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SEISMIC VULNERABILITY OF EXISTING RC BUILDINGS IN INDIA

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SUMMARY

The recent devastating earthquakes have exposed the vulnerability of the existing reinforced concrete buildings in India. The Bhuj earthquake (2001) saw a great deal of damage to multi-storey buildings in the urban area of Gujarat. This has posed a serious threat to the many existing Indian RC buildings which are designed mainly for gravity loads. The need for evaluating the seismic adequacy of the existing structures has come into focus following the damage and collapse of numerous concrete structures during recent earthquakes. In order to assess the vulnerability, a simplified procedure for evaluation is highly in need for a country like India which is prone to earthquakes. It is important to estimate the response of buildings under earthquakes from the viewpoint of life reservation and risk management. The adequacy and the performance of the building are checked with the codal provisions of IS 1893:2002. A procedure for evaluating the seismic performance of existing building in India is proposed. The procedure is based on the capacity spectrum method (ATC 40) and is intended to provide practicing engineers with a methodology for determining the performance level of the building. The distribution of lateral forces used in pushover analysis is as given in IS1893 (Part 1):2002. The proposed methodology is applied to a representative Reinforced Concrete Moment Resisting Frame (RC MRF) building. This procedure gives an in-depth sight into the distribution of damage and the global failure mechanism.

INTRODUCTION

The need for evaluating the seismic adequacy of existing buildings has come into focus following the enormous loss of life and property during the recent earthquakes in India. After the Bhuj Earthquake (2001) considerable interest in this country has been directed towards the damaging effect of earthquakes and has increased the awareness of the threat of seismic events. Most of the mega cities in India are in seismically active zones and are designed for gravity loads only. A large number of existing buildings in India need seismic evaluation due to various reasons such as, non compliance with the codal requirements, updating of codes and design practice and change in the use of building. Hence evaluation of existing RC buildings in India is a growing concern. The evaluation of the seismic performance of buildings that are designed for gravity loads is governed by the modeling of certain detailing aspects such as discontinuous positive flexural reinforcement, lack of joint shear reinforcement; and inadequate transverse reinforcement for core confinement which are inherent in the existing buildings in India.

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Most reinforced concrete (RC) buildings in India are framed constructions with unreinforced masonry infill ranging from 2 to 8 storeys. Mid rise buildings (4 to 8 storeys) having open ground storey for parking facilities is a common construction practice in the whole of India. These buildings have undergone major damage in the recent earthquakes. Soft storey mechanism of failure is observed in many of the cases.

The analytical technique proposed in ATC40 [1] uses the capacity spectrum approach. The capacity spectrum method requires the construction of the strength capacity curve expressed in standard acceleration versus period format and compared with the elastic response displacement response spectra earthquake demands. The strength capacity curve is established from a pushover analysis by the code based parabolic loading distribution (loading proportional to the first mode shape). The structural capacity and the demand are represented in the acceleration displacement response spectrum format introduced by Mahaney et al. [2]. This procedure provides an estimate of the performance in terms of storey drift and possible failure mechanism. The building performance is compared with the established performance objectives such as compliance with the code and the possible failure mechanisms. The inadequate joint reinforcements and lack of confinement in columns govern the performance of the majority of existing Indian RC buildings. This paper brings out the intricacies in modeling such inadequacies through pushover analysis.

RESEARCH SIGNIFICANCE

In a seismically active region like India, there is potential risk for existing RC buildings. The need for a simple yet reliable evaluation of existing buildings is of growing concern to the practicing community. While analytical tools for nonlinear static analysis exist, the real issue is whether the modeling of certain non ductile detailing is properly accounted for in the evaluations. The purpose of this study is to provide a simple rational procedure to analyze existing RC buildings that were designed for gravity loads. The procedure allows modeling of non ductile detailing in an implicit manner so that existing analytical tools can be used to carry out the required seismic evaluation. The analysis provides an insight into the behaviour of the components and the failure mechanism of the structure as a whole. The evaluation procedure is applied to typical four storey RC MRF building that reveals the inherent deficiencies as compared to current earthquake resistant design requirements in India.

BACKGROUND AND PREVIOUS RESEARCH

Though the evaluation of vulnerability of existing RC MRF buildings is not new the application of the same techniques to non ductile or gravity load designed buildings is not so well developed in India. Various computational tools are available in the published literature comprising of analytical models and procedures. They systematically predict the vulnerability associated with the buildings and give an assessment of the risk level either qualitatively or quantitatively. To this end, in the recent past, ATC-40 has covered the standard recommendations and the guidelines for the seismic assessment. However, these procedures will have to be checked for their applicability in the case of Indian buildings. This paper follows the ATC-40 procedure to perform the push-over analysis to assess the vulnerability of existing RC MRF buildings.

