Nat. Volatiles & Essent. Oils, 2021; 8(5): 2923-2934

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Seismic Response of a Three Span Continuous Bridge Isolated with And Without Friction Pendulum System

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ABSTRACT

Seismic response of a three span deck slab continuous bridge isolated with and without Friction pendulum bearing is studied. Friction pendulum bearing is one type of sliding bearing which is used as an isolator in reducing seismic response of a structure. Linear time history analysis is carried out using SAP2000 to find the seismic response of the bridge. El Centro, Northridge, Kobe ground motion records are considered for the linear time history analysis. The main response parameters considered are such as base shear, deck displacement and structural time period. Also, the effectiveness of the isolation system (FPS) is compared to the bridge with non isolated condition in terms of its response parameter.

Keywords: Base isolation, Friction Pendulum bearing (FPB), Continuous Bridge.

1. INTRODUCTION

In earthquake resistant design of structures the non structural components of the structure get collapsed and also the structural components get impaired after earthquake. The structure becomes unserviceable after earthquake. Base isolation is one of an appreciated approach where the non structural components also are able to withstand loads after earthquake. In base isolation the earthquake forces are filtered out in the interface between the foundations to superstructure. Most important structures like bridges and hospitals have to be in service for rehabilitation of life after earthquake. Bridges are generally designed with conventional Sliding bearing, elastomeric rubber bearing which can resist vibration due to the traffic load and it can sustain minor earthquake if the bridge is designed for seismic loading.

2. LITERATURE REVIEW

Several studies were made on the investigation of effectiveness of isolation system for bridges. The most recent research was about the use of sliding system with pendulum response known as Friction pendulum system. R.S Jangid [2, 3] has done an extensive study on seismic behavior of isolated bridges and concluded that with increase in base isolation period the optimum friction coefficient of FPS decreases and also found that optimum friction coefficient of FPS increases with increase in intensity of ground motion. Kim & Yun [13] have investigated seismic response of bridges using Double concave friction pendulum system i.e two different radius of curvature in two different directions. Murat Eroz [8] has studied about the effect of modeling parameters and assumptions on the response of a multi span continuous bridge model seismically isolated by FPS. Jangid R.S and Panchal V.R [4] studied an advanced isolator variable curvature friction pendulum system under near fault ground motions in which the radius of concave surface varied with isolator displacement. Jose et al [5] investigated the physical model for FPS which incorporated in existing software packages and developed a new model which accounts large deformation, P-δ, sticking, impact in the structural response. Toshiyuki Sugiyama [11] compared the effectiveness of isolation with sliding bearing to that of laminated bearing. Murat Diceli [7] investigated the provision of supplemental elastic stiffness for seismically isolated bridge to control the isolator displacement. Ying Hui Lei et al [14] have developed analytical scheme for developing stressed condition of isolators in curved bridges and analyzed behavior of bridges under seismic event.

3. FRICTION PENDULUM BEARING

Friction Pendulum Bearings is one type of base isolation systems.[9,10] In this system specially designed concave surfaces are used to isolate the superstructure from the substructure and allowed to sway under seismic forces. FPB consists of top plate, bottom plate and articulated slider on spherical curved surface with Polytetrafluoroethylene (PTFE) as shown in fig2. The operation of the bearing is the same whether the concave surface is facing up or down. The FPB system consists of two plates, the upper plate is attached under the bridge super structure and lower plate is attached on top of the pier. The weight of the structure is supported on articulated slider and get activated when the external forces exceeds the frictional force at the interface. A Friction Pendulum supported structure responds like a conventionally supported structure when the earthquake forces are below the friction force level, at its non-isolated period of vibration. FPB isolator works on the same principal as a simple pendulum. Thus fundamental period of the structure is shifted and depends upon the radius of curvature.

It is functionally equal to the existing bearing such as Lead Rubber Bearing in lengthening the structures fundamental period with additional advantage of restoring capability, temperature resistance and durability. The goal of the study is to capture the seismic response of bridges isolated with Friction Pendulum Bearing. For this present study a typical RCC deck slab three span continuous bridges is considered [6, 12].

