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Comparison between Seismic Performance of Semi-Integrated Bridge and Conventional Bridge

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Abstract

The performance of a three-span integrated bridge is evaluated and compared with a conventional bridge for unidirectional and bi-directional excitation. The conventional bridge deck is connected to abutment through elastomers and the pinned connection is assumed at pier location. The height of the piers is 9.5 m, and the central and end spans are 38.0 m and 15.5 m respectively. A nonlinear time history analysis of the bridge is performed by using CSI Bridge software, for unidirectional and bi-directional excitation. The responses of the integrated bridge are compared with those of the conventional bridge in which bearings are provided between the deck and the support. The parameters varied are the major direction of the application of earthquake time history and PGA. The response quantities of interest include the maximum base shear of piers, maximum stresses developed at the critical sections of the deck, maximum deck deflection at the mid-span, and at the pier supports. The results of the numerical study show that as compared to the conventional bridge the integrated bridge has less base shear but has more stresses in the deck near pier supports; however, the stresses developed at the mid-span of the deck are significantly reduced.

Keywords: Monolithic Bridge, Multicomponent earthquake, Nonlinear seismic analysis, Bridge deck deflection

1. Introduction

Failure of Bridge during any seismic even can't be tolerated as it is an essential service for the rescue team to reach the affected area and to provide relief to earthquake victims. Secondly, the construction of a bridge is required a considerable amount of funds and labor in any transportation project. Hence the seismic performance of various techniques of protection from the earthquake or various structural forms of bridges is continuously investigated. Integrated bridge (IB) is one of the structural form gaining popularity especially in USA and UK[1,2]. IB can be described as a joint less deck monolithically connected to the substructure. The teen run bridge is the first IB in USA constructed in 1938[3]. The main advantages of IB are 1) It eliminates joints and requirement of bearing which reduces the capital cost of bridge 2) due to the absence of joints and bearing deicing activity, corrosion protection and other maintenance expenses reduce so it proves economical over the conventional bridge (CB). 3) It facilitates speedy construction of bridge 4) As deck surface is joint-free it provides a smooth surface for traveling vehicle and 5) IB possess more redundancy than CB so it provides better earthquake resistance. The term IB is used for a bridge in which a joint less deck is monolithically connected to abutment and pier. Various structural arrangements of IB have developed according to site condition, design requirement, and traffic condition. Only two structural forms of IB have discussed here one is a semi-integrated bridge (SIB) and an integrated abutment bridge (IAB). If the deck is connected monolithically to piers but connected to abutment through bearing then this type of form is called a semi-integrated bridge[3]. IB, SIB, and IAB have shown in Fig. 1(a), (b) and (c) respectively. In some cases, the deck is connected monolithically to abutment only and if the pier is provided then it is connected through bearing such structural form is called an integrated abutment bridge (IAB). These structural forms of IB have investigated by many researchers to establish design guidelines and appreciate it's behavior under gravity as well as lateral loading.

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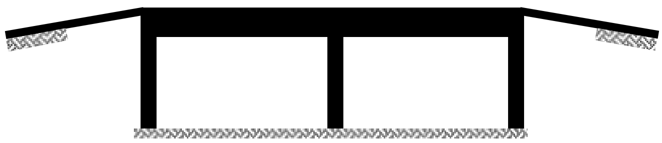
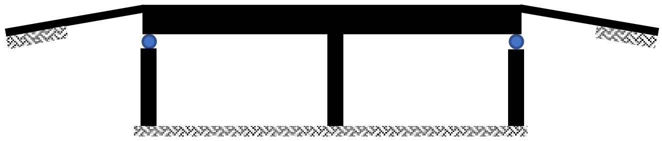
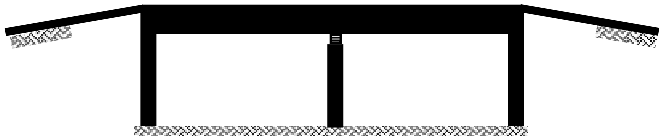
Wolde-Tinsae et. al. [1] surveyed existing bridges in USA and reported that its performance of IBs is satisfactory. Kunin and Alampalli[4] also surveyed existing bridges in USA and Canada putting a focus on design assumptions, thermal movement limits, and soil pressure. from the responses received from various agencies on the survey, author concluded that the performance of IB reported excellent or good with minor problems. Design assumptions largely based on local conditions and past experience. Dicleli[5] proposed a simplified model for computation analysis of IAB considering fixity at monolithic connection instead of considering pin connection as in case of conventional method of analysis, assuming responses do not vary much for gravity load. A computational program was developed which was able to analyse IAB for various load in accordance with construction stages and lateral thermal load along with gravity load. The difference between the two methods was compared and reported in the conclusion. The major difference reported that axial force due to earth pressure and the beneficial effect of earth pressure in single-span IAB get neglected in the conventional method. Thippeswamy et al. [6] analysed five different structural arrangements of IAB and for static vertical or lateral load. In loading secondary effects were also considered. Support condition at deck level, footing type (spread or pile) was the parameter for variation. Results for both primary, secondary loads and it's combination were compared. it was concluded that the performance of IAB with a flexible pile foundation was better. Caner and Zia [7] tested 3 span deck with continuous deck girder for various combinations of support conditions. roller and pin are two support condition and steel and RC girder were used for test and It was concluded that the effect of hinge or roller support does not changes drastically. Kozak[8] studied the effect of soil by considering soil - structural interaction. For the study, a three-span existing IAB in Illinois (USA) was simulated in Opensees. NLTHA and pushover analysis were performed in both directions For NLTHA suite of 20 earthquakes were used. From results obtained it was concluded that pile capacity reduces in soft soil as compared to stiff soil. Knickerbocker and Basu[9] studied the behavior of IAB as a whole. For the purpose of the study, an existing bridge in Dickson TN (USA) was considered. Skew angle and thermal loading on the bridge were varied to study the effect of it. It was concluded that short abutment accommodates a wide range of deformation as compared to others. Dowell [10] presented a closed-form approach of incremental form for NLTHA and cyclic pushover analysis written in FORTRON for automated analysis. One 2-D three-span bridge was considered for analysis. and results from the program presented mentioning limitations of it. Thomas [11] conducted the performance-based design of a bridge. A three-span bridge having unequal pier height was considered. Bridge under consideration was having prestressed deck monolithically connected to pier and roller bearing provided at the abutment. From the study, it was recommended that provisions of IRC 112 for a minimum percentage of reinforcement are inadequate for bridge having unequal pier height.



