential Material (HPM).

d. Ratio of Building Height, $\frac{Hx}{H_n}$

Worst case for equipment is simulated for component placed at building top is with this ratio assigned a valueof 1.0.

e. Horizontal Response Acceleration at Short Periods, S_{ds}

By considering the conservative worst case is and in reference to ASCE 7 Table 13.5 – 2 the value of horizontal response acceleration at short periods, Sds factor is assigned the value of 1.024.

f. Seismic Hazard Analysis

A seismic hazard at a site is defined as a quantitative estimation of the most possible ground shaking at the site. It may be obtained either by a deterministic approach or by a probabilistic approach. The possible groundshaking may be represented by peak ground acceleration, peak ground velocity, or ordinates of the response spectrum. Whatever the approach or the representation of ground shaking are, the seismic hazard analysis requires the information about some important factors in the neighbourhood of the site. They include geologicevidence of earthquake sources, fault activity, fault rupture length, historical, and instrumental seismicity. Geologic evidence of earthquake sources is characterized by the evidence of ground movement of the two sides of a fault, disruption of ground motion, topographic changes, and so on. Fault activity is characterized by movements of ground at the fault region; it is the active fault that leads to future earthquakes. Past earthquake data regarding the relationship between the fault rupture length and the magnitude of earthquake provide valuable information for predicting the magnitude of future earthquakes and, thus, help in seismic hazard analysis. Historical records of earthquakes and instrumentally recorded ground motions at a site also provide valuable information on potential future earthquake sources in the vicinity of the site.

As mentioned above, seismic hazard analysis may be carried out using two approaches, namely, deterministic seismic hazard analysis and probabilistic seismic hazard analysis.

a. Deterministic Hazard Analysis

Deterministic hazard analysis (DSHA) is a simple procedure which provides a straightforward framework for the computation of ground motions to be used for the worst-case design. For specialty or special structures such as nuclear power plants, large dams, and so on, DSHA can be used to provide a safe design. DSHA involves many subjective decisions and does not provide any information on the likelihood of failure of the structure over a given period of time. Because of these reasons, its application is restricted when sufficient information is not available to carry out any probabilistic analysis. The DSHA is carried out using the following steps.

i. Identification of all potential earthquake sources surrounding the site, including the source geometry.
ii. Evaluation of source to site distance for each earthquake source. The distance is characterized by the shortest epicentral distance or hypocentre distance if the source is a line source.
iii. Identification of the maximum (likely) earthquake expressed in terms of magnitude or any other parameter for ground shaking for each source.
iv. Selection of the predictive relationship (or attenuation relationship) to find the seismic hazard caused at the site due to an earthquake occurring in any of the sources.
v. Determination of the worst-case ground shaking parameter at the site.

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b. Probabilistic Hazard Analysis

Probabilistic hazard analysis (PSHA) uses probabilistic concepts to predict the probability of occurrence ofa certain level of ground shaking at a site by considering uncertainties in the size, location, rate of occurrenceof earthquake, and the predictive relationship. The PSHA is carried out using the following steps.

i. The first step is to identify and characterize the earthquake sources probabilistically. This involves assigninga probability of occurrence of an earthquake at a point within the source zone. Generally, a uniform probability distribution is assumed for each source zone, that is, it is assumed that the earthquake originating from each point within the source zone is equally likely. Secondly, the probability distribution of the sourceto site distance, considering all points in the source zone to be potential sources of an earthquake, is determined from the source geometry.
ii. The second step is to characterize the seismicity of each source zone. The seismicity is specified by a recurrence relationship indicating the average rate at which an earthquake of a particular size will be exceeded.
iii. In the third step, a predictive relationship is used to obtain a seismic parameter at the site for a given magnitude of earthquake and source to site distance for each source zone. Generally, the uncertainty is expressed by a log normal distribution by specifying a standard deviation for the seismic parameter and thepredictive relationship is expressed for the mean value of the parameter.

