EFFECT OF LINK SLAB ON SEISMIC RESPONSE OF TWO SPAN STRAIGHT AND SKEW BRIDGES

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Abstract Highway bridges are frequently constructed as simple span structures with steel or concrete girders and a cast-in-place concrete deck, spanning from one pier to another. At each end of the simple span deck, a joint is provided for deck movement due to temperature, shrinkage, and creep. Bridge deck joints are expensive and pose many problems with regard to bridge maintenance. Elimination of deck joints at the support of multi-span bridges has been the subject of recent studies. Recent researches have led to the development of a design concept and approach for jointless bridges where the expansion joints are replaced with continuous link slabs. Further studies have indicated the proper performance of such bridges under service loading conditions. This paper presents analytical study of seismic behavior and response of a two span bridge connected by link slabs. Three dimensional finite element analyses of straight and skew bridges with skew angles varying from 15 to 60 degrees is performed. Both linear time history and response spectrum analyses method are carried out in order to investigate the response of the bridge. The results indicate that the force and displacement demands of the interior bent maybe reduced considerably, if link slab is used in the middle of the bridge instead of an expansion joint.

Keywords Bridge, Structure, Concrete, Earthquake, Link Slab

چکیده پل های تیر و دال چند دهانه با تکیه گاه های ساده از متداول ترین پل های بزرگراهی می‌باشند. در این پل ها معمولاً درزهای انبساط در پایه های میانی و کوله ها به منظور تأمین حرکت طولی ناشی از تغییرات دما و خزش تعبیه می‌گردد. در هنگام بهره برداری از پل، وجود درزهای انبساط باعث مشکلات فراوانی می‌شوند. حذف درز انبساط در پایه های میانی از رویکردهای پژوهشی اخیر در جهان بوده است. این تحقیقات منجر به ارائه سیستم جدیدی شده است که در آن تیرهای تابلیه دو سر ساده محاسبه و اجرا می‌گردند ولی دال عرشه در محل پایه های میانی به صورت یکسره اجرا می‌شود. مطالعات میدانی نشان می‌دهد که پل هایی که با این روش طراحی و احداث می‌شوند عملکرد مناسبی در هنگام بهره برداری دارند. در این مقاله رفتار لرزه ای پل های تیر و دال بتنی دو دهانه با دال یکسره در محل پایه های میانی با انجام تحلیل های دینامیکی طیفی و تاریخچه زمانی مورد مطالعه قرار می‌گیرد. نتایج این مطالعات نشان می‌دهد که استفاده از دال یکسره تقاضای لرزه ای در پایه میانی را بطور قابل ملاحظه ای کاهش می‌دهد.

1. INTRODUCTION

Highway bridge construction often involves multiple spans of steel or concrete girders supported at piers or bents. At each end of the span, expandable mechanical joints are installed to permit the bridge deck movement and other deformations due to concrete shrinkage, temperature variations, and girder deflection. A significant negative economic impact of mechanical joints in all phases of bridge service life, from design to construction and maintenance is well documented [1]. Deterioration of joint functionality due to the accumulation of debris, may lead to severe damage in the bridge deck and its substructure. The durability of bridge could also be compromised by water leakage and flow of deicing chemicals through the joints. A possible approach to alleviate these problems is the elimination of the mechanical joints in multi-span bridges.

There are two methods to eliminate deck joints, specifically, an integral construction concept with girder continuity and a jointless bridge deck with simply supported girders. However, the construction of jointless deck with simply supported girders is more efficient than the common integral bridge construction. A study of jointless bridge deck construction [2] indicates that jointless decks generally perform better than decks with joints.

A jointless deck is created by replacement of the expandable mechanical joint with a concrete slab, typically called a link slab (see Figure 1). Researchers have analyzed the performance of jointless bridge decks and proposed methods to design link slabs [3]. They have noted that link slabs are subjected to bending and axial strain under typical traffic and environmental conditions. The high tensile strain on top of the link slab leads to crack formation in the concrete. They pointed out that controlling crack development and crack width in the link slab is critical for its survivability. Their recommendation was to use epoxy coated reinforcing bars in the link slab to avoid reinforcement corrosion. To reduce crack width, debonding of the link slab over the girder joint for a length equal to 5 % of each girder span was also recommended. Further research on using high performance materials to control cracks in the link slabs and to provide a durable jointless bridge deck, has also been carried out [4].

