EARTHQUAKE EVALUATION OF URBAN BRIDGE WITH COMPLICATED CONFIGURATION

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ABSTRACT:
The Liulin Bridge, which locates in Tianjin across the Haihe River with a main span of 100m, is a beautiful bridge with a careful design of aesthetics. However, the bridge is highlighted on seismic evaluation because of the complicated structural system. This paper firstly presents the general information of the bridge structure system. Then earthquake evaluation based on response spectrum method and time history analysis is provided. The results show that the bridge is of capability against the presented intensity of ground motion.

KEYWORDS: Seismic evaluation, Steel bridge, Response spectrum, Time history analysis

1. INTRODUCTION

With the development of urbanization of China society, the population and resources are becoming more and more concentrated in big cities. This situation presents more and more pressure on transportation system and infrastructure against earthquake. Being functioned as lifeline projects for life rescue after earthquake attack, the importance of modern bridges in transportation system against earthquake has been highlighted worldwide. Many powerful earthquakes, such as Tangshan Earthquake in 1976 and Wenchuan Earthquake in 2008, have shown that, if bridge structures collapsed or are seriously damaged in earthquake attacks, great lose would present. Disasters resulting from bridge collapse always result in huge amount of life loses over the world. Nowadays, the challenge facing engineers is to design structures with sufficient capacity against earthquake.

Located in Tianjin across the Haihe River, the Liulin Bridge is a six-lane urban steel bridge with two continuous spans all measured as 100m long. In across bridge direction, the bridge deck consists of 0.25m(rail)+7.25m(bike lane and sidewalk)+0.25m(barrier)+11.75m(car and truck lanes)+0.25m(central barrier)+7.25m(bike lane and sidewalk)+0.25m(rail), which means a total bridge deck width of 44m. The central slotted bridge deck utilizes orthotropic steel deck system with two separated box girders connected by cross beams. In locations without piers, the bridge deck is supported by stayed cables, which are anchored on top by the main wings erected upon along the bridge central line and the second wings arranged upon along the upstream and downstream bridge sides. Close to tips of each main wing or second wing, a slanted column is erected as to provide support in vertical and longitudinal directions. For a general view, the structure shows aesthetics of a butterfly flying over water while trying to touch the water. Fig.1 show an aesthetics view of the bridge erected at bridge site. Fig.2 and Fig.3 show elevation and cross section design of the bridges.

