ANALYSIS FOR EARTHQUAKE-RESISTANT OF BRIDGE STRUCTURE SUBJECTED TWO EARTHQUAKES*

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ABSTRACT:
The bridge structure damage of two earthquakes is studied deeply in this paper. The bridge model under two earthquakes effect is bulit by the way of connecting the end-to-end of two seismic wave, and the elasto-plastic response of bridge under one and two earthquakes separately are studied and compared in the conditions of different intensities and different peak accelerations. Which illustrate that the cumulate response of bridge structure is more serious under the effect of two earthquakes than under only one. This method above will be useful for earthquakes-resistant performance decision in practical bridge structure.
KEYWORDS: bridge structure,the effect of two earthquakes,Analysis nonlinear temporal analysis

0 INTRODUCTION

It is ubiquitous phenomenon to arise after-shock after the main earthquake under the effect of the complex geology. Because of the structure cumulating damage domino effect under two earthquakes, it is faultiness and unsafe only to consider the earthquake-resistant design under main earthquake. In history, there are a lot of phenomenons about the structure damage exacerbation or collapse induced by after-shock.. For example in TangShan earthquake ,which happened in 1976, many bridges and industrial and civil buildings had been subject to certain damage in the main earthquake, but the aftershock resulted in more damage even collapse. The cumulate damage effect is very serious.

At present ,there are less literatures coming down to the effect analysis of the buildings under two earthquakes, only including the forecast and damage analysis of the reinforced concrete frame structure [1,2,3]. And there is no literature coming down to the respond analysis on the bridge structure under the two earthquakes. Now RHA is the best exact method to calculate earthquake –resistant requirement, so in this paper the elasto-plastic response and damages of long-span cable-stayed bridge under one and two earthquakes are compared based on ANSYS nonlinear temporal analysis procedure.. The bridge structure suffering two earthquakes effect is simulated by the the way of connecting the end-to-end of two seismic wave,.This method above will be useful for earthquakes-resistant performance decision in practical bridge structure.

1 THEORETICAL BASIS AND MODEL BUILDING

1.1 The build of dynamic equation

Compared to that the bridge could turn into plastic state in strong earthquake, the bridge structure also could put into plastic state under two earthquakes in succession when the main earthquake intensity is stronger. So it is needed to do elasto-plastic temporal analysis. In this paper, the way of connecting the end-to-end of two seismic wave ,which is regarded as a time-keeping extended seismic wave ,is used to analyze the elasto-plastic earthquake response under the main earthquake and aftershock effect. Thereby the problem about the response of the bridge structure under two earthquakes effect in succession has been transformed into the earthquake response of the structure under a time-keeping

extended seismic wave. The analysis method—— $Newmark-\beta$ is used to do the numerical value integral.
The dynamical balance equation is:

$$[M]\{\Delta\ddot{x}_i\}+[C]\{\Delta\dot{x}_i\}+[K]\{\Delta x_i\}=-[M]\{\Delta\ddot{x}_g\} \qquad (1.1)$$

Here, $[\Delta\ddot{x}_i]$、$[\Delta\dot{x}_i]$、$[\Delta x_i]$——is the acceleration increment of the structure response, speed and displacement increment;
$\Delta\ddot{x}_g$——is the ground earthquake acceleration increment
the common Rayleigh damp matrix is adopted:

$$C=\alpha[M]+\beta[K] \qquad (1.2)$$

$$\alpha=\frac{2(\xi_i\omega_i-\xi_j\omega_j)}{\omega_j^2-\omega_i^2}, \quad \beta=\frac{2(\xi_j\omega_j-\xi_i\omega_i)}{\omega_j^2-\omega_i^2}$$

Here, ω_i、ω_j——is the frequency of the i,j earthquake type
ξ_i、ξ_j——is the damp ratio of the i,j earthquake type.