3.1 Mechanical Properties of FPB:

One of an important parameter is the structural time period which influences the structural response and mainly depends upon the mass and stiffness of the structure. The natural period of this bearing is independent of mass and mainly depends upon the radius of the curvature due to its geometry which resembles pendulum response.

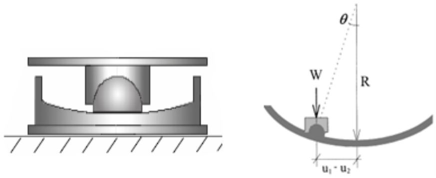


Fig 1. Friction Pendulum Isolator

Isolated time period $\mathrm{T} = 2\pi \sqrt{\frac{\mathrm{R}}{\mathrm{g}}}$

Where R= radius of the spherical surface
g = acceleration due to gravity
Restoring force = K_r x
Where x= deformation

If the isolator is considered as single degree of freedom oscillator with stiffness K and mass m, then $K_r = m\omega_r$

Where $\omega_{r} =$ isolator frequency
Then $F = m\,\omega_{r}^{2} x$,
For the conventional spherical surface the frequency

$$\omega r = \sqrt{\frac{R}{g}}$$

The lateral stiffness of the bearing providing the restoring capability of the system $k = mg/R$
In this study isolated period of the bearing is taken as 1.5 seconds. The co-efficient of friction $\mu = 0.05$, by static analysis the effective stiffness of the isolator considering restoring force and friction force,
Effective stiffness $K = [(1/R) + (\mu/D)]\ W$
Where W = weight of the structure on the bearing D= design displacement

3.2 Idealized Hysteric Loop for FPS:

The idealized hysteretic loop for FPS is shown in Fig 2. which is approximately rigid plastic with post yielding hardening. The actual hysteresis loop is more complex, which depends on series of factors. One of the important factor which makes the hysteresis loop complex is its strong dependence of its response on the axial force variation on the device.

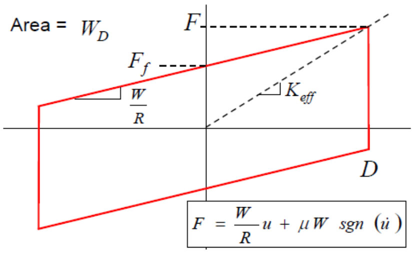


Fig 2. Idealized Hysteric Loop for FPS

4. A THREE SPAN CONTINUOUS DECK SLAB BRIDGE ISOLATED WITH FPS

The bridge taken for the study is solid deck slab continuous bridge with three spans each 20m as shown in Fig.3. The cross section of the bridge is with 3m width and 1 m depth. The pier dimension is 3mx1m. The bottom of the pier is resting on rock stratum. Youngs modulus of deck and pier is taken as 2.2×10^{7} kN/m^{2}

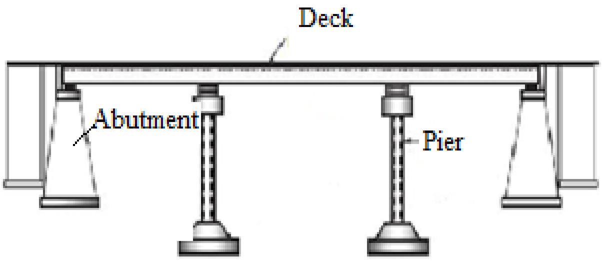


Fig 3. Three Span Continuous Deck Slab Bridge

5. MODELLING AND ANALYSIS

5.1 Modeling of the Non Isolated Three Span Continuous Deck Slab Bridge:

Structural analysis software SAP 2000 is used to model the bridge. The bridge deck and pier is modeled using frame elements. The abutment is modeled by spring element. The pier is connected to the deck slab by a linear link element in which directions and rotation are restrained as per the pinned condition requirement. The bottom of the pier is considered as fixed. A Constant damping of 0.05 is taken for the deck and pier. The weight of the structure on the pier is 1500 kN. A three span continuous deck slab bridge properties are listed in the Table1.