III. METHODOLOGY

1. ANALYTICAL METHODS

A. Equivalent Static Analysis

The principle of equivalent static analysis is to simplify the seismic dynamic response of the structure to static response, and conduct seismic analysis of the structure in the static mode of equivalent seismic load. It assumes that the vibration of each part of the structure is the same as the ground motion, and the inertial force generated under the action of ground horizontal acceleration is regarded as static force acting on the structure.

B. Response Spectrum Method

The response spectrum method is based on the dynamic relationship between structural dynamic characteristics and ground motion characteristics, and uses response spectrum to calculate the resonance effect generated by structural dynamic characteristics. It assumes that the earthquake is a stationary stochastic process, the structure is in the linear elastic response stage and the response can be superimposed, ignoring the interaction between the ground and the structure.

C. Bottom Shear Method

The bottom shear method can actually be regarded as a simplified mode decomposition response spectrum method. Its principle is to first calculate the total horizontal seismic action acting on the structure, that is, the shear force acting on the bottom of the structure, and then distribute the bottom shear force to each particle according to a certain rule, so as to obtain the horizontal seismic action of each particle, and then calculate the seismic response of the structure according to the static method.

D. Nonlinear Static Method

The nonlinear static method is a method that considers that the structure enters the elastic-plastic work stage under earthquake damage. Its representative is the capacity spectrum method combined with Pushover analysis. The basic principle is to establish one capacity curve and another demand curve. The two curves are placed in the same coordinate system, and the intersection point of the two curves is the "target displacement point". Compared with the allowable displacement value, it can be judged whether or not the structure meets the seismic performance requirements.

E. Time History Analysis Method

Time history analysis method is a deterministic dynamic analysis method. It starts from selecting the appropriate seismic wave input (earthquake acceleration time history), and uses multi-node finite element dynamic calculation models to establish vibration differential equations for linear or nonlinear structures, then directly integrate and solve the equation step by step to calculate the acceleration, velocity and displacement response of each instantaneous structure in the earthquake process, so as to obtain the time history relationship of structural stress and strain.

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F. Energy Design Method

During the earthquake, the structure is in the energy field, and there is continuous energy input, transformation and dissipation between the ground and the structure. The energy design method believes that the response of structure in earthquake is a process of dissipating seismic input energy, which is to consider solving the problems of energy input and dissipation calculation of different structures, that is, to determine the energy needed to be dissipated by the structure and the energy dissipation capacity of the structure itself.

G. Random Vibration Method

At present, the random vibration method mainly used in seismic response analysis is the frequency domain random vibration method, and there is also the time domain random vibration method which is not widely used. The frequency domain random vibration method is to obtain the statistical characteristics of the structure seismic response by establishing the relationship of the power spectrum function between the ground motion input and the structure seismic response output.

2. NUMERICAL METHODS

Most of the numerical methods for seismic modelling belong to one of the following three categories: spectral methods, finite difference methods, or finite element methods.

A. Spectral Method

This method approximates the wave field using Fourier modes. They are very efficient for certain specific geometries, such as a layered earth with purely horizontal interfaces, but are usually not applicable to more generic geometries.

B. Finite Difference Method

This method approximates the wave field on a uniform grid. They can be applied to generic geological structures and are very easy to implement, which makes them currently the most popular choice for large- scale modelling and inverse problems. For complex topographies and sharp contrasts in the rock material, however, they require a very fine grid resolution to remain accurate.

C. Finite Element Method

This method can handle complex geological interfaces more efficiently by carefully subdividing the earth's geometry into simple geometries called elements. The wave field is then approximated on each element using simple interpolation functions, usually polynomials up to a certain degree. Finite elements methods are more difficult to implement compared to finite difference methods and require more computation time and memory to model simple rock structures. For complex geological structures, however, they can remain very accurate without having to refine the element mesh as long as the elements are well-aligned with the geological interfaces. Finite element methods can therefore significantly outperform finite difference methods in such cases.

