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SECONDARY RESISTANCE ARRANGEMENT TO PREVENT EXCESSIVE RELATIVE MOVEMENTS IN A BRIDGE DURING A SEVERE EARTHQUAKE

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ABSTRACT

The excessive relative movements in bearing of a bridge during earthquake can cause loss-of-span type of failures. Such types of damages must be prevented by design of a suitable device. This study is made for existing hammer head bridge in which excessive relative movements are envisaged in bearings of suspended span in severe earthquake. A suitably designed Secondary Resistance Arrangement (SRA) in the form of cable connecting two main spans through suspended span is proposed. The seismic response of two adjoining spans along with SRA is computed for a range of parameters. The device is seen to be effective in controlling excessive movements and forces in the structure. Such a device can thus be used as a retrofit measure in the bridge for future earthquakes.

KEYWORDS

Bearing ; bridge ; mathematical model ; response control ; retrofitting ;secondary resistance ; seismic analysis ; seismic response;

INTRODUCTION

It is important to prevent damage in bridges particularly that caused by excessive movements in bearings during earthquakes. The excessive movements can result in loss-of-span type of failure, such damages must be prevented by design of a suitable device. The earthquake resistant design of bridges are based on dynamic analysis for postulated earthquake motion. The present philosophy of design in codes is based on safe performance in Design Basis Earthquake (DBE) and allowing controlled structural damage under Maximum Credible Earthquake (MCE). This is essentially a philosophy of economy to achieve safe performance in earthquakes. In order to follow the design philosophy, it is important that a certain amount of redundancy is introduced in the structure that would serve as a secondary line of resistance and would further add to the safety.

The problem considered in this study was that of an existing hammer head bridge (Earthquake Engineering Studies, 1991) located in seismic zone V of the country. The bridge was subjected to two moderate earthquakes in August 1988, that caused only minor damages which were subsequently repaired. The behaviour of bridge during earthquakes indicated occurrence of significant displacements in the expansion joints and bearings. It was clear from the behaviour that in a design basis earthquake undesirable relative movements can occur in bearing/expansion joint that may result into more severe damage.

The objective of this study was to design a Secondary Resistance Arrangement (SRA) for an existing bridge with the aim to introduce certain amount of redundancy by providing secondary line of resistance and to prevent excessive displacements in the event of a severe earthquake. If any distress occurs during an earthquake in a certain stretch of bridge, remaining portion of bridge offers resistance with such a device. Such a mechanism may also act as a force control device and retrofit measure for the structure. The aim of this paper is to present the results of study of seismic response of bridge with SRA and study of effectiveness of this device for range of parameteric variations for the bridge.