Fig.1 Aesthetics view of Liulin bridge

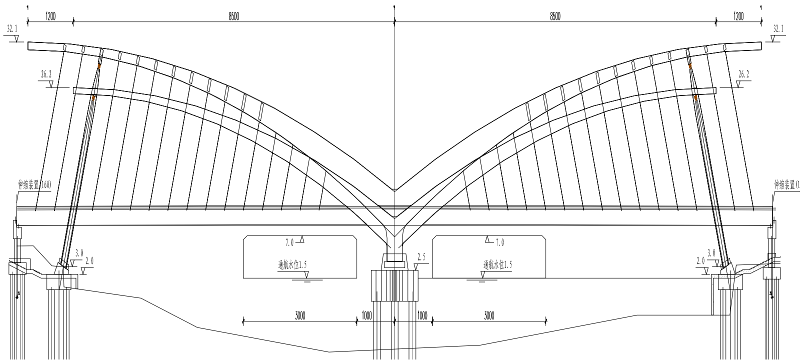

Fig.2 Elevation arrangement of bridge

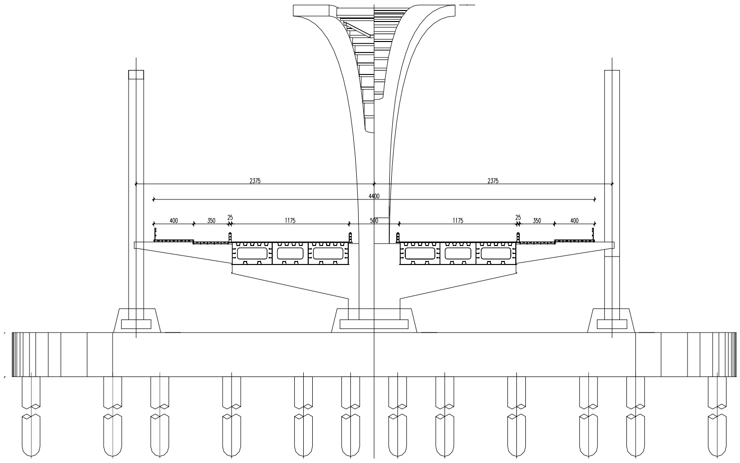

Fig.3 Cross section design of bridge

According to the China Code of Seismic Design for Highway Bridges, Tianjin locates in region of high seismic intensity, where the powerful earthquake rocked Tangshan in 1976. The peak ground acceleration at the bridge site is provided as of 150 gal. While geological survey shows that even under 80m depth below the river bed, the detected soft soil can not provided enough end support for piles. With this complicated structure system, soil condition as well as high ground motion intensity, the bridge should be highlighted on seismic evaluation as to ensure its safety against the earthquake.

2. DYNAMICAL ANALYSIS OF BRIDGE

Dynamical analysis of the whole structure is carried out based on the software ANSYS. Fig.4 shows the developed whole FEM model in ANSYS. In this model, the girders, the main wings, the second wings, the piers and the bents, as well as the wing support column are all modeled by the beam element. While the stayed-cables are modeled by bar element. For local stiffeners, where they attach to the girder and wings, etc. their effects on dynamics are considered only with lumped mass and mass element. In order to reflect rigid zones among different connections, rigid arms are employed and modeled by the beam element. In addition, FEM analysis has been performed as to obtain equivalent stiffness of the Large-Diameter Shafts at main pier and side piers, and the effects of coupled soil-foundation-structure interaction has been partly taken into account through FEM modeling with the beam element.

Dynamical analysis provides fifty vibration modes. Fig.5 and Fig.6 show the first and second vibration modes of the bridge, the corresponding frequencies are 0.607Hz and 0.612Hz, respectively. The two modes are all focused on the main wings, with the first one showing symmetrical vibration in out-plane and the second one anti-symmetrical vibration in out-plane. Results show that the following four vibration modes are all focused on the out-plane vibration of the second wings. This indicates that the main wings and the second wings own lower out-plane stiffness, compared with the stiffness of the main girder. This is true even after checking the vibration modes from the seventh to the twentieth, since the wings always show different participation in most of these modes.

