第二届结构工程新进展国际论坛论文集

Proceedings of the Second International Forum on Advances in Structural Engineering

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李宏男 伊廷华 主编

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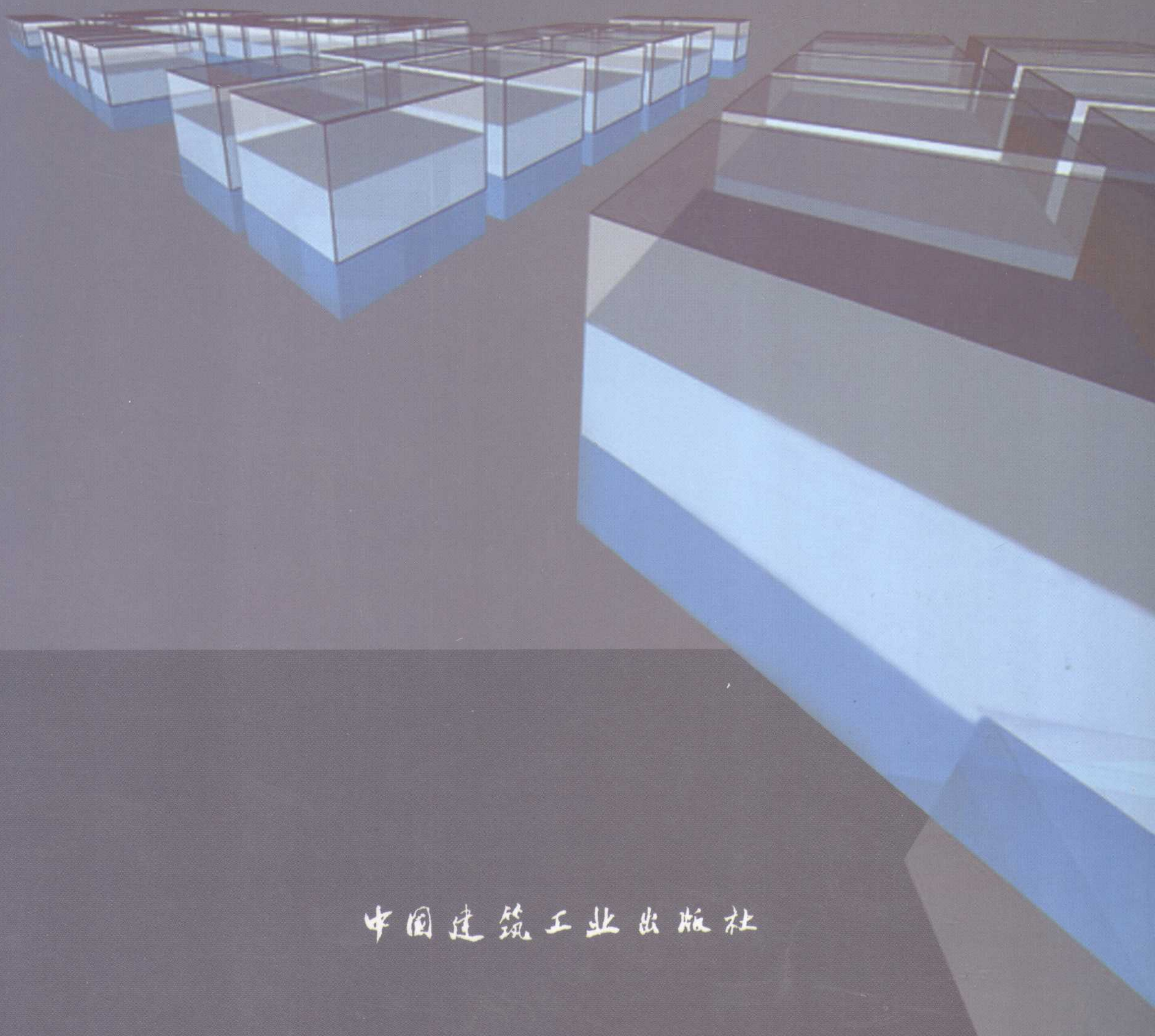

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Application of wavelet transform in multi-component seismic response of offshore platform

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Abstract: A convenient and reliable method is presented to search the critical angle of seismic wave in multi-component seismic response of offshore platform in this study. Wavelet transform is used to visually reveal the time-frequency information of the earthquake wave. Based on both the basic frequency of platform and the time-frequency characteristic of the earthquake, the key wavelet coefficient curve can be drawn to obtain the effective energy time-history curve, then the critical incidence can be determined through the effective energy curve. Using the method presented in this paper, the critical incidence is determined in an actual platform under ten groups of seismic loads and in a group of single degree of freedom systems under one seismic load. Different cases are verified through time-history analysis with ANSYS program too. It is shown that when the structure is sensitive to incidence, the effective total energy and the structure's response reach their peak value at the same incidence, and this angle is just the critical angle of seismic wave.
Keywords: wavelet transform, platform, multi-component seismic response