Table.1. Properties of the Three Span Continuous Deck Slab Bridge

Properties	**Super structure**	**Pier**
Area (m^2)	3.0	3.0
Moment of Inertia (m^4)	2.08	0.64
Young's modulus(kN/m^2)	$2.2x10^7$	$2.2x10^7$
Span/height (m)	20	8

The governing dynamic equation of motion of the bridge is $M[\ddot{x}] + C[\dot{x}] + K[x] = \{F(t)\}$

[M] and [C] are the mass and damping matrix respectively.

$[\ddot{x}]$, $[\dot{x}]$ and $[x]$ are the acceleration, velocity and displacement vectors.

$F(t)$ is the nodal load vector which is calculated using the equation.
$\{ F(t)\} = -M\{I\}\, \ddot{u}_g$(t)

Where $\ddot{u}_g$(t) is ground acceleration; I is influence vector.

5.2 Modeling of the isolated Three Span Continuous Deck Slab Bridge:

The same bridge is modeled for the isolated condition with FPS. The bridge is isolated along the longitudinal direction. The pier is connected to the deck slab by a link element in which the calculated stiffness (k=2678kN/m) is assigned. The bottom of the pier is considered as fixed.

The governing equation of motion of the isolated bridge under sliding is $M[\ddot{x}] + C[x] + K[x] = \{F(t)\}$+$F_b$

Where F_b is isolator force which consists of frictional force and restoring force.

5.3 Analysis of the Three Span Continuous Deck Slab Bridge with and without FPS:

The three span continuous deck slab bridge with and without FPS is subjected to normal component of ground motions in its longitudinal direction. Modal linear time history analysis [1] is carried out for finding the dynamic response. The ground motions considered for the study are the N-S component of El Centro 1940, Northridge 1994, and Kobe 1995. These data are scaled to 0.2g. Earthquake data considered is shown in Table 2.

Table 2. Earthquake Data

Earthquake data	**PGA (m/sec^2)**	**Duration (Sec)**
Elcentro	3.417	91.38
Northridge	8.27	60
Kobe	8.18	149.98

Where, PGA means Peak Ground Acceleration.

6. RESULTS FOR A THREE SPAN CONTINUOUS DECK SLABE BRIDGE

6.1 Time Period

One of an important parameter is the structural time period for seismic response of a structure. The bridge is isolated in longitudinal direction. Modal analysis is carried out to find the natural modes. The structural time period for the first 4 modes for the bridges are listed in Table 3. From the analysis of the non isolated bridge 99% of mass participates in the first mode along x direction and 70.4% of mass participates in transverse direction.

For the isolated bridge 87.61% of mass participates along x direction in the first mode. 67.83% mass participates along y direction in the second mode.

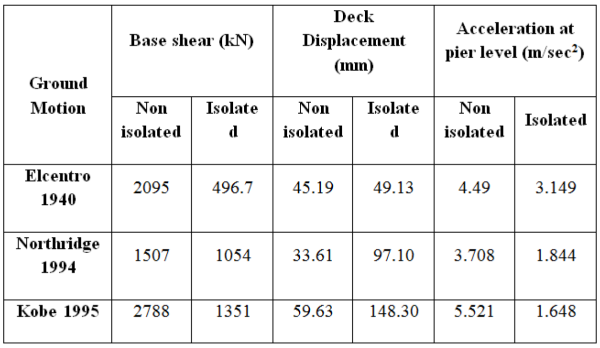
Table 3. Structural Time Period For the First 4 Modes

Time Period	Mode 1	Mode 2	Mode 3	Mode 4
Non isolated	0.638	0.189	0.147	0.046
Isolated	1.35	0.190	0.148	0.140

5.2 Base Shear, Deck Displacement and Acceleration at top of Pier Level on Three Span Continuous Deck Slab Bridge (TSCDSB):