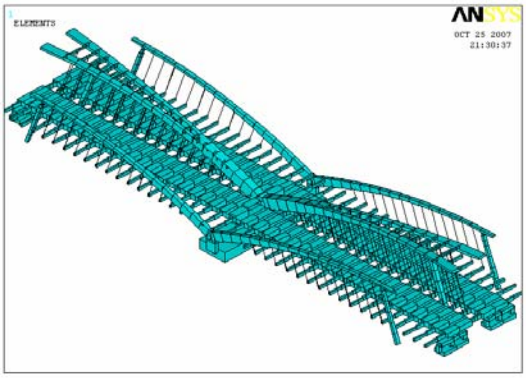

Fig.4 Dynamical analysis model of bridge in ANSYS

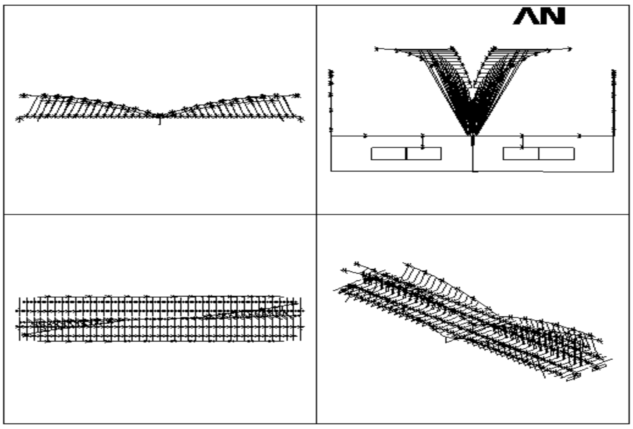

Fig.5 First vibration mode of bridge

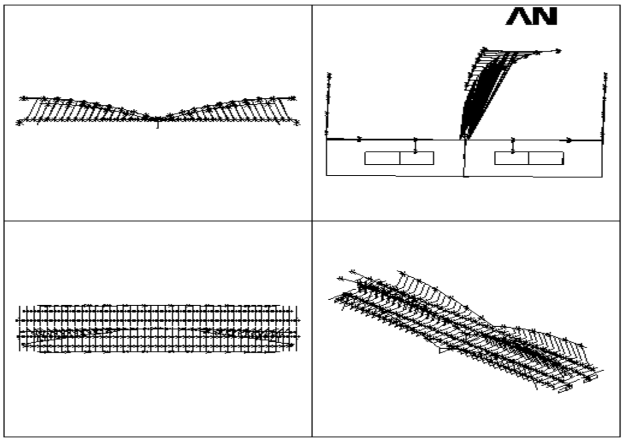

Fig.6 Second vibration mode of bridge

3. RESPONSE PREDICTION BY MULTIMODE SPECTRAL METHOD

3.1 Parameters of response spectrum

Seismic assessment based on two ground motion intensities has been performed, i.e., the first level corresponding to a 465 year return period with 10% probability of exceedance during 50 years of service. The second level corresponding to a 2475 year return period with 2% probability of exceedance during 50 years of service. In terms of China Code of Seismic Design for Highway Bridges(JTJ004-89), present study adopts the acceleration response spectrum(ARS) with the following forms:

$$\beta(T)=\begin{cases}1+(\beta_{\max}-1)T/T_1\cdots\cdots 0<T\leq T\\ \beta_{\max}\cdots\cdots\cdots\cdots\cdots\cdots\cdots T_1<T\leq T_g\\ \beta_{\max}(T_g/T)^k\cdots\cdots\cdots\cdots T>T_g\end{cases} \tag{3.1}$$

Where, $\beta(T)$ is the ARS value; T is the bridge natural period in second; T_1=0.1s is the beginning period corresponding to the section of line on ARS; $\beta_{\max}$ is the maximum amplifying coefficient of ARS; $T_g(s)$ is the prominent period of soil in bridge site; k is the curve decay index.

The seismic response analysis based on ARS will be carried out in three different directions, i.e., the bridge longitudinal direction, the bridge lateral direction and the vertical direction. The intensity of ARS in vertical direction will be scaled to half of the value measured in horizontal direction. It is required by China Code of Seismic Design for Highway Bridge that the seismic response of bridge should be combined with dead loads, and for bridge with complicate configuration, response from one of the horizontal direction should be combined with the response from the vertical direction. In this paper, the CQC multimode combination method is used to obtain a reasonable seismic prediction of the structure, and responses from 150 vibration modes are taken into account as to consider the participation of higher-order modes. Because of space limited, the following section will only present the results based on the first level evaluations.

3.2 Excitation Along Bridge Axis

For seismic excitation along the bridge axis, the maximum displacement is of 0.021m, with its main contribution from longitudinal and vertical direction. Fig.7 shows the structure displacement along the bridge axis.

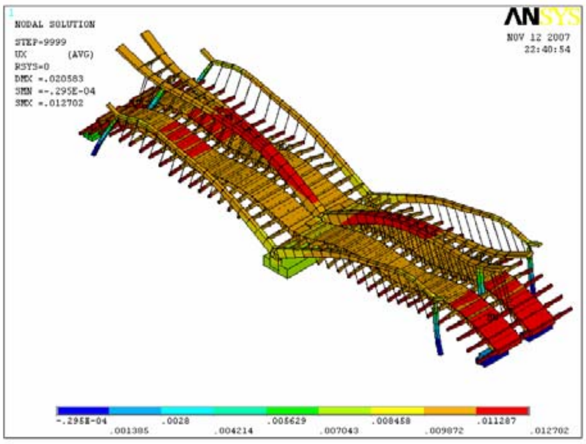

Fig.7 Bridge displacement along bridge axis

3.3 Excitation Across Bridge Axis

The maximum displacement of the bridge is of 0.15m excited by earthquake across bridge axis, which is much bigger compared with the earthquake along the bridge axis. The main component of displacement presents in lateral direction. Fig.8 is the contour showing the structure displacement across bridge axis.

