International Journal of Advance Engineering and Research Development
Scientific Journal of Impact Factor (SJIF): 4.72
Special Issue SIEICON-2017,April -2017
e-ISSN : 2348-4470 p-ISSN : 2348-6406

SEISMIC RESPONSE OF ISOLATED SKEW BRIDGE UNDER NEAR-FAULT GROUND MOTIONS

Durgesh Zala [1], Ms Neha Chauhan[2], Dr. V. R. Panchal[3], Dr. D. P. Soni[4]

[1] P. G. Student, M. S. Patel Department of Civil Engineering, CSPIT, CHARUSAT, Changa, Gujarat, (India)
[2] Assistant Professor, M. S. Patel Department of Civil Engineering, CSPIT, CHARUSAT, Changa, Gujarat, (India)
[3] Professor and Head of Department, M. S. Patel Department of Civil Engineering, CSPIT, CHARUSAT, Changa, Gujarat, (India)
[4] Head of Civil Engineering Department, Sardar Vallabhbhai Patel Institute of Technology, Vasad, Gujarat, (India)

Abstract —*Bridges are the most important structures of the transportation system. Past earthquake shows that skew bridges are more vulnerable to the ground motions as compared to non skew bridges. A few studies have been carried out regarding responses of skew bridges. The present study focuses on evaluating the performance of The Triple Friction Pendulum System (TFPS)-isolated skew bridges under the near-fault ground motions. TFPS is an adaption of single concave friction pendulum system. Skew Bridges are designed at the interval of 10° from 0° to 50°. Responses of the bridges are obtained in the direction along the length of the bridge with different near-fault ground motions. The result shows that TFPS decreases the effect of skew angle in isolated bridges as compared to non-isolated bridges.*

Keywords- *Seismic Response, Skew Bridge, Isolation System, Time History Analysis, Triple friction pendulum system*

I. INTRODUCTION

Skew angle of bridge is defined as the angle made by the bents or abutments with the axis along the transverse direction of the bridge. The skewness of the structure result in a different load transfer mechanism in the bridge than the normal bridge. The seismic damage of the skew bridges is more as compared to normal bridges. Failure of the bridges will result in major economy losses and also result in loss of life. Hence, safety, serviceability and performance of bridges and its components under all loading scenarios are important. Structural control systems interact between structure and earthquake motion, and reduce the structural damage. New techniques are developed with sliding isolation system. Sliding isolation devices are one of the most popular and effective isolation system for seismic isolation. The simplest sliding system is pure friction isolation system. From past research, it is concluded that there is a lack of study regarding isolated skew bridge. This study deals with the effect of skew angle on different response quantities such as bearing displacement, deck acceleration and base reactions with or without TFPS-isolated bridges.

II. LITERATURE SURVEY

Haque and Bhuiyan (2002) studied the seismic response of simple span concrete deck girder skewed bridge. They considered two type of earthquake time history for the analysis; one with large amplitude and long duration and the other one with strong acceleration and short duration. They concluded that the seismic responses are affected with the change of skew angles. The maximum value of the bearing reactions attains at the exterior girder. From the research, it is found that increase in skew angle, increase in all the responses like base shear, deck acceleration and bearing reactions of the bridge. Jangid and Kunde (2006) investigated the seismic response of isolated bridge with different isolation system. They considered multi-span continuous bridge. For the analysis, they have considered different earthquake ground motions and compared their responses. The parameters selected are the flexibility of the deck and piers. Kothari and Murnal (2015) investigated the seismic analysis of skew bridges by using finite element software SAP 2000. They considered two earthquake ground motion records. The selected bridge is single span simply supported bridge with different skew angle vary from 10° to 50°. They concluded that there was a significant increase in deck acceleration and bearing reactions of the bridge with increasing in skew angle. The axial force in the external girders is quite more than internal girder. Sompura and Soni (2015) studied the seismic response of asymmetric building using multiple sliding isolation system. The seismic response of one story building with base isolated structure isolated by double concave friction pendulum (DCFP) bearing is investigated. In their study, they considered different isolator, time period and coefficient of friction. They found that displacement of the DCFP system is almost similar to the friction pendulum system (FPS). Patel and Panchal (2016) investigated the seismic response of curved continues bridge isolated with FPS and TFPS. They concluded that TFPS is more effective than FPS.

III. TRIPLE FRICTION PENDULUM SYSTEM

TFPS exibits multiple changes with the change in stiffness and strength with the increase in displacement. This isolators are designed for different level of earthquakes. The stiffness can be changed at different controlled amplitudes. The TFPS consists of two facing concave of stainless steel surfaces. The TFPS offers better seismic perfomance, lower bearing cost and lower construction cost as compared to other isolation systems. The force-displacement relationship is more complex than any other isolation systems.

Table 1 Link Properties of TFPS

	TFPS			
Parameters	Outer Top	Outer Bottom	Inner Top	Inner Bottom
Effective stiffness (kN/m)	119	119	119	119
Elastic stiffness (kN/m)	3427.26	1714.12	571.33	571.33
Friction coefficient fast and slow	0.06	0.03	0.01	0.01
Rate parameter (s/m)	1	1	1	1
Net radius (m)	1.1176	1.1176	0.508	0.508
Stop distance (m)	0.2344	0.1998	0.0476	0.0476

IV. BRIDGE DATA

A single span of 30m T-Girder concrete bridge design using CSi Bridge, finite element software is conducted for the analysis. The four girders are provided and abutments are considered as rigid element. The TFPSs are provided at the top of the abutment and bottom of the girder. The skew angle varies from 0° to 50° at the interval of 10°.