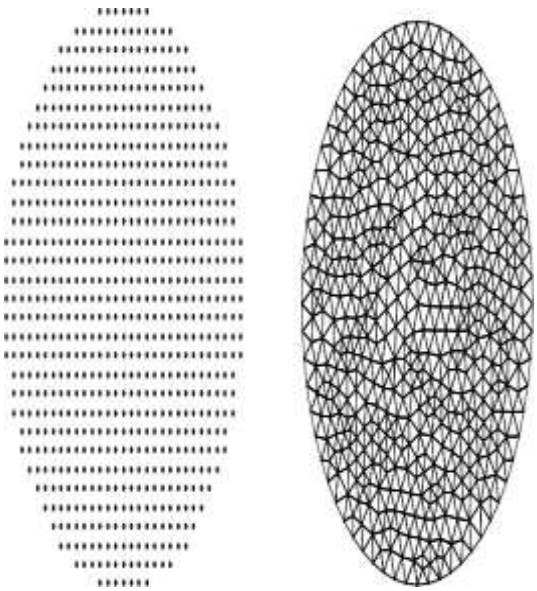


Fig. 1. Finite difference grid (left) and triangular element mesh (right) for a circular domain.

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3. SEISMIC ANALYSIS METHOD

As the structural enclosure are vulnerable to seismic loads, hence it is important to investigate the structure's performance under seismic activity. The strength and stiffness of the structure subjected to seismic loads are analysed using the specifications prescribed by the International Building Code (IBC). The stepwise procedure to determine the results are as follows,

A. Develop a Finite Element Model

As all analyses in the study are dependent on this model, this is a crucial stage that will likely take more time to complete. To account for the mass attributes of all significant components, significant effort must be made. Each significant component's load path in relation to the main structure must be specified and accurately described. It is necessary to account for and assign each material property correctly. The system centre of mass ought to match the actual dimensions as closely as feasible. There must be tie down points in the model, and these points should be represented by "fixed" constraints.

B. Perform Static Analysis

The structure's stress status under normal load circumstances is reported by this analysis. The only loading condition that should be taken into account is gravity. The modal analysis is a precursor to this approach. With loading, the structural modal response modifies. Therefore, the stresses on the structure due to gravitational loading must be determined and input into the modal analysis.

C. Perform Modal Analysis

Modal analysis must be conducted on a pre-stressed frame. In this step, structural stiffness is determined. Typically, we seek to identify the structure's first three main modes. The value of the lowest modal frequency determines structural stiffness. If this frequency is more than or equal to 17 Hz, the structure is stiff or rigid.

D. Run Equivalent Seismic Analysis

This stage involves doing an analogous static analysis on the structure based on loading scenarios that take structural stiffness and potential material hazards into account. In comparison to a rigid system, a flexible system necessitates evaluation at higher loads.

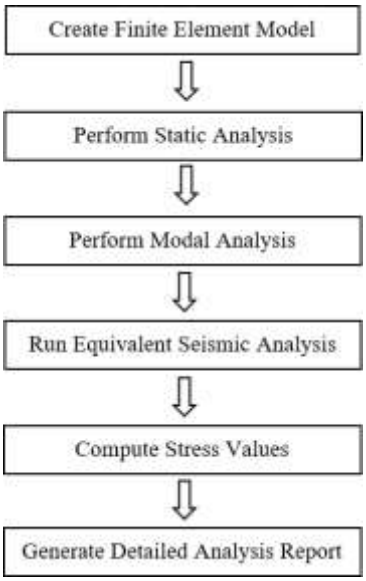


Fig. 2. Seismic Analysis Flowchart

IV.RESULTS

When the Kobe wave with maximum acceleration of 0.4 cm/$s2$ was input into the shake table control system, the experimental model shook very violently, large displacement occurring on top of the experimental model. In addition, the roof board fixed to the roof truss almost fell off the top of the experimental model. Many cracks appeared on the surface of the mortar filled to the corner of the enclosure wall. Besides, cracks also appeared on the surface of prefabricated strip slabs, but prefabricated strip slabs had no fracture. For the flexible connection between the steel frame and enclosure walls, they were not damaged at all.

