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An Investigation on the Seismic Behavior of Segmental Boxed Bridges with Post-Tensioning

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Abstract: A case study has been performed on a prestressed bridge with simple span in order to investigate the seismicbehavior of prestressed segmental bridges. In this study, nonlinear dynamic time history analysis has been used in the 3-dimentional finite element model of the structure under one-component vertical excitement and tree-component earthquake. Consequently, the degree of vulnerability of different parts of the bridge deck has been evaluated under vertical and horizontal components of the earthquake. The decks of prestressed segmental bridges are usually designed for vertical loading from permanent and service loads. The design of these bridges against the loads from earthquake is mainly performed for horizontal components of the earthquake and mostly the piers and foundation will be under effect. However, in such bridges concerning the long spans, the vertical excitements of the earthquake might be very impressive. The main focusing is on the vertical excitations of earthquake in the present study.

Key words: Prestressed bridge, Seismic behavior, vulnerability, vertical excitations of earth quake

INTRODUCTION

Along with the development of using different building technologies and the use of pre-stressing technic in the construction of buildings, the tendency to use these methods in construction of bridges with medium to long spans has been dramatically increased in the last decades. The segmental construction of prestressed precast concrete bridges with boxed girders is highly deemed desireable due to economic aspects and the speed and ease of implementation. The decks of prestressed segmental bridges are usually designed for vertical loading from permanent and service loads. The design of these bridges against the loads from earthquake is mainly performed for horizontal components of the earthquake and mostly the piers and foundation will be under effect. However in such bridges regarding the long spans, the vertical excitations of the earthquake might be very effective. In the regulations for seismic design of bridges such as AASHTO and Caltrans (California transportation standard) in order to calculate the effect of vertical component of earthquake on the amount of seismic demand of members, it is recommended to apply a percent of dead load to the structure upwards and downwards instead of considering the vertical component of earthquake in calculations. This value is different in various regulations. For instance AASHTO and Caltrans standards 20 and 25% are suggested, respectively. The vertical component of earthquake is more severe in the regions near to faultand is less strong in the regions far from the faults. Hence, the values suggested in these regulations can be non conservative in the near fields and very conservative in the areas far from the fault.

There is not many researches performed in the issue of the effect of vertical motion of earthquake on the bridges. Saadeghvariri and Foutch (1991) investigated the behavior of RC bridges without energy-dissipation systems under the three-component effects of earthquake. Button and colleagues have studied the effect of vertical moves of earthquake on six different types of bridges. Kim *et al.* (2010a, b) have studied and validated a finite element model of a prestressed post tensioned simple beam, comparing it with experimental results. Sung and colleagues studied the effect of the vertical component of earthquake on the piers of two concrete bridges. Yuan *et al.* (2013) have studied the behavior of precast concrete boxed bridges with combined

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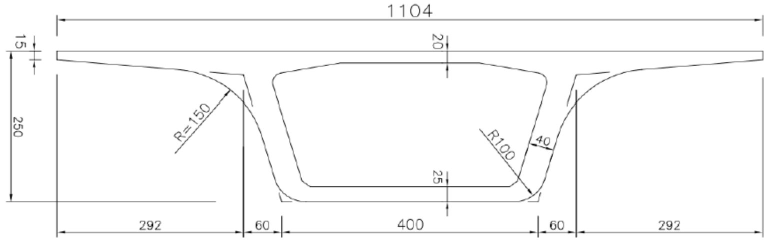

Fig. 1: The section of studied bridge

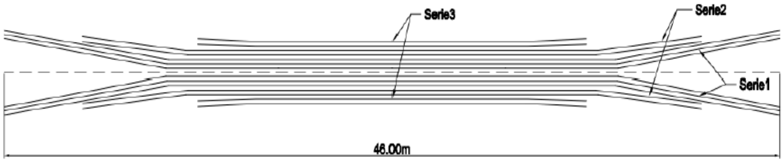

Fig. 2: Plan of the layout of prestressing cables

tendons (internal and external). Ebrahimkhanlou *et al.* (2015, 2016) have investigated surface cracking of concrete under cyclic loading.

Introducing the studied bridge: The studied bridge is a prestressed boxed bridge with post tensioned tendons. This bridge is located in the crossing of Sheikh-Fazlollah and Hakim highways. This bridge has been constructed with cantilever method. The span length is about 46 m, the piers are 6 m in height and the deck of structure is placed on seismic isolators. 14 prestressing tendons are used along this bridge which 6 of them are implemented as external and the rest of them (8 tendons) are internal (glued) prestressed tendons (Fig 1 and 2).