(a) Structural arrangement of IB



(b) Structural arrangement of SIB



(c) Structural arrangement of IAB

Fig. 1 Structural Forms of IB, SIB and IAB

From the above literature review, it can be seen that structural behavior of IB or IAB for gravity or lateral loading has investigated for static or dynamic loading. But the performance of SIB has not reported much especially for seismic loading. In present study performance of SIB has investigated for a nearfield earthquake with forward directivity effect. Scaled time history of Kobe earthquake (1995) has used for unidirectional and bidirectional analysis. The level of PGA and major direction of earthquake excitation are varied and response quantities have compared with CB. Responses of interests are stresses in the deck at the support and mid-span, deck level deflections, and base shear.

2. Theoretical Background

Apart from the main advantages listed above IB is preferred as it is simple in construction. Deck or deck girder subjected to more uniform BM due to fixity moment and moment distribution is possible in vertical as well as lateral loading. This results in economical c/s of members. On the other hand, when the deck is monolithically connected to substructure (pier and abutment) then the relative horizontal movement of the deck is restricted and it has to transfer to the foundation beneath the abutment and pier. This movement has to be accommodated by the foundation in the form of rotation. Hence foundation has to be flexible which can accommodate this movement[6]. Secondly, thermal movement of deck increases with an increase in the length of the deck so various US transportation codes (like AASHTO, Caltrans) prescribe maximum length. These are the main limitation of IB and similarly valid for IAB also. Problems of maximum length of the deck can be solved if the deck is connected through bearing at the abutments. Thus, the length of the deck of SIB is not governed by the flexibility of foundation