Due to the in-plane rigidity of link slab, seismic performance of a link slab bridge is expected to be different from that of a bridge with expansion joints. This paper presents the results of an analytical study on seismic performance of two span straight and skew bridges with either a link slab or an expansion joint over the interior bent.

2. ANALYTICAL STUDY

A two span bridge with equal span lengths of 20 meters is considered for this study. Figure 2 shows the cross section of the superstructure. Each span consists of six simply supported precast concrete girders, spanning between an interior bent at middle and an abutment at either end of the bridge. The girders are supported by laminated rubber bearings at each end. The surface dimension of each bearing is 30^{cm} x 30^{cm} and its height is 4.9 centimeter. Shear keys are placed on bent caps and on the abutments to restrain transverse displacement of the superstructure. The girders are free to move on the rubber bearings in longitudinal direction.

Figure 3 shows typical cross section of the precast concrete girders. The girders are connected to each other by three transverse diaphragms at the mid-span and also at each end.

Figure 4 shows details of the interior bent. It

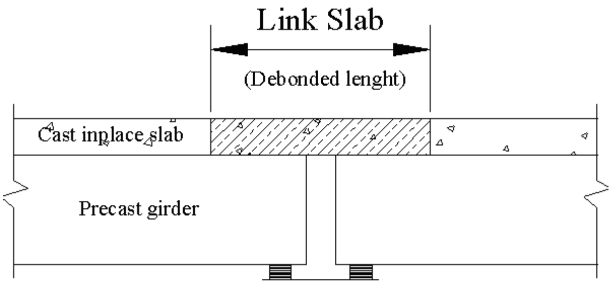


Figure 1. Link slab.

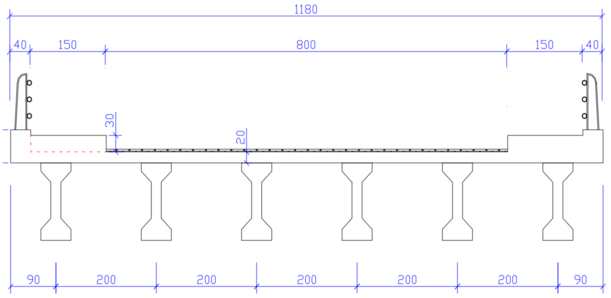


Figure 2. Cross section of bridge superstructure.

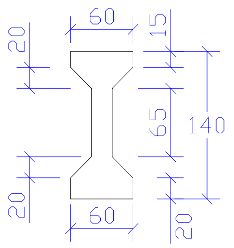


Figure 3. Typical cross section of concrete girder.

consists of three reinforced concrete columns with a diameter of 1.2 meter. The columns which are supported on pile caps are seven meters tall. The bent cap cross sectional dimension is 1.6 x 1.5 meters.

2.1. Description of FEA Model Figure 5 shows the FEA representation of a typical bridge. The columns and bent caps are modeled using frame elements. The columns are fixed at pile cap interface. The abutment at each end of the bridge is assumed to be rigid. The shear keys are modeled by constraining the transverse displacement of underside of superstructure to the cap beam.

The rubber bearings are modeled by spring elements. The stiffness properties of the spring in either direction are calculated from following equations.

$$\text{Vertical Stiffness: } k_v = \frac{GA_b a^2}{Cnt^3} \qquad (1)$$

$$\text{Rotational Stiffness: } k_\theta = \frac{GA_b a^4}{C_1 nt^3} \qquad (2)$$

$$\text{Shear Stiffness: } k_u = \frac{GA_b}{nt} \qquad (3)$$

$$\text{Torsional Stiffness: } k_\phi = \frac{GC_2 a^4}{t} \qquad (4)$$

Where:

G	Shear Modulus = 1.6 MPa.
A_b	Bearing Area
a	Length of Square Bearing
n	No. of Elastomer Layer
t	Layer Thickness
C, C_1, C_2	Dimensional Coefficients

Table 1 lists the stiffness properties of the rubber bearing as calculated from the above equations.