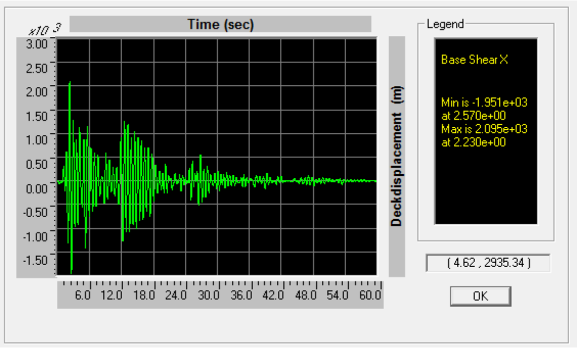
For various ground motions, the important parameters like base shear, deck displacement and acceleration at top of pier level are listed in Table 4.

Table 4. Base Shear, Deck Displacement, Acceleration at top of Pier Level for Three Span Continuous Deck Slab Bridge



Ground Motion	Base shear (kN)		Deck Displacement (mm)		Acceleration at pier level (m/sec^2)	
	Non isolated	Isolated	Non isolated	Isolated	Non isolated	Isolated
Elcentro 1940	2095	496.7	45.19	49.13	4.49	3.149
Northridge 1994	1507	1054	33.61	97.10	3.708	1.844
Kobe 1995	2788	1351	59.63	148.30	5.521	1.648

Fig.4 and Fig.5 shows the maximum base shear for the non isolated and isolated three span continuous deck slab bridge for Elcentro Earthquake respectively.

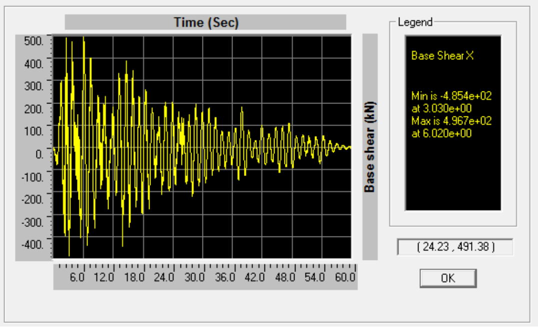


Base Shear X

Min is -1.951e+03
at 2.570e+00
Max is 2.095e+03
at 2.230e+00

(4.62 , 2935.34)

Fig 4. Maximum Base Shear for Non Isolated TSCDSB for Elcentro Earthquake



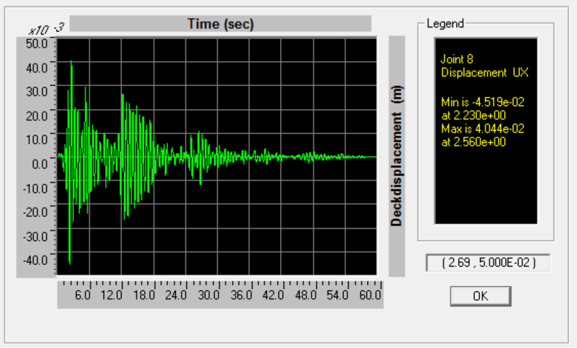
Base Shear X

Min is -4.854e+02
at 3.030e+00
Max is 4.967e+02
at 6.020e+00

(24.23 , 491.38)

Fig 5. Maximum Base Shear for Isolated TSCDSB for Elcentro Earthquake

Fig.6 and Fig.7 shows the maximum deck displacement for the non isolated and isolated three span continuous deck slab bridge for Elcentro Earthquake respectively.

