# Studying the Seismic Behavior of a Kind of Floating Bridges by Using Finite Element Analysis

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**SUMMARY:**
In this paper a double-arch steel movable bridge, similar to Yumemai, Japan, floating bridge, having a total weight of around 34000tonf, mounted on two separate hollow 58x58m pontoons, has been studied under 3-dimensional earthquake excitations. For this purpose the bridge was modeled in a powerful finite element analysis program, and a set of earthquakes were considered, containing low frequencies close to that of the bridge, and their dominant horizontal accelerograms were normalized to Peak Ground Acceleration levels of 0.4g. The effect of existing water beneath and around the pontoons was also modeled by using axial links, in which the specifications have been determined based on Archimedes reaction force at pontoons. Numerical results show that in some cases, particularly low-frequency near-source earthquakes, due to the tendency of bridge arches to extensive lateral motions, the end supports of the deck may get damage, and their design modifications seems to be necessary.

*Keywords: Double-arch movable bridge, Hollow pontoons, Low-frequency near-source earthquakes*

## 1. INTRODUCTION

The use of floating bridges goes back to around 4000 years ago, which has been mainly for military purposes. However, today these bridges are used in urban transportation systems, particularly when construction of piers is very difficult either due to the large depth of water or inappropriate water bed conditions. Damages to, or even total collapse of this kind of bridges have been reported in recent decades. Sinking events of Hood Canal and Lacey V. Murrow bridges on Washington lake, respectively in 1979 and 1990, are samples of these failures (Lwin 1994). Although no case of damage due to earthquake has been reported so far, several bridges of this type have been installed in earthquake prone areas, and this is while, based on available publications, in some cases their seismic behavior has not been studied thoroughly.

Ueda and his colleagues (1999) seem to be one of the first groups of researches who have worked on the seismic response analysis of floating bridges. Abrams (2006) has also worked on the seismic design of floating bridges. He has stated that a floating bridge is typically a very large floating mass articulated by a link to the adjacent land mass and can not respond to seismic motions. Thus the typical approach that one might apply to the seismic analysis of a fixed bridge may not be appropriate when evaluating a floating bridge. Abrams then has discussed the seismic design of two floating bridges. The Hood Canal Bridge, a 1.5-mile long concrete floating bridge that was designed and built in 1960 to extend Highway 104 across Hood Canal, a fjord-like arm of Puget Sound, and approximately 1-mile-long Ford Island (Admiral Clarey) Bridge, comprised of a 3,638-foot-long pile-supported fixed bridge element and a 1,035-foot-long movable element, which provides two 12-foot-wide traffic lanes, two 8-foot-wide shoulders/bikeways, and a 4-foot-wide sidewalk.

In this paper a double-arch steel movable bridge, similar to Yumemai floating bridge (Figure 1) in Osaka, Japan (Maruyama et al. 1998, Watanabe et al. 2004), having a total length of around 380m, mounted on two separate hollow pontoons has been studied under 3-dimensional earthquake excitations. For this purpose the bridge has been modeled in a powerful finite element analysis (FEA) program, and the effect of existing water beneath and around the pontoons has been also modeled by using axial links, in which the specifications have been determined based on Archimedes reaction force at pontoons. For dynamic analysis of the bridge subjected to earthquake excitations, the selected records cover a wide range of frequencies, particularly low frequencies close to that of the dominant modes of the bridge. The accelerograms have been normalized to Peak Ground Acceleration (PGA) level of 0.4g. Both near-source and far-source earthquakes have been considered for seismic response analyses. The details of the study are given in the following sections of the paper.

**Figure 1.** Yumemai floating bridge in Osaka, Japan (Watanabe et al. 2004)

## 2. THE BRIDGE FEATURES AND ITS MODELING

The considered floating bridge is a double-arch steel movable bridge, similar to Yumemai bridge, having a total length of around 380m, a free span of around 280m and a deck width of 38m, mounted on two separate hollow pontoons of 58x58m plan and 8m height, which has been chosen to be studied under 3-dimensional earthquake excitations. Figure 2 shows general and close-up views of the bridge.