Table 2 Geometry of the bridge

Properties	Specification
Cross section of girder (m^2)	0.3048 × 1.2192
Number of girder	4
Young's modulus of elasticity of concrete (kN/m^2)	25×10^6
Density of concrete (kN/m^3)	24

V. TIME HISTORY DATA

For the seismic response of the bridges, three different near-fault ground motions such as Imperial Valley (1979), Sylmar (1994) and Landers (1992) are used for the analysis. Table 3 shows the peak ground acceleration (PGA), peak ground displacement (PGD) and peak ground velocity (PGV) of near-fault ground motions.

Table 3 Details of earthquake ground motions

Near-fault earthquake ground motions (Normal component)	Recording station	Duration (sec)	PGD (m)	PGV (m/sec)	PGA (g)
1979, Imperial Valley, California	El Centro Array #5	39.42	0.765	0.98	0.37
1994, Northridge, California	Sylmar	36.9	0.311	1.22	0.73
1992, Landers, California	Lucerne Valley	42.284	2.3	1.36	0.71

VI. ANALYSIS RESULTS AND DISCUSSION

After the modal analysis of the bridge, the non linear time history analysis is carried out. The three different ground motions are applied in the longitudinal direction of the bridges. The different response quantities of the skew bridges are compared like base reactions, deck acceleration and bearing displacement.

