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SYNOPSIS In this paper, a comprehensive study of seismic response of base isolated bridge is made by varying different parameters such as soil stiffness, embedment depth, hydrodynamic pressure and earthquake response spectrum. The object is to determine effect of soil-structure interaction on seismic response when isolation by elastomeric bearing is provided between superstructure and substructure. Elastomeric bearing is seen to be effective in reducing seismic response of substructure on rocky site. The increase in embedment depth also causes reduction in bending moments and shear forces in the substructure. The use of elastomeric bearing in place of Rocker-Roller bearing is seen to be beneficial from seismic considerations.

INTRODUCTION

Seismic base isolation is an alternative strategy for protecting structures from earthquake damage. In this technique, a structure is decoupled from earthquake ground motion by ensuring that the fundamental time period of the structure lies in a zone of response spectrum characterized by low energy content ($T > 1.5$ s). This results in appreciable reduction in seismic response in terms of forces but not so much in terms of displacement. The concept of isolation is sound and is well proven in past one and half decades, numerous buildings and bridges are constructed on this concept. In the case of bridges, isolation can be achieved by using elastomeric bearings on the top of piers in place of conventional rocker and roller bearings. This results in isolation of girders which is effective in reducing acceleration response of girders and thus reduction in forces transmitted to piers and abutments. The base isolation is an attractive proposition for new design as well as for retrofit of existing bridges. As bridge foundations may rest on different types of soil, it is necessary to determine effectiveness of base isolation under different types of soil conditions. In this paper a comprehensive study of dynamic response of base isolated bridge is made by varying different parameters, more importantly the soil type, embedment depth, hydrodynamic pressure and different types of earthquake response spectrum; code, rocky site and alluvium site.

BRIEF HISTORIC REVIEW

The elastomeric bearings on the top of piers for supporting superstructure in bridges are used as an alternative to conventional rocker and roller bearings, these bearings permit desired movements and transmit vertical loads in normal manner. Such bearings has not been viewed as isolating elements but where designed properly, they can also act as isolating devices for earthquake forces.

The review of base isolation studies in India is given in a paper (Thakkar,1993).The seismic base isolation technique has been effectively used for new design and retrofit of existing bridges in Newzeland (Robinson, 1993). The most common form of isolation system uses lead-rubber bearings installed between superstructure and supporting piers. This form of isolation has the merit of combining isclation and energy dissipation in a single unit. The energy dissipation is achieved by yielding of lead plug under earthquake loading.

Seismic isolation has been used for protection of bridge structures and retrofitting in Italy (Parducci,1993). Elasto-plastic dissipating devices are used for energy dissipation. Because of greater transversal strength of piers, the seismic isolation in bridges is often required only in longitudinal direction. This is more so for single span structures where uni-directional devices are employed.

Seismic isolation has gained acceptance for design and retrofit of bridges in low and moderate seismic zones in U.S.A. (Mayes, 1993). Two possible design philosophies are included in AASHTO Specification. The first is to take advantage of the reduced seismic forces and provide most economical bridge design. The second design option is to provide a bridge with much better seismic performance characteristics than that of a conventional design.

In China rubber bearings and roller as isolator has been used as isolation system for bridges (Zhou, 1993).

On the basis of studies of structures other than bridges, it is known that seismic base isolation is not so much suited for foundation on soft soil. The effect of soil-structure interaction on seismic response of base isolated bridges is still not studied adequately. The purpose of this paper is to study this effect for bridges founded on different types of soil. Besides, influence of other parameters affecting seismic response is also studied.

THE BRIDGE AND MATHEMATICAL MODEL

The bridge considered for study comprises of seven simply supported spans Fig. 1. One typical span of this bridge is considered in this study for seismic isolation in the longitudunal direction, Fig.2. The superstructure consists of open truss which is supported on elastomeric bearings. The substructure consists of reinforced concrete pier and well foundation. The well foundation is taken deep to a level of hard soil. In order to study effect of foundation soil characteristics on the seismic response the soil stiffness values are varied to cover a range of shear modulus values for soft, medium and hard soil.

