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Pushover Analysis of Reinforced Concrete T-Beam Bridge

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ABSTRACT

After 2001 Gujarat Earthquake and 2005 Kashmir Earthquake, there is a nation-wide attention to the seismic vulnerability assessment of existing buildings. There are many literatures available on the seismic evaluation procedures of multistoried buildings using nonlinear static (pushover) analysis. There is no much effort available in literature for seismic evaluation of existing bridges although bridge is a very important structure in any country. There are presently no comprehensive guidelines to assist the practicing structural engineer to evaluate existing bridges and suggest design and retrofit schemes. In order to address this problem, the aims of the present project were to carry out a seismic evaluation case study for an existing RC bridge using nonlinear static (pushover) analysis. Bridges extends horizontally with its two ends restrained and that makes the dynamic characteristics of bridges different from building. Modal analysis of a 3D bridge model reveals that it has many closely-spaced modes. Participating mass ratio for the higher modes is very high. Therefore, pushover analysis with single load pattern may not yield correct results for a bridge model.

INTRODUCTION

India has had a number of the world's greatest earthquakes in the last century. In fact, more than fifty percent area in the country is considered prone to damaging earthquakes. The north-eastern region of the country as well as the entire Himalayan belt is susceptible to great earthquakes of magnitude more than 8.0. After 2001 Gujarat Earthquake and 2005 Kashmir Earthquake, there is a nation-wide attention to the seismic vulnerability assessment of existing buildings. Also, a lot of efforts were focused on the need for enforcing legislation and making structural engineers and builders accountable for the safety of the structures under seismic loading. The seismic building design code in India (IS 1893, Part-I) is also revised in 2002. The magnitudes of the design seismic forces have been considerably enhanced in general, and the seismic zonation of some regions has also been upgraded. There are many literature (e.g., IITM-SERC Manual, 2005) available that presents step-by-step procedures to evaluate multistoried buildings. This procedure follows nonlinear static (pushover) analysis as per FEMA 356.

LITERATURE REVIEW

General

The available literatures on pushover analysis of RC bridges are very limited whereas we can get a number of published literatures in pushover analysis of buildings. Hence the literature survey is presented here in two broad areas: (i) standard pushover analysis and its improvements and (ii) application of pushover analysis to bridges.

Pushover Analysis

The use of the nonlinear static analysis (pushover analysis) came in to practice in 1970's but the potential of the pushover analysis has been recognised for last 10-15 years. This procedure is mainly used to estimate the strength and drift capacity of existing structure and the seismic demand for this structure subjected to selected earthquake. This procedure can be used for checking the adequacy of new structural design as well. The effectiveness of pushover analysis and its computational simplicity brought this procedure in to several seismic guidelines (ATC 40 and FEMA 356) and design codes (Eurocode 8 and PCM 3274) in last few years.

Pushover analysis delivers all these benefits for an additional computational effort (modelling nonlinearity and change in analysis algorithm) over the linear static analysis. Step by step procedure of pushover analysis is discussed next.

The analysis results are sensitive to the selection of the control node and selection of lateral load pattern. In general, the center of mass location at the roof of the building is considered as control node. For selecting lateral load pattern in pushover analysis, a set of guidelines as per FEMA 356 is explained in Section 2.2.2. The lateral load generally applied in both positive and negative directions in combination with gravity load (dead load and a portion of live load) to study the actual behavior.

Structural Modelling

The study in this thesis is based on nonlinear analysis of RC bridge models. This chapter presents a summary of various parameters defining the computational models, the basic assumptions and the bridge geometry considered for this study. Accurate modelling of the nonlinear properties of various structural elements is very important in nonlinear analysis. In the present study, piers were modelled with inelastic flexural deformations using point plastic model. This chapter also presents the properties of the point plastic hinges.

Computational Model

Modelling a building involves the modelling and assemblage of its various load-carrying elements. The model must ideally represent the mass distribution, strength, stiffness and deformability. Modelling of the material properties and structural elements used in the present study is discussed below.

Material Properties

M-25 grade of concrete and Fe-415 grade of reinforcing steel are used for all members of the bridge. Elastic material properties of these materials are taken as per Indian Standard IS
456 (2000).

