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Investigation of Seismic Performance of RC T-Beam Bridges Using Isolation Technique

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Abstract: The aim of study is to investigate the effect of seismic isolation on the seismic response of bridge components. In this study, RC T-Beam bridges with Elastomeric bridge bearing is modeled and analyzed to get the seismic response of bridge components. With reference to this, 105 bridge models with variations in bearing stiffnesses and pier heights are modeled and analyzed with help of Structural Analysis Program 2000 Software. Time history analysis of bridge is conducted for 1940 Imperial Valley earthquake ground motion record for X, Y and Z components. It is found from analysis results that the peak responses; Base shear and Acceleration decreases with the increase in the flexibility of piers and decks and also with the decrease in bearing stiffness.

Keywords: Bridge bearing, El-Centro Earthquake, FEA method, RC T-Beam Bridge, Seismic Response, Time History Analysis.

I. INTRODUCTION

Many structures have their fundamental frequencies of vibration within the band of frequencies where the energy of earthquake ground motions is the maximum. In such cases, a structure amplifies the seismic ground vibrations and produces accelerations within the structure that increase from the bottom of the structure to its top. Besides producing undesirable levels of acceleration in the structure, these amplified structural motions can cause severe distress in the structural elements and large relative motions between different parts of the structure. This may result in permanent damage to different parts of the structure, or may even lead to catastrophic collapse. The amplified accelerations throughout the structure act on the occupants and contents of the structure, causing harm and damage to the occupants and contents even when no structural damage may occur.

Conventional idea of designing an earthquake resistant structure is having stiff and strong enough structural components to accommodate foreseeable lateral forces induced due to earthquake. The drawback of conventional approach lies in absorbing all lateral forces induced due to earthquake. This resulted into increase in cost of construction of earthquake resistant structure. Somewhere around 1900 idea of base or seismic isolation came into theory and become practically viable in 1970 for earthquake resistant design of structure. The concept of seismic isolation consists of installation of support mechanism, which decouples structure from earthquake induced ground motion. Seismic isolation reduces fundamental frequency of structural vibration to a value lower than predominant energy-containing frequencies of earthquake. Also, it provides a means energy dissipation, which dissipates energy transmitted to structure. In other words seismic isolation is a strategy that attempts to reduce seismic forces to or near elastic capacity of structural member, thereby eliminating or reducing inelastic deformations. In short, in conventional approach capacity of structural elements is increased and in seismic isolation approach, demand arising due to earthquake is reduced.

II. LITERATURE REVIEW

R S Jangid in 2004, studied the seismic response of isolated bridges and compared with that of non-isolated Bridges. He also investigated the effects of the bidirectional interaction of restoring forces of isolation bearings and concluded that the increase in the bearing displacements due to bidirectional interaction is crucial, and must be included for the effective design of the L-RB for the seismic isolation of bridges [1].

M C Kunde and R S Jangid in 2006 studied the Effects of Pier and Deck Flexibility on the Seismic Response of Isolated Bridges by analyzing three different models. He concluded that the difference in the peak responses predicted by three mathematical models increases with the increase in the flexibility of piers and decks [2].

Analytical seismic response of a three span continuous bridge retrofitted using base isolation devices were investigated in 2008 by Vasant A Matsagar and R S Jangid and the study showed the reduction in the seismic forces by a factor ranging from 0.3 to 0.8 in the superstructures and also reduction in the pier base shear was found to be 70% [3].

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Effect of Ealstomeric bearing modeling parameters on the seismic design of highway bridges with precast concrete girders was studied by Can Akogul and Oguz C Celik. It was shown that the elastomers add extra stiffness to the system. In this case, shear forces at pier bases decreased by 50% since the lateral loads are shared between the piers and abutments. Fundamental period was elongated by 80% and thus the internal forces got reduced by 60% [4].
Roy A. Imbsen, P.E used Isolation for Seismic Retrofitting Bridges by studying the effect of Isolation at different locations like california, Tennesse-Arkanas and New York in producing cost effective solutions for bridge owners. He found that the selected Isolation strategy offered structurally safe and economic solutions since there was 40% reduction in the cost [5].
A Comparative Study on Seismic Response of Bridge with Elastomeric Bearing and Elastomeric Isolator was conducted by Nitin Chavan, Pranesh Murnal. Time history analysis of bridge is conducted for 1940 Imperial Valley earthquake ground motion record. It is found from analysis results that elastomeric bearing can be replaced with elastomeric isolator as it reduces significant amount of the base shear coming on pier. So the reduction in size and amount of reinforcement in pier and foundation can be achieved and ultimately economy of structure [6].