1.2 Establishment of cable stayed bridge finite element model

In the paper, the entity modeling method is applied, and in the process of creating model, the combination analysis mode of the space girder、the cablel and the plane element is adopted. The concrete girder、tower and cable-stayed cable are simulated by beam4、link10 element separately, and the model is divided into 608 elements and has 371 freedom. The whole bridge structure model is shown by chart 1.1. The simulation of the compute mode emphasizes the strong degree of the structure , quality and border condition. The simulation mode of parts of the cable-stayed bridge example in dynamical compute mode is:

(1) The main girder is in great float state, and it releases portrait restriction both in cable tower and the two ends;
(2) The bridge surface system adopts backbone mode, and its stiffness(vertical, lateral flexible rigidity, and torsional rigidity) and quality(translation and rotational quality) centralize in the middle nodes.The vertical rigid arm is used to link the nodes and cable-stayed.
(3) The girder and tower adopt the Beam4 element, and cable-stayed adopts the space Link10 element which is only effected by the tension; meanwhile, because whether the cable elasticity decreases or not has less effect on dynamical, so it is dealt as linear element.
(4) The pile foudation is simulated with elasticity -ground continuous girder, and the soil around the pegs is simplified to press-resistant spring according to the equal stiffness.

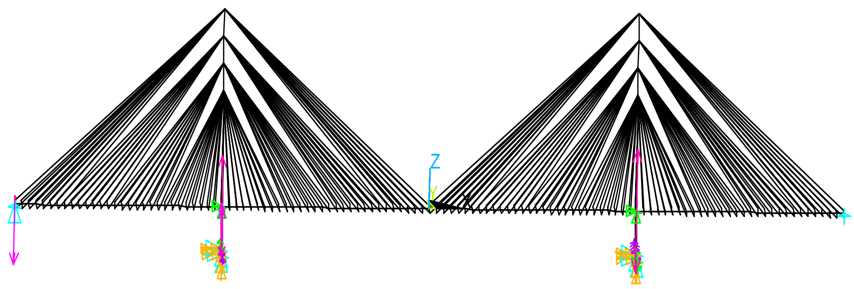


Fig. 1.1 the model of cable-stayed bridge

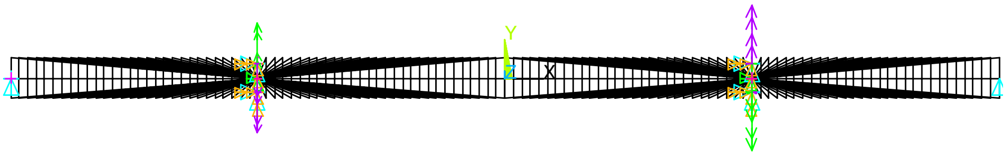


Fig. 1.2 the top view of cable-stayed bridge

2 THE CHOICE OF SEISMIC WAVES

Because the structure response of the bridge in earthquake has much connection with the inputted earthquake-shake time history [4,5], the representative E1 Centro wave has been choosed in this paper, and it is suitable for the III kind field [6]. The recorded acceleration peak value of E1 Centro wave in practical earthquake-shake is converted into basic intensity needed by the structure. In practical account of this case, the earthquake load adopts the lateral and longitudinal leffect;the first earthquake-shake is 8 degree strong shock, and the second is 7, the earthquake-shake time and displacement curve are shown in Fig 2.1~2.4.

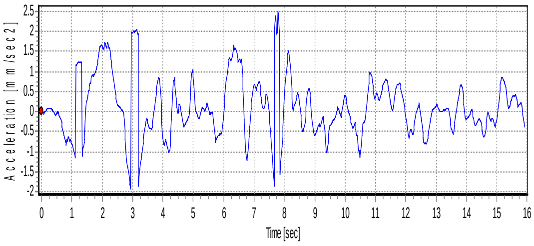


Fig.2.1 Time history of acceleration. of one earthquake in the direction of normal line