[1] Base reactions

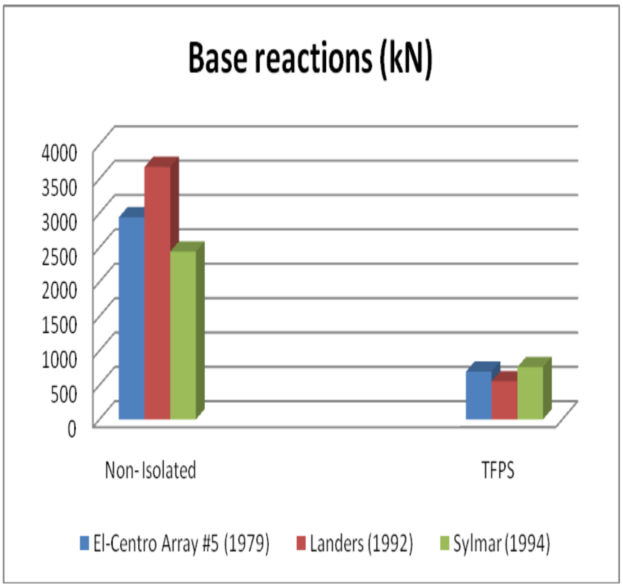

Figure 2 Comparison of base reactions for 0° angle

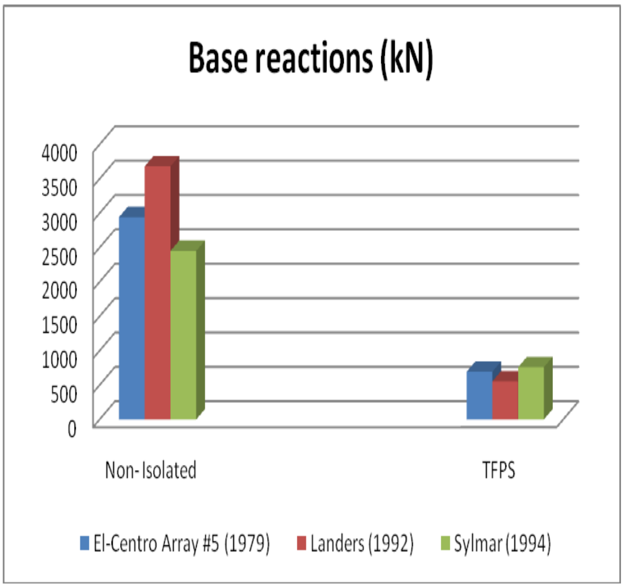

Figure 3 Comparison of base reactions for 10° angle

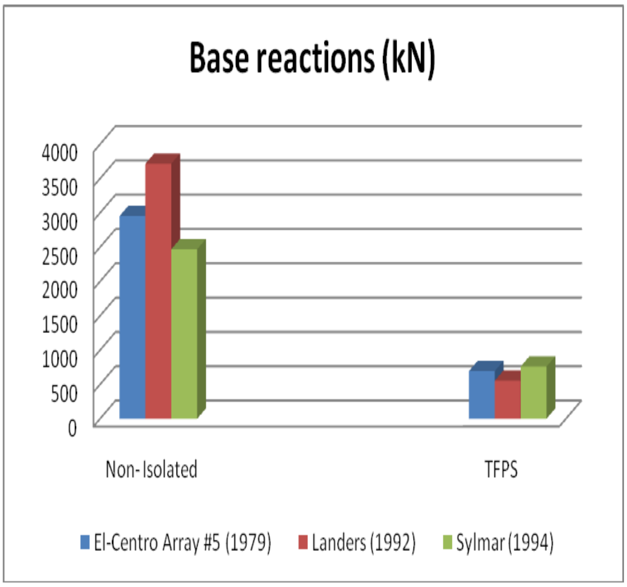

Figure 4 Comparison of base reactions for 20° angle

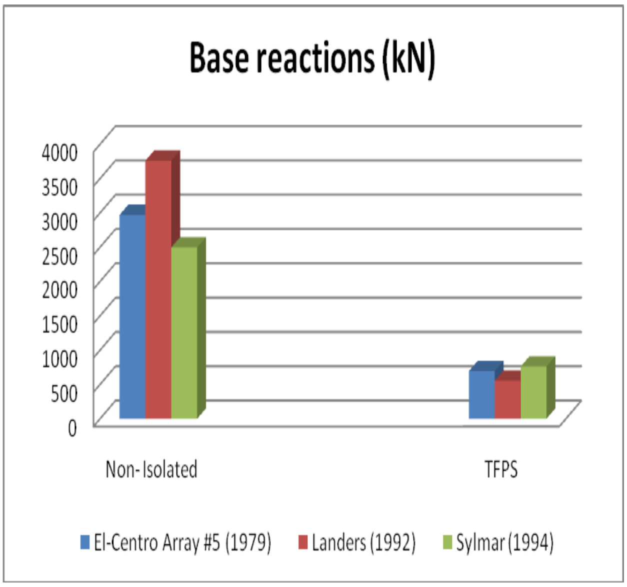

Figure 5 Comparison of base reactions for 30° angle

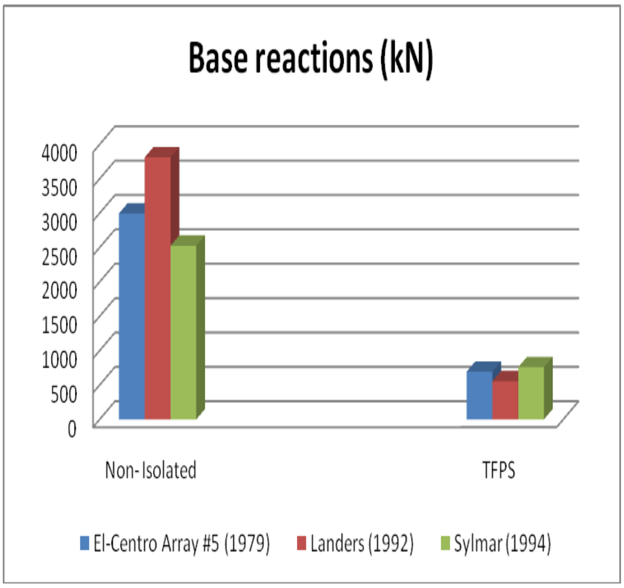

Figure 6 Comparison of base reactions for 40° angle

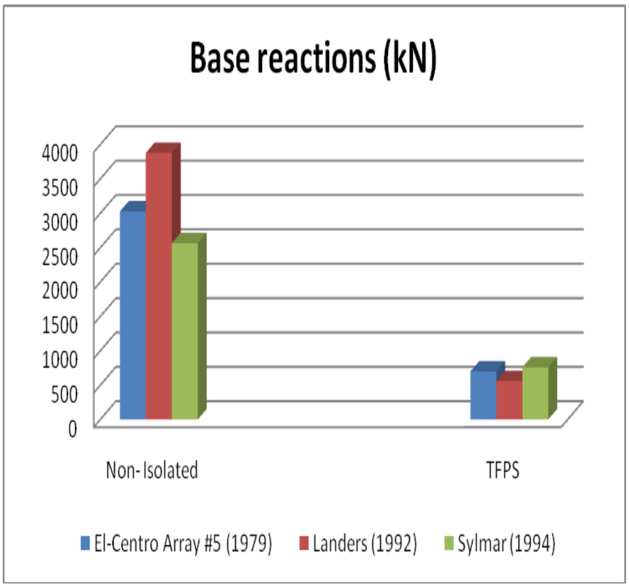

Figure 7 Comparison of Base reactions for 50° angle

Figure 2 to 7 show the comparison of base reactions for non-isolated and TFPS-isolated bridges for 0° to 50° skew angle. These figures represent the results of three different near-fault ground motions. The result shows that for the non-isolated bridges with the increase in a skew angle, base reactions of the bridges also increase. For the TFPS-isolated bridges, the effect of skewness decreases. Tables 4 to 6 represent the increase rate of base reactions for the non-isolated and TFPS-isolated skew bridge. It is observed that the increase rate of base reactions for non-isolated bridges is higher as compared to TFPS-isolated bridges.

