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Nonlinear Response of RC FramesUsing Plastic Hinge Model

Varun Kumar Sikka[1], Sanjeev Kumar[2]

[1]Assistant Professor, Department of Civil Engineering, Rattan Institute of Technology and Management, Haryana, India
[2]Research Scholar, Department of Civil Engineering, Rattan Institute of Technology and Management, Haryana, India

ABSTRACT

Lumped plasticity hinges are popularly employed in many software packages due to easy implementation and simplicity of the computational models. The present study is an attempt to implement a concentrated plasticity hinge model to simulate the nonlinear behavior of RC frame and to perform a probabilistic analysis. The model introduced by Monfortoon and Wu (1962) is implemented in MATLAB 2012 and a probabilistic analysis is carried out by considering the uncertainty in the modeling and geometry parameters to obtain the uncertainty in the responses.

INTRODUCTION

Approaches for Non-linear analysis of RC frames can be divided into two in general, namely, concentrated or lumped plasticity model and spread plasticity models. The concentrated plasticity model assumes that non-linearity is lumped in at member ends. Spread plasticity models assume that yielding starts at beam ends and that yield zone of finite length spread inwards. Concentrated plasticity approaches are popular as it is easy to implement. Many software packages like SAP2000 etc., implemented this approach due to the simplicity of the computational models. Motivation of the present study is to simulate to the nonlinear behavior of RC frame implementing a concentrated plasticity hinge and to employ it for probabilistic analysis.

Pushover Analysis

Static push-over analysis is a simplified nonlinear analysis technique in which a structure modelled with non-linear properties (such as plastic hinge properties) and permanent gravity loads is subjected to an incremental lateral load from zero to a prescribed ultimate displacement or until the structure is unable to resist further loads. The sequence of yielding, plastic hinge formation and failure of various structural components are noted and the total force is plotted against displacement to define a capacity curve. The analyser can monitor the behaviour of the structure in every single load step.

REVIEW OF LITERATURE

As the present study deals with non-linear static pushover analysis of the RC frames, a detailed literature review has been conducted on modelling of RC frames and the previous work done in the area of the lumped plasticity model has been explained in section 2.2.

Plastic Hinge Models

Mon fortoon and Wu (1962) employed the rigidity-factor concept to develop a first-order elastic analysis technique for semi-rigid frames, where the elastic stiffness matrix (K) of each member with semi-rigid moment-connections is found as the product of the standard elastic stiffness matrix (Se) for a member having rigid moment-connections and a correction matrix (Ce) formulated as a function of the rigidity-factors for the two end-connections, i.e., K= Se.Ce. The detailed formulation of Monfortoon and Wu is explained in section 3.2.

Hasan and Grierson (2002) presented a simple computer-based push-over analysis technique for performance-based design of building frameworks subject to earthquake loading. Used the plasticity-factor concept that measures the degree of plastification, the standard elastic and geometric stiffness matrices for frame elements are progressively modified to account for nonlinear elastic–plastic behavior under constant gravity loads and incrementally increasing lateral loads.

Tullini *et al.* (2010) vibration frequencies and mode shapes of space frames with semi-rigid joints are analyzed using Hermitian finite elements. Several frame analysis examples were presented to show the effects of joint flexibility and highlighted the effects of semi-rigid connections, on the natural frequencies.

Razavi (2014) presented the concept of the hybrid steel frame system, as it pertains to mixtures of fully rigid and semi-rigid steel connections used in frames. Several different patterns and locations of semi-rigid connection replacements within the frame were examined in order to identify hybrid frames with the best seismic performance. Comparison of performance of the rigid frames with its corresponding hybrid frames showed a superior performance for the hybrid frame.

NON-LINEAR STATIC ANALYSIS OF RC FRAME

This chapter deals with the development of the pushover curve of an RC portal frame using the lumped plasticity model. A lumped plasticity model proposed by Monfortoon and Wu (1962) is used in the present study as it is simple and a convenient technique. The nonlinear analysis of the frame requires incremental loading and hence the incremental analysis procedures, namely, Newton Raphson method, and Displacement Control method proposed by Batoz and Dhatt (1979) are discussed in this Chapter. Having implemented the lumped plasticity model, a probabilistic analysis is also carried out considering uncertainties in various parameters involved such as Young's modulus, moment rotation envelope and geometric parameters of the frame. The details of the frame considered, random variables that are considered for probability analysisand their statistical properties are also presented in this Chapter.

Element Formulation

The lumped plasticity model proposed by Monfortoon and Wu (1962) uses the rigidity-factor concept to develop a first-order elastic analysis technique for semi-rigid frames. Elastic stiffness matrix *(K)* of each member with semi-rigid moment-connections is expressed as the product of the stiffness matrix (*Se)* of the elastic beam and a correction matrix (C_e) to consider the effect of plastic hinge as shown below.

$$K = S_e C_e$$

Incremental Analysis Procedure

Modified Newton-Raphson method (MNR) is used in the present study for incremental analysis. It evaluates the out-of-balance load vector, which is the difference between the internal forces (the loads corresponding to the element stresses) and the applied loads. The program then performs a linear solution as explained in section 3.4 and checks for convergence. If convergencecriteria is not satisfied, the out-of-balance load vector is re-evaluated.

Displacement Control Method

In this section the Standard Incremental Displacement Algorithm Fig.3.11 proposed by Batoz and Dhatt (1979) has been discussed. The numerical problem that may be encountered when tracing the nonlinear load-deflection curve is the ill-conditioning of the tangent stiffness matrix near the peak point. This may lead to numerical over-flow and divergence in the computer analysis. In case of divergence, it is difficult to figure out whether the system is failed structurally or numerically. To overcome this difficulty displacement method is used, it gives a good solution for nonlinear problems because it presents a great stability at the critical points. Also, it presents the adaptability of the load parameter, which reflects variations in the stiffness, and the ability to determine the direction of load automatically.

SUMMARY

The first part of this chapter presents modeling of the frame for nonlinear analysis. The next part of the chapter explains the numerical methods, Newton Raphson method and displacement method which have been used for nonlinear analysis. Newton Raphson method becomes unstable after passing through limit points and fails to follow the equilibrium path. To overcome this problem displacement control method has been used. The later part of the chapter presents pushover curves (static linear and static non-linear) for the modeled RC frame. In the last part of the chapter validation of the study and the probabilistic analysis is presented.

CONCLUSIONS

The following are the major conclusions from the present study:

- Load control Newton Raphson method failed to yield the entire load –displacementresponse in the post-peak region.
- The Displacement Control method could yield the post peak behaviour of the pushovercurve.
- The base shear versus displacement curves obtained from the lumped plasticity model and SAP2000 are fairly

matching. Hence the implemented model in MATLAB 2012 is used for Probabilistic analysis.

- Probability analysis shows that there is uncertainty in the values of maximum base shear indicated by the COV value of about 8.64%. This uncertainty is due to the uncertainty in the input parameters such as Young's modulus of concrete (7.6%), moment-rotation constants (2.75%), the width of the section (0.108%), and depth of the section (0.9%).

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