Introduction

Modeling of the structure, inputting seismic actions and analysis of the structure's dynamic response are the most three common topic in aseismatic domain. Therefore, the reliability of aseismatic analysis depends not only on the proper model of the structure, high-precision of the method adopted in analysis but also on the input mechanism of the seismic wave, which includes the selection of the seismic waves and determination on seismic incidence. Although in the seismic design of structures the directions of ground motion incidence are usually applied along the fixed structural reference axes, it is known that for most world tectonic regions the ground motion can act along any horizontal directions. This implies the existence of a possible different directions of seismic incidence that would lead to an increase of structural dynamic response. The maximum structural response associated to the most critical direction of ground seismic motions has been examined in several papers. Wilson and Button proposed a method to calculate the critical angle of incidence and the structural response (Wilson *et al*. 1982). This method is however approximate, because it does not take into account the proper correlation of ground motion components they act along the structural principal directions. Smeby and Der Kiureghian using random vibration theory developed an explicit formula to determine the critical angle for the case of two horizontal ground components with identical spectral shapes that takes into account the proper correlation between seismic components (Smeby and Kiureghian 1985). Based on the results of Lopez and Smeby's research, Menun and Der Kiureghian developed a new method named CQC3. Based on the elastic response spectrum (Lopez 1997; Menun and Kiureghian 1998). Feng calculated the maximum deformation energy and deduced the formula to determine the incidence angle of seismic wave, then a frame structure was taken as an example (Feng and Li 1991). Zhu et al. presented a method to obtain the incidence angle by spectrum analysis twice. Most researchers give their formula to calculate the critical angle of seismic wave basically on the spectrum analysis without verification by time-history analysis (Zhu *et al* 2000). So an efficient convenient and reliable method named effective input energy is presented to determine the seismic incidence angle, and an actual platform and a group of single freedom systems are analyzed as the examples to verify the validity of this method.

Relative theory

Wavelet transform

As a time domain signal the earthquake record itself can reflect the total energy input by earthquake. It is known that for a certain earthquake the total energy is the same but the dynamic response of different structures caused by that earthquake is different. So it is necessary to obtain the frequency domain information of earthquake to reflect its overall characteristics. The conventional method to obtain the frequency information of earthquake contains Fourier Spectral Analysis and Power Spectral Density Analysis. However the nonstationary time series characteristic was not considered using these transforms. Based on Fourier transform, scholars present a method called the Short-Time Fourier Transform to analyze only a small section of the signal at a time-a technique called windowing the signal. Due to the fixed window, the precision and the amount of calculation can not be solved well. Then with the adjustable window Fourier spectral analysis technique presented, Wavelet transform is developed. Using this brand-new method the time-history information with different frequencies can be obtained from the original earthquake record to reflect its essential information (Li and Sun 2003; *Yi et al* 2006; Ling *et al* 2007).

Basic theory (Yang 2005; Albert and Francis 2004)

The continuous wavelet transform is defined as the sum over all time of the signal multiplied by scaled, shifted versions of the wavelet function:

$$C(a,b) = \int_{-\infty}^{\infty} f(t)\psi(a,b,t)\,\mathrm{d}t \tag{1}$$

in which, $\psi(a,b,t)$ is the wavelet function. The results of continuous wavelet transform are many wavelet coefficients $C(a,b)$, which are a function of scale a and position b.

For the continuous wavelet transform the relations between the scale a and the frequency can be expressed as:

$$F_a = F_c / \Delta \cdot a \tag{2}$$

where Δ denotes the sampling period, F_c means the center frequency of a wavelet in Hz and F_a is the pseudo-frequency corresponding to the scale a in Hz. The frequency maximizing the Fourier transform of the wavelet modulus is F_c.

Application conception

The basic frequency of the platform is the most important factor in the structure's characteristics that influent the dynamic response of the structure. When earthquake energy containing different frequency components reach the structure system, the structure will magnify some earthquake energy action that containing the frequency component close to the structural basic frequency and filter other earthquake energy action. While wavelet transform can just break up the earthquake input energy into different frequency components input energy. Based on these conceptions wavelet transform is applied to determine the critical angle of seismic wave in multi-component seismic response of offshore platform.