Table 4 Comparison of base reactions for El Centro Array #5 (1979)

Base reactions (kN)				
El Centro Array #5 (1979)				
Skew Angle	Non-Isolated	Non-Isolated Increase Rate (%)	TFPS	TFPS Increase Rate (%)
0	2938.15	-	693.121	-
10	2941.746	0.12	693.137	0.0023
20	2952.643	0.37	693.162	0.0036
30	2969.744	0.59	693.53	0.053
40	2996.635	0.90	694.28	0.108
50	3026.332	0.98	696.121	0.378

Table 5 Comparison of base reactions for Lucerne Valley (1992)

Base reactions (kN)				
Lucerne Valley (1992)				
Skew Angle	Non-Isolated	Non-Isolated Increase Rate (%)	TFPS	TFPS Increase Rate (%)
0	3671.074	-	554.224	-
10	3680.567	0.25	554.231	0.0012
20	3715.254	0.93	554.227	0.00072
30	3759.39	1.17	554.636	0.073
40	3812.927	1.14	555.519	0.15
50	3877.56	1.66	558.537	0.54

Table 6 Comparison of base reactions for Sylmar (1994)

Base reactions (kN)				
Sylmar (1994)				
Skew Angle	Non-Isolated	Non-Isolated Increase Rate (%)	TFPS	TFPS Increase Rate (%)
0	2441.2005	-	759.211	-
10	2450.865	0.39	759.234	0.003
20	2469.216	0.74	759.315	0.010
30	2495.538	1.05	759.172	0.018
40	2525.653	2.23	758.728	0.058
50	2563.559	1.47	757.342	0.18

[2] Deck acceleration

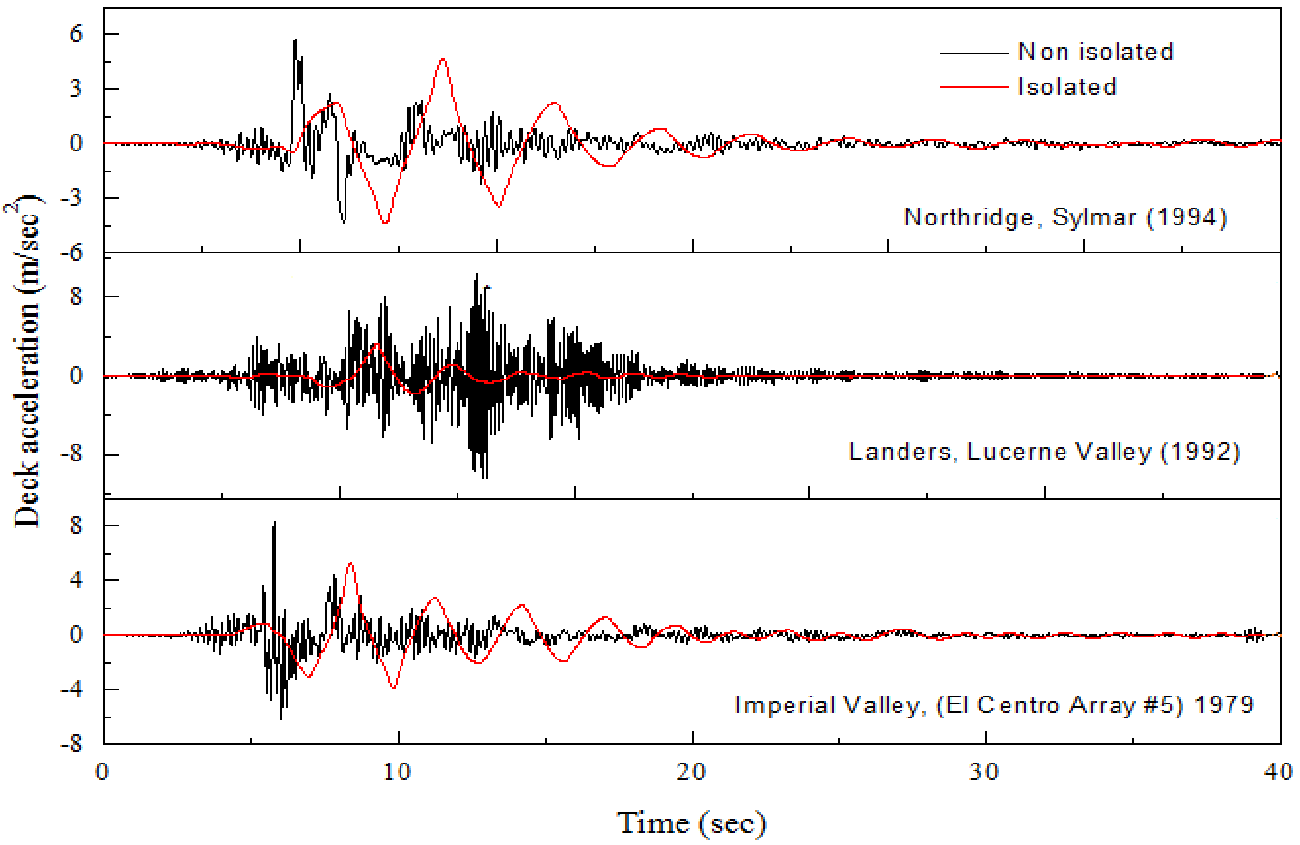

Figure 8 Comparison of deck acceleration for non isolated and isolated bridge (0° Skew Angle)

Figure 8 represents the comparison of deck acceleration for 0° skew angle of non-isolated and TFPS-isolated bridge. The figure shows the result of three different earthquake data for the deck acceleration. Maximum value of deck acceleration under El-Centro Array (1979), Landers (1992) and Sylmar (1994) is 8.296 m/sec^2, 10.5 m/sec^2 and 6.893 m/sec^2, respectively for non-isolated bridges and 5.233 m/sec^2, 3.2701 m/sec^2 and 6.181 m/sec^2, respectively for TFPS-isolated bridges.