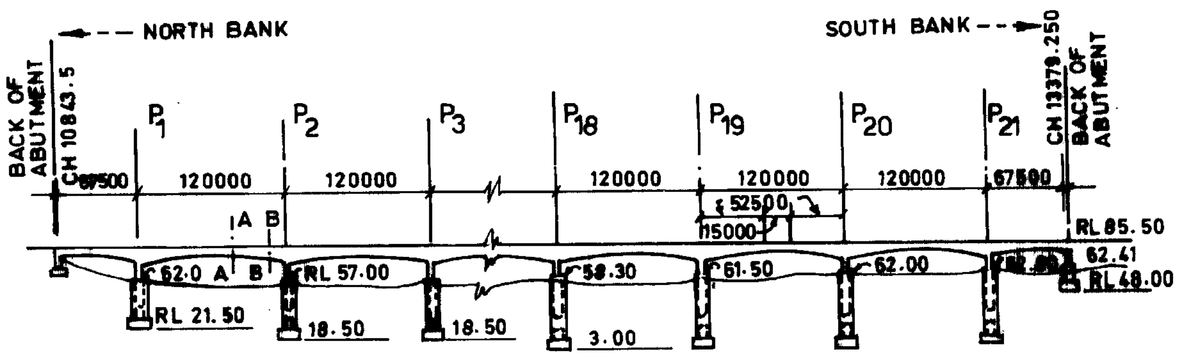

FIG. 1_ GENERAL VIEW OF HAMMER HEAD BRIDGE

THE BRIDGE

A hammer head bridge having 24 spans, each span being 120.0 m is considered, Fig.1. Two modules of such a bridge are connected by a suspended span of 15m length, which is supported on ends of main spans on elastomeric pot bearings. At one end of suspended span almost no movement is permissible, while at other end a designed relative movement of $\Delta = \pm 116$ mm is permissible in the bearing. The main spans of superstructure are made of prestressed concrete box girder while suspended spans are of reinforced concrete. The substructure consists of reinforced concrete pier built on well foundations. The right abutment of the bridge is of buried type built on rocky foundation while left abutment is made on pier-well foundation on alluvial soil. The bridge is initially designed without SRA for site dependent response spectrum on the basis of dynamic analysis. It was subsequently considered to design a SRA as a retrofit measure, device to control displacements and force in the structure.

SECONDARY RESISTANCE ARRANGEMENT

The SRA consists of a cable passing through suspended span and anchored at the ends of two main spans. A typical arrangement is shown in Fig. 2. The functions of SRA would be following:

i. It permits normal temperature movement without offering any resistance.
ii. It permits movements in seismic conditions without any distress in spring element when the two modules move in phase.
iii. When two modules move out of phase, the movement equal to $\Delta = \pm 116$ mm would be permissible in bearings. When the movement exceeds Δ, the SRA comes into action and restricts such a movement. In doing so, a certain tensile force would develop in the spring element. When two modules move towards each other beyond the relative movement Δ, the suspended span itself would act as a spring in compression of stiffness, $K = AE/L$ (A = cross-sectional area of suspended span, E = modulus of elasticty, L = length of suspended span).

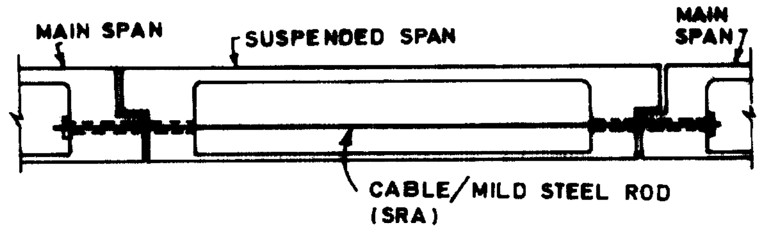

FIG. 2 _ SECONDARY RESISTANCE ARRANGEMENT(SRA)