**Figure 2.** The general and close-up views of the floating bridge considered in this study

Figure 3 shows the geometric features of the floating bridge considered in this study and some of its facilities.

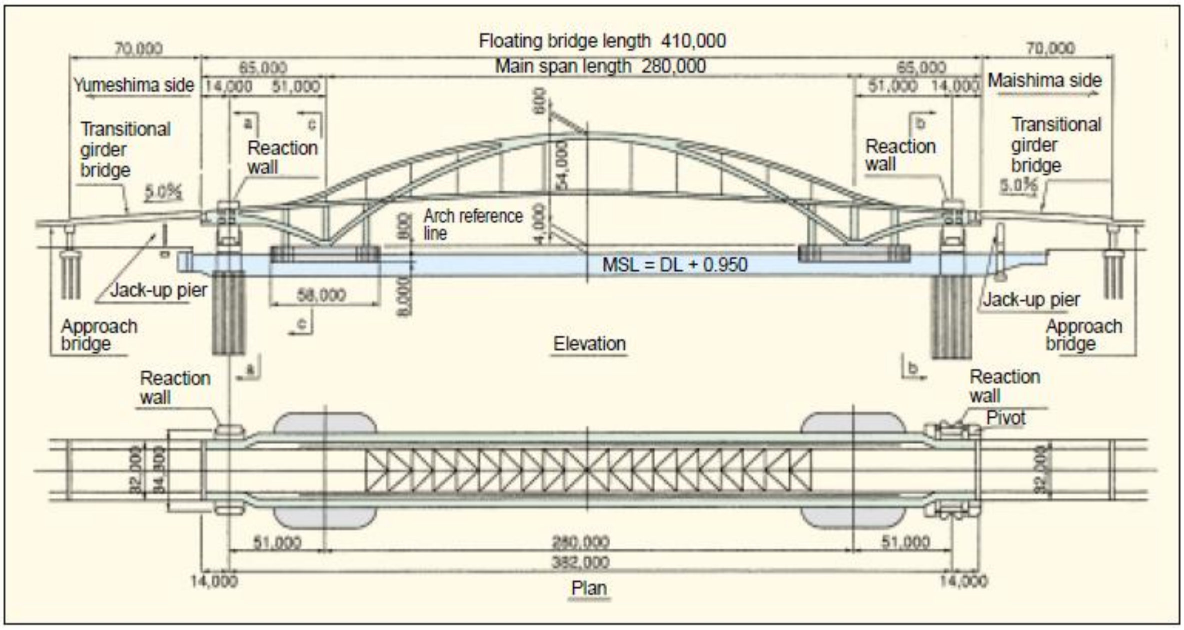


**Figure 3.** Geometric features of the floating bridge considered in this study

To model the bridge for its seismic analysis, a powerful Finite Element (FE) analysis program have been employed and 8-node shell elements with 6 degree of freedom at each node have been used for all parts of the bridge except the top V-bracing between the two arches, which have been modeled by axial link elements. An important point with regard to using the axial link elements is the stability of intersection points of the link elements at the longitudinal center line of the bridge. To make these nodes stable their vertical motion should be constrained to the vertical motion of the either side nodes at the other ends of the axial links.

It is also worth mentioning that by using shell elements the number of degrees of freedom of the numerical model of the bridge gets very large, and therefore, the required time for its dynamic analysis gets extremely long. A very good remedy to overcome this difficulty is using the equivalent beam (stick) model of the bridge, as shown in Figure 4.