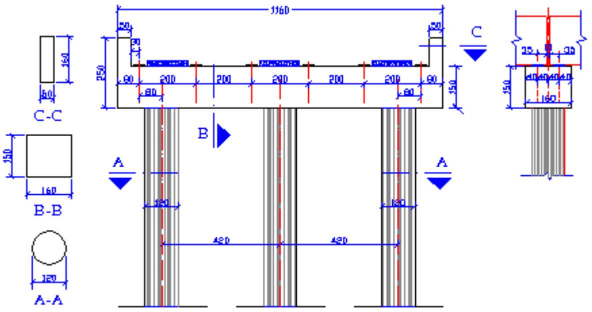


Figure 4. Interior bent.

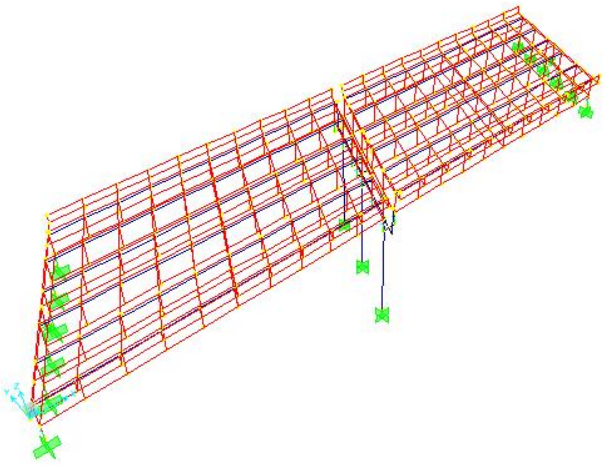


Figure 5. FEA representation of a bridge with 30 degree skew angle.

TABLE 1. Stiffness Properties of the Laminated Rubber Bearing.

Dimensions (mm)	k_v (kN/m)	k_θ (kN.m)	k_u (kN/m)	k_ϕ (kN.m)
300 x 300 x 49	1359000	243.4	3790.0	48.0

Figure 6 shows the FEA representation of the superstructure. The girders are modeled using shell elements for the web and frame elements for top and bottom flanges. The concrete slab which is modeled by shell elements is connected to the top flange by rigid link elements. This model, places the mass of each superstructure component at its suitable locations.

The structural mass is directly taken from the FEA model using a material density of 2500 kg/m^3. Mass of wearing surface, 270 kg/m^2, and guard rail mass of 100 kg/m, are also added to the structural mass. Concrete compressive strengths are 30 MPa for girders and 25 MPa for slab. The modulus of elasticity for girders and slab are respectively 26800 MPa and 24500 MPa.

2.2. Results of Analyses Three dimensional finite element analyses of straight and skew bridges with skew angles ranging from 15 to 60 degrees are performed. Both linear time history and response spectrum analyses method were carried out to investigate the bridge response. The response of link slab bridge is compared with that of simply supported bridge with an expansion joint.

2.2.1. Dynamic characteristic Figure 7 shows periods of vibration of the first two modes at various skew angles. The periods of vibration are shown for both link slab bridges and bridges with expansion joint in the middle. In all cases the first mode of vibration is the translation of superstructure in longitudinal direction and the second mode of vibration is primarily the translation in transverse direction. In the first mode, the superstructure vibrates primarily on rubber bearings in the longitudinal direction and the period is not significantly influenced by type of joint construction or skew angle. In the second mode, the superstructure and the interior bent vibrate in transverse direction and period of vibration increases with increasing skew angle. This period of vibration is reduced significantly when link slab replaces the expansion joints in bridges.

2.2.2. Spectrum analysis Spectrum analyses are performed using the acceleration spectrum of Iranian seismic design code [5] for soil type II. This type of soil is defined by the Iranian seismic design code as a stiff soil that transmit shear waves a rate between 375 to 750 meters per second. Figure 8 shows design acceleration spectrum of the Iranian seismic code.