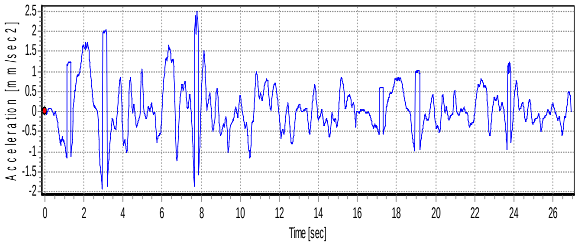


Fig 2.2 Time history of acceleration of two earthquakes in the direction of normal bridge

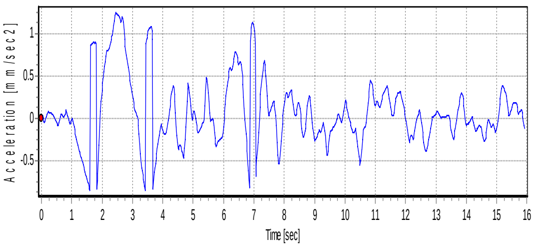


Fig.2.3 Time history of acceleration. of one earthquake in the direction of along line

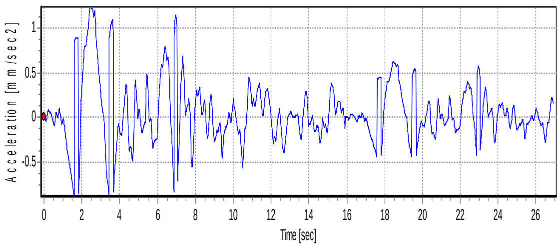


Fig 2.4 Time history of acceleration of two earthquakes in the direction of along bridge

3 CALCUTED MODEL ANALYSIS

In this paper, a space cable-stayed bridge is choosed. The main bridge is the concrete float system structure with two tower and three stride type;The main span is 360m, the side span in both is 174m, and the bridge width is 28m. The cable tower is the converse Y type, whose height is 162m, and it is composed of two parts——the upside tower body and the below tower pier. The divarication point of the converse Y is apart from the bridge 60m, the distance between bridge bottom and surface is 30m, and the distance of the bridge bottom in lateral direction is 20m. There is one inclined cable on the main girder at 6m intervals, and the transbeam ,that is suspended by the cable-stayed bridge, is also laid on the cable tower. the inclined cable tension focus point is set on the main tower from the top down at each 18m intervals, including 4 points. The each side of the upside 3 focus points could pull 7 cables, the fourth could pull 8 cables, and the divarication point of the tower converse Y also can pull 1. It comes to 117. The simplifed main girder is solid type, and its material parameter attribute is: the tower girder elastic ratio E= 3.5×10^{10} pa、Poission’s ratio : 0.17、bulk density:2500 N/m^3 , elastic ratio of cable :1.9×10^{10} pa， Poission's ratio : 0.25、0.17、bulk density:1200 N/m^3。The section parameter is shown in table 2， the finite element of the whole model is shown in Fig .3.

Tab.2 The parameter table of rectangular sections

component	Section characteristics					
	a/m	b/ m	A/ m^2	Iy/ m^4	Iz/ m^4	Ix/ m^4
girder	16	1.6	25.6	2000	20	21.8
Upper cable tower	4.7	3.4	16	39.7	77.7	61.6
Middle cable tower	9	6	54	200	450	61.6
Cable tower	8	5	40	83.3	213.3	333.3
Rigidity herringbone transbeam and cable tower transbeam	1	1	1	1/12	1/12	1/3
Inclined cable	A=0.012					

3.2 THE ESTABLISHMENT WITH THE COMPLETED BRIDGE STATE AND THE MODEL ANALYSIS

Because the flexility of the cable-stayed bridge is relatively greater, it is more necessary to firm the completed bridge state. If the model hasn't achieved a certain state, it would directly affect the structure dynamics analysis. The establishment with the completed bridge state includes position and internal force. In this paper, the vector deformation pattern is shown in Fig 3.1,and the most displacement is 0.0352m which satisfies the request of the achievement of the completed bridge state.