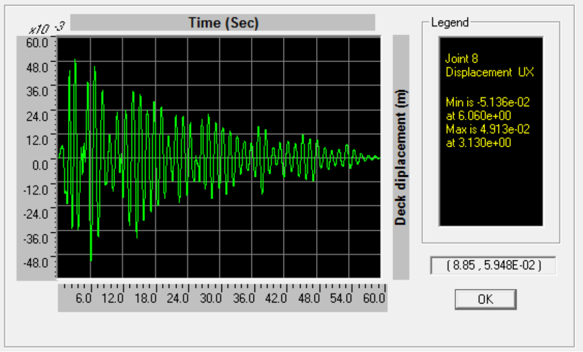


Joint 8
Displacement UX

Min is -4.519e-02
at 2.230e+00
Max is 4.044e-02
at 2.560e+00

(2.69 , 5.000E-02)

Fig 6. Maximum Deck Displacement for Non Isolated TSCDSB for Elcentro Earthquake



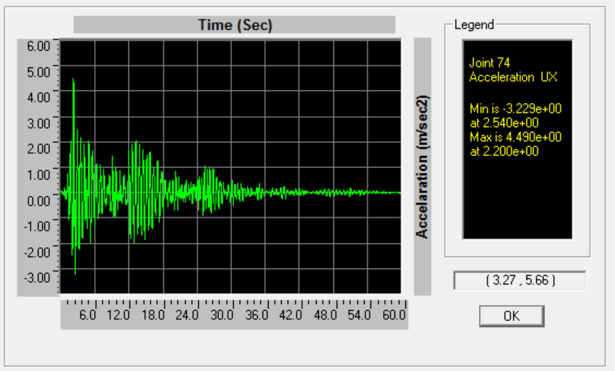
Joint 8
Displacement UX

Min is -5.136e-02
at 6.060e+00
Max is 4.913e-02
at 3.130e+00

(8.85 , 5.948E-02)

Fig 7. Maximum Deck Displacement for Isolated TSCDSB for Elcentro Earthquake

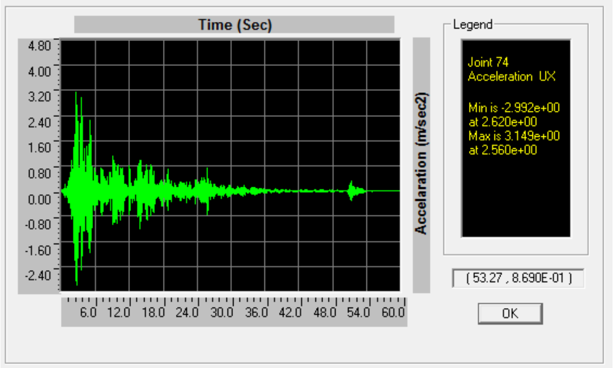
Fig.8 and Fig.9 shows the maximum acceleration at top of pier level for the non isolated and isolated three span continuous deck slab bridge for Elcentro Earthquake respectively.


Joint 74
Acceleration UX

Min is -3.229e+00
at 2.540e+00
Max is 4.490e+00
at 2.200e+00

(3.27 , 5.66)

Fig 8. Shows Maximum Acceleration at top of Pier Level for Non Isolated TSCDSB for Elcentro Earthquake

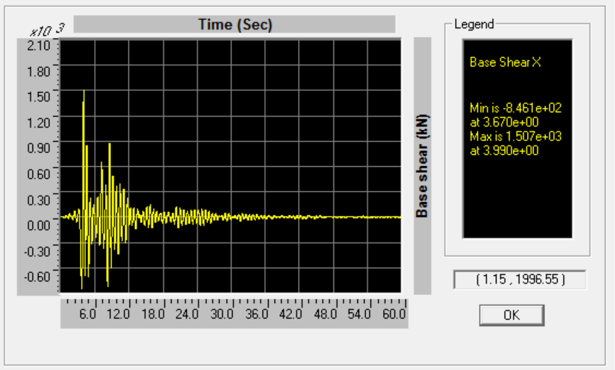

Joint 74
Acceleration UX

Min is -2.992e+00
at 2.620e+00
Max is 3.149e+00
at 2.560e+00

(53.27 , 8.690E-01)

Fig 9. Maximum Acceleration at top of Pier Level for Isolated TSCDSB for Elcentro Earthquake

