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SEISMIC MITIGATION PERFORMANCE ANALYSIS STUDY OF IRREGULAR BRIDGES

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Abstract: **Bridges are lifeline structures and their performance is critical during and after the earthquake. The RC Bridge decks, supported on unanchored elastomeric pad bearings are free to move over substructure during an earthquake. Excessive deck displacement causes unseating and sometimes complete collapse of the deck leading to closure of the bridge for long periods. The problem worsens for irregular bridge with significant variations in the pier/pile heights. For example, decks of 268 m long Chengappa bridge across Austen Strait in Andaman islands was unseated during the 2004 Sumatra-Andaman earthquake, which had taller piers in the middle for navigational purposes. The bridge was modelled in AutoCAD and exported to CSI SAP2000 software to analytically investigate the performance of the bridge using the finite element (FE) analysis. The FE model was able to predict the observed response in the 2004 Sumatra-Andaman earthquake for comparable ground motions. Under design level earthquake ground motions, the model experienced unseating of the decks and possible collapse indicating higher vulnerability of irregular bridges with unanchored elastomeric pad bearings. A suitable retrofitting technique is proposed in the form of restrainers in order to arrest the displacement of deck slab and girders.**

Keywords: **Irregular Bridge, Response Spectrum Analysis, Deck Displacement, Restrainer, Time History Analysis.**

I. INTRODUCTION

Bridges with elastomeric pad bearings have not performed well during past earthquakes. It is generally found that damage is limited to excessive displacement of bridge deck causing unseating and sometimes collapse of the superstructure. One such bridge, Chengappa Bridge, suffered from problem like unseating of the bridge deck from its bearings during 2004 Sumatra-Andaman earthquake. The bridge is 268 m long RC bridge, simply supported over 12 cast-in-place piers. The intensity of ground shaking during the 2004 Sumatra-Andaman earthquake in Port Blair was VI–VII on the MSK intensity scale . Rai et al.reported that fifth, sixth, and seventh spans of Chengappa bridge were displaced by about 700 mm horizontally and 220 mm vertically from their original position and fell off the bearings. Other spans, including the third, fourth, eighth, ninth, tenth, and eleventh spans moved by about 20–150 mm horizontally as shown in Fig.1.The unsatisfactory seismic performance of Chengappa bridge during the 2004 Sumatra-Andaman earthquake was primarily due to uneven distribution of pier/pile stiffness and lack of restrainers to arrest excessive displacement of the bridge deck.

The objectives of the study are to perform response spectrum analysis and nonlinear time-history analysis in the transverse and the longitudinal directions to determine the response in both the directions and to compare the performance of the bridge using response spectrum and Non Linear Time History analysis. Also to propose a retrofitting method for the bridge to arrest displacement of deck slabs and avoids future disasters.

II. LITERATURE REVIEW

Priestly et al (1996), reviewed the bridge damages caused by earthquakes, and identified basic design deficiencies which were the direct consequences of the elastic design philosophy. **Symans et al (2003)** evaluated the effectiveness of various commercially available computer programs namely, SAP2000, and GT-STRUDL, for performing practical displacement-based seismic analysis of highway bridges. **Lupoi et al (2007)** studied the applicability of the MPA proposed by Chopra et al .**Fu and AlAyed (2008)** aimed at studying the applicability of a nonlinear static procedure, by implementing the displacement coefficient method (DCM) in bridges. **Paraskeva and Kappos (2009)** suggested an improvement to the MPA procedure, that the deformed shape of the structure responding. Seismic vulnerability of an irregular bridge with elastomeric pads was done by **Nirav Thakkar and Durgesh C. Rai (2014).**

III. MODELLING AND ANALYSIS

The bridge deck is 9.3 m wide and length of bridge is divided into 20.61 m individual spans with an expansion gap of 50 mm. It consists of 200 mm thick RC slab, supported on four 1.35 m deep RC precast I-girders at 2.3 m spacing. The size of the elastomeric bearing pad used is 500 mm×320 mm and 52 mm thick. The shear modulus of elastomer used in the bearing pad is assumed as 1 MPa. Material and section properties of various components of bridge are provided in table 1.

TABLE I: MATERIAL PROPERTIES AND SECTIONS

Sl.No.	Element	Dimensions			Concrete Grade N/mm^2	Reinforcement Grade (MPa)
		Length(m)	Depth(m)	Width(m)		
1.	Longitudinal Girder	20.61	I section Depth-1.35m, Flange Width-0.8m, Web Thickness-0.6m, Flange Thickness-0.15+.155m		30	415
2	Cross Girder	2.3	1	0.25	30	415
3.	Pier	varies	---	1.5 (dia.)	30	415
4.	Pier Cap	7.9	0.8	1.8	30	415
5.	Pile	varies		0.8 (dia)	30	415
6	Pile Connecting Beam	6.9	0.8	1	30	415
7	Pile Cap	----	1	1.8	30	415
8	Deck Slab	20.61	0.2	9.3	30	415

