Seismic responses analysis of long continuous rigid-framed bridge subjected to multi-support excitations

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ABSTRACT : In this paper, effects of multi-support excitations on seismic responses of an existing long span prestressed concrete continuous rigid-framed bridge are investigated by time-history method. This bridge is named Houzhu Bridge, in Quanzhou, Fujian province. There is no material difference between the result of the 3-D finite element model modal analysis and modal test that confirms the 3-D finite element model reasonable. The ground motions come from relatively non-stationary earthquake accelerograms simulation with EI-centro wave. Wave passage effect, incoherence effect and local effect is consider in the numerical simulation. The contrast of results multi-support excitations and uniform excitation is that the wave passage effect is very important for the continuous rigid frame bridges, the other effect is not very important. A conclusion is given that the uniform seismic excitation is not able to control the seismic design for long span prestressed concrete continuous rigid-framed bridge, and the influence of the multi-support excitations on the seismic responses of the long span prestressed concrete continuous rigid-framed bridge must be considered.

KEYWORDS: continuous rigid-framed bridge, multi-support excitations, seismic response analysis

1. Introduction

The seismic excitation of large-span structure is quite complex with a high variability in time and space. In calculation of the dynamic response about these long-span structures, the assumption of the uniform ground supports motion cannot be considered valid. For long-span bridges, many researchers have studied about multi-support and traveling seismic wave effects. Nazmy AS and Garevsky M especially have illuminated the requirement of consideration of multi-support and traveling seismic wave effects for the dynamic response analysis of long-span bridges[1-2]. Abdel-Ghaffar and Rubin has analyzed long-span bridges under multi-support seismic excitation through random vibration method[3]. Harichandran studied the Golden Gate suspension bridge to a general spatially varying earthquake ground motion which neglects the site-response effect through coherent model in reference [4]. It was concluded that the use of identical excitations is in general unacceptable for those long-span bridges[5]. Zembaty presented a numerical sensitivity study of the local site effects on a four-span bridge response with an analysis of a bridge response with supports founded on different soils[6]. Zanardo et al. carried out a parametrical study of the pounding phenomenon associated with the seismic response of multi-span simply supported bridges and highlighted that multi-support analysis gives results markedly different from the uniform dynamic analysis[7]. Dumanoglu and Soyluk investigated the stochastic response of a cable-stayed bridge subjected to spatially varying ground motions based on a recently developed model. The spatial variability of ground motions is considered with incoherence, wave-passage and site-response effects. The importance of site-response effect was investigated particularly[8]. Nicholas A. Alexander investigated a novel correction scheme which is employed to reprocess the SMART-1 data. The errors in seismically induced forces is considered, that can be accrued if identical support excitation (ISE) analysis is used in place of a multi-support excitation(MSE) analysis[9]. Many long-span bridges is analyzed with multi-support seismic excitation in the world. But these kinds of bridge mainly is including suspension bridge, cable-stayed bridge and arch bridge, the rigid frame bridge is less investigated with multi-support seismic. And now total length of many continuous rigid-framed bridges is more than hundreds of meters. It is very importance to analyze rigid-framed bridge with multi-support seismic.

2. Description of the bridge models

This continuous rigid-framed bridge is Houzhu Bridge, in Quanzhou, Fujian province, 66m+3×120m+66m，Zong Zhouhong et al investigated modal and dynamic characteristics of this bridge through test[10]. This paper compare with this bridge mode result of Zong Zhouhong through finite element renew simulating. Zong Zhouhong result miss four mode through initial 20 modes comparison of Houzhu bridge. Other modes of these 20 modes are consistent between test result and finite element simulating result. It illuminate that the bridge dynamic characteristics of the finite element simulating are coincident with dynamic characteristics of actual structure. There show results of both in table1. The first model shape is longitudinal, the second model shape is transversal and the third model shape is vertical bending. In test: their fundamental frequencies in the three directions are 0.742Hz, 0.821 Hz and 1.222Hz respectively. And in computation: their fundamental frequencies in the three directions are 0.740Hz, 0.825Hz and 1.190Hz respectively. There are several initial mode characteristics in Figures 1-3.