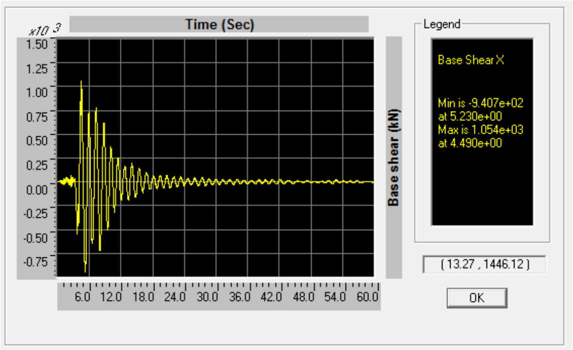
Fig.10 and Fig.11 shows the maximum base shear for the non isolated and isolated three span continuous deck slab bridge for Northridge Earthquake respectively.


Base Shear X

Min is -8.461e+02
at 3.670e+00
Max is 1.507e+03
at 3.990e+00

(1.15 , 1996.55)

Fig 10. Maximum Base Shear for Non Isolated TSCDSB for Northridge Earthquake



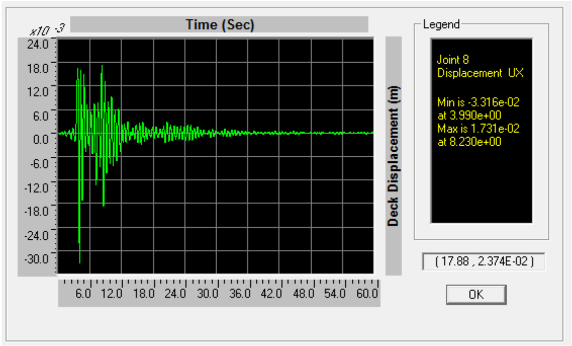
Base Shear X

Min is -9.407e+02
at 5.230e+00
Max is 1.054e+03
at 4.490e+00

(13.27 , 1446.12)

Fig 11. Maximum Base Shear for Non Isolated TSCDSB for Northridge Earthquake

Fig.12 and Fig.13 shows the maximum deck displacement for the non isolated and isolated three span continuous deck slab bridge for Northridge Earthquake respectively.

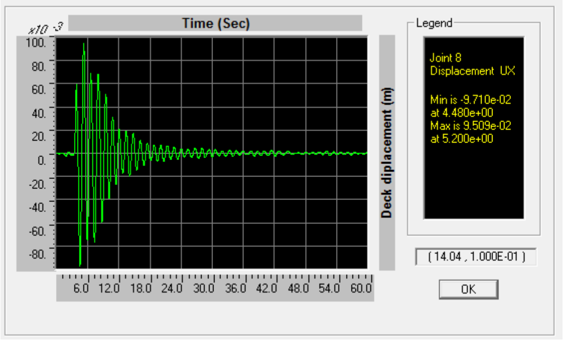


Joint 8
Displacement UX

Min is -3.316e-02
at 3.990e+00
Max is 1.731e-02
at 8.230e+00

(17.88 , 2.374E-02)

Fig 12. Maximum Deck Displacement for Non Isolated TSCDSB for Northridge Earthquake



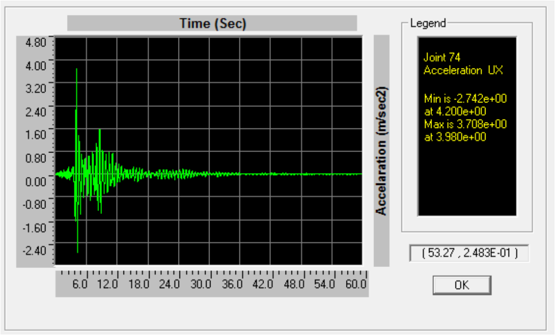
Joint 8
Displacement UX

Min is -9.710e-02
at 4.480e+00
Max is 9.509e-02
at 5.200e+00

(14.04 , 1.000E-01)

Fig 13. Maximum Deck Displacement for Isolated TSCDSB for Northridge Earthquake

Fig.14 and Fig.15 shows the maximum acceleration at top of pier level for the non isolated and isolated three span continuous deck slab bridge for Northridge Earthquake respectively.