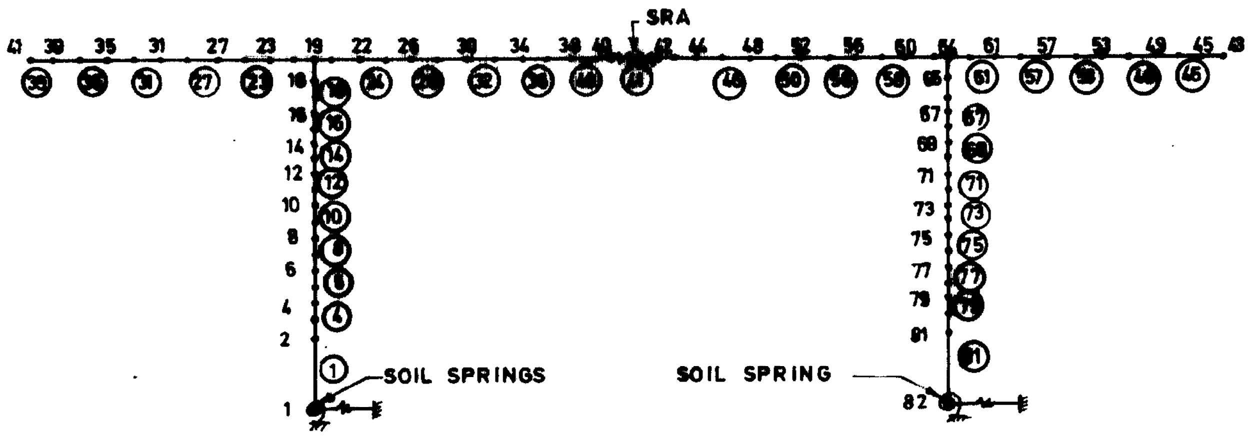

FIG.3 _ MATHEMATICAL MODEL OF BRIDGE FOR DYNAMIC ANALYSIS

MATHEMATICAL MODEL OF BRIDGE

Figure 3 shows mathematical model of two bridge modules connected by SRA. The SRA is represented by a spring element. The superstructure and substructure of two modules are represented by a lumped mass system having beam elements. The modules are considered to be elastic and displacements are small. The well foundation and soil is represented by soil springs obtained from Berdugo-Novak formulation. The whole structure is considered as a plane frame.

DYNAMIC ANALYSIS OF BRIDGE

The dynamic analysis of mathematical model for earthquake motion in longitudinal direction is carried out using response spectrum method. The steps involved in dynamic analysis are as follows:

i. Determination of natural frequencies and mode shapes for in plane vibrations.
ii. Determination of spectral acceleration in each mode using response spectrum.
iii. Determination of response in each mode of vibration, that is, determining bending moment, shear force and displacements at different locations in the bridge.
iv. Determination of the total response by square root of sum of squares method.

The site dependent response spectrum for DBE used in this study is shown in Fig. 4. The damping is assumed to be 10% of critical. The dynamic resposne of the structure in ten modes of vibration are obtained by a plane frame computer program. The modes of vibrations include, (i) in-phase vibration of piers (ii) out of phase vibration of piers (iii) vertical vibration of deck, and (iv) vertical vibration of pier.

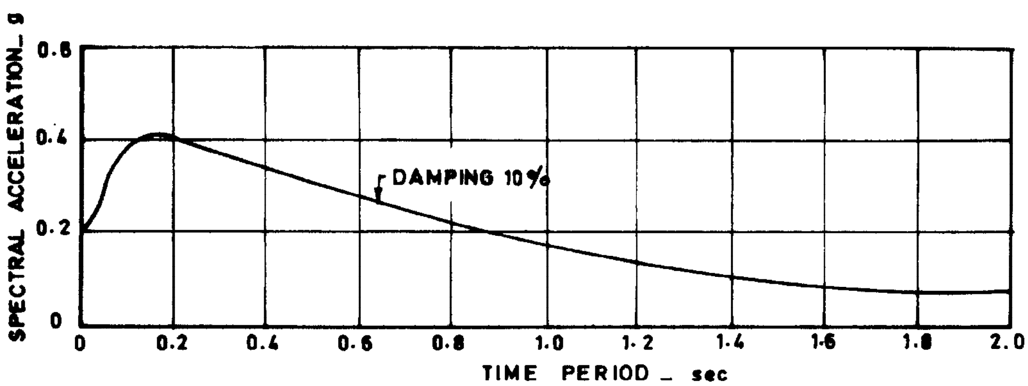

FIG. 4 _ SITE DEPENDENT ACCELERATION RESPONSE SPECTRUM
(Multiplying factor = 1/1.85 for DBE)

PARAMETER VARIATIONS

The following parameters influence the seismic response of bridge:

i. foundation levels of modules 1 and 2
ii. foundation soil properties of two modules
iii. stiffness of secondary resistance arrangement
iv. presence of live load on the bridge

The range of parameters are described in Table 1. G_b and G_s denote shear moduless of base and side soil respectively. The subscripts 1 and 2 in this notation refer to any two adjoining piers. The aim of parametric variations in a practical range is to work out maximum probable force produced in SRA, and relative displacements in the bearings, which is required for safe design of spring element.