Tab.1 Houzhu Bridge dynamic characteristics

Mode	Computational Result(Hz)	Reference[10] test result(Hz)	Modal characteristics
1	0.740	0.742	First Longitudinal
2	0.825	0.821	First Lateral(symmetric)
3	0.893	0.97	Second Lateral(antisymmetric)
4	1.077	1.21	Third Lateral(symmetric)
5	1.190	1.221	First Vertical(symmetric)
6	1.408	Missed	Forth Lateral(antisymmetric)
7	1.448	1.475	Second Vertical(antisymmetric)
8	1.772	1.787	Third Vertical(symmetric)
9	1.940	Missed	Fifth Lateral(symmetric)
10	2.610	Missed	Sixth Lateral(antisymmetric)
11	2.702	2.754	Forth Vertical(antisymmetric)
12	2.809	2.8	Fifth Vertical(symmetric)
13	3.399	3.428	Sixth Vertical(antisymmetric)
14	3.413	Missed	Seventh Lateral(symmetric)
15	3.722	3.868	Second Longitudinal

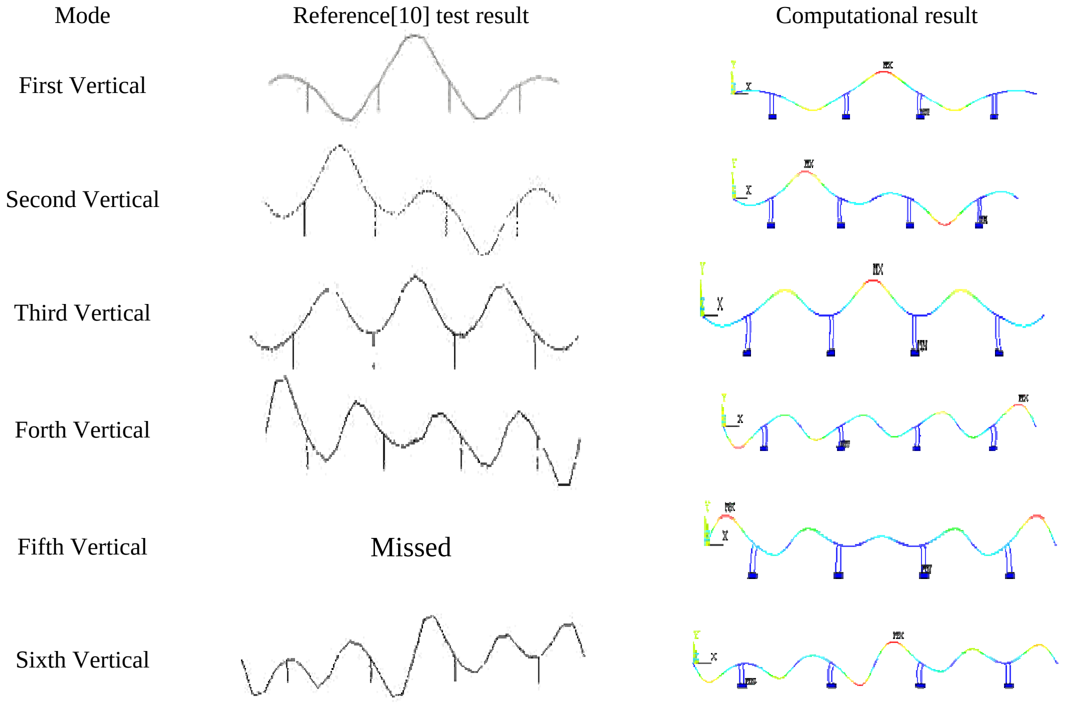


Fig1.Vertical modal frequencies of Houzhu Bridge

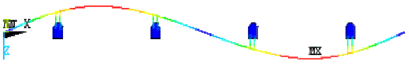
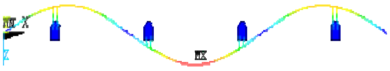
Mode	Reference[10] test result	Computational result
First Lateral		
Second Lateral	Missed	
Third Lateral		

