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Retrofitting of an earthquake damaged reinforced concrete bridge

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ABSTRACT: A multispan reinforcement concrete balanced cantilever bridge across Sonai River in Assam, India was damaged during a 5.6 Magnitude earthquake occurrence on Dec. 31, 1984. The seismic resistance of the bridge is investigated in this paper and found inadequate to meet the requirements of IS:1893-1984. Two methods of its seismic resistance upgrading are proposed and investigated to cater for site dependent response spectra for future earthquake protection.

INTRODUCTION

Need for retrofitting of existing bridges may arise due to a number of reasons. Increase of live load intensity as well as frequency in the modern times as compared with that more than even a few decades back, alongwith concurrent increase in tractive and braking forces will require not only strengthening the superstructure but also the substructure including the foundations. Then upgrading of a seismic zone, as happened in Koyna area of India after Dec. 11, 1967 damaging earthquake wherein the design intensity was changed from M.M.V to M.M.VIII, will require a re-evaluation of the seismic safety of all existing bridges in the zone and retrofitting as found necessary (4). Some of the old bridges were either designed without earthquake consideration or for arbitrary factor of g/10 or g/20. They may also need retrofitting if modern concepts of seismic force calculation are applied to them. Prediction of a severe earthquake in a region, such as in Tokai region of Japan where a Mag. 8.0 earthquake has been predicted, has necessitated the re-evaluation and retrofitting of the bridges in the region (10). Lastly, if a bridge is damaged during an earthquake and is considered repairable, the opportunity should be utilized while repairing, to retrofit the bridge to meet the seismic safety requirements in future probable maximum earthquake. This is the case studied here in this paper wherein a bridge across Sonai River in Cachar District of Assam, India, damaged during an earthquake has been investigated for reasons of damage, need for retrofitting and the methods that could be adopted for required seismic upgrading of the bridge (1).

THE BRIDGE

The Sonai Bridge is a reinforced concrete T-beam balanced cantilever type having single lane and five spans. It is located on Sonai-Motinagar Didarkosh road in the Cachar District of Assam. The total length of the R.C. bridge is 102m, which has been extended using semipermanent timber bridges on both sides - 10m on Sonai side and 29m on Motinagar side. The piers are twin solid circular connected by a vertical diaphragm. The cap on pair is rectangular in plan. The well and its cap are circular.

This bridge was constructed about 20 years before the earthquake that damaged it. Its approximate dimensions are shown in Fig. 1.

SEISMIC DAMAGE

The bridge was severely shaken on Dec. 31, 1984 during an earthquake of M=5.6 on Richter Scale with its epicentre at about 6.0 km from the bridge. The damages to the bridge were observed and recorded by the Public Works Department of the Assam Government, as briefly stated here below:

(a) The roller bearings of the main span were generally displaced from their original positions which lead to the shifting of the superstructure longitudinally as well as laterally. However there

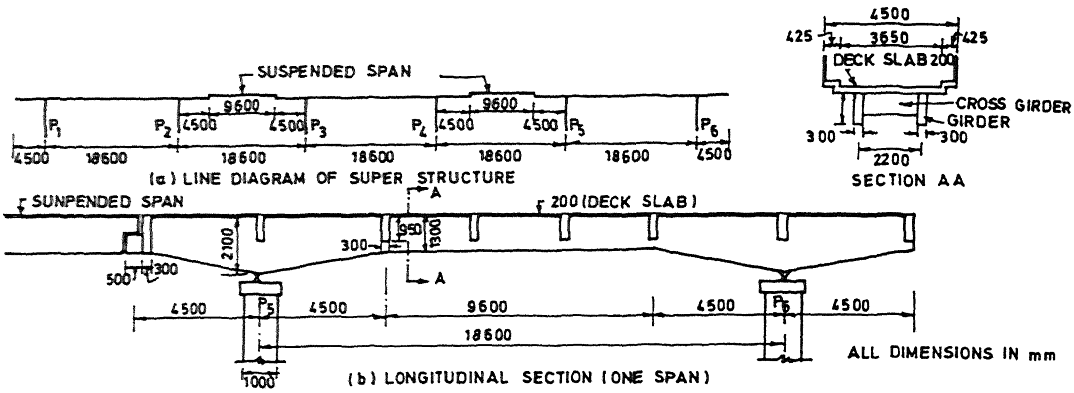

FIG.1_ DIMENSIONS OF SUPER-STRUCTURE

was no damage in the superstructure slabs or girders.