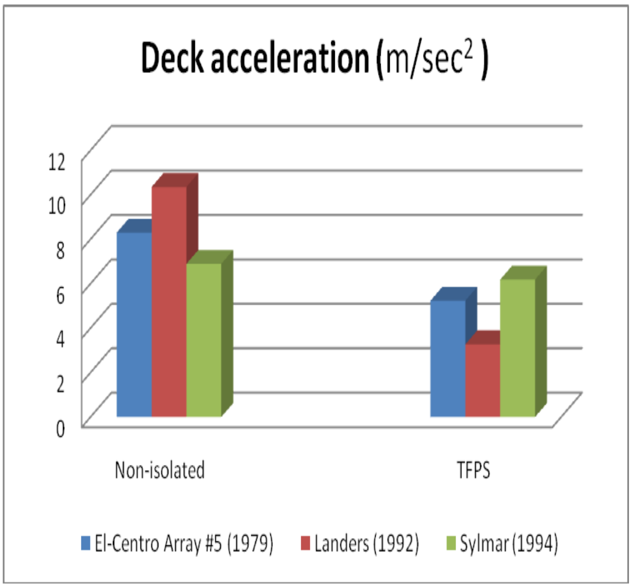

Figure 9 Comparison of deck acceleration for 0° angle

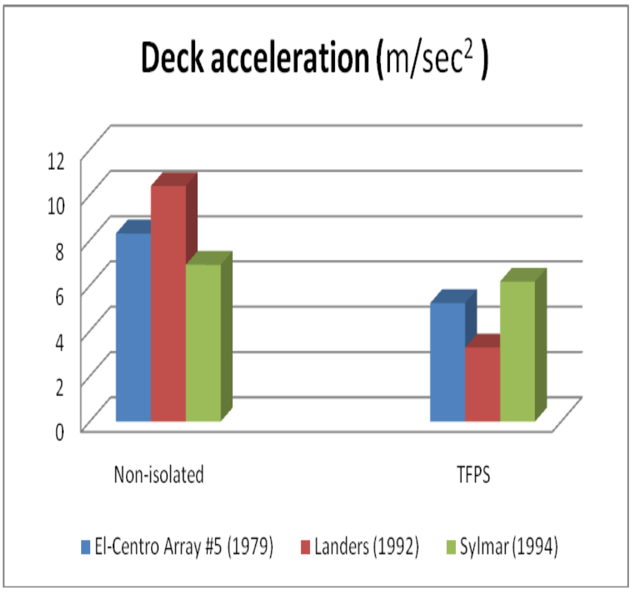

Figure 10 Comparison of deck acceleration for 10° angle

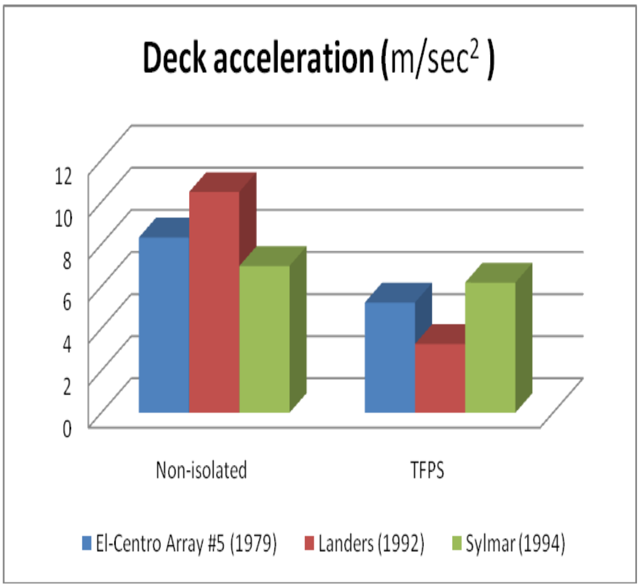

Figure 11 Comparison of deck acceleration for 20° angle

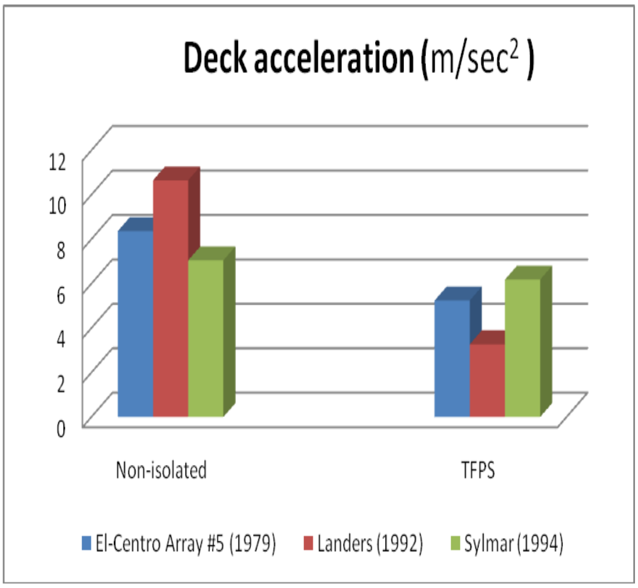

Figure 12 Comparison of deck acceleration for 30° angle

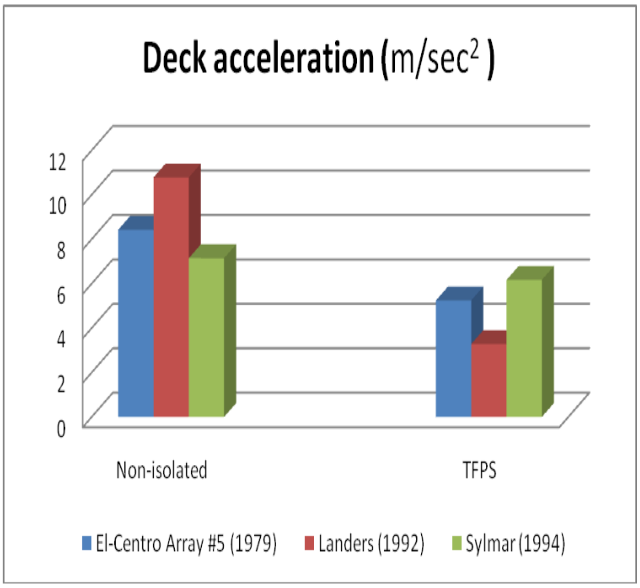

Figure 13 Comparison of deck acceleration for 40° angle

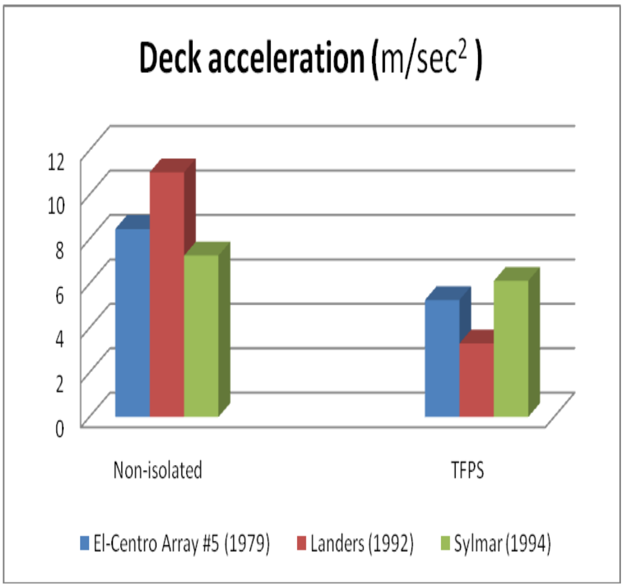

Figure 14 Comparison of deck acceleration for 50° angle

Figures 9 to 14 show the comparison of deck acceleration for the 0° to 50° skew angle with and without TFPS isolation system. It is observed that deck acceleration decreases for the TFPS-isolated bridges as compared to non-isolated bridges.

Table 7 Comparison of deck acceleration for El Centro Array #5 (1979)

Deck Acceleration (m/sec^2)				
El Centro Array #5 (1979)				
Skew Angle	Non-Isolated	Non-Isolated Increase Rate (%)	TFPS	TFPS Increase Rate (%)
0	8.296	-	5.233	-