Steps to determine the earthquake incidence

First of all, actual measurement earthquake records (containing two horizontal directions) should be selected and decomposed along structure's X and Y axes in order to obtain the earthquake components with different input angles. Earthquake input angle is defined as θ, the earthquake components along structure's X and Y axes are denoted as $X\theta$ and $Y\theta$ respectively. The coordinate system of the structure and earthquake input angle are defined in Fig. 1.

Secondly, continuous wavelet transform will be calculated for the earthquake component $X\theta$ and $Y\theta$ in order to obtain wavelet coefficients spectrum which reflects the energy time-history process with different frequency components. The Daubechies4 wavelet which has the similar characteristic as seismic wave is selected as the wavelet in this paper, and the wave shape of this wavelet function is shown in Fig. 2.

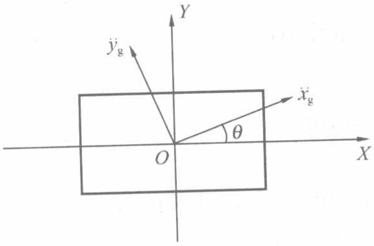


Fig. 1 Definition of platform coordinate and earthquake input direction

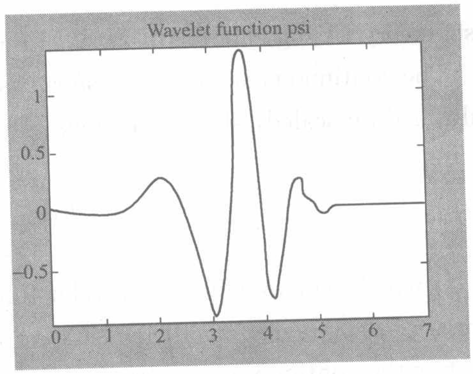


Fig. 2 Sketch map of the db4wavelet function

Then the key wavelet coefficient curve corresponding to the structure's basic frequency is extracted to calculate its "effective input energy". As for db4 wavelet, its center frequency is 0.7143Hz. According to the equation (2), the scale a1 corresponding to the structure's basic frequency can be obtained. Let $a = a_1$, then the wavelet coefficient curve which has a key effect on the maximum response of the structure can be obtained from the wavelet coefficient spectrum $C(a,b)$. Effective Energy is defined as the area below the wavelet coefficient curve discussed above. It is a function of time, the Total Energy is the one corresponding to the end time of earthquake.

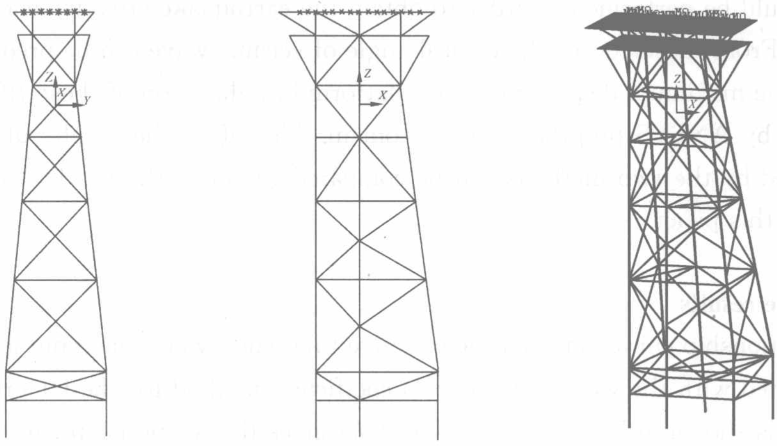
In the end, Effective Energy time-history curve can be utilized to predict the critical angle of seismic wave for platform's response.

Numerical calculation and verification

An actual platform calculation

Platform model and earthquake records

The model of platform is constructed based on an actual platform in China (Xie and Zhai 2003). The x-dirction profile、y-direction profile and spatial diagram are shown in Fig. 3. The platform with two-story deck has a total height of 137.8m. The upper deck and the orlop deck sections are 55.5×29 m^2 and 50×20 m^2 respectively, and their elevations are EL+24.8m and EL+32.8m(EL is the abbreviation of elevation). The platform has six horizontal levels with elevations as EL+7m, EL-11m, EL-34m, EL-62m, EL-95m and EL-105m. Six jacket legs are variable cross sections. All the six legs' slope in y direction is 10 : 1, while only two legs in one side their slope in x direction is 8 : 1. The mass of jackets and piles are 5500t and superstructure's mass is 1760t. The platform's working depth is 105m. The first six natural frequencies of the platform are listed in Table 1.



(a) (b) (c)

Fig. 3 Sketch map of the platform model

(a)X-direction profile; (b)Y-direction profile; (c)The graphic model

The first six natural vibration frequency **Table1**

	First	Second	Third	Fourth	Fifth	Sixth
Frequency(Hz)	0. 6369	0. 6885	0. 9844	1. 3957	1. 4041	1. 4143

Ten groups of typical earthquake records representing four types of grounds are selected based on the Xie[13] et al. research achievements. The detail information of earthquake records is listed in Table2.

