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Analysis of Reinforced Concrete Beam in a 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 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. 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. A 12-span existing RC bridge was selected for the case study. Standard pushover analysis using FEMA 356 (2000) displacement coefficient method and an improved upper bound pushover analysis method were used to analyse the building. Some of the analysis parameters were suitably modified to use in a bridge structure. The evaluation results presented here shows that the selected bridge does not have the capacity to meet any of the desired performance level.

INTRODUCTION

Background

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 multi-storeyed buildings. This procedure follows nonlinear static (pushover) analysis as per FEMA 356.

Objectives

Following are the main objectives of the present study:

a) To understand the standard pushover analysis procedures and other improved pushover analysis procedures available in literature.

b) To carry out a detailed case study of pushover analysis of a reinforced concrete bridge using standard pushover analysis and other improved pushover analyses.

METHODOLOGY

a) A thorough literature review to understand the seismic evaluation of building structures and application of pushover analysis.

b) Select an existing RC bridge with geometrical and structural details

c) Model the selected bridge in computer software SAP2000.

d) Carry out modal analysis to obtain the dynamic properties of the bridges and generate input parameters for pushover analysis from the modal properties of the bridge.

e) Carry out pushover analysis of the bridge model and arrive at a conclusion. ORGANISATION OF THESIS

This introductory chapter presents the background; objectives and methodology of the project. The first part of Chapter 2 discusses details about pushover analysis procedures as per FEMA 356 and different improvements of this procedure available in literature. The second part of this chapter presents previous researches on seismic evaluation of RC bridges. Chapter 3 presents different issues on the bridge modelling including nonlinear hinge model used for pushover analysis. Chapter 4 presents the analysis results and different interpretations of the results. Finally, in Chapter 5 the summary and conclusions are given.

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 is defined as an analysis wherein a mathematical model directly incorporating the nonlinear load-deformation characteristics of individual components and elements of the building shall be subjected to monotonically increasing lateral loads representing inertia forces in an earthquake until a 'target displacement' is exceeded.

The analysis accounts for geometrical nonlinearity, material inelasticity and the redistribution of internal forces. Response characteristics that can be obtained from the pushover analysis are summarized as follows:

a) Estimates of force and displacement capacities of the structure. Sequence of the member yielding and the progress of the overall capacity curve.

b) Estimates of force (axial, shear and moment) demands on potentially brittle elements and deformation demands on ductile elements.

c) Estimates of global displacement demand, corresponding inter-storey drifts and damages on structural and non-structural elements expected under the earthquake ground motion considered.

d) Sequences of the failure of elements and the consequent effect on the overall structural stability.

e) Identification of the critical regions, where the inelastic deformations are expected to be high and identification of strength irregularities (in plan or in elevation) of the building.

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Lateral Load Patterns

In pushover analysis the building is pushed with a specific load distribution pattern along the height of the building. The magnitude of the total force is increased but the pattern of the loading remains same till the end of the process. Pushover analysis results (*i.e.*, pushover curve, sequence of member yielding, building capacity and seismic demand) are very sensitive to the load pattern. The lateral load patterns should approximate the inertial forces expected in the building during an earthquake. The distribution of lateral inertial forces determines relative magnitudes of shears, moments, and deformations within the structure. The distribution of these forces will vary continuously during earthquake response as the members yield and stiffness characteristics change. It also depends on the type and magnitude of earthquake ground motion. Although the inertia force distributions vary with the severity of the earthquake and with time, FEMA 356 recommends primarily invariant load pattern for pushover analysis of framed buildings.

Target Displacement

Target displacement is the displacement demand for the building at the control node subjected to the ground motion under consideration. This is a very important parameter in pushover analysis because the global and component responses (forces and displacement) of the building at the target displacement are compared with the desired performance limit state to know the building performance. So the success of a pushover analysis largely depends on the accuracy of target displacement.

Capacity Spectrum Method (ATC 40)

The basic assumption in Capacity Spectrum Method is also the same as the previous one. That is, the maximum inelastic deformation of a nonlinear SDOF system can be approximated from the maximum deformation of a linear elastic SDOF system with an equivalent period and damping. This procedure uses the estimates of ductility to calculate effective period and damping.