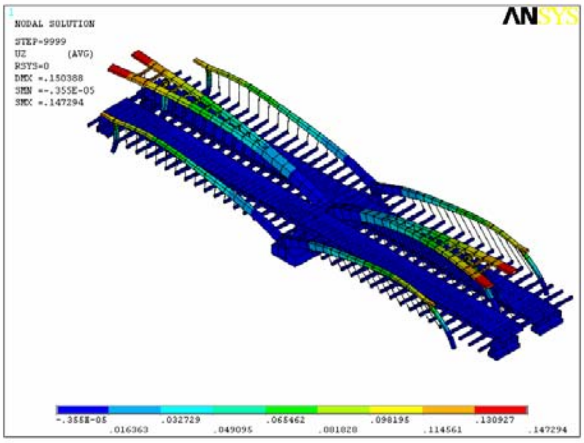

Fig.8 Bridge displacement across bridge axis

3.4 Excitation in Vertical Direction

When excitation is applied along vertical direction, the maximum displacement is of 0.022m, which indicates a much smaller response under vertical excitation, compared with that under horizontal excitation. Fig.9 shows the contour plot indicating the vertical displacement in this case.

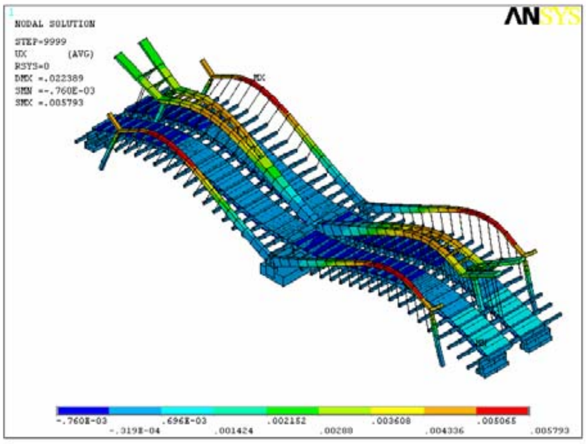

Fig.9 Displacement response in vertical direction

4. TIME HISTORY ANALYSIS

4.1 Earthquake Records and Input Selection.

Time history analysis is applied to the Liulin Bridge based on ANSYS. The Tianjin earthquake records in horizontal direction and vertical direction recorded during 1976 Tianjin earthquake are selected as input time history of acceleration in horizontal and vertical direction, with a scaled peak value acceleration of 150gal and 75gal, respectively. Fig.10 shows the selected records in horizontal direction with the duration of 19.2 seconds.

Simultaneous earthquake excitation at all bridge supports can be input along three directions. In this paper, two kinds of combinations are employed. The first one simulates the response of bridge with input along bridge axis and input in vertical direction. The other one uses input along bridge lateral direction with records input in vertical direction.

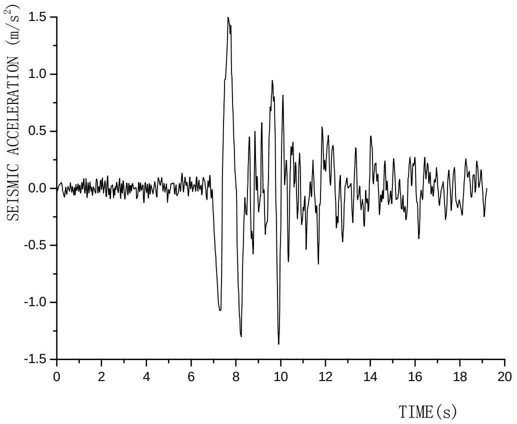

Fig.10 Earthquake records in horizontal direction

4.2 Response with Longitudinal and Vertical Input

Under earthquake excitation along the bridge axis as well as vertical direction at all bridge supports, structure response, such as displacement and inner force, can be obtained. Fig.11 shows the maximum stress time history of main girder at center of the span. While Fig.12 indicates displacement time history of main wing at its tip.