The whole structure including two piers, well foundation, girder and bearings are idealized as a lumped mass system. The beam elements are used between the nodes. The founding soil is replaced by soil springs (Beredugo-Novak, 1972). The soil springs are coupled and idealized at centre of gravity of embedded portion of foundation. The hydrodynamic effect of surrounding water is considered as an added mass. The mathematical model of entire bridge is shown in Fig.3. The elastomeric bearing is replaced by a beam element with high axial stiffness and low shear stiffness. The modelling of bearing elements is shown in Fig. 4.

METHOD OF DYNAMIC ANALYSIS

An integrated plane frame analysis of all components of bridge starting from founding soil to girder is made. The natural frequencies and mode shapes of the structure are first determined from lumped mass mathematical model. Using the earthquake response spectrum, modal analysis is then carried out to determine the earthquake response. The response quantities of interest are forces and displacements in the structure and bearings.

PARAMETERS CONSIDERED

The various parameters that affect seismic response have been varied in this study. The brief description of variation of these parameters is given below.

Soil characteristics: To study the influence of soil stiffness on the dynamic response of bridge, three types of soil are considered, namely, soft, medium and hard. The shear wave velocity corresponding to these soils are respectively 400 m/s, 1200 m/s and 2000 m/s.

Embedment depth: To study the influence of embedment depth on the dynamic response of bridge, two cases with different embedment depths are considered, that is (i) embedment upto scour level, (ii)embedment upto well cap.

Bearing stiffness and type: To study the influence of bearing stiffness, three types of elastomeric bearing stiffnesses are considered, one is designed for vertical load and other values are varied +20% of designed value. Besides conventional rocker-roller bearing are also considered.

Added mass of water: The mass of water in the enveloping cylinder for submerged part of the pier is considered to be attached with the pier for dynamic analysis. The enveloping cylinder is made as per guideline, given in IS:1893-1984.

Type of earthquake motion: The earthquake motion is considered to act in longitudinal direction only, its effect is considered by response spectrum approach. Three types of response spectrum are used, (i) IS code 1893, Zone V, b=1.0, I=1.50 (ii) Alluvium site and (iii) Rock site, Fig.5. Alluvium and rock site spectrum are normalized in such a way so as to get zero period acceleration same as for I.S. code spectrum.

DISCUSSION OF RESULTS

Table I gives the summary of influence of various parameters on seismic response of base isolation system. Table II gives the comparison of base forces for conventional bearing system and base isolation system. Brief discussion of results of parametric study are presented below.

Variation of soil stiffness: From Table I it is clear that increase in soil stiffness results in greater forces in the bearings although results in lesser bending moments at the base of pier. In soft soil the effectiveness of elastomeric bearings decrease as compared to hard soil.

TABLE-I : Influence of Various Parameters on Base Isolation System

Parameter	Bearing Response		Forces at pier Base	
	Rel. Disp.	S.F. (t)	S.F. (t)	B.M. (t-m)
Soil Stiffness				
Hard Soil	25.9	3.53	177.8	1989
Medium	25.8	3.55	177.1	1977
Soft Soil	25.0	3.65	169.5	1863
Bearing stifness				
G=181.5 t/m^2	19.6	4.38	177.4	1982
G=150.0 t/m^2	22.4	4.00	177.7	1986
G=120.0 t/m^2	25.9	3.53	177.8	1989
Response Spectrum				
I.S. Code	22.3	4.01	176.8	1973
Alluvium site	23.9	4.30	184.2	1967
Rock site	8.0	1.98	134.4	1525
Water Level				
Upto scour level	22.3	4.01	176.8	1973
Low water level	22.5	3.98	161.7	1915
Embedment Depth				
Scour level	22.3	4.01	176.8	1973
Upto well cap	23.3	3.90	159.5	1780

TABLE-II : Comparison of Forces at Base of pier for Conventional Bearing and Base Isolation System

Bearing	Left pier (Rocker)		Right Pier (Roller)	
	S.F.(t)	B.M.(t-m)	S.F.(t)	B.M.(t-m)
Conventional	214.6	2899.2	120.7	1386.5
Elastomeric	177.7	1986.8	177.7	1986.8
Conventional	214.5	2891.6	120.2	1382.5
Elastomeric	176.8	1973.1	176.8	1973.1
Conventional	207.9	2775.3	116.0	1342.5
Elastomeric	169.7	1863.4	169.7	1863.7

Embedment depth: With the increase in embedment depth, the shear force and bending moments reduce at the base of pier as is evident from Table I. There is a slight increase in displacement of bearing with the increase in embedment depth.