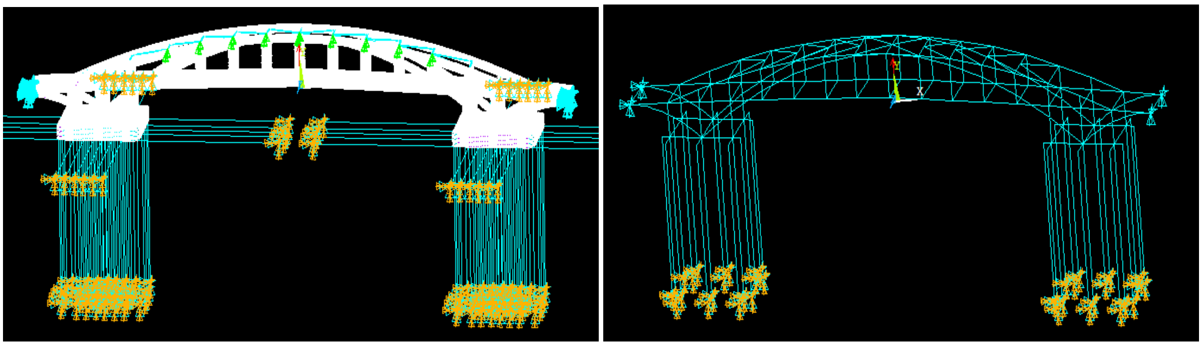

**Figure 4.** The original (left) and the simplified (right) model of the bridge-water system

Finally, to complete the model of the bridge-water system the effect of the existing water beneath and around the pontoons should be taken into account as well. In this study this effect has been also modeled by using axial links (see Figure 4), in which the specifications have been determined based on Archimedes reaction force at pontoons. The length of these axial links have been chosen long enough, as shown in Figure 4, that their deformation does not affect geometrically on the deformation of the bridge structure. The total weight of the bridge is around 34000tonf which causes each pontoon to sink around 5.60m in the water.

To verity the developed numerical model of the bridge for its dynamic analysis, a box-section beam of 20m length, made of plates of 1.0m width and 2.5cm thickness, was modeled by the same 8-node shell elements and axial links, as shown in Figure 5, and its natural frequencies were obtained and compared to the exact solutions, as given in Table 1.

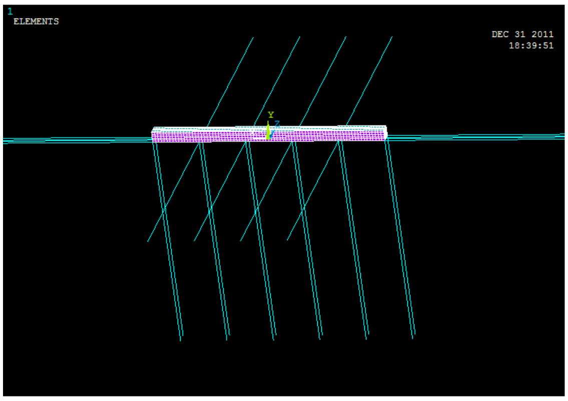


**Figure 5.** The FE model of the box-section beam with axial link supports

**Table 1.** The modal frequencies (in Hz) of the box-section beam for verification of FE model

| Mode number | Frequency obtained by FE model | Frequency obtained by exact method | Error (%) |
|---|---|---|---|
| 1 | 0.556 | 0.570 | -2.4 |
| 2 | 17.460 | 18.910 | -7.6 |
| 3 | 73.279 | 51.132 | -43.1 |

It is seen in Table 1 that the amount of error in obtained frequencies for the first and the second modes are acceptable, and therefore the developed FE model is satisfactory for dynamic analysis of the floating bridge.

## 3. DYNAMIC ANALYSES AND RESULTS

An important point with regard to the dynamic analysis of the bridge subjected to earthquake excitations, is the necessity of considering some initial forces, equivalent to the effect of bridge weight in each one of the water equivalent axial links, for nullifying the effect of gravity forces in the dynamic analyses. By considering these initial forces the bridge deck top surface elevation became the same as the elevation of the ground (road) at either ends of the bridge. An overall damping ratio of 2% was also assumed for the bridge-water system.

As the first set of dynamic analysis results the modal frequencies and effective masses of both the original model and the simplified beam model of the bridge (see Figure 4) are given in Table 2.