MATERIALS AND METHODS

Modeling: In order to model the bridge, the finite element software, ANSYS which is one of the most powerful finite element software has been used. Three dimensional element SOLID65 is used for modeling concrete material. This element is capable to model different phenomena such as cracking, crushing and creep. This element is also able to model rebars in three directions by uniform and distributed volumetric ratio throughout the element. Rod element Link180 is also used for modeling the prestressing tendons and steel plates are used in the end of tendons in order to avoid creating stress concentration. After meshing and initial modeling, a half of the live load equals to 500 kg/m 2 was placed on the structure which is almost equivalent with the heavy traffic load in AASHTO. The mass of the non-structural elements and a half of the live load which is participating in the weight based on AASHTO standard was calculated per a unit length of the bridge and added to the concrete density.

RESULTS AND DISCUSSION

Analysis of characteristic values: The analysis of characteristic values was performed with the aim to investigate the dynamic properties of the structure. The results of this analysis are used in the scaling of earthquake records. The mode shapes of the first three modes of structure are presented in Fig 3-5.

As is evident in the bridge the primary mode of structure is in the vertical direction, hence the vertical excitement of earthquake can significantly affect the bridge (Table 1).

Time history analysis: The time history analysis was conducted on the studied bridge under one-component vertical excitement and three-component excitement of Kobe, Northridge and Tabas earthquakes.

Time history analysis under one-component excitement of earthquake: The results of time history analysis under one-component excitement of earthquake are obtained in the forms of the response of prestressing tendon stress, vertical displacement of the middle of the span and the maximum stress of concrete in the bottom of the section.

The vertical displacements of the middle of the bridge span under the effect of one-component excitement of Northridge and Kobe earthquakes are shown in Fig. 6 and 7, respectively. The stress changes in tendons of series 1-3 under the effect of one-component excitement of earthquake are shown in Fig. 8-11.

The stress response of one element of each series of tendons in the middle of the span under one-component excitement for three mentioned earthquakes is shown. As can be seen, the maximum stress of tendons has a large

Table 1: The results of analysis of characteristic values

Mode No.	Frequency	Period	Cumulative percent of mass participating in x directioin	Cumulative percent of mass participating in y directionin	Cumulative percent of mass participating in z direction
1	2.32	0.43	0.00	0.994	0.005
2	3.41	0.29	0.52	0.994	0.005
3	5.47	0.18	0.52	0.999	0.958
4	6.55	0.15	0.99	0.999	0.958
5	7.95	0.13	0.99	1.00	1.00
6	9.09	0.11	1.00	1.00	1.00

Fig. 3: Mode shape 1

Fig. 4: Mode shape 2

Fig. 5: Mode shape 3

distance until reaching the yielding stress (1675 MPa) and failure (1860 Mpa) where indicates that the risk of tendon rupturing does not exist. In addition, it is clear that the stress levels in the tendons of series 1 which is of type unglued are less than the stress levels of tendons of series 2 and 3 which are of glued type. Moreover, the different between maximum and minimum stresses in this group of tendons is alsoless than the other series. The maximum and minimum axial stresses (in bending) in the concrete section at the middle of the span is presented in Fig. 12. The results show that the concrete is not reached its tensile strength limit and does not crack. In fact, the deck mainly acts elastic and no energy dissipation of earthquake would be performed.

Time history analysis under three-component excitement of earthquake: The time history analysis of the bridge under three-component excitements of the introduced earthquakes were done, consequently and the results are specified in the forms of the stress response of the prestressing tendons, vertical displacement of the middle of the span and the maximum concrete stress in the bottom of section. As is obvious by applying three-component excitement there was not created a significant difference in the structure response compared to the case which one component vertical excitement is applied. The vertical displacement at the middle of the span under the effect of three-component excitation o f earthquake is shown in Fig. 13 and 14.

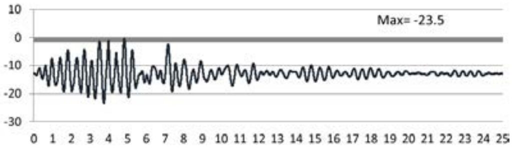

Fig. 6: Time history of vertical displacement of the middle of the span under one-component excitement of Northridge earthquake (mm)

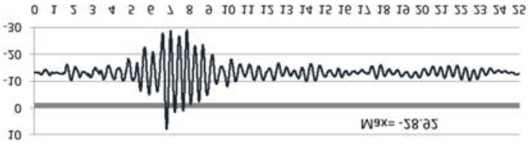

Fig. 7: Time history of vertical displacement of the middle of the span under one-component excitement of Kobe earthquake (mm)

The stress response the presressing cables under three-component excitement is shown in Fig. 15-17. The maximum stress in tendons is increased a few in comparison with the case for one-component excitement, although, the stress in tendons is far from the yielding and failure limits. According to the results from this condition with previous one, it can be concluded that the stress level of side cables (i.e., cables of series 3) is more than the middle cables i.e. Series 1 and 2).