(b) There was no damage to the pier caps but the piers were found tilted and cracked indicating unequal settlement of soil below as well as lack of strength in the piers body to resist the seismic force. Pier 6 tilted 1 in 67 towards Sonai; Pier 5 tilted by 1 in 39 towards Motinagar and by 1 in 233 towards down-stream; Pier 4 tilted by 1 in 67 towards Motinagar and 1 in 249 towards down-stream. One leg of Pier No.4 cracked horizontally at three levels at 1.0, 2.5 and 3.0m above the well cap, while the other leg had one crack about 35cm measured above its base. Some spalling of concrete was also found to occur.

(c) The well caps also got cracked, in particular that of pier No.5 got a 20mm wide crack extending in well steining too. Also it appeared sheared and separated from the steining.

ANALYSIS AND DESIGN OF BRIDGE

In order to evaluate the strength of the present design and to work out the retrofitting need of the bridge, a complete analysis and design of the bridge was carried out under (a) working loads without earthquake as per the Standards of the Indian Road Congress (6,7,8) and (b) under seismic conditions.

In the working load stage, the loads considered were :

(i) 100% dead load,
(ii) 100% live load with impact. Impact is considered for superstructure, bearings and pier cap only.
(iii) Longitudinal forces due to tractive effort or braking of vehicles.
(iv) Water current pressures on scoured portion of piers and wells under maximum flood discharge in the river.
(v) Reduction in weight due to buoyancy (100% considered here) on submerged portions of well and pier.

The normal working stresses are used at this loading stage to check the design of members.

Under the seismic loading stage, the loads were taken as follows :

(i) 100% dead load.
(ii) 50% of live load with proportional impact only present on the bridge, seismic force in longitudinal direction ignore and in the transverse direction considered on half of the load present.
(iii) Longitudinal braking force.
(iv) Water current pressures based on 90% of maximum flood discharge and corresponding scour depth.
(v) Buoyancy as above.
(vi) Hydrodynamic pressure on pier and well under water due to earthquake vibrations.
(vii) Seismic force, as calculated under the three alternatives in the present case by using.
    (a) Seismic coefficient method as per IS:1893-1984(5).
    (b) Response Spectrum method as per IS:1893-1984(5). See Fig.2.
    (c) Site-dependent response spectra (9). See Fig.2.

For the seismic cases (a) and (b) the ultimate load design method is used with a load factor of 1.2 over all the loads and under strength factors of 0.87 and 0.67 for steel and concrete respectively. For case (c), where the site response spectrum is used for the Design Basis Earthquake (DBE), no increase in seismic force was necessary.

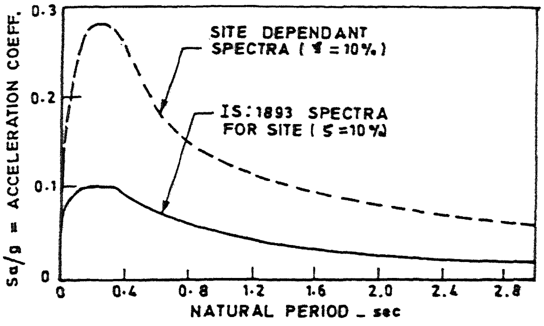

FIG.2 _ ACCELERATION SPECTRA

Seismic Force

(a) Seismic coefficient method : The bridge is situated in the most severe seismic zone of India based on M.M. Intensity IX or more. Using basic seismic coefficient of 0.08, soil-foundation factor for individual well foundation resting on stiff soil as 1.0 and importance factor 1.5, the design seismic coefficient was 0.12.