Fig2. First 3 Lateral modal frequencies of Houzhu Bridge

Mode	Reference[10] test result	Computational result
First Longitudinal		

Fig3. Longitudinal modal frequencies of Houzhu Bridge

3.ANALYSIS METHOD OF MULTIPLE EXCITATIONS

There are three methods always used in the seismic analysis of long-span structures, response spectrum method, time history method and random vibration method. The previous two methods are determinate analysis and last method is indeterminate analysis. The response spectrum method based on the excitation of SDOF, is widely used, but hard to adopt in the accurate seismic analysis under multiple excitation. The time history method, which is more accurate than other methods if the inputted excitations are accurate, needs more complex computing. But it is hard to determine the exact excitation that would be inputted. The random vibration method which is often studied in recent years may be widely used in the future. There are still many problems of the method should be solved.

There are two different analysis models of structure under seismic in time-history analysis method. In the first method, the displacement time-history is putted as the ground excitation of structure, and the dynamic equation is derived according to the displacement of ground motion in the absolute coordinate. On the second method, the acceleration time-history is putted as the ground excitation of structure, and the dynamic equation is derived according to the acceleration of ground motion in the absolute coordinate[11]. In this paper the displacement time history method is used in the seismic analysis of the continuous rigid-framed bridge.

In the absolute coordinate, the ground motion leads to the motion of structure under the seismic. The freedom of structure can be divided into the freedom of superstructure and the freedom of base. So, the dynamic equation of structure under seismic can be written as

$$\begin{bmatrix} M_{ss} & M_{sb} \\ M_{sb} & M_{bb} \end{bmatrix} \begin{Bmatrix} \ddot{u}_s \\ \ddot{u}_b \end{Bmatrix} + \begin{bmatrix} C_{ss} & C_{sb} \\ C_{sb} & C_{bb} \end{bmatrix} \begin{Bmatrix} \dot{u}_s \\ \dot{u}_b \end{Bmatrix} + \begin{bmatrix} K_{ss} & K_{sb} \\ K_{sb} & K_{bb} \end{bmatrix} \begin{Bmatrix} u_s \\ u_b \end{Bmatrix} = \begin{Bmatrix} 0 \\ R_b \end{Bmatrix} \qquad (1)$$

Where, $\ddot{u}_s, \dot{u}_s, u_s$ are the motion vectors of superstructure in the absolute coordinate; $\ddot{u}_b, \dot{u}_b, u_b$, are the ground motion vectors in the absolute coordinate; M_{ii}, C_{ii}, K_{ii} are the matrix of mass, the matrix of damping and the matrix of stiffness, the meaning of lower figures ss, bb, sb are the freedom of superstructure, the freedom of base and the freedom of their couple item; R_b is reaction of base (If the response of structure have been got, the R_b can be calculated by the second equation of formula (1). So the dynamic equation about $\ddot{u}_s, \dot{u}_s, u_s$ can be got from the first equation of formula(1) as

$$M_{ss}\ddot{u}_s + C_{ss}\dot{u}_s + K_{ss}u_s = -(M_{sb}\ddot{u}_b + C_{sb}\dot{u}_b + K_{sb}u_b) \qquad (2)$$

If the lumped mass model of structure is used, the M_{sb} is equal to zero; the damping matrix is difficult to be calculated, and the damping force $-C_{sb}\dot{u}_b$ is always neglected[12]; so the equation (2) can be written as

$$M_{ss}\ddot{u}_s + C_{ss}\dot{u}_s + K_{ss}u_s = -K_{sb}u_b \tag{3}$$

Where, u_b is the vector of ground motion; $-K_{sb}u_b$ is the force of superstructure for the ground motion in the absolute coordinate. Equation (3) is the displacement model of analysis structure under ground motion.