Variations of water levels: There is not very significant change by lowering the water level in relative displacement and shear force in the bearing element. By lowering the water level, shear force and bending moment decreases at the base of pier (Table I).

Type of response spectrum: Table I gives the various response parameters for three types of spectrum, viz. IS code, Alluvium site and Rock site. It can be observed that bending moment and shear force at the base of pier is minimum for rock spectrum and maximum for IS code spectrum. The relative displacement in the bearing is also minimum for rock spectrum. Thus elastomeric bearing is most effective for rocky site.

Conventional bearing vs elastomeric bearing: Table II gives the comparison of forces for conventional rocker-roller bearing and elastomeric bearing. It can be observed that the bending moments at base of rocker pier decreases while at the base of roller pier it increases. But overall, there is a reduction in bending moments in the pier with the use of elastomeric bearing.

Mode shapes of bridge with elastomeric bearing: Fig. 6 shows the first-three mode shapes of bridge with elastomeric bearings with hard soil base. It can be observed that girder behaves as a rigid body and the first mode of vibration is basically oscillation of girder as a rigid body on elastomeric bearing, the piers do not move. The bending of piers is observed in second and third mode.

CONCLUSIONS

In comparison to conventional system of bearing use of elastomeric bearings result in reduction of forces in the substructure. In soft soil, the effectiveness of elastomeric bearings decrease as compared to hard soil. The elastomeric bearing is seen to be more effective for rocky site. The increase in embedment depth results in reduced bending moments and shear forces. The use of elastomeric bearing in place of conventional bearing is thus seen to be benefical from seismic considerations.

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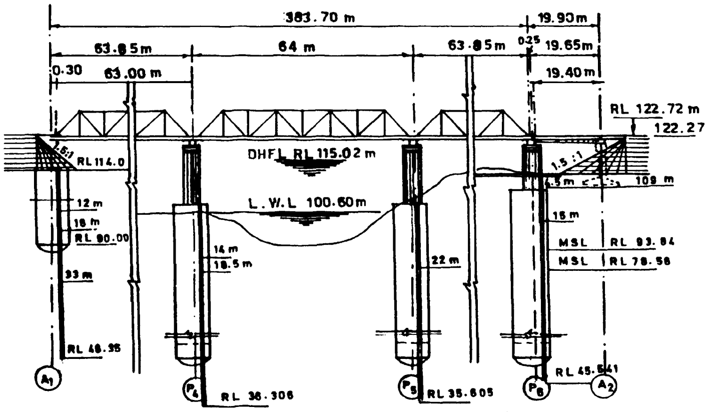