Seismic loads are applied in either longitudinal or transverse direction. The results of analyses indicate that when seismic load is applied in longitudinal direction, the responses of the interior

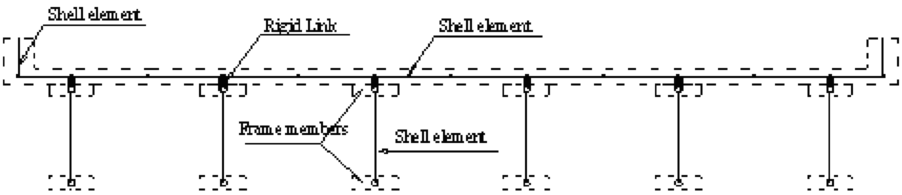


Figure 6. FEA representation of the superstructure.

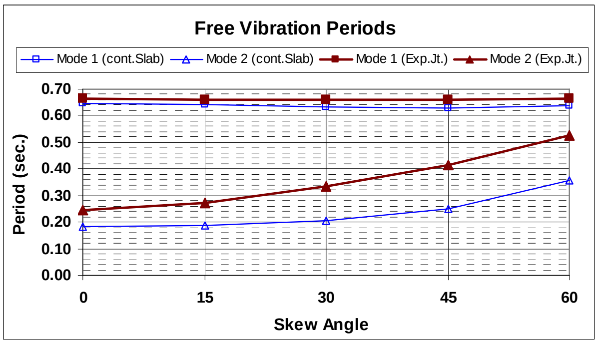


Figure 7. Natural period of vibration.

bent for the two types of joint constructions are not significantly different from each other. However when seismic load is applied in transverse direction, the response of interior bent differ considerably. Figure 9 shows the distribution of transverse base shear in various component of the bridge for two different skew angles. The columns of the interior bent are represented by support nos. 8-10, the rubber bearings on the abutments are represented by support nos. 2-7 and 11-16, and the shear keys on the abutments are represented by support nos. 1 and 17. Figure 9 indicates that shear forces in the columns reduce significantly when link slabs replaces expansion joints. This reduction is more profound in low skew bridges. The reduction of columns shear forces is accompanied by a significant increase of the shear key forces on the abutments.

Figure 10 shows maximum bending moment of the columns for transverse loading condition. Figures 11 and 12 show maximum axial force and torsional moment of the columns for the same loading condition. These figures indicate the force responses of the column are significantly reduced when link slabs replace expansion joints.

Figure 13 shows lateral displacement of the interior bent for the transverse loading condition. This figure shows that lateral displacement increases with skew angle. It also indicates that the displacement is reduced significantly when link slabs replace expansion joints.

2.2.3. Time history analyses Time history analyses are performed using acceleration time history records of (1) El Centro 1970, (2) Tabas 1978 and (3) Manjil 1990 earthquakes. The records are scaled such that their average response in periods ranging from 0.1 second to 1.0 second

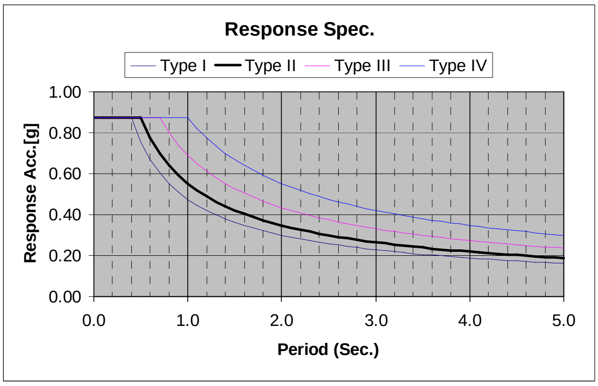


Figure 8. Acceleration spectrum.

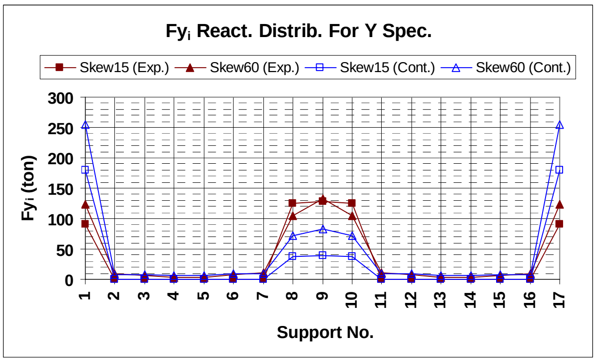


Figure 9. Base shear distribution for transverse loading condition.