SHORT COMINGS OF STANDARD PUSHOVER ANALYSIS

Pushover analysis is a very effective alternative to nonlinear dynamic analysis, but it is an approximate method. Major approximations lie in the choice of the lateral load pattern and in the calculation of target displacement. FEMA 356 guideline for load pattern does not cover all possible cases. It is applicable only to those cases where the fundamental mode participation is predominant. Both the methods to calculate target displacement (given in FEMA 356 and ATC 40) do not consider the higher mode participation. Also, it has been assumed that the response of a MDOF system is directly proportional to that of a SDOF system.

ALTERNATE PUSHOVER ANALYSIS PROCEDURES

As discussed in the previous Section, pushover analysis lacks many important features of nonlinear dynamic analysis and it will never be a substitute for nonlinear dynamic analysis as the most accurate tool for structural analysis and assessment. Nevertheless, several possible developments can considerably improve the efficiency of the method. There are several attempts available in the literature to overcome the limitations of this analysis.

Modal Pushover Analysis (MPA), developed by Chopra and Goel (2002), is an improved procedure to calculate target displacement. Recent research shows that this procedure is capable of analysing buildings with plan asymmetry (Chopra and Goel, 2004) and some forms of vertical irregularity (Chintanapakdee and Chopra, 2004).

However, a recent paper (Tjhin et. al., 2006) concludes that the scope of the applicability of multimode pushover analysis is not very wide and should be used with caution when analysing a particular category of buildings. Park et. al. (2007) presents a new modal combination rule (factored modal combination) to estimate the load profile for pushover analysis.

STRUCTURAL MODELLING

INTRODUCTION

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.

Structural Elements

Piers and girders supporting deck are modelled by 3D frame elements. The girder-pier joints are modelled by giving end-offsets to the frame elements, to obtain the bending moments and forces at the beam and column faces. The girder-pier joints are assumed to be rigid .The pier end at foundation was considered as fixed. All the pier elements are modelled with nonlinear properties at the possible yield locations. Deck is not modelled physically. However, the weight of the deck is applied on the beam as Dead Load. Also, mass of the deck is considered for modal analysis.

BRIDGE GEOMETRY

The details of this bridge are obtained from literature (Muljati and Warnitchai, 2007). The bridge deck is supported by single-span pre-stressed concrete girders. Girders are placed on the concrete pier-head through the bearing and locked in the transverse direction. The supporting piers are in various heights, but in this study equal height of 7.7 m is selected.

MODELLING OF FLEXURAL PLASTIC HINGES

In the implementation of pushover analysis, the model must account for the nonlinear behaviour of the structural elements. In the present study, a point-plasticity approach is considered for modelling nonlinearity, wherein the plastic hinge is assumed to be concentrated at a specific point in the frame member under consideration.

Flexural hinges in this study are defined by moment-rotation curves calculated based on the cross-section and reinforcement details at the possible hinge locations. For calculating hinge properties it is required to carry out moment–curvature analysis of each element. Constitutive relations for concrete and reinforcing steel, plastic hinge length in structural element are required for this purpose. Although the axial force interaction is considered for pier flexural hinges the rotation values were considered only for axial force associated with gravity load.

Stress-Strain Characteristics for Concrete

The stress-strain curve of concrete in compression forms the basis for analysis of any reinforced concrete section. The characteristic and design stress-strain curves specified in most of design codes (IS 456: 2000, BS 8110) do not truly reflect the actual stress-strain behaviour in the post-peak region, as (for convenience in calculations) it assumes a constant stress in this region (strains between 0.002 and 0.0035). In reality, as evidenced by experimental testing, the post-peak behaviour is characterised by a descending branch, which is attributed to ‘softening’ and micro-cracking in the concrete. Also, models as per these codes do not account for strength enhancement and ductility due to confinement. However, the stress-strain relation specified in ACI 318M-02 consider some of the important features from actual behaviour.

SUMMARY

This chapter presents details of the basic modelling technique for the linear and nonlinear analyses of RC framed structures. It also describes the selected bridge geometries used in the present study. This chapter briefly discusses about modelling plastic flexural hinge.

RESULTS AND DISCUSSIONS

Introduction

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.

Pushover Analysis

Pushover analyses carried out using FEMA 356 displacement coefficient method as well as upper bound pushover analysis (UBPA) method. A triangular load pattern was used for standard pushover analysis (FEMA 356). Fig. 4.3 shows the load pattern used for standard pushover analysis.

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 generalised evaluation procedure for bridge structures with different configurations.

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