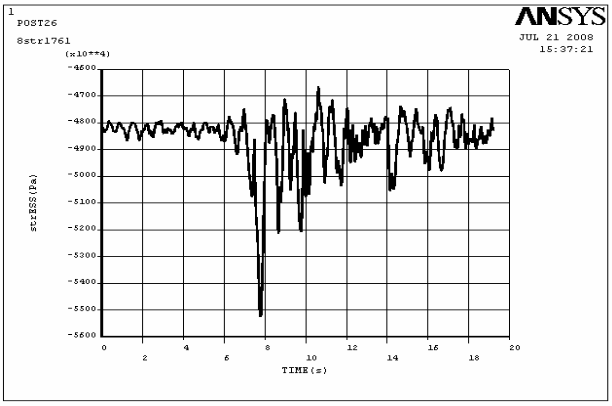

Fig.11 Maximum stress time history of main girder at center of span

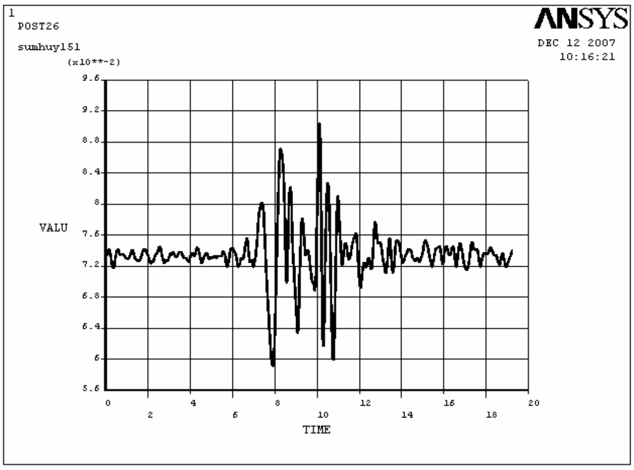

Fig.12 Displacement time history of main wing at tip in longitudinal direction (unit: m)

4.3 Response with Lateral and Vertical Input

Another situation with earthquake records input in bridge lateral and vertical direction should be addressed. Such kind of combined excitation can also produce displacement and inner force among structure system. Fig.13 indicates maximum stress time history of main wing at its bottom. Fig.14 plots the displacement time history of main wing at its tip in lateral direction.

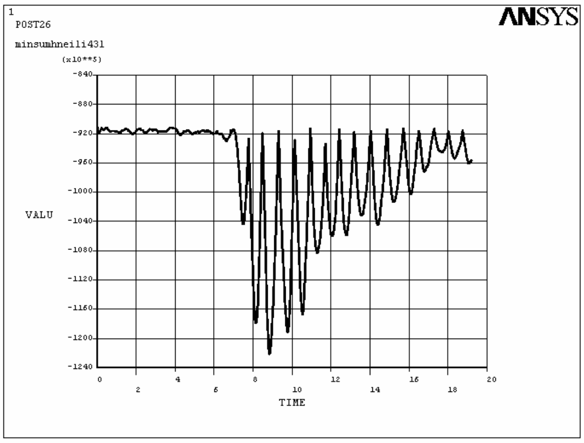

Fig.13 Maximum stress time history of main girder at its bottom(unit: Pa)

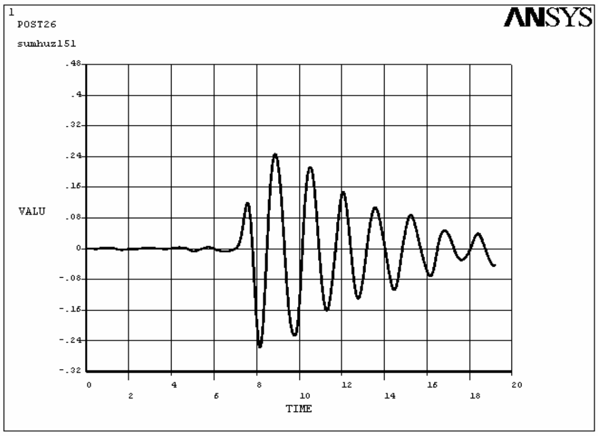

Fig.14 Displacement time history of main wing at tip in lateral direction (unit: m)

5. CONCLUSION

Seismic evaluation for Liulin Bridge is performed based on ARS and time history analysis, respectively. Seismic responses under excitation in different directions, as well as response under dead loads, are combined. The results show that the maximum stresses among the structure are all under the elastic range of its material, and the maximum displacement of the bridge can be accepted in bridge engineering practice. Based on present study, this complicated bridge system shows elastic performance under code required ground motion.

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