10	8.305	0.11	5.2304	0.04
20	8.331	0.31	5.234	0.068
30	8.365	0.40	5.238	0.076
40	8.424	0.70	5.243	0.095
50	8.458	0.40	5.263	0.38

Table 8 Comparison of deck acceleration for Lucerne Valley (1992)

Deck Acceleration (m/sec^2)				
Lucerne Valley (1992)				
Skew Angle	Non-Isolated	Non-Isolated Increase Rate (%)	TFPS	TFPS Increase Rate (%)
0	10.35	-	3.2701	-
10	10.40	0.48	3.270	0.003
20	10.49	0.85	3.271	0.030
30	10.65	1.50	3.2703	0.02
40	10.78	1.20	3.282	0.35
50	11.01	2.08	3.307	0.75

Table 9 Comparison of deck acceleration for Sylmar (1994)

Deck Acceleration (m/sec^2)				
Sylmar (1994)				
Skew Angle	Non-Isolated	Non-Isolated Increase Rate (%)	TFPS	TFPS Increase Rate (%)
0	6.893	-	6.181	-
10	6.922	0.41	6.182	0.016
20	6.974	0.74	6.184	0.032
30	7.049	1.06	6.180	0.06
40	7.144	1.32	6.167	0.21
50	7.261	1.61	6.120	0.76

Table 7 to 9 represents the comparison of increase rate for deck acceleration of with and without TFPS isolation system. The result shows that increasing rate of deck acceleration is higher for non-isolated bridges as compared to TFPS isolated bridges.