III. DESCRIPTION OF BRIDGE MODELING

A total of 105 RC T-Beam bridge models are analyzed which includes single-span, two-span and three-span models. Width and span length of the bridge is taken as 9.5m and 15m respectively. Superstructure consists of 400 mm deep reinforced concrete deck slab supported by 4 reinforced concrete girders of 1200 mm depth. Solid piers of 1.5 m width and 1.2 m thick rest on firm soil strata. Elastomeric bearing is modeled as linear type link element. Figures below show the models of bridge analyzed using SAP 2000.

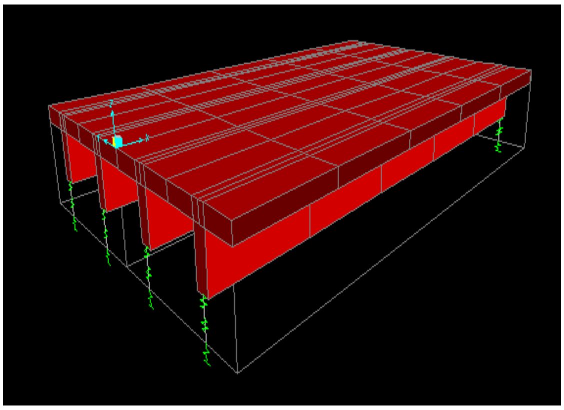

Fig.1 Single-span bridge model

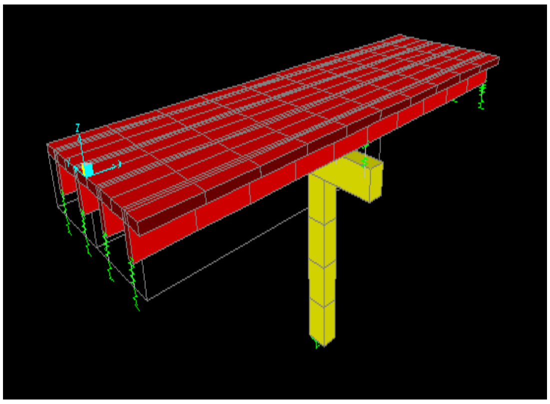

Fig.2 Two-span bridge model

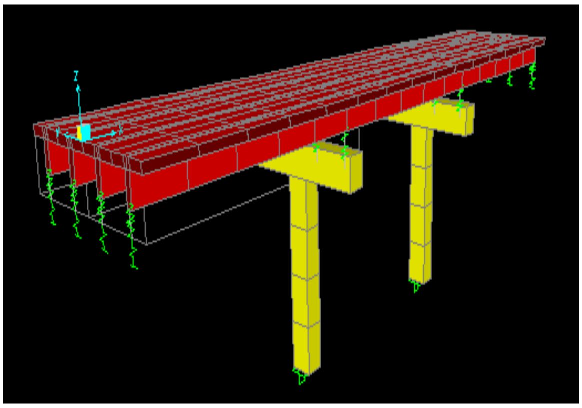

Fig.3 Three-span bridge model

In present study, first the bridge is modeled and analyzed with conventional elastomeric bridge bearing. Then the bearing stiffness values are reduced by 25% and 50% and also increased by 25% and 50% with respect to the conventional elastomeric bridge bearing. The bearing stiffness values are tabulated in Table 1. The difference between the response of conventional elastomeric bridge model and that of the other models are investigated. Another parameter of study is the variation in pier height. Three different pier heights; 10m, 15m and 20m are considered for the investigation. All the bridge models are subjected to Time history analysis using 1940 Imperial Valley earthquake ground motion record in X, Y and Z directions.