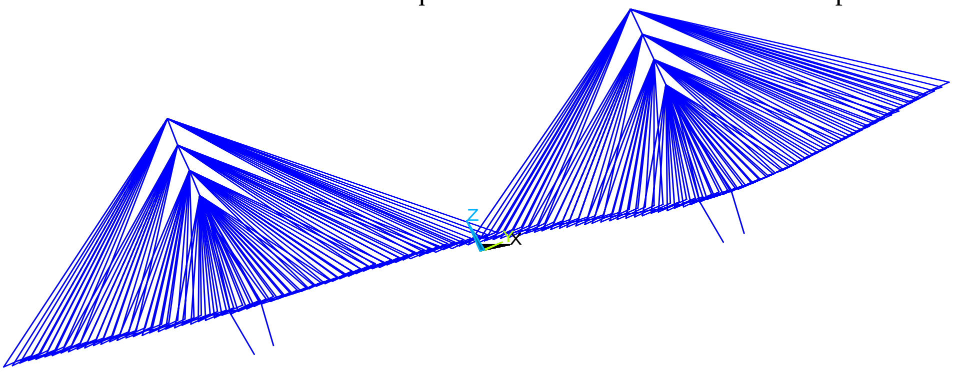
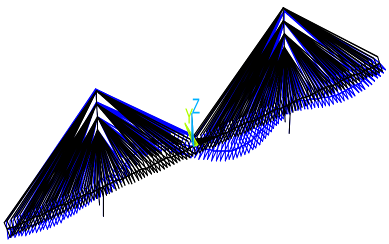


Fig3.1 the static vector deformation view of bridge structure

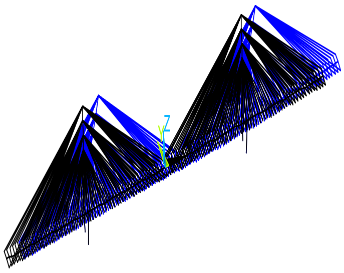
The natural frequency of vibration and modal of structure is the basis to do the dynamics calculation and analysis. For getting the dynamics characteristics closed to the reality structure, it is necessary to do modal analysis before doing the earthquake analysis. The first ten steps natural frequency and modal of this long span cable-stayed bridge structure are as follows:

Table3 first 10 frequency value of cable-stayed bridge structure

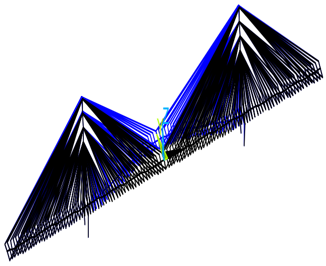
Step	1	2	3	4	5
Frequency	0.0964	0.126	0.270	0.271	0.272
Step	6	7	8	9	10
Frequency	0.336	0.506	0.513	0.528	0.686



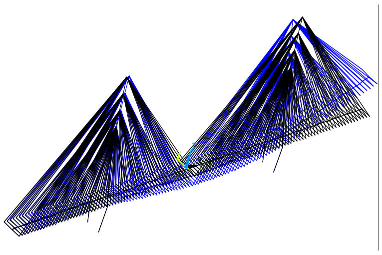
the first step



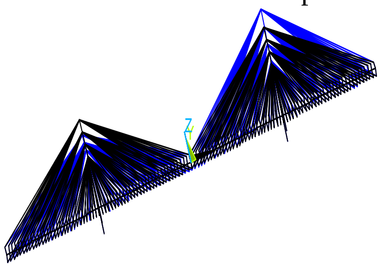
the second step



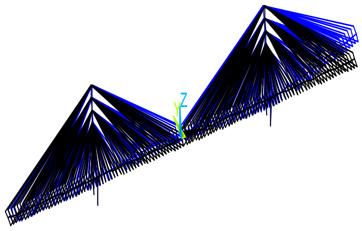
the third step



the sixth step



the eighth step



the tenth step

Fig3.2 first 10 frequency view of cable-stayed bridge structure

From the modal in Fig3.2 we can see that, the first step is longitudinal translation, the second is lateral bending; the steps in succession are bending in horizontal plane, and from the sixth step it becomes vertical flexible shake.