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Joint 74
Acceleration UX

Min is -2.742e+00
at 4.200e+00
Max is 3.708e+00
at 3.980e+00
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( 53.27 , 2.483E-01 )
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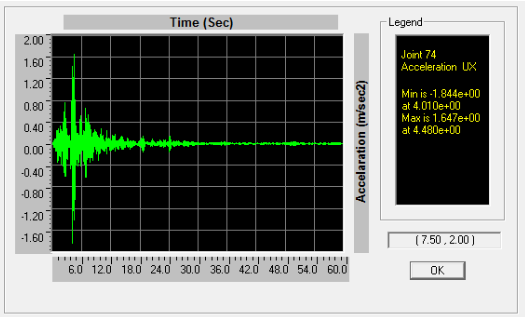
Fig 14. Maximum Acceleration at top of Pier level for Non Isolated TSCDSB for Northridge Earthquake



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Joint 74
Acceleration UX

Min is -1.844e+00
at 4.010e+00
Max is 1.647e+00
at 4.480e+00
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( 7.50 , 2.00 )
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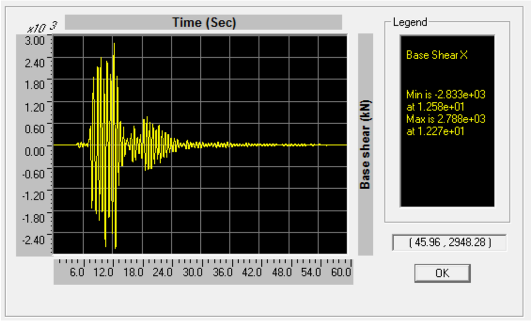
Fig 15. Maximum Acceleration at top of Pier level for Isolated TSCDSB for Northridge Earthquake

Fig.16 and Fig.17 shows the maximum base shear for the non isolated and isolated three span continuous deck slab bridge for Kobe Earthquake respectively.