(b) Response spectrum method: For the free vibration characteristics of the bridge, a stick model was used as shown in Fig. 3 wherein the embedded part of well in the soil was replaced by elastic springs placed at its centre of gravity according to Beredugo & Novak (3) for the soil properties taken appropriately as angle of internal friction $\phi=30^{\circ}$, unit weight of soil = $1.8 t/m^3$, shear modulus of soil at base $G_B=55010$ kN/sqm and at sides $G_S=11900$ kN/sqm. The natural periods of vibration in the longitudinal and transverse direction thus found alongwith the spectral acceleration values for 10% of critical damping are shown in Table 1. The total seismic response was calculated using square-root-of-sum-of-squares (SRSS) combination.

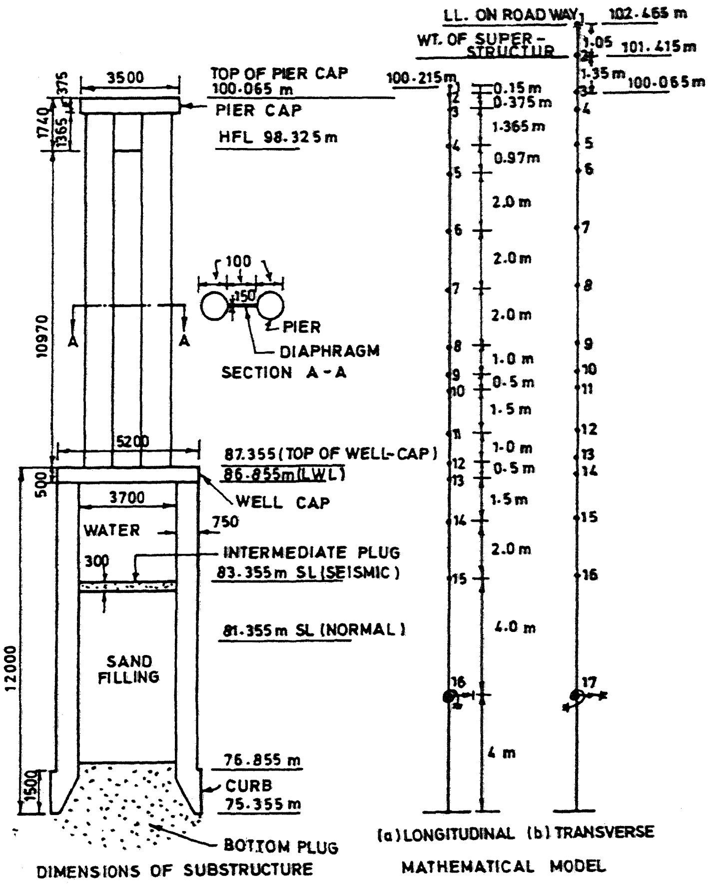

FIG. 3 _ DIMENSIONS OF SUBSTRUCTURE AND MATHEMATICAL MODEL OF EXISTING BRIDGE

Table 1. Response spectrum analysis results

Mode	Time periods, sec.		Acc.Spectrum (IS: 1893)Sa/g		Acc.Spectrum(site DBE)Sa/g	
	Long.	Trans.	Long.	Trans	Long.	Trans.
I	1.3596	0.6113	.036	.072	.070	.116
II	0.2784	0.1728	.096	.096	.194	.175
III	0.1238	0.0486	.096	.086	.160	.107

STRENGTH CHECK OF EXISTING BRIDGE

The forces and moments computed at some critical sections of the pier and well under various load combinations are given in Table 2. Using the geometrical properties of the pier, well cap and well steining along with the material properties of concrete (28 day characteristic 15cm cube strength = 20 N/sqmm and reinforcing steel (yield stress = 250 N/sqmm), the following results are obtained (2):

(i) Under normal load combination without earthquake, the pier and well cap both are found to be safe except that the shear stress in well cap exceeds the allowable value.