Information of earthquake records **Table2**

Num	Time	Earthquake	Station, Component	PGA(cm · s^{-2})
D1	1976	Tangshan	Tianjin Hospital, WE/SN	104. 18/145. 80
A2	1985	Michoacan Mexico	La Union, N90E/N00E	147. 06/162. 79
B3	1979	Imperial Valley	El Centro, Array #10, N69W/N21E	168. 21/221. 69
D4	1984	Coalinga	Parkfield Fault Zone 14, 90/0	268. 96/256. 96
A5	1988	Langcang	Zhutang A, S00E/S90E	541. 66/518. 42
C6	1988	Gengma2	Gengma, S00E/S90E	90. 02/92. 20
B7	1988	Gengma1	Gengma, S00E/S90E	140. 75/134. 25
C8	1940	El Centro	El Centrolmp Vall lrr Dist, 180/270	210. 10/341. 70
C9	1952	Kern County	Taft, N21E/N69W	152. 70/175. 90
D10	1949	Western Washington	Olympia Hwy Test Lab, 356/86	274. 63/161. 63

Calculation and verification scheme

A total of 19 cases are calculated for a certain earthquake records (with two horizontal direction) when the input angle θ takes as 0°, 10°, 20°up to 180°respectively. According to the steps of section 1. 4, the wavelet transform of the earthquake component $X\theta$ in different cases should be performed in order to obtain the earthquake effective energy time-history curves. From these curves the critical angle of seismic wave can be predicted. At the same time, the maximum displacements of platform in x direction of these 19 cases should be calculated by ANSYS program in time domain. Therefore the results of seismic incidence obtained by the two methods can be compared to verify the validity of the method presented by this paper.

Comparing the results

The relationship curve between the effective total energy and the input angle of earthquake calculated with the wavelet transform coefficient method for the D1 group of earthquake record is shown in Fig. 4(*a*), and Fig. 4(*b*) gives the relationship curve between the maximum displacement of platform in x direction calculated by ANSYS program and the earthquake input angle. Comparing the two figures, it is found that the total energy of earthquake and the maximum response of the structure have the similar rule with the earthquake input angle. The typical time-history curves of D1 group of earthquake's effective energy are given in figure 5(*a*), in which 19 curves represent 19 cases. The types of the curves are marked by the sequence of the maximum displacement computed by ANSYS program. The curve type of the case in which its maximum displacement is also the maximum value in the sequence is bold-type real line. The 95% case means the case in which the ratio of its maximum displacements to the head of the maximum displacement sequence is larger than 95%, and the curve type of such case is real line. The curve type of other cases is brokenline. The time-history curves of effective energy for the other nine groups of earthquake records in different cases are shown in 5(*b*)—5(*c*) respectively. The standardization results are listed in Table3. The standardization here means the larger peak value of the two horizontal earthquake records will be modified to 1 $m \cdot s^{-2}$ and keep the ratio of these two peak values as the constant at the same time. The notations of texmax and texmin in this table denote the maximum and the minimum values of effective total energy

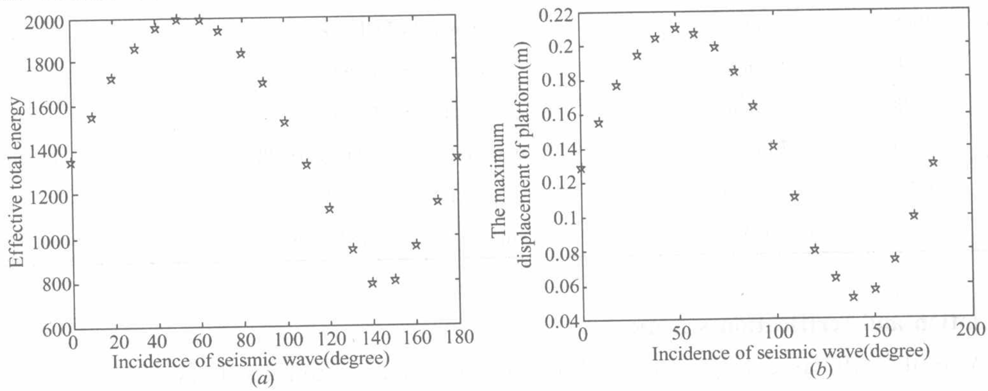


Fig. 4 Comparison of effective energy method and ANSYS time-history analysis method in searching for the worst incidence angle of earthquake