4 RESULT ANALYSIS

According to the field condition on which the bridge lay, the typical American EI Centro wave in 1940 is choosed to do the structure response analysis under two earthquakes, and its time history and displacement analysis results are shown from Fig 4.1 to Fig 4.9.

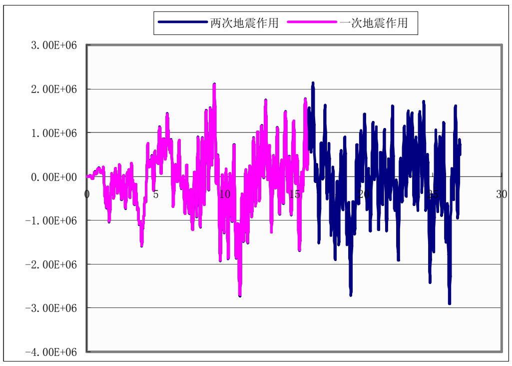


Fig. 4.1 shear force in right tower(N)

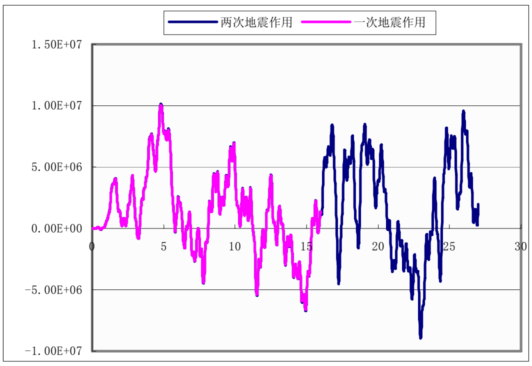


Fig. 4.2 moment in right tower(N・m)

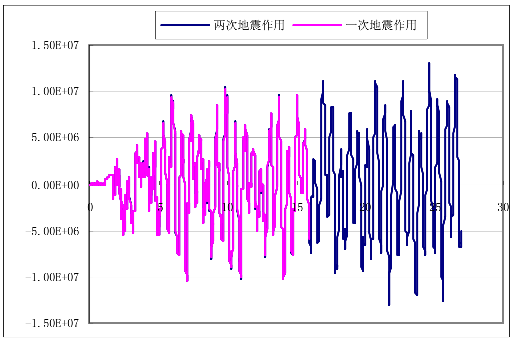


Fig.4.3 shear force in span centre (N)

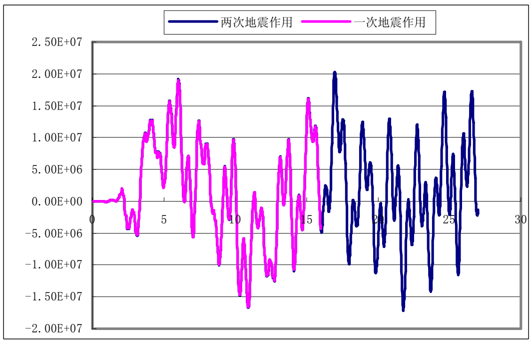


Fig.4.4 mement in span centre(N . m)

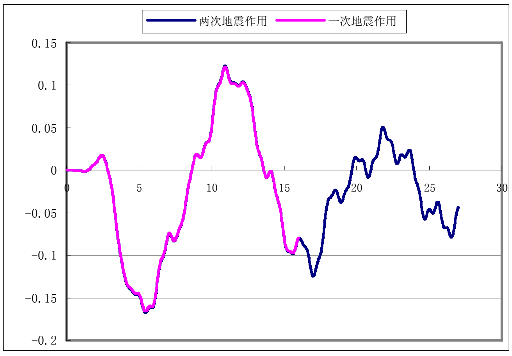


Fig4.5 Y-displacement in span centre (m)