The maximum and minimum axial stress (in bending) in the concrete section at the middle of span under three-component excitement is also shown in Fig. 18. It is resulted that the concrete is not reached its tensile strength limit and does not crack.

Comparison of the displacement in the middle of the span in one-component and three-component cases: As an example, the comparison between the response of vertical displacement at the middle of the structure span in one-component and three-component cases is shown in Fig. 19. As can be seen the curve of responses area harmonious with each other.

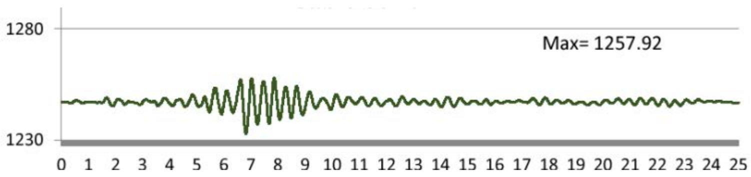

Fig. 8: Time history of changes in the stress of tendons of series 1 under the effect of one-component excitement of Kobe earthquake (MPa)

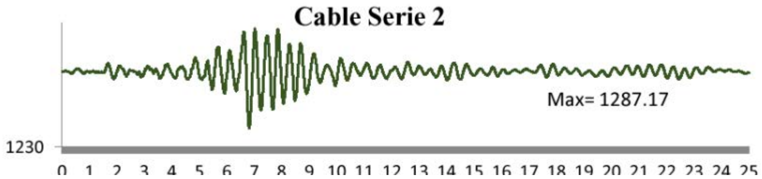

Fig. 9: Time history of changes in the stress of tendons of series 2 under the effect of one-component excitement of Kobe earthquake (Mpa)

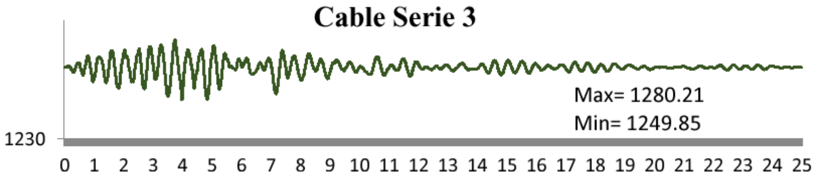

Fig. 10: Time history of changes in the stress of tendons of series 3 under the effect of one-component excitement of Northridge earthquake (MPa)

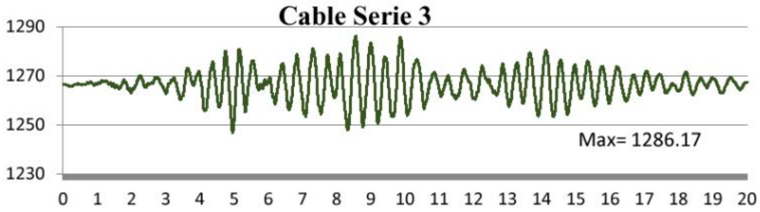

Fig. 11: Time history of changes in the stress of tendons of series 3 under the effect of one-component excitement of Tabas earthquake (MPa)

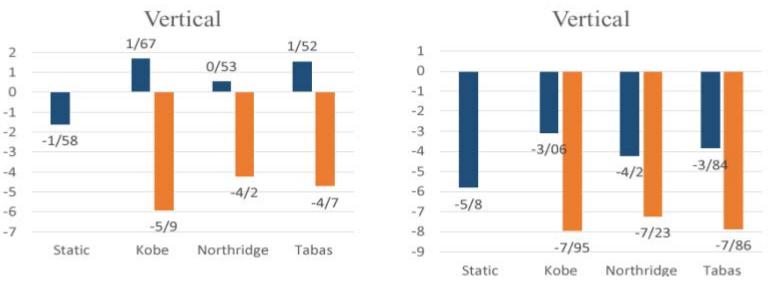

Fig. 12: The maximum stress of concrete under one-component excitement of different earthquakes (MPa): a) Stress in the span in top of the scetion and b) Stress in the bottom of the scetion

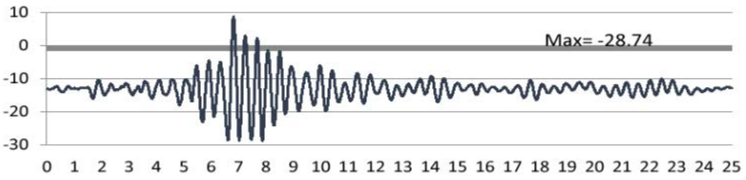

Fig. 13: Time history of vertical displacement of the middle of the span at stress point 1, under one-component excitement of Kobe earthquake (mm)