(ii) Under seismic load combinations, the pier is found to be unsafe near its base at ERl.87.355 and upto 2.5m height for all the cases (a), (b) and (c). Case (c), that is, site dependent spectrum case, it shows weakness even above 2.5m level, i.e. above El.89.855 in Table 2. Hence most piers were found cracked at base and one of them even at higher elevations, showing the severity of the earthquake more than that given by the code based spectra.

(iii) Well cap is found to be weak in shear but strong enough in bending. The well steining is seen to be safe under all load combinations.

Thus besides uprighting the tilted substructures, the piers need not only restoration of strength but also retrofitting to be able to withstand seismic forces of the level as proposed by case (c) in the retrofitted structure.

PROPOSED RESTORATION AND STRENGTHENING METHODS

For restoration of the lost strength of the concrete elements, it was proposed to grout the fine cracks with epoxy and the wide cracks with cement-sand mix in 1:1 proportion.

For increasing the strength to meet not only the 1984 code requirements but also the site-dependent spectra of DBE developed for an important nearby bridge across Barak River, two methods were tried as given below (2):

I. To use an overlay of reinforced concrete 750mm thick on the well cap ensuring its bonding with the existing cap so as to increase its overall thickness to 1250mm to meet the shear requirements; and to enclose the twin circular piers into one rectangular pier with semi-circular ends, as shown in Fig. 4(a).

II. To jacket the circular piers individually, remaining connected through existing diaphragm; to strength the well cap by reinforced concrete beams projecting above the cap and bonded with it with dowel bars. This is shown in Fig.4(b).

Since in both the arrangements, the stiffnesses, masses as well as exposed surface areas increase, affecting not only the seismic forces but also water current pressure and seismic hydrodynamic pressures (or the virtually added mass of vibrating water with the pier), it was essential to recalculate all the loads,

Table 2. Forces and moments on critical sections of existing bridge pier.

Section	Elevation (m)	W_N (kN)	M_{RN} (kNm)	W_{EQ} (kN)	Longitudinal Seismic $M_{R(a)}$ (kNm)	Longitudinal Seismic $M_{R(b)}$ (kNm)	Longitudinal Seismic $M_{R(c)}$ (kNm)	Transverse Seismic $M_{R(a)}$ (kNm)	Transverse Seismic $M_{R(b)}$ (kNm)	Transverse Seismic $M_{R(c)}$ (kNm)
HFL	98.325	2309	251	1812	402	392	531	634	603	1004
	93.355	2437	972	1940	1544	1480	1949	1864	1822	2832
	89.855	2527	1547	2031	2577	2287	2955	2972	2802	4251
Base	87.355	2592	1985	2096	3358	2908	3730	3813	3538	5300

W_N = Vertical load under working load, M_{RN}= Resultant moment under normal loads
W_{EQ}= Vertical load under seismic condition, $M_{R(a)}$, $M_{R(b)}$, $M_{R(c)}$= Resultant moment under seismic conditions (a), (b) and (c) respectively.

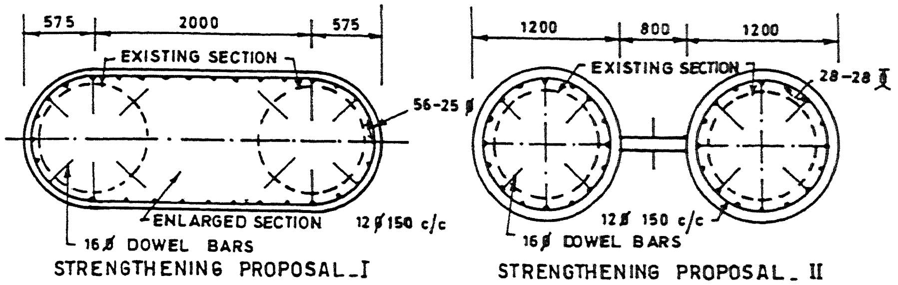

FIGURE_ 4

forces and moments in the pier well system. The fundamental time periods of the modified structures were found to be 0.928 and 1.029 sec. in longitudinal and 0.608 and 0.600 sec in transverse directions in retrofit cases I and II respectively. The relevant forces are given in Table 3 and a comparison of values with those of the existing pier is shown in Table 4.. Checking of the various strengthened sections for the enhanced seismic forces showed that they are adequate in both the proposals. From considerations of ease of construction, better stream-line flow in the river around the piers, proposal I is to be preferred although proposal II is more economical in the consumption of cement concrete.