RESULTS AND DISCUSSIONS

The selected bridge model is analysed using upper bound pushover analysis. This chapter presents elastic modal properties of the bridge, pushover analysis results and discussions. Pushover analysis was performed first in a load control manner to apply all gravity loads on to the structure (gravity push). Then a lateral pushover analysis in transverse direction was performed in a displacement control manner starting at the end of gravity push. The results obtained from these analyses are checked against the seismic demand corresponds to the Zone V (PGA = 0.36g) of India.

MODAL PROPERTIES

Modal properties of the bridge model were obtained from the linear dynamic modal analysis. Table 4.1 shows the details of the important modes of the bridge in transverse direction (Y direction). The table shows that participating mass ratio in the first mode is only 56% cumulative mass participating ratio for first four modes is 65%. Therefore, unlike regular buildings the higher mode participation in the response of bridge is significant. Figs.

4.1 and 4.2 present the first four mode shapes in the transverse direction.
One of the main assumptions for the standard pushover analysis (FEMA 356) is hundred percent fundamental mode contributions in the structural response which is not true for the bridges. Therefore, standard pushover analysis as per FEMA 356 is not suitable for the bridges.

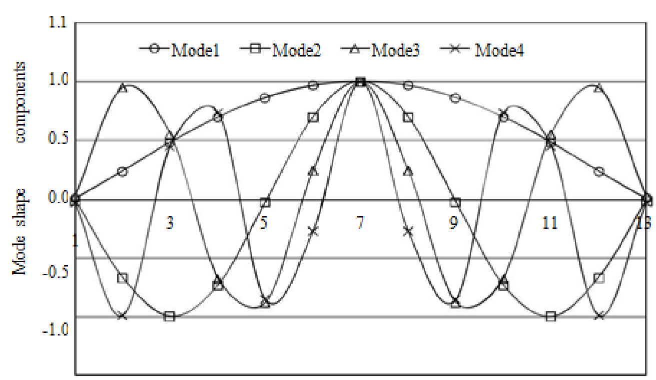

Fig. 4.1: First four modes of the bridge (normalised to Pier# 7)

SUMMARY AND CONCLUSIONS

Summary

After 2001 Gujarat Earthquake and 2005 Kashmir Earthquake, there is a nation-wide attention to the seismic vulnerability assessment of existing buildings. There are many literatures available on the seismic evaluation procedures of multi-storeyed buildings using nonlinear static (pushover) analysis. There is no much effort available in literature for seismic evaluation of existing bridges although bridge is a very important structure in any country. There are presently no comprehensive guidelines to assist the practicing structural engineer to evaluate existing bridges and suggest design and retrofit schemes. In order to address this problem, the aims of the present project was to carry out a seismic evaluation case study for an existing RC bridge using nonlinear static (pushover) analysis.

To achieve this, a multi-span RC bridge is selected from literature. The bridge was modelled using SAP2000 for nonlinear analysis. Nonlinear hinge properties were generated using improved stress-strain curve of concrete and reinforcing steel. The bridge is analysed using pushover analysis procedure as per FEMA 356 and Upper Bound Pushover Analysis procedure. Both of these two procedures are developed for multi-storeyed building. These procedures were suitably modified to use for multi-span bridges.

Conclusions

Bridges extends horizontally with its two ends restrained and that makes the dynamic characteristics of bridges different from buildings. By analysing the structure using 'Upper Bound Pushover Analysis' (UBPA) and FEMA-356 (TLP) pushover analysis, it was concluded that:

i) Here the performance of the bridge, according to FEMA-356 and UBPA, is not acceptable. Therefore, it requires retrofitting.
ii) The distributions of the hinges are different for the two pushover analyses carried out in this study. For FEMA-356 loading hinges are concentrated at the middle of the bridges.
iii) For UBPA loading, hinges are distributed over the entire length of the bridge.
However, the formation of hinges initiated from Pier# 5 and Pier# 10.
iv) Modal analysis of a 3D bridge model reveals that it has many closely-spaced modes.

v) Participating mass ratio for the fundamental mode is only 56%. Therefore, the contribution from the higher modes is very high (44%).
vi) Further investigation is required in order to make a generalized evaluation procedure for bridge structures with different configurations.

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