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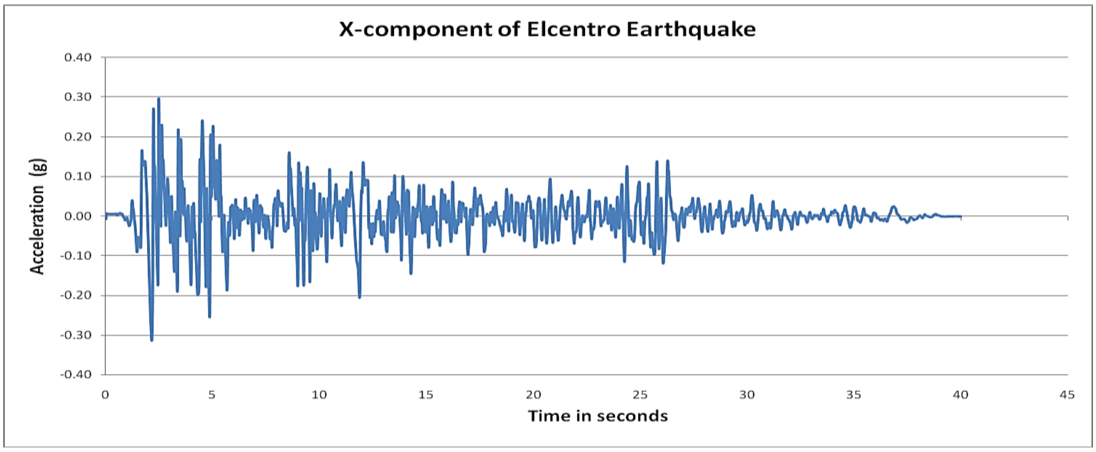
The following assumptions are made for the seismic analysis of the isolated bridges under consideration.
1. The bridge superstructure and piers are assumed to remain in the elastic state during the earthquake excitation. This is a reasonable assumption, as the increase in stiffness attempts to reduce the earthquake response in such a way that the structure remains within the elastic range.
2. The deck of bridge is straight. Deck and abutments of bridge are assumed to be rigid.
3. The bridge piers are assumed to be rigidly fixed at the foundation level.
4. The bridge is founded on firm soil or rock and soil structure interaction effect is ignored.
5. The bearings provided at abutment and pier has same dynamic properties.

Table.1 Stiffness values of bridge bearings

		KV (kN/m)	KH (kN/m)	KL (kN/m)
1	Conventional elastomeric bridge bearing stiffness	67000	300	300
2	Stiffness reduced by 25%	50250	225	225
3	Stiffness reduced by 50%	33500	150	150
4	Stiffness increased by 25%	83750	375	375
5	Stiffness increased by 50%	100500	450	450

IV. INPUT GROUND MOTION

Ground motion recorded at EL-Centro during 1940 Imperial Valley earthquake were obtained and used in study which are shown in the figures below



V. RESULTS AND DISCUSSIONS

After performing time history analysis of bridge, seismic responses; Time period, Base shear, Acceleration and Displacement of bridge is scrutinized and compiled results are presented in following Table 2, Table 3 and Table 4.

Table.2 Results of Time period, Base Shear, Acceleration and Displacement of single span bridge

		Time period (s)	Base Shear (KN)	Acceleration (g)		Displacement (mm)	
	1-Span (15m)			Absolute	Relative	Absolute	Relative
1	Conventional elastomeric bridge bearing stiffness	1.95	391.50	0.17	0.28	237.46	177.22
2	Stiffness reduced by 25%	2.25	350.40	0.14	0.24	257.97	207.84
3	Stiffness reduced by 50%	2.75	270.20	0.12	0.26	287.46	226.56
4	Stiffness increased by 25%	1.75	417.20	0.18	0.30	203.87	134.99
5	Stiffness increased by 50%	1.60	440.00	0.20	0.32	176.06	106.33

Table.3 Results of Time period, Base Shear, Acceleration and Displacement of two span bridge