[3] Bearing displacement

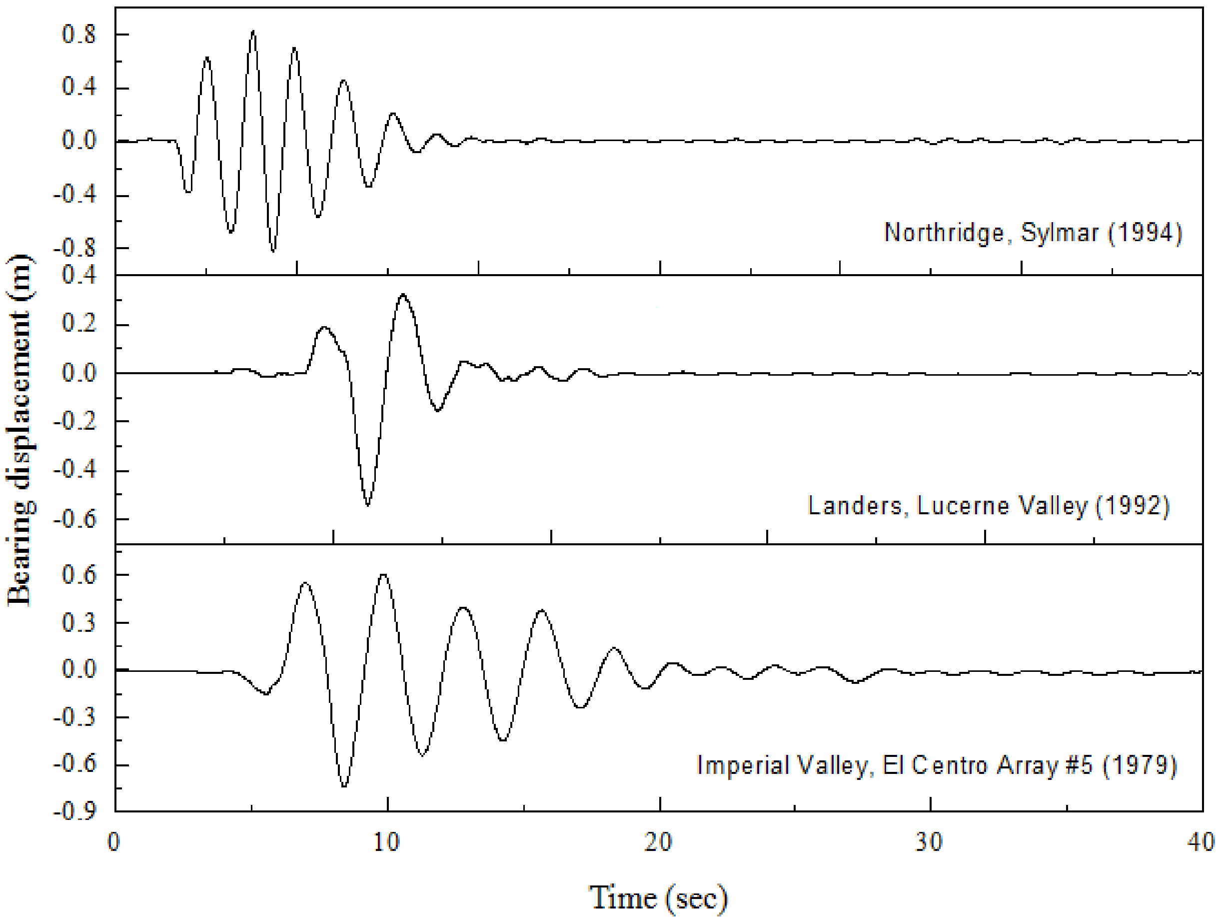

Figure 15 Comparison of bearing displacement for 0° bridge

Figure 15 represents the comparison of bearing displacement of 0° bridge for different earthquake data. Maximum value of bearing displacement in bridge is 0.6088m, 0.3594m and 0.8157m under El-Centro Array (1979), Landers (1992) and Sylmar (1994) near-fault ground motions, respectively.

Table 10 Comparison of bearing displacement

Bearing Displacement (m)						
Skew Angle	El Centro Array #5	Increase Rate (%)	Lucerne Valley	Increase Rate (%)	Sylmar (1994)	Increase Rate (%)

	(1979)		(1992)			
0	0.6088	-	0.3594	-	0.8157	-
10	0.6094	0.98	0.3601	0.19	0.8164	0.085
20	0.6102	0.13	0.3607	0.17	0.8171	0.085
30	0.6114	0.19	0.3620	0.35	0.8180	0.11
40	0.6133	0.30	0.3638	0.49	0.8191	0.13
50	0.6178	0.72	0.3685	1.275	0.8205	0.17

From the Table 10, it is observed that bearing displacement increases with the increase in skew angle.