4.Spatially Varying Ground Motions

The design basic acceleration of ground motion at Quanzhou, Fujian province is 0.15g and the site class is 2 based with Code for seismic design of buildings[13]. The ground motions come from relatively non-stationary earthquake accelerograms simulation with a known seismic record. The known seismic wave is EI-centro and interval is 0.01s. The acceleration peak value is adjusted to location design intensity from 0.307g to 0.15g. To ensure the displacement time-history is equal to zero at the start time and end time, the acceleration is adjusted. The adjustment method is frequency filtering with SeismoSignal software. The bridge model subjected to spatially varying ground motions is presented in Figure 4. The correlation function used Harichandran-Vanmarcke (1986) model[14]. The displacement time-history is integrated with the correction acceleration and showed in Figure 5.

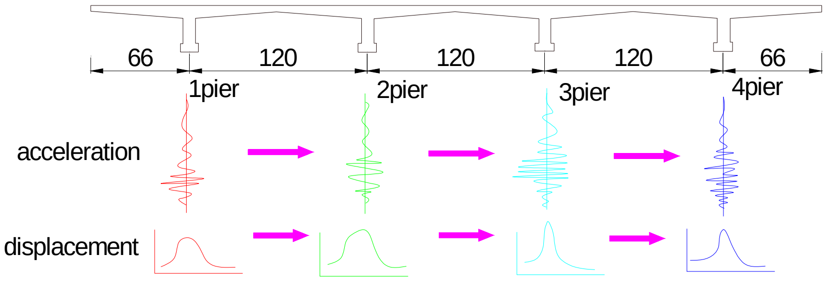
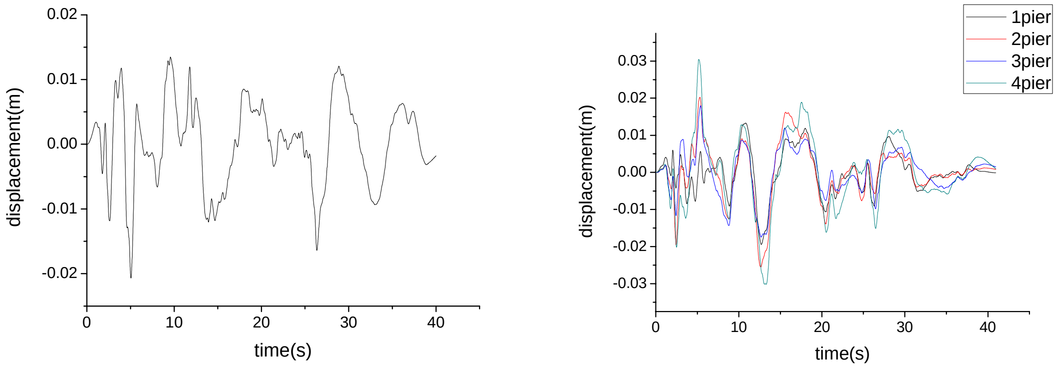


Fig.4 Houzhu Bridge system subjected to spatially varying ground motions



Uniform Excitations Multiple Excitations

Fig.5 Time history of displacement of seismic excitations

5.Seismic responses analysis of bridge

The dynamic response of long continuous rigid-framed bridge is calculated. The model can be got in Fig.4. There are comparison of uniform seismic excitation and multiple support excitations analysis.

5.1 Non-traveling wave effect

The bridge is subjected with longitudinal seismic motions excitation without regard to traveling wave effect. Figure 6 show that the responses of the bridge are maximum total displacement of deck. The deck displacement responses with multiple supports seismic excitation is less than that of uniform excitation. The piers maximum displacement response is presented in Figure 7. Four piers displacement responses with multi-support excitation more than that with using uniform support excitation.