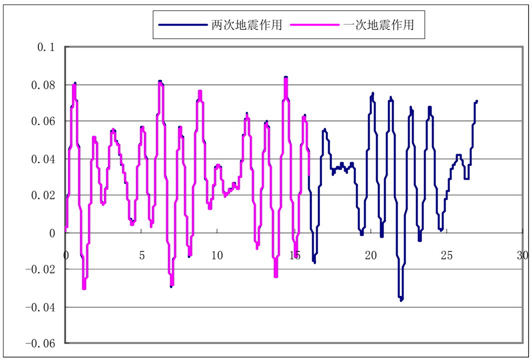


Fig4.6 Z-displacement in span centre (m)

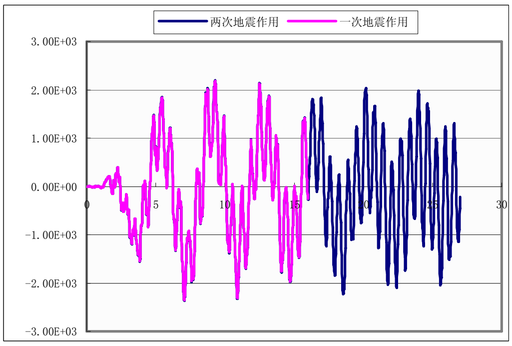


Fig.4.7 moment in left archorage pier(N)

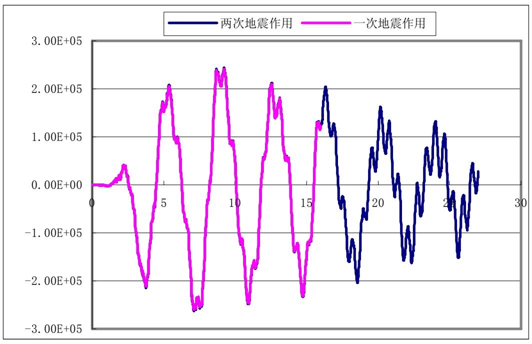


Fig.4.8 shear force in left archorage pier (N . m)

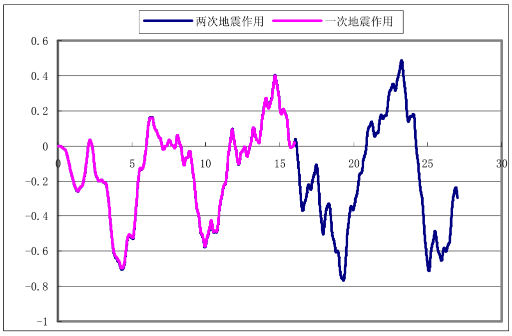


Fig.4.9 X-displacement in right tower (m)

From Fig 4.1~4.4, Fig 4.6 and Fig 4.9, we can see that under two earthquakes in succession the shear and moment in right tower bottom and the main girder span centre, and X-displacement in right tower top are obvious increased compared with those under one earthquake. The reason is that: the girder is coming to plastic damage in the main earthquake; at that time if the bridge suffered aftershock again, the stress and distortion would be relatively obvious. But in the Fig 4.5 , Fig 4.7 and Fig4.8, the lateral displacement of the main girder in span centre don't change obviously. At the same time the moment in archorage pier also decrease gradually, which shows that the flexural rigidity of the anchor pier is bigger and it can completely endure the effect of two earthquakes.

5 CONCLUSION

In this paper, the bridge model under two earthquakes effect is bulit by the way of connecting the end-to-end of two seismic wave, The Ansys nonlinear analysis method is employed do the elasto-plastic tempotal analysis for long span cable-stayed bridge structure. From the analysis results, we can see the internal force and distortion of long span cable-stayed after suffering two earthquakes increase obviously compared to the single earthquake. It is necessary to consider the aftershock effect on bridge structures at a certain extent in the earthquake-resistant design, so that the bridge structure would be more security when suffering earthquake.

The earthquake combination that the main earthquake and aftershock only has been discussed in this paper. For analyzing the response of bridge structure under two earthquakes more comprehensive, another two earthquakes combination concluding former-main earthquake and double earthquakes type also should be considered. Furthermore, the structure response including many kinds of dsesmic inputs needs further studied.

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