FIG.1_ LONGITUDINAL ELEVATION OF BRIDGE

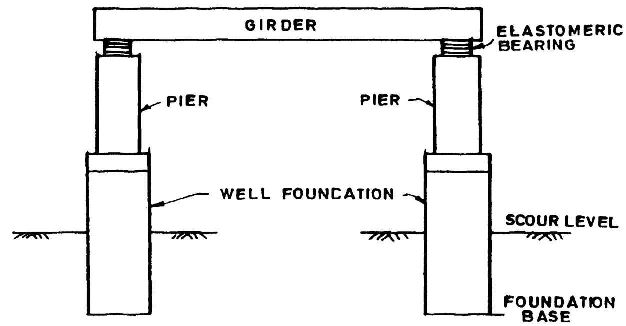

FIG. 2 _ SINGLE SPAN BRIDGE ON ELASTOMERIC BEARINGS

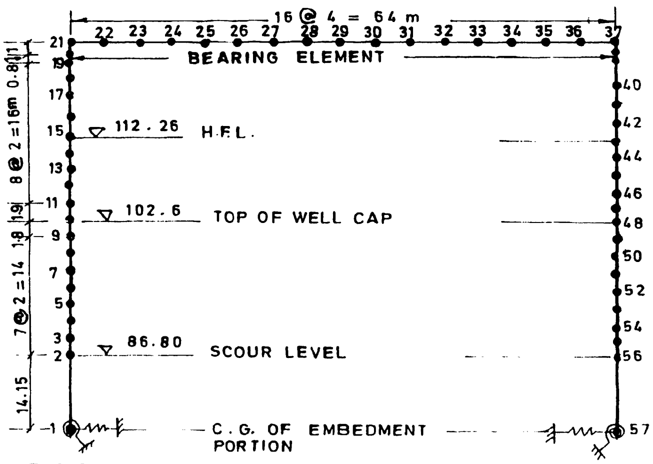

FIG. 3 _ MATHEMATICAL MODEL OF BRIDGE

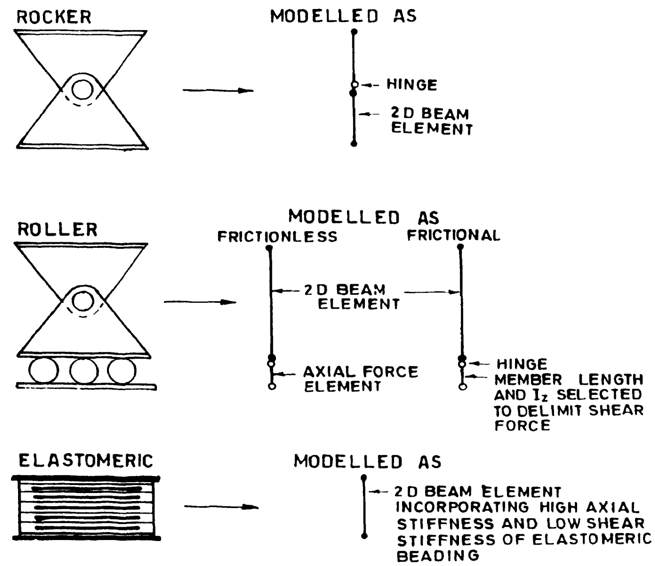

FIG.4_MODELLING OF BEARING ELEMENTS

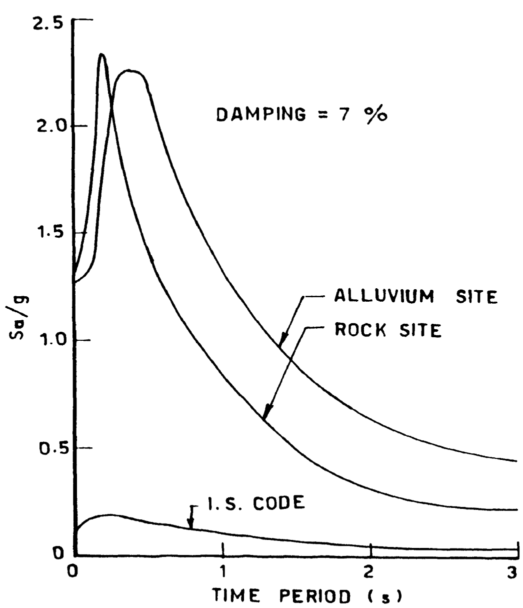

FIG.5_RESPONSE SPECTRUM CONSIDERED IN STUDY

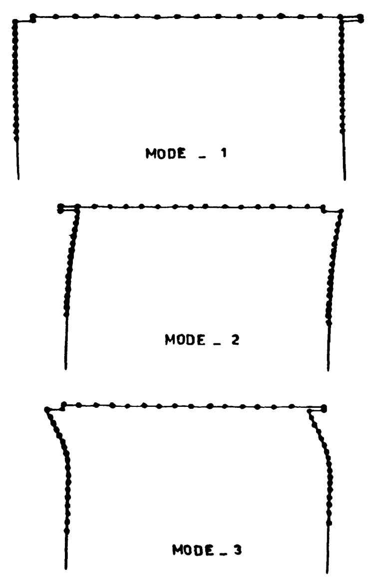

FIG.6_MODE SHAPES OF BRIDGE WITH ELASTOMERIC BEARINGS WITH HARD SOIL BASE