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Base Shear X

Min is -2.833e+03
at 1.258e+01
Max is 2.788e+03
at 1.227e+01
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( 45.96 , 2948.28 )
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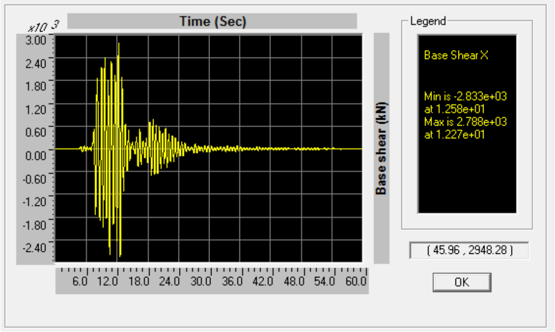
Fig 16. Maximum Base Shear for Non Isolated TSCDSB for Kobe Earthquake



```
Base Shear X

Min is -2.833e+03
at 1.258e+01
Max is 2.788e+03
at 1.227e+01
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( 45.96 , 2948.28 )
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Fig 17. Maximum Base Shear for Isolated TSCDSB for Kobe Earthquake

Fig.18 and Fig.19 shows the maximum deck displacement for the non isolated and isolated three span continuous deck slab bridge for Kobe Earthquake respectively.

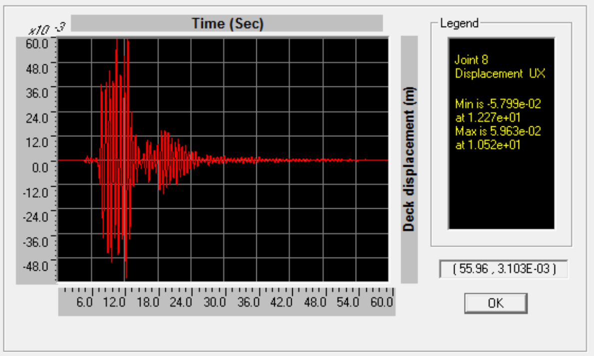


Fig 18. Maximum Deck Displacement for Non Isolated TSCDSB for Kobe Earthquake

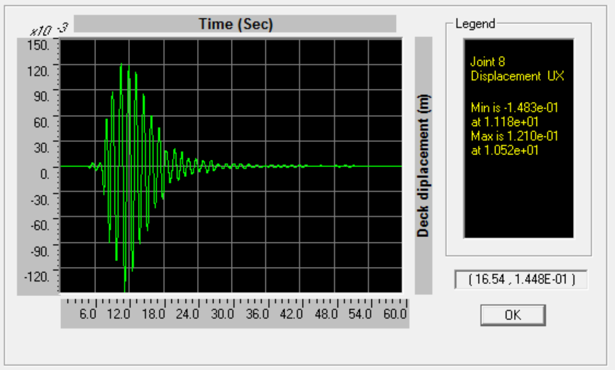


Fig 19. Maximum Deck Displacement for Isolated TSCDSB for Kobe Earthquake

Fig.20 and Fig.21 shows the maximum Acceleration at top of Pier level for the non isolated and isolated three span continuous deck slab bridge for Kobe Earthquake respectively.

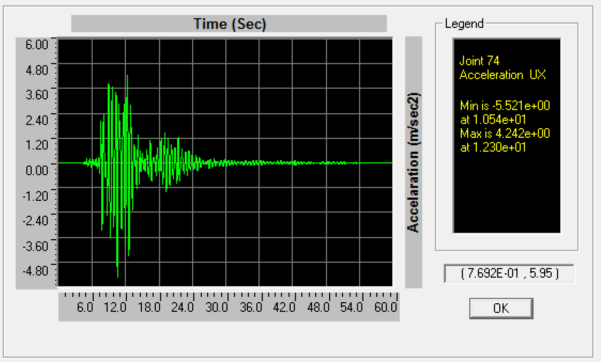
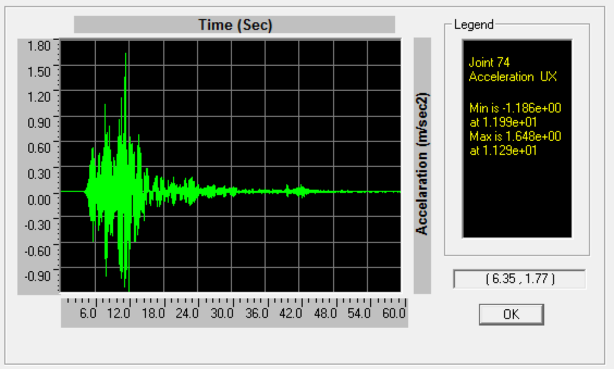


Fig 20. Maximum Acceleration at top of Pier level for Non Isolated TSCDSB for Kobe Earthquake



Joint 74
Acceleration UX

Min is -1.186e+00
at 1.199e+01
Max is 1.648e+00
at 1.129e+01

Fig 21. Maximum Acceleration at top of Pier level for Isolated TSCDSB for Kobe Earthquake

6. CONCLUSIONS

The seismic response of the three span continuous deck slab bridge isolated with and without FPS has been studied for three types of ground motions namely Elcentro, Northridge, and Kobe. There is shift in structural fundamental time period from 0.64 sec to 1.35 seconds in the first mode for the three span continuous deck slab bridge. Hence the shift in fundamental period makes the structure flexible under earthquake.

The base shear of the three span continuous deck slab bridge structure after isolation is greatly reduced. Thus Friction pendulum systems greatly reduce the adverse effect of earthquake by increase in fundamental period and decrease in base shear. This bearing has good re-centering capability and residual displacement is greatly eliminated and additional damping system along with the isolation device can control the deck displacement.

7. ACKNOWLEDGEMENT

The authors thank the Principal and the Head of the Department of Civil Engineering and for providing the necessary facilities and guidance to complete the work successfully.

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