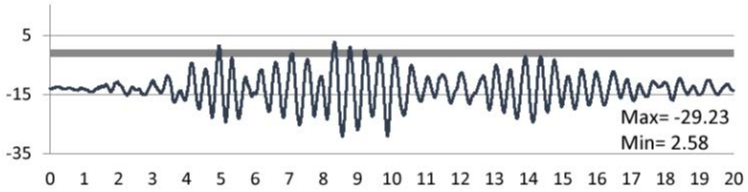

Fig. 14: Time history of vertical displacement of the middle of the span at stress point 1, under one-component excitement of Tabas earthquake (mm)

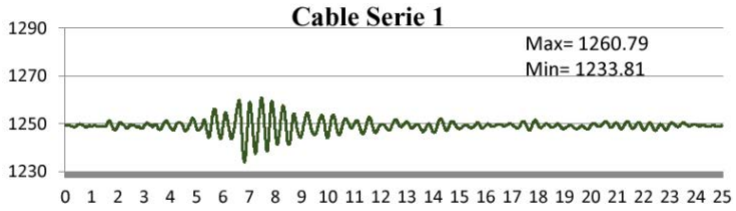

Fig. 15: Time history of changes in the stress of tendons of series 1 under three-component excitement of Kobe earthquake (MPa)

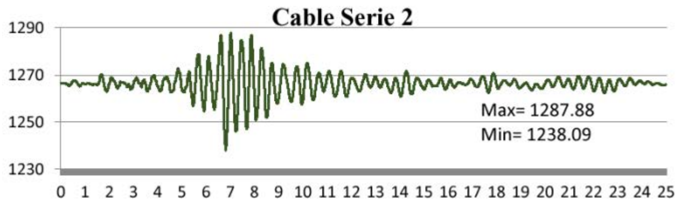

Fig. 16: Time history of changes in the stress of tendons of series 2 under three-component excitement of Kobe earthquake (MPa)

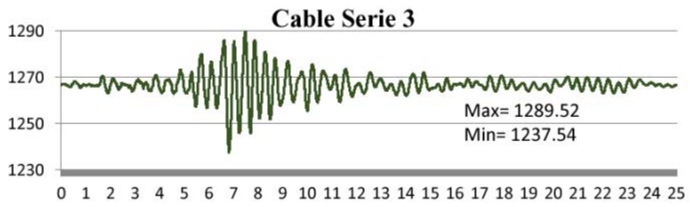

Fig. 17: Time history of changes in the stress of tendons of series 3 under three-component excitement of Kobe earthquake (MPa)

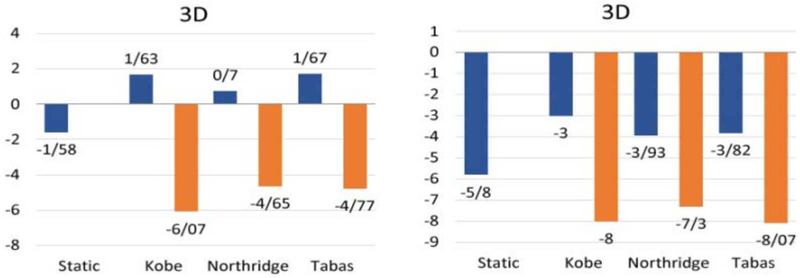

Fig. 18: The ultimate limit of stress of concrete in the middle of span in top and bottom of the scetion under three-component excitement of different earthquakes (MPa): a) Stress in the top of the section and b) Stress in the bottom of the section

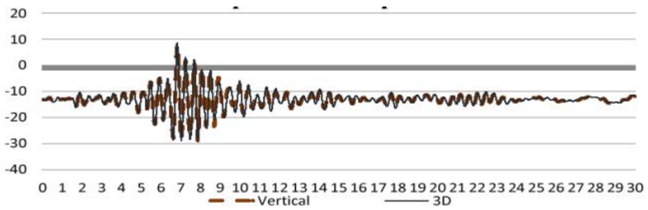

Fig. 19: Comparison between the effects of vertical and three-dimensional components of Kobe earthquake on the displacement of the middle of span

CONCULSION

After performing the intended analysis, it was specified that the concrete stress under one-component and three-component excitements for different earthquakes was almost similar and a little difference was observed. The maximum stresses at the bottom of s ection in the middle of span didn't reach the tensile strength limit of concrete and wide cracks were not created and the structure showed elastic performance. The stress of cables in all the conducted analysis has not showed a noticeable increase or reduction compared to static state and the stress levels had a large distance with yielding and failure limits. The stress level and the range of its changes in the glued cables are more than unglued cables. This matter has been previously noted in the experimental researches.

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