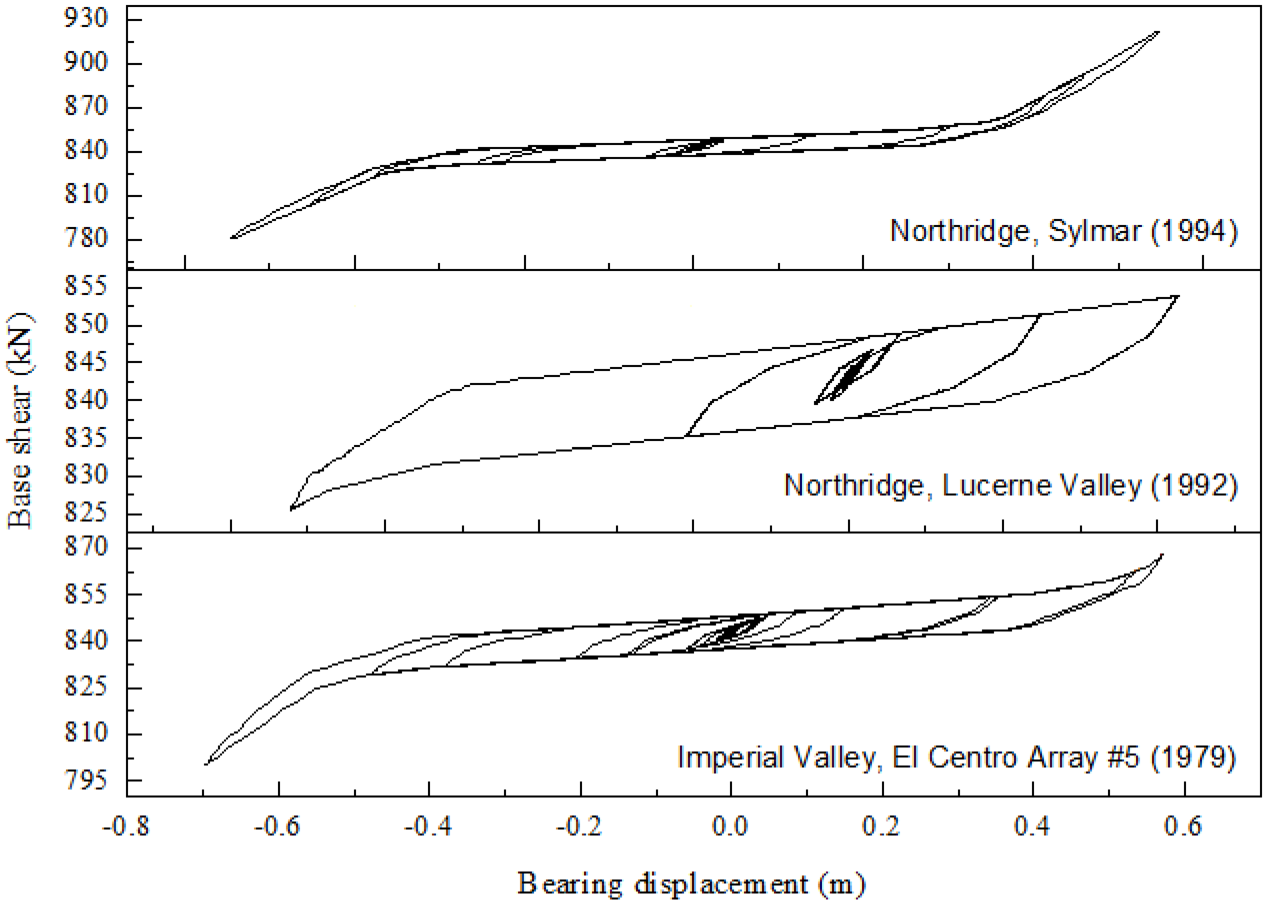

Figure 16 Comparison of hysteresis behavior of 0 ° skew bridge under near-fault ground motions

Figure 16 shows the hysteresis behavior of the bridge under near-fault ground motions. It is observed that hysteresis behavior of the bridge depends on the ground motions characteristics. For the El Centro Array #5 (1979) and Northridge, Sylmar (1994) TFPS isolators reach to the regime V.

VII. CONCLUSIONS

From the non linear time history analysis of the bridges, with different skew angle, with and without TFPS isolator following conclusions are made on the basis of the results obtained:

(A) The TFPS isolators are very effective for the skew bridge. It will reduce the effect of skew angle in the structure.
(B) For El-Centro Array #5 (1979), Lucerne-Valley (1992) and Sylmar (1994) average increase rate of base reactions is observed around 0.59%, 1.03%, and 1.18%, respectively for non-isolated bridges and around 0.10%, 0.15% and 0.05%, respectively for TFPS-isolated bridges.
(C) For El-Centro Array #5 (1979), Lucerne-Valley (1992) and Sylmar (1994) average increase rate of deck acceleration is observed around 0.38%, 1.22%, and 1.02%, respectively for non-isolated bridges and around 0.13%, 0.23% and 0.21%, respectively for TFPS-isolated bridges.
(D) For El-Centro Array #5 (1979), Lucerne-Valley (1992) and Sylmar (1994) average increase rate of bearing displacement is observed around 0.46%, 0.50%, and 0.12% respectively for TFPS-isolated bridges.

REFERENCES

[1] Kothari V., and P. Murnal, “Seismic Analysis of Skew Bridges”, Journal of Civil Engineering and Environmental Technology, Volume 2, pp. 71-76, April-June, 2015.
[2] Haque M. N. and Bhuiyan M. A. R, “Seismic response analysis of simple span concrete deck girder skewed bridge: effect of skew angles”, Journal of Civil Engineering, Volume 40, pp. 227-237, 2012.
[3] M. C. Kunde, and R. S. Jangid, “Effect of pier and deck flexibility on the seismic response of Isolated bridges”, Journal of bridge Engineering, Volume 3, pp. 140-170, Jan/Feb 2006.
[4] Sompura P. R., and Soni D. P., “Seismic Response of Asymmetric Building using Multiple Sliding Isolation System”, Afro-Asian International Conference on Science, Engineering & Technology, Volume 3, pp. 164-170, 2012.
[5] Patel B, and Panchal V. R, “Seismic response of Curved Continues Bridge Isolation with Triple Friction Pendulum System.” International Journal of Innovative Research in Science and Engineering, Volume 4, pp. 215-224, 2016
[6] S. Kitayama, and M. C. Constantinou, “Evaluation of Triple Friction Pendulum Isolator Element In Program SAP 2000”, Report, August 27, 2015.