Table 1. Parameter variations considered for seismic study

Parameter	Range
• Foundation levels of modules	F.L. of module 1=6.49 F.L of module 2=5.27
• Foundation soil properties	G_{b1} =8300 MN/m^2; Gs_1 =84.50 MN/m^2 Gb_2 = 352.30 MN/m^2; Gs_2 = 60.90 MN/m^2
• Stiffness SRA	K, K/10, K/50,K/100,K/500,K/1000 (K = 8326 MN/m)
• Live load on bridge	No live load; 50% of live load; Full live load

RESULTS OF DYNAMIC ANALYSIS

The dynamic analysis of bridge modules in Fig. 3 has been carried out for a range of parameters and probable combinations described in Table 1. The deflections at end nodes of spring element (40 and 42), axial force in SRA and dynamic bending moment in members for different stiffness of SRA are computed. The seismic response results are discussed below.

Axial Force in SRA

Table 2 shows axial force in spring element for different stiffnesses of SRA. The axial force varies between 0.24 MN to 2.82 MN. The presence of live load does not appreciabley affect the axial force in SRA. A value of stiffness of SRA equal to K/500 is selected for design in view of small force 0.42 MN developed in SRA. Also horizontal displacements of node 40 and 42 are small with this stiffness of SRA.

Displacements in SRA

Table 2 also shows the displacements of nodes 40 and 42 for design basis earthquake. The horizontal displacement of node 42 for design basis earthquake is of the order of 32.8 mm. The influence of presence of live load on displacement is small.

Table 2. Displacements and forces in SRA under DBE

Stiffness of SRA	Horizontal Defelection (mm)		Verticle Defelection (mm)		Axial force in SRA (MN)
	Node 40	Node 42	Node 40	Node 42	
No. L.L					
K	26.50	26.70	89.87	57.70	2.82
K/100	23.67	29.18	59.93	61.43	1.15
K/500	14.79	32.83	47.89	67.24	0.42
K/1000	12.17	31.90	44.82	64.55	0.24
Full L.L.					
K/100	22.16	26.62	52.13	56.47	1.15

Bending Moment At Critical Sections

Table 3 shows the bending moment at critical sections, that is scour level, top of well, top of pier, junction section of cantilever arm in superstructure for various values of stiffness of SRA. The bending moments obtained without SRA are also presented in this Table. It can be observed that by connecting two modules by secondary element, the bending moments in sub and super structure under seismic conditions are reduced. Thus spring element besides acting as displacement control mechanism also acts as force control device. The presence of live load is seen to be small on bending moments.

Table 3. Bending moment in members

Stifness of SRA	Bending Moment (MNm)			
	Scour Level	Top of Well	Top of Pier	Cantilever Arm Junction (MNm)
No.L.L				
K	311.52	123.53	140.95	74.17
K/100	269.62	92.73	80.29	39.99
K/500	243.71	93.30	93.62	50.38
K/1000	234.15	90.75	94.60	51.37
Values without SRA	273.55	107.12	110.72	57.30
Full L.L.				
K/100	250.00	86.32	72.66	49.85

DESIGN CONSIDERATIONS FOR SRA

The following design consideration are suggested on the basis of analysis carried out in this study:

i. The force level of 0.42 MN for stiffness of SRA equal to K/500 is suitable for designing SRA. This will maintain the suspended span in position by preventing excessive displacements.
ii. It is desirable to tie two main spans through free cables passing through holes in diaphragms of suspended span. These cables will take all the tension and no tensile force will be transmitted to suspended span.

CONCLUSIONS

This paper presents the study of effect of Secondary Resistance Arrangement on seismic behaviour of bridge. In this regard, the dynamic analysis of bridge was carried out by connecting two adjoining modules by secondary resistance element. The following main conclusions are derived from this study

i. A secondary resistance element connecting the two main spans by cables through suspended span would be effective in controlling excessive movements in a severe earthquake.
ii. The SRA will also act as a force control device for substructure as well superstructure under seismic conditions.

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