			Time period (s)	Base Shear (KN)	Acceleration (g)		Displacement (mm)	
					Absolute	Relative	Absolute	Relative
	2-Span (30m)							
1	Conventional elastomeric bridge bearing stiffness							
		Pier height 10m	2.28	751.60	0.59	0.52	259.88	209.75
		Pier height 15m	2.34	743.80	0.47	0.49	260.52	211.69
		Pier height 20m	2.44	724.84	0.46	0.44	268.61	221.88
2	Stiffness reduced by 25%							
		Pier height 10m	2.63	627.30	0.55	0.50	279.84	221.93
		Pier height 15m	2.68	616.20	0.46	0.44	297.53	249.34
		Pier height 20m	2.77	602.84	0.44	0.41	311.64	266.75
3	Stiffness reduced by 50%							
		Pier height 10m	3.20	528.30	0.53	0.48	310.42	235.30
		Pier height 15m	3.25	482.20	0.44	0.43	338.00	255.44
		Pier height 20m	3.33	422.60	0.43	0.40	355.44	274.35
4	Stiffness increased by 25%							
		Pier height 10m	2.05	785.60	0.61	0.54	251.48	196.10
		Pier height 15m	2.12	783.50	0.49	0.53	260.16	205.83
		Pier height 20m	2.21	727.62	0.47	0.46	264.54	213.04
5	Stiffness increased by 50%							
		Pier height 10m	1.88	796.54	0.63	0.57	229.09	164.57
		Pier height 15m	1.95	784.66	0.53	0.55	243.98	183.73
		Pier height 20m	2.05	726.96	0.48	0.47	255.46	200.08

Table.4 Results of Time period, Base Shear, Acceleration and Displacement of Three span bridge

			Time period (s)	Base Shear (KN)	Acceleration (g)		Displacement (mm)	
	3-Span (45m)				Absolute	Relative	Absolute	Relative
1	Conventional elastomeric bridge bearing stiffness							
		Pier height 10m	2.44	1071.00	0.59	0.52	251.57	204.84
		Pier height 15m	2.54	1005.00	0.47	0.49	275.35	243.63
		Pier height 20m	2.70	994.00	0.40	0.42	296.29	295.57
2	Stiffness reduced by 25%							
		Pier height 10m	2.80	990.70	0.55	0.50	281.45	229.79
		Pier height 15m	2.89	987.70	0.46	0.45	305.10	276.17
		Pier height 20m	3.04	910.10	0.39	0.44	339.69	298.99
3	Stiffness reduced by 50%							
		Pier height 10m	3.41	770.50	0.51	0.48	302.29	287.43
		Pier height 15m	3.49	748.50	0.40	0.45	339.25	307.27
		Pier height 20m	3.62	726.20	0.37	0.42	350.15	322.11

4	Stiffness increased by 25%							
		Pier height 10m	2.20	1181.00	0.61	0.54	221.12	200.11
		Pier height 15m	2.31	1078.00	0.49	0.49	237.21	214.08
		Pier height 20m	2.47	1019.00	0.43	0.40	261.44	235.47
5	Stiffness increased by50%							
		Pier height 10m	2.02	1209.00	0.64	0.55	217.83	191.30
		Pier height 15m	2.13	1191.00	0.53	0.53	220.37	210.36
		Pier height 20m	2.30	1169.00	0.46	0.39	250.21	220.08

From the tabulated results in Table 2, Table 3 and Table 4, it is observed that there is increase in the time period in the bridge models in which the bearing stiffness is reduced by 25% and 50%, due to horizontal flexibility of the bearings. The observed resultant change in the seismic response is the reduction in the base shear and Acceleration values. Similar results are obtained as the pier height is increased from 10m to 20m as it increases the flexibility of the structure.

It is also found that the displacement is increased by 30% as the stiffness of the bearings is reduced. So special care is to be taken to arrest this increased displacement by providing dampers or supplementary energy dissipating devices.

VI. CONCLUSION

1) The seismic isolation reduces the seismic response in the superstructure and controls the distribution of the reduced lateral forces among the substructures.
2) From the study it is concluded that elastomeric bearing can be replaced with bearings with lower stiffness as it reduces significant amount of the base shear coming on pier. Hence, the reduction in size and amount of reinforcement in pier and foundation can be achieved and ultimately economy of structure. But the limitation is that special care is to be taken to arrest the increased displacement.
3) It is observed that there is increase in the time period for the bridge models in which the bearing stiffness is reduced by 25% and 50%, due to horizontal flexibility of the bearings. As a result, there is reduction in the base shear and Acceleration values.
4) Similar results are obtained as the pier height is increased from 10m to 20m as it increases the flexibility of the structure.
5) It is found that the displacement is increased by 30% as the stiffness of the bearings is reduced. So special care is to be taken to arrest this increased displacement by providing dampers or supplementary energy dissipating devices.

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