**Table 2.** Modal frequencies and effective masses of original and simplified models of the bridge

| | Mode | Frequency (Hz) | Period (Sec) | Effective Mass |
|---|---|---|---|---|
| Original Model | 1 | 0.381387 | 2.6220 | 0.27151*E+08* |
| | 2 | 0.660027 | 1.5151 | 12749.6 |
| | 3 | 1.51577 | 0.65973 | 0.299034*E+07* |
| | 4 | 2.08992 | 0.47849 | 512367 |
| Simplified Model | 1 | 0.396102 | 2.5246 | 0.264936*E+08* |
| | 2 | 0.769478 | 1.2996 | 5301.94 |
| | 3 | 1.50282 | 0.66541 | 0.426497*E+07* |
| | 4 | 2.19119 | 0.45673 | 32678.3 |

The second set of dynamic analyses results relates to the seismic response of the bridge. The considered earthquakes cover a wide range of frequencies, particularly low frequencies close to that of the dominant modes of the bridge, their dominant horizontal accelerograms have been chosen to have the Peak Ground Acceleration (PGA) value between 0.3g and 0.7g. Both near-source and far-source earthquakes have been considered for seismic response analyses.

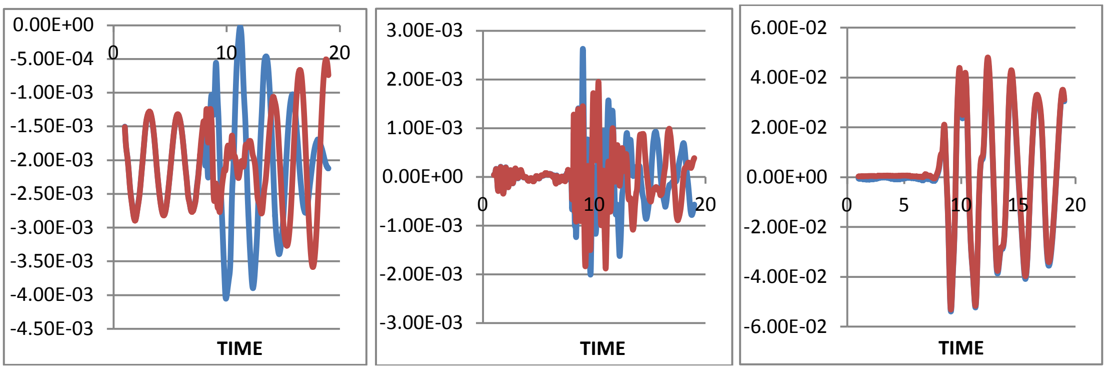


**Figure 6.** Displacement values of the center point of the deck to the arch on both sides of the bridge subjected to Chi-Chi earthquake

The numerical results related to Chi-Chi earthquake are given here, and more results can be found in the main report of the study (Abbasian 2012).

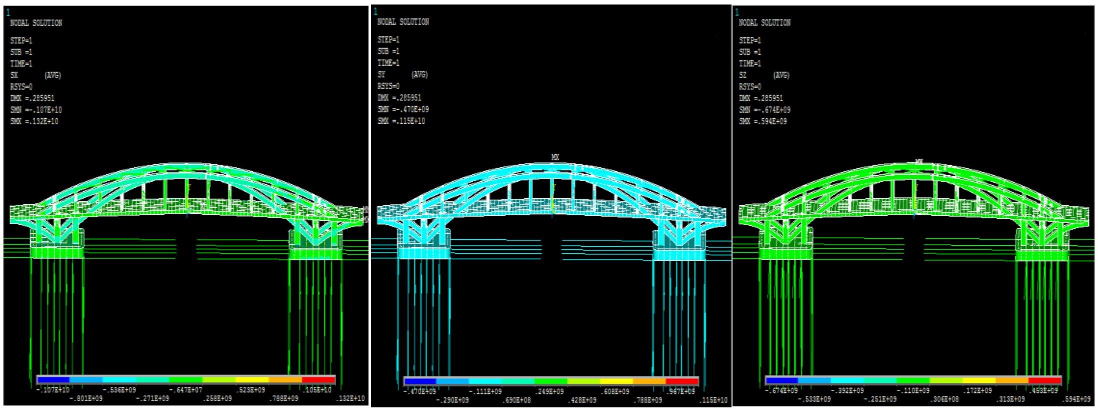

**Figure 7.** Stress values in the bridge body subjected to Chi-Chi earthquake

## 4. CONCLUSIONS

Numerical results of the FE analysis show that in some cases, particularly low-frequency near-source earthquakes, due to the tendency of bridge arches to extensive lateral motions, the end supports of the deck may get damage, and their design modifications seems to be necessary.

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