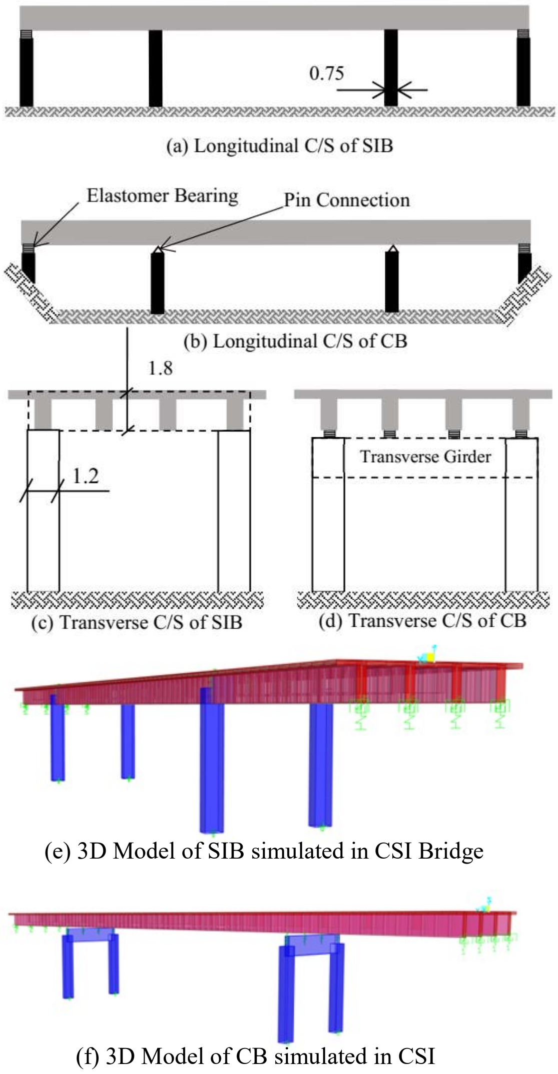


Fig.2 Geometric details of SIB and CB

3. Numerical Study

A three-span RC bridge is considered in the form of SIB and CB for the study. Cross-section and longitudinal elevation of both bridges have shown in Fig. 2. Member sizes, reinforcement, geometric and cross-sectional details of both bridges are the same except deck connection with pier bent. in SIB deck is monolithically connected to pier bent, whereas in CB deck is connected with pier through bearing. Total Longitudinal girder depth is taken 1.8 m including slab thickness. The cap bent beam is provided as a transverse girder to connect piers in the transverse direction. The depth of the cap bent beam is also considered as 1.8 m. Width of longitudinal and transverse girder is taken as 0.5 m. The column cross-section size is considered 1.2×0.75 m with 1.42 % longitudinal reinforcement. Cross Diaphragms (CDs) of size 1 m depth and 0.5 m wide are provided at the equal spacing to make deck stiff.

This bridge is modeled in CSI Bridge. Deck slab, longitudinal girders, and CDs are modeled as area elements whereas columns and cap beams are modeled as line elements. Fixed support is assumed at the column base. Abutments at both ends are not modeled but it is assumed as unyielding support and only elastomers below girders and above fixed supports are modeled in both SIB and CB. The deck is monolithically connected to pier bent in SIB whereas, in the case of CB, the deck is connected to pier bent through bearing which is modeled as a hinge in CSI Bridge. The dead load includes the self-weight of members and wearing coat load. The self-weight of a member is calculated by the CSI Bridge whereas wearing coat load is assumed as 2 kN/m^2 and applied as area load. A superimposed load of 2 kN/m^2 is also applied as an area load. Default plastic hinges available in CSI bridge as per ASCE 41-13 (Table 10-7 and 10-8) is applied in column and transverse beam of CBand also in a column of SIB. NLTHA is performed by applying times history mentioned in Table 1 [12]. This time history scaled to PGA 0.2, 0.4, 0.6, and 0.8 and these time histories have deployed for uni-directional and bi-directional analysis. In the case of bi-directional analysis, one lateral direction is a major direction while another lateral direction is a minor direction of application. The ratio of PGA of time history applied in minor to major direction is 0.667 for bi-directional analysis and zero in case of unidirectional analysis.

4. Result and Discussion

To compare the behavior of SIB and CB response quantities for parameters varied viz PGA and bi-directional interaction are presented. Instead of the pure numerical value of response quantities, normalized values of responses are used to compare the response between SIB and CB. The normalized response is the ratio of response quantity of SIB to the response quantity of CB. As it is the ratio of the same quantity it will be unitless. If the value of normalized response is more than 1 then the response quantity of SIB is more than CB and vice-a-versa if it is less than 1 then the response quantity of SIB is less than CB.

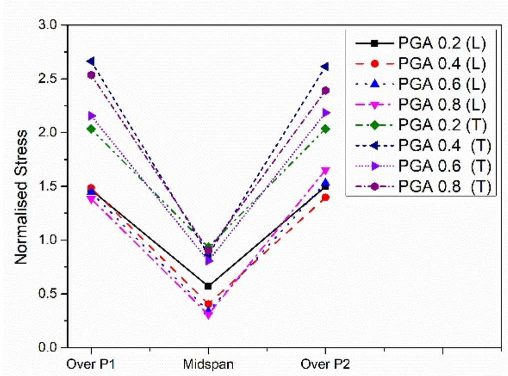
Comparative performance of SIB and CB: From Fig. 3 (a-e) it is clear that deck stresses at the support of SIB is more than CB at support and drastically reduced at mid-span. Stresses in SIB at support increases due to fixity provided. The deflection of the deck in SIB has reduced as compared to CB due to high redundancy in SIB. Base shear in SIB also reduced as compared to CB this is due to distribution of load between column and beam occurs at the monolithic joint.

Effect of PGA level: All response quantities viz deck stress, deck deflection, and base shear of both SIB and CB increases as the level of PGA increases. but the reduction or amplification of normalized response is compared w.r.t PGA level is compared. Normalized stresses in the deck at support and midspan both increase w.r.t PGA level. It means the rate of increase of stress in SIB is more than CB. Similarly, as the PGA level increases reduction in deflection and base shear of SIB decreases w.r.t CB.