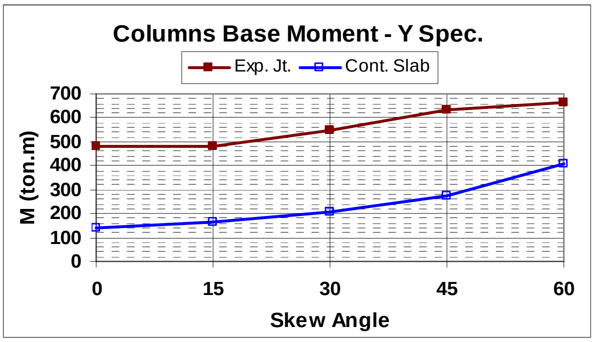


Figure 10. Maximum bending moment of bent columns.

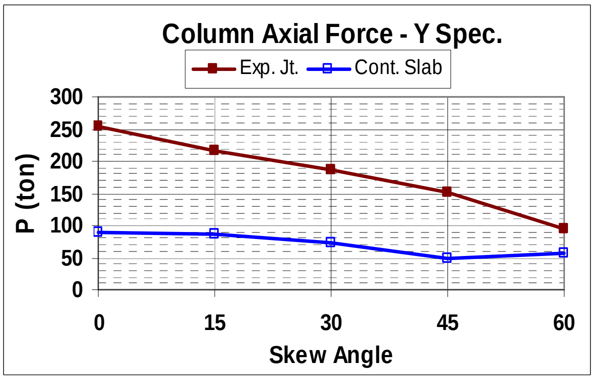


Figure 11. Maximum axial load of bent columns.

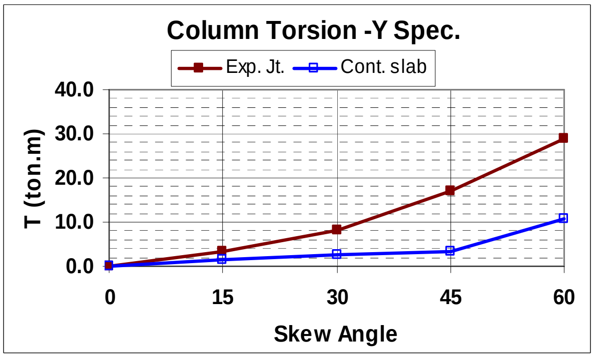


Figure 12. Maximum torsional moment of bent columns.

corresponds with the acceleration spectrum of Standard 2800 for soil type II. Figure 14 shows the acceleration spectrum of the scaled records with 5 % damping. Figure 15 show the scaled acceleration history records. All three scaled records have a PGA of 0.51 g.

Figure 16 shows peak lateral displacement of the interior bent when the time history records are

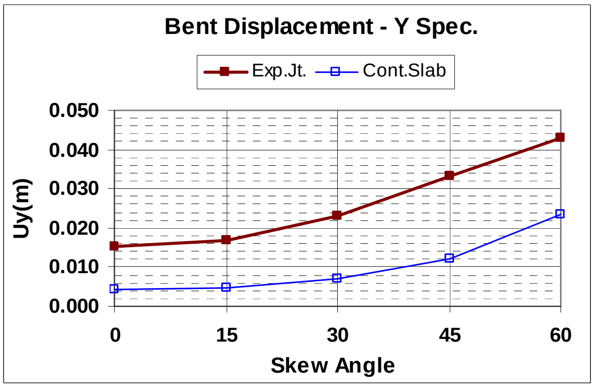


Figure 13. Lateral displacement of the interior bent.

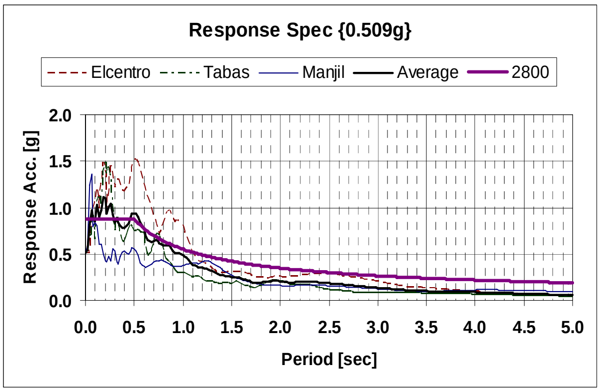


Figure 14. Acceleration spectrum.