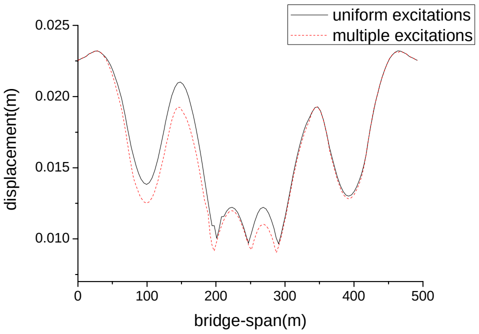


Fig.6. Displacement variances of the deck(non-traveling wave effect)

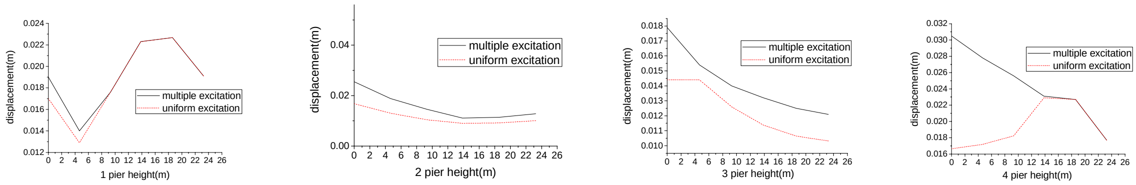


Fig7 Displacement variances of four piers

5.2 Traveling wave effect

Apparent velocity is 1000m/s，1500m/s，2000m/s respectively. Figure8 show the 4 piers different maximum displacement response of traveling wave effect from that under uniform excitation. All 4 piers maximum displacement responses of seismic motions excitation with apparent velocity 2000m/s and 1000m/s is high than that of uniform seismic excitation, and responses of 2000m/s is most. The deck displacement responses of apparent velocity 2000m/s and 1000m/s are more than that uniform excitation, and the deck displacement responses of apparent velocity 1500m/s is less.

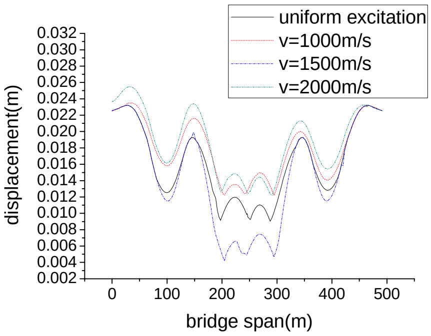


Fig.6. Displacement variances of the deck（traveling wave effect）

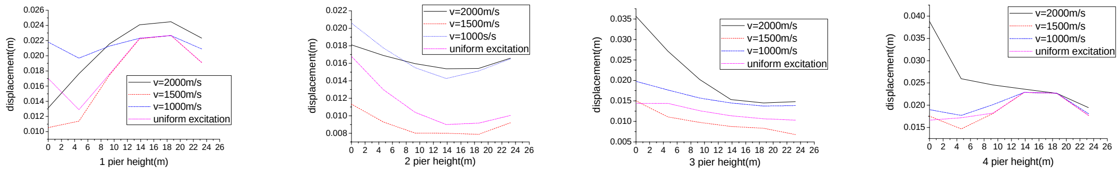


Fig8. Displacement variances of four piers(traveling wave effect)

6.Conclusion

Based on the displacement time history method, The Houzhu continuous rigid-framed bridge is investigated with multiple excitation and uniform excitation. The spatial variability of the ground motion is considered with the incoherence wave-passage and site-response effects. Mean of maximum values of the four piers displacement responses of multiple excitations more than that of uniform excitation whether considered with wave-passage or no. some mean of maximum values of the deck displacement with multiple excitations is more than that with uniform excitation, and some less. The long-span structure response under multiple excitations may be more intensive than those under uniform excitations. Thus, seismic analysis under multiple excitations in indispensable as that under uniform excitations in the design process of long-span structures.

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