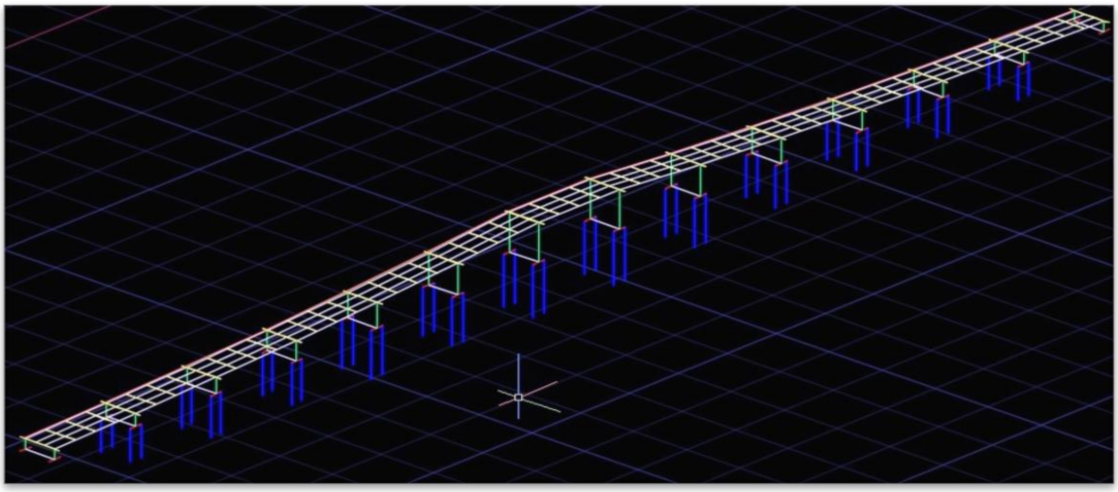

Fig 1: 3D View of the Chengappa Bridge Model

A. Response Spectrum Analysis:

Response spectrum analysis (RSA) is a linear-dynamic statistical analysis method which measures the contribution from each natural mode of vibration to indicate the likely maximum seismic response of an essentially elastic structure.The bearing displacement under IS 1893:2002 earthquake spectrum is found to be varying from 100 mm to 625 mm, with an average of 350 mm, along the transverse direction of the bridge. Fig. 2 shows the transverse displacement of the deck slab at each pier after response spectrum analysis. The average transverse displacement of deck over all the piers is more than the threshold limit of 250 mm, which indicates that if the bridge is subjected to earthquake spectrum, it will become unusable.

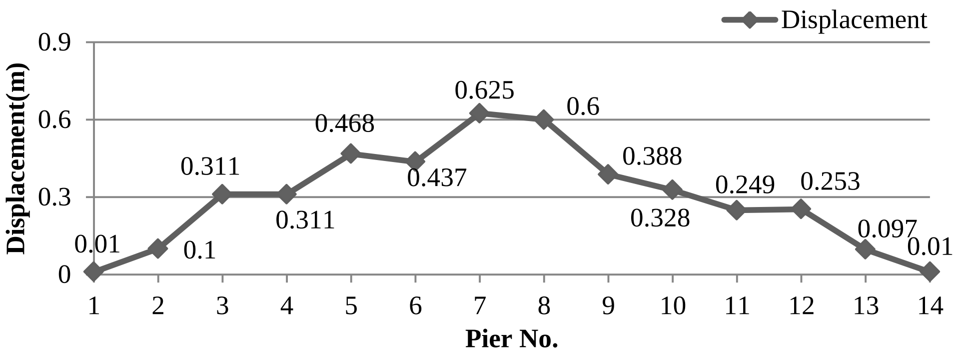

Fig 2: Transverse Displacement of The Deck Slab

B. Non Linear Time History Analysis (NLTH):

ASCE 07-05 standard specifies a requirement of minimum three accelerogram for the analysis. For the present case seven earthquake accelerograms are used in the analysis. The earthquake data is obtained from Peer Ground motion database. The target spectrum is the IS 1893:2002 spectra at soft rock(Site Class C). The earthquake data's are then scaled with respect to the target spectrum. The scale factor is then applied for the relevant load case in SAP2000. The component considered is the maximum Horizontal component for defining the time history functions. The maximum deck displacement under design earthquake is found to be varying from 74 mm to 1718 mm, with an average of 470 mm, along the transverse direction of the bridge. Thus we can conclude that the structure will be damaged again once an earthquake of similar magnitude occurs in this region. Retrofitting of the bridge needs to be done in order to avoid future damage due to earthquakes.

One of the methods suggested by US Department of Transportation (Federal Highway Administration) for retrofitting is by providing restrainers using high tensile cables bolted to pier cap and longitudinal girder in transverse and longitudinal direction for minimizing the displacement in their respective directions (Fig.3).