IMPLEMENTATION OF RETROFITTING

Since some of the piers have tilted out of plumb, before carrying out the retrofitting operations, it will be necessary to upright the tilted piers. The operations should be carried as indicated here below :

(i) Carry out restoration work by grouting the cracks in the piers and the well cap, so that they remain strong during the uprighting process.

(ii) Jack up the superstructure with the help of grillages made outside the well cap in river bed (which gets dry in certain months of the year) so that the tilted piers are relieved of the vertical load.

(iii) Erect kentledge on the well cap with eccentricity so as to apply a moment to the well opposite to the direction of tilting. If found necessary, a horizontal pull may be exerted on the pier by taking the reaction from the well of the adjoining pier. This is to be done till either the well becomes vertical or the maximum tilt is reduced to 1 in 100 permitted for well foundations.

(iv) For bonding the new concrete of the well cap to the old one, its roughening and use of epoxy-coarse sand mortar will be necessary. Besides, steel dowels may be installed by drilling holes into the well steining through old concrete. The reinforcement of the additional concrete and that of the casing of the piers should be lapped with these

Table 3. Forces and moments on critical sections of retrofitted pier.

Section Elevation		Retrofit Proposal No.I			Retrofit Proposal II		
		W_{EQ}	Long. Seismic $M_{R(c)}$	Trans. Seismic $M_{R(c)}$	W_{EQ}	Long. Seismic $M_{R(c)}$	Trans. Seismic $M_{R(c)}$
m		kN	kNm	kNm	kN	kNm	kNm
HFL	98.325	1868	687	1076	1836	601	1073
	93.355	2117	2788	3119	2019	2304	3047
	89.855	2292	4388	4764	2149	3511	4603
Base	87.355	2393	5289	5739	2241	4034	5291

W_{EQ} = Vertical load under seismic conditions.
$M_{R(c)}$ = Resultant moment under seismic condition (c).

Table 4. Comparison of values for existing and retrofitted pier.

Particulars	Time Period (sec.)		Displacement (mm)		Moment at Base of Pier (kNm)	
	Longitudinal	Transverse	Longitudinal	Transverse	Longitudinal	Transverse
Existing	1.360	0.611	40.5	17.2	1770	4590
Proposal I	0.928	0.608	23.8	17.7	3138	4966
Proposal II	1.029	0.600	29.4	17.4	2230	4635

dowels.

(v) Similarly for the casing concrete of the pier, the surface of the piers will be cleaned and roughen by sand blasting and chiselling marks. For bonding, neat cement slurry (in 1:1 cement water mix) application to the wetted surface just before casting fresh concrete will be necessary. Here epoxy-mortar is not essential since new concrete will by itself tend to grip the old concrete due to shrinkage while setting.

(vi) The pier cap may need widening to accommodate the bearings properly if a certain amount of tilt of pier remains un-rectified.

(vii) Finally the superstructure may be lowered on the bearings installed in the proper position.

CONCLUSION

The study presented hereabove shows that the Sonai bridge as existing was not adequate to meet even the seismic requirements of the Indian Standard IS:1893 what to say the spectra of site-dependent Design Basis Earthquake. Two methods of seismic upgrading of the bridge to meet the current safety needs are suggested which are found to be adequate on re-analysis.

In conclusion, it may be recommended that all old existing bridges, starting with the important ones, should be analysed and retrofitted before they are attacked by the probable earthquakes and it becomes too late to do anything to save them.

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