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When the El-Centro wave with maximum acceleration of 0.6 cm/$s2$ was input into the shake table control system, shaking of the experimental model was also very violent and a large number of cracks appeared on the surface of mortar filled to the corner of the enclosure wall, but the mortar was not damaged. The roof board fixed to the roof truss fell off the top of the experimental model. In addition, large deformation of the steel frame did not occur and the enclosure walls were also not damaged (The seismic performance of the post-earthquake temporary prefabricated light-weight steel structure was investigated by the test method. According to the inputting Kobe wave and El-Centro wave into the shake table control system, the full-scale two-story experimental model could vibrate and the following conclusions can be drawn:

(1) The seismic performance of the post-earthquake temporary prefabricated light-weight steel structure was good, and the steel frame and enclosure walls composed of prefabricated slender columns and prefabricated strip slabs were not damaged when the experimental model was subjected to earthquake with maximum acceleration. In addition, only a lot of cracks appeared on the surface of enclosure walls.
(2) The natural frequency of the experimental model decreased with increasing maximum acceleration of El-Centro wave, and it dropped sharply when maximum acceleration of the El-Centro wave was equal to 0.4 cm/$s2$.
(3) When the maximum acceleration of seismic signals was less than 0.4 cm/$s2$, the collaborative performance of the steel frame and enclosure wall was good.

1.Seismic Qualification of Electrical Cabinet Using High-Fidelity Simulation under High Frequency Earthquakes
a. Introduction
An electric cabinet system, is the key facility to support electrical power distribution in power plants and it must be expected to remain functional during and after strong earthquakes. Over the past decade, most components have received less attention in comparison to the structural system regarding their behaviour and design, in spite of it being the cause of economic losses and mechanical damage during a seismic event. Such problems cause a loss of operation and a loss of electrical power in critical facilities, for example, due to overturning of the cabinet system, and component rocking and component sliding by inadequate restrain anchorage in the cabinet system during an earthquake. Consequently, most damage of electrical cabinets was related to structural damage in terms of sliding or overturning and also, the damage was associated with sensitivity due to the amplification of acceleration in the cabinet. The cabinet instrument is related to the fundamental frequency of the components and it is sensitive to the response of acceleration during and after an earthquake.

More specifically, the detailed study of this seismic analysis include the following subjects:

- Identification of the dynamic characteristics such as global and local modes of a single door cabinet on the shaking table test, by using sinusoidal sweep (2 octave/min, 1~50 Hz).
- Evaluation of the dynamic response such as acceleration time histories at the inside and outside of the cabinet, using measurement of accelerometers at the single door on the shaking table test due to ICC-ES AC156.
- Development of a 3D Finite Element (FE) model using the ABAQUS platform to validate the numerical model compared with the responses observed from the shaking table test.
- Analysis of the dynamic response of the single door cabinet system subjected to high and low frequency
- ground motions, using time history analyses of the 3D FE model.

V.CONCLUSION

On the whole, the response spectrum method is the first choice for the seismic theoretical calculation method of the structural enclosures, and the time history analysis method can be used to supplement the seismic design of the structural enclosures with special irregularities or special requirements, and take the larger value between the average of the calculation result of multiple time history curves and the calculation result of the mode decomposition response spectrum method.

Secondly, the static method can be used for rigid components, the bottom shear method can be used for components meeting the application conditions of bottom shear method, and the nonlinear static method should be used for seismic calculation of components requiring elastic-plastic analysis.

However, as the seismic performance of structural enclosures becomes more complex, the existing theoretical calculation methods will not be able to meet the requirements of the development of seismic performance analysis. So, the following will be the future development direction of seismic design analysis theory for structural enclosures:

(1)Considering the nonlinear characteristics of the structure under earthquake action, when using the time history analysis method, consider the changes in structure quality, stiffness and damping, or when using the response spectrum method, use the elastic-plastic response spectrum instead of the elastic response spectrum to analyse and calculate the structural response under earthquake.
(2)Research on the correct and reasonable structural simplification method of electrical equipment will not only help reduce the amount of seismic theoretical calculations, but also help expand the application range of seismic theoretical calculation methods.
(3)Due to the characteristics of large span, wide range of structural enclosures and the influence of the spatial variation characteristics of ground motion (travelling wave effect, coherence effect and local site effect), the seismic response obtained by using non-uniform seismic excitation instead of uniform seismic excitation as the input of vibration equation is more reasonable and closer to reality.

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