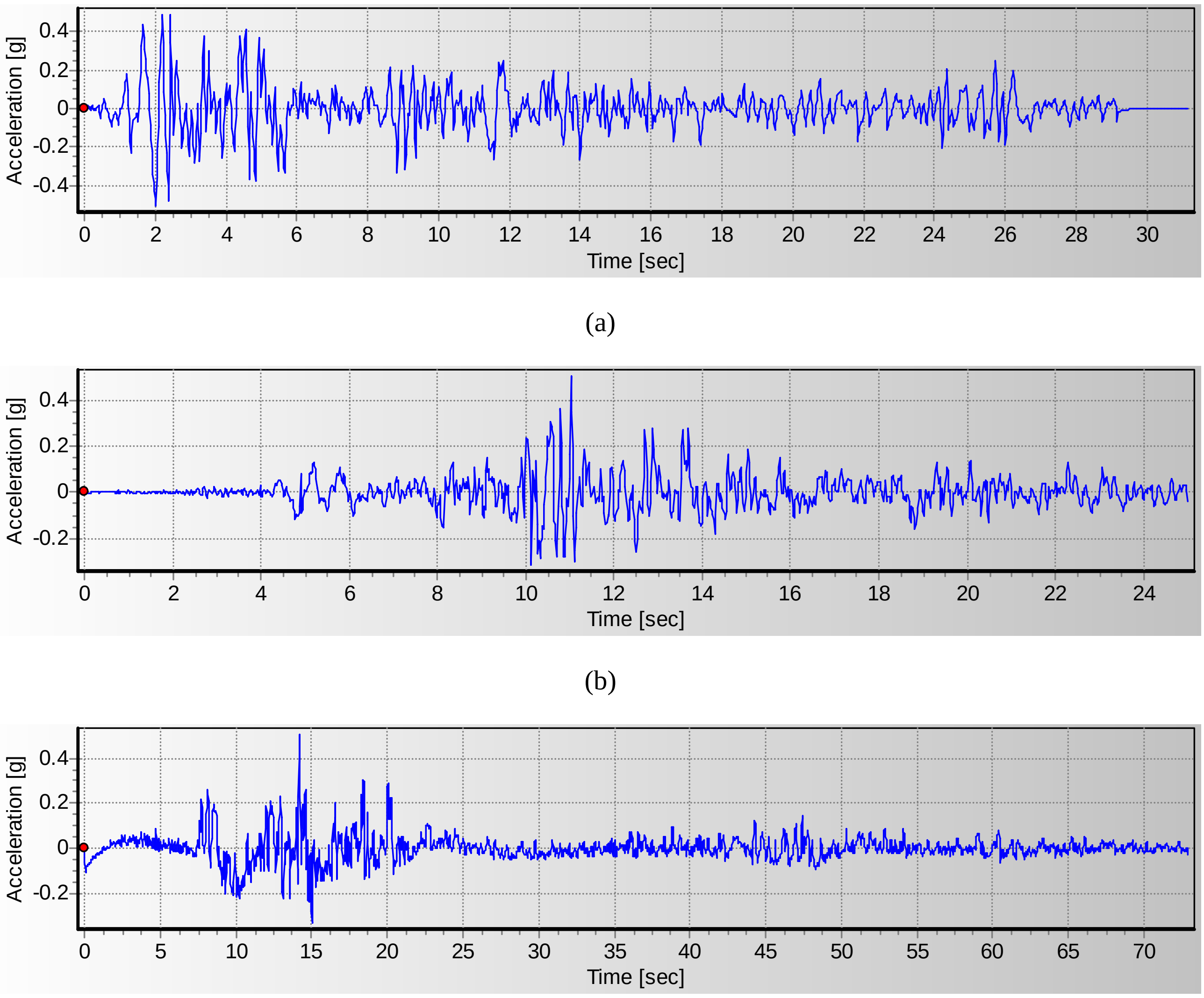
applied in transverse direction. The general trend is similar to the results of spectrum analysis (see Figure 13). While increasing with skew angle, the displacement of link slab bridge is significantly less than that of conventional bridge.