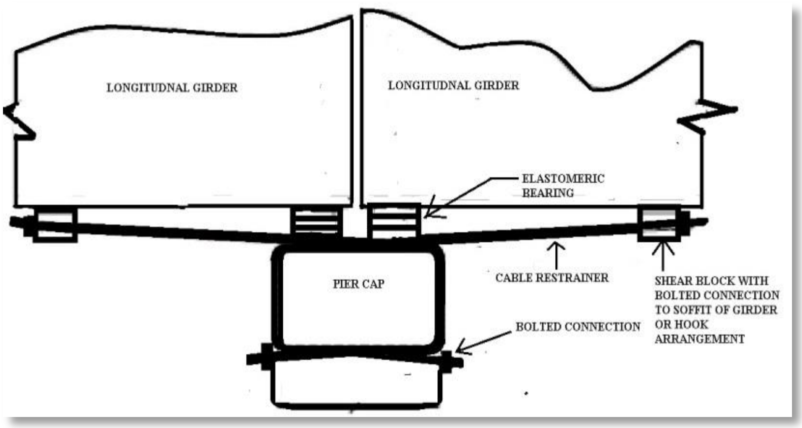

Fig 3: Cable Restraints for Minimizing Longitudinal Displacement

IV. RESULTS AND DISCUSSION

The deck displacement using RSA and NLTH analysis. It was found that average displacement was around 350 mm for RSA and 500mm for NLTH. It was also observed that there was sufficient variation in individual values of deck displacement. Values obtained were greater for NLTH analysis than RSA.

Therefore it can be suggested that for a critical structure especially in a seismic zone area, NLTH analysis can provide greater and more accurate responses in comparison to Response Spectrum analysis

Provision of restrainers in transverse and longitudinal direction adds to overall stiffness of the system and the fundamental period of structure along transverse direction and longitudinal direction decreased from 2.300s and 2.030s to 1.512s and 1.066 s, respectively. Due to restrainers, the dynamic characteristics of the bridge improved significantly as first two modes contribute to most of the dynamic response as opposed to multiple modes in absence of restrainers.

The deck displacements with and without restrainers are compared in Table 2. For the seismic analysis without restrainer, the average of maximum displacement along transverse direction is found to be between 74 mm and 1148 mm and for analysis using restrainers, as expected showed a significant reduction in displacement along transverse direction. The average maximum displacement was observed between 3mm and 162mm.

TABLE II: AVERAGE TRANSVERSE DECK DISPLACEMENT WITH AND WITHOUT RESTRAINER

Ground Motion No.	Average Transverse Displacement(mm)	
	Without Restrainer	With Restrainer
ED1	74	3
ED2	233	6
ED3	210	5
ED4	60	2
ED5	481	17
ED6	1084	157
ED7	1148	162

TABLE III: AVERAGE LONGITUDINAL DECK DISPLACEMENT WITH AND WITHOUT RESTRAINER

Ground Motion No.	Average longitudinal Displacement(mm)	
	Without Restrainer	With Restrainer
ED1	77	2
ED2	200	6
ED3	173	4
ED4	47	0
ED5	407	13
ED6	765	22
ED7	831	27

The deck displacements in longitudinal directions were also reduced significantly due to the effect of restrainer. It can be seen in Table 3 that the average longitudinal displacement without restrainer varied between 77mm to 831mm. This will result in severe pounding between deck slab which will ultimately lead to damage of deck slab, bearing , expansion joint. It was observed that the deck displacements with restrainers varied between 2mm to 27mm.

V. CONCLUSIONS

Response spectrum and time history analysis was performed on an irregular bridge. For time history analysis data from seven past earthquakes were used. Also a retrofitting method was proposed to reduce the deck slab displacement of bridges using cable restrainers. From the analysis following conclusions can be recorded.

- The results obtained in response spectrum analysis vs time history analysis shows greater variations which leads to a conclusion that based upon criticality of the structure, geometric irregularity and seismic zones, specific type of seismic analysis method should be adopted for the design.
- Bridges with varying pier heights or having high degree of structural irregularity needs to analysed using non-linear dynamic analysis in order to get more accurate analysis results.
- Simply supported Girder bridges needs to be properly restrained with help of cable restrainers or any another form of restrainers in order to minimise the deck and girder displacements and thus increasing the stiffness of the bridge as a whole.
- Depending upon the analysis longitudinal, transverse or combination of both type cable (high tensile strength steel wire rope) restrainers can be provided in order arrest displacement and damage due to seismic effects on the structure.
- Fundamental time period of the structure decreased from 2.30 s to 1.51 s as the restrainers were provided which increased the stability of structure in case of future earthquakes.
- Replacing elastomeric bearing may not be a possible solution for retrofitting bridges in all cases. Bridges which use elastomeric bearings have a bearing thickness of 52 mm when compared to roller bearing or friction pendulum bearing which requires a minimum thickness of 250mm.

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