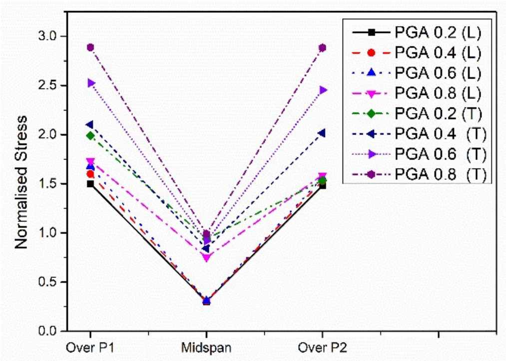
Table 1[12]

Earthquake -Station - Component (Year)	Mw	PGA (g)	PGV (cm/s)	PGD (cm)
Kobe-KJMA-00 (1995)	6.9	0.82	81.62	17.71

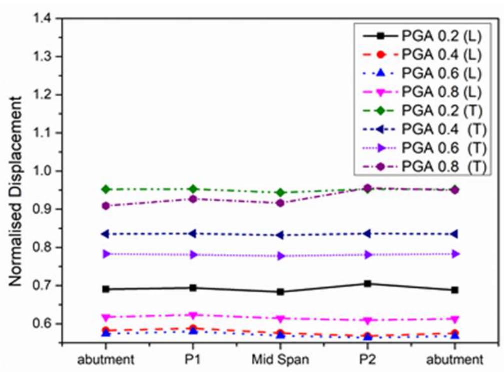
Effect of major direction of earthquake: Trends of response quantity vs PGA is very similar in both direction but the reduction of response is different w.r.t major earthquake direction. Stress reduction at mid-span of SIB is more if the major direction of the earthquake is the longitudinal axis of the bridge than the transverse direction. Very little stress reduction occurs in SIB if the major direction of the earthquake is along the transverse axis of the bridge. A similar trend can be seen in other response quantities.



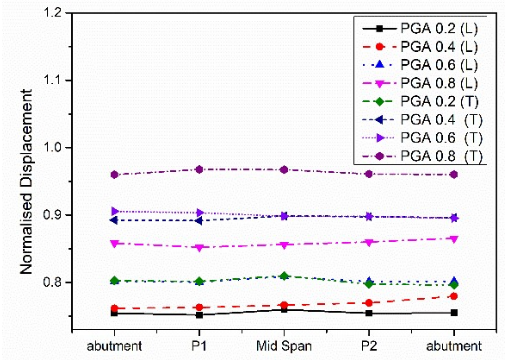
(a) Normalized Deck stress for the unidirectional excitation



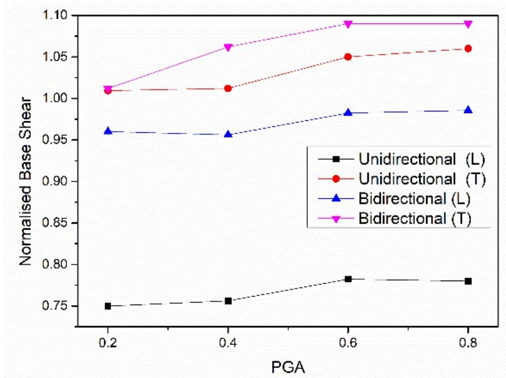
(b) Normalized Deck stress for bidirectional excitation



(c) Normalized deflection of the deck for Unidirectional excitation



(d) Normalized deflection of the deck for bidirectional excitation



(e) Normalized Base shear for unidirectional and bidirectional excitation

Fig. 3 Normalized response quantities (major direction of excitation is mentioned in the bracket in legend)

5. Conclusions:

Comparative study of responses obtained from nonlinear time history analysis of SIB and CB has done and presented in result. From the above discussion following major conclusion can be drawn

1) Deck stress at support though increased in SIB but at the same time stresses at the mid-span reduced. This is due to the effect of fixities provided at the support.

2) Due to monolithic joint, deck deflection reduced in SIB. Again, base shear also reduced in SIB because of load shearing between column and beam

3) When the major direction of the earthquake was along the longitudinal axis of the bridge, response reduction is more than the other lateral direction. This is because the portal provided below deck in CB is similar to SIB.

4) The effect of unidirectional and bi-directional excitation has seen in the pure numerical result. Though the numerical responses in case of bi-directional excitation increases as compare to unidirectional excitation, normalized responses were the same for both unidirectional and bi-directional excitation. Hence reduction or amplification of responses was marginally the same in case of unidirectional and bi-directional excitation, except base shear. The reduction of base shear for bi-directional earthquake was less than a unidirectional earthquake.

Disclosures

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