Figure 17 shows time history for lateral displacement of the interior bent for 45 degree skew angle. This figure also indicates the displacement response of link slab bridge is less than that of conventional bridge.

The results of time history and spectrum analyses clearly indicate that force and displacement demands of the interior bent of two span straight or skew bridge are reduced considerably when link slab is used instead of an expansion joint in the middle of the bridge. This reduction is however accompanied by an increase in force demand of shear keys on the abutments. Such results implies that replacements of expansion joints with link slabs could be an effective tool for seismic retrofitting of multi-span simply supported bridges where seismic demands on interior bents or foundations are higher than their capacities.

3. CONCLUSIONS

Seismic performance of straight and skew bridges with link slabs is considerably different from that of bridges with expansion joints when seismic load is applied in transverse direction. Seismic demand of the interior bent of a link slab bridge is significantly lower than that of a bridge with an expansion joint.



(a)

(b)

(c)

Figure 15. Scaled acceleration time history records, (a) El centro, (b) Tabas and (c) Manjil.

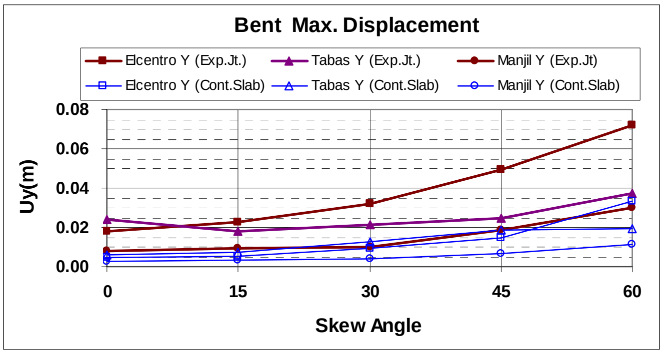
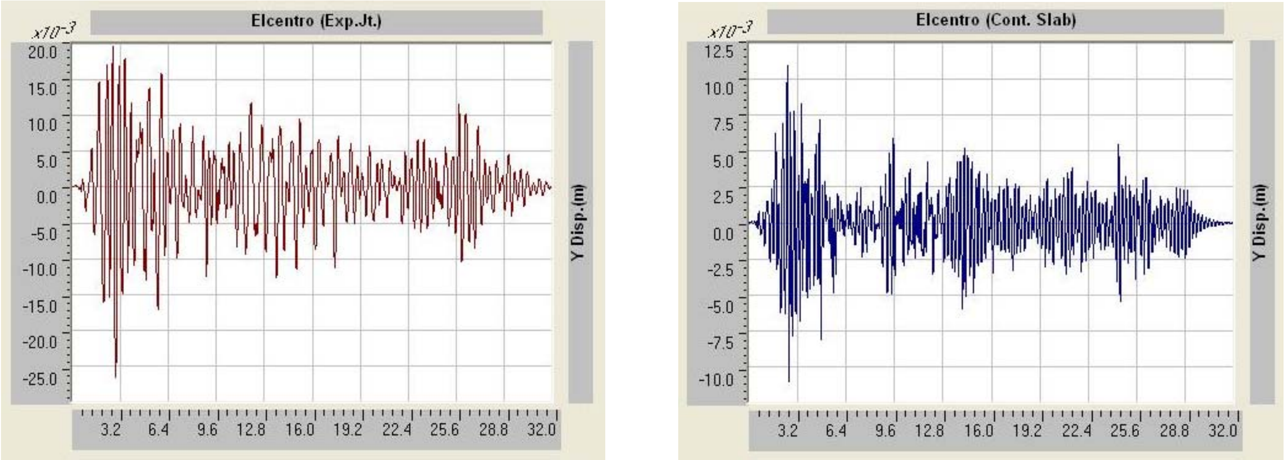
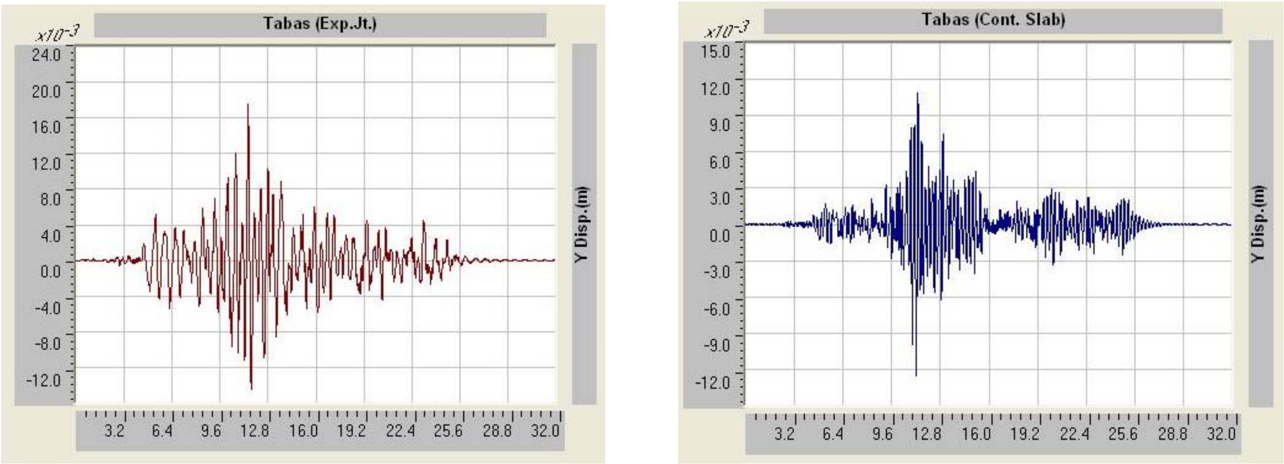


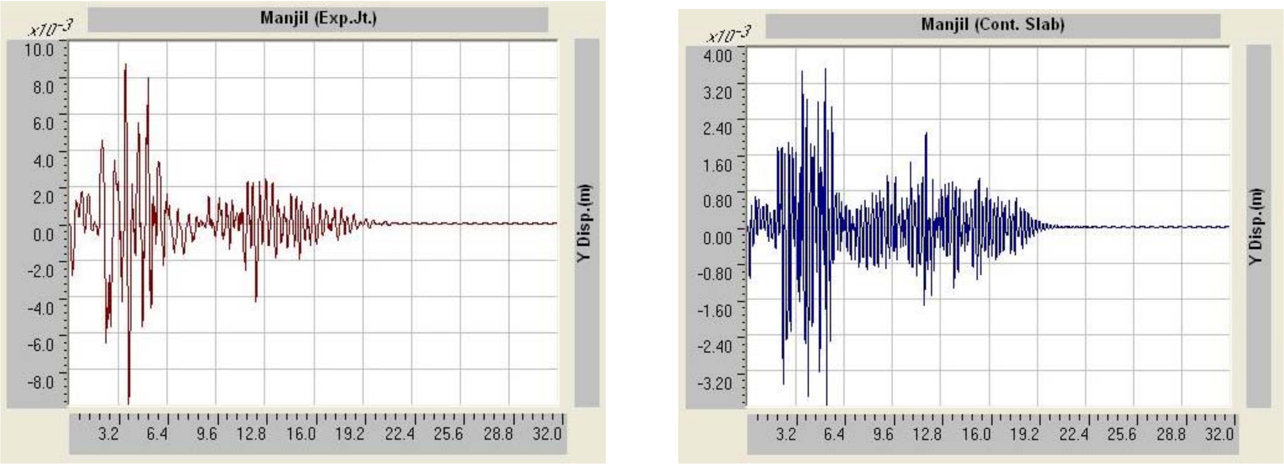
Figure 16. Peak lateral displacement of interior bent.



(a)



(b)



(c)

Figure 17. Time history displacement response of bent, (a) El centro, (b) Tabas and (c) Manjil.

The demand on the abutment is higher when link slabs are used instead of expansion joints.

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