DESCRIPTION OF A REPRESENTATIVE INDIAN RC BUILDING

The building configuration selected was a representative residential building that is common in Indian seismic zones. A symmetric floor plan and floor levels of equal height were used to avoid any irregular behaviour that might lead to complexities in the interpretation of the response. Since this study is an investigation into the adequacy of reinforcement detailing, it was necessary to assure that the model was free from any peculiar features that could obscure the results obtained from the modeling of separate reinforcing details. Fig. 1 shows the elevation and floor plan of a typical 4 storey building.

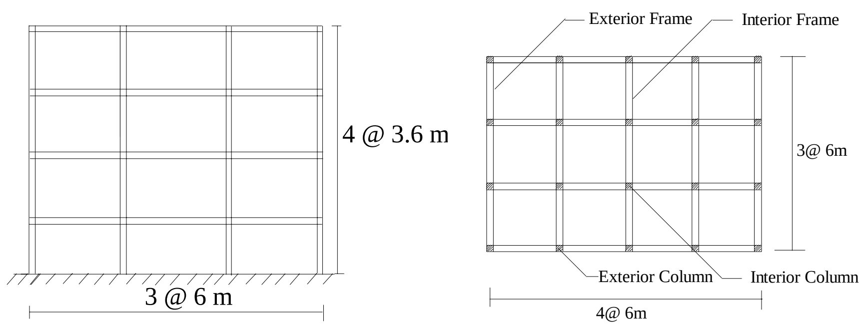

Fig 1 Typical Floor Plan

General Aspects of Indian RC MRF Building

The buildings were designed for gravity loads (1.5 (DL+LL)) and no lateral loads are considered in accordance with code requirements prescribed in IS456:1978 [3]. Proportioning of structural elements is performed as per SP34 (S&T):1987 [4], which are meant for gravity load design. The grade of concrete considered is M20 and that of reinforcement steel is Fe415. Dead loads are computed considering the unit weight of concrete as 25 kN/m^3 and the live load on the floors are taken as 2.5 kN/m^2 and for roof as 1.5 kN/m^2 from IS 875 (Part 2): 1987 [5].The reinforcement patterns were arrived on the basis of gravity load design as per IS 456-1978 and the details are given in Fig. 2 and Fig.3.

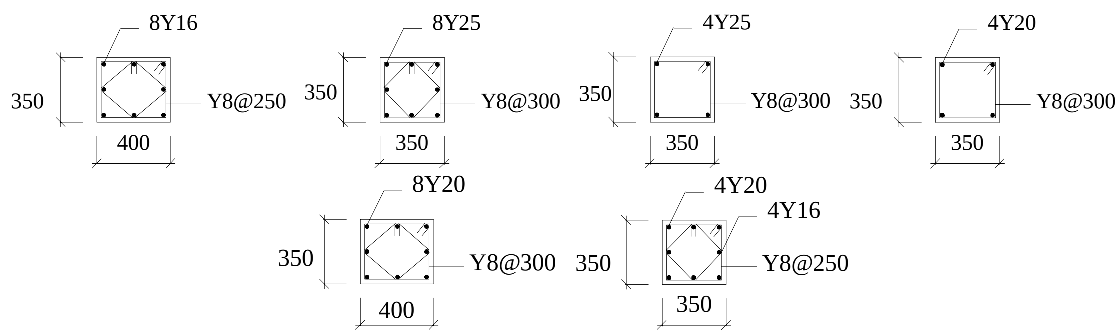

Fig 2 Column Reinforcement Details

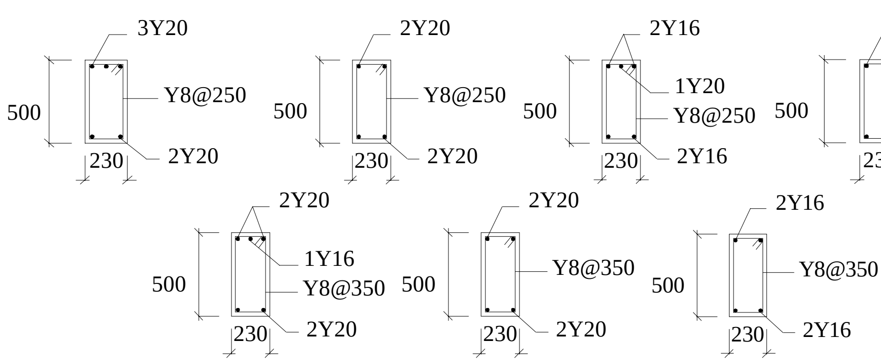

Fig 3 Beam Reinforcement Details

Deficiencies of Indian RC MRF Buildings

The deficiencies associated with the reinforcement detailing in gravity load designed building under seismic loads are discussed below. These contribute to the vulnerability of the RC MRF under seismic loads. The first issue is the transverse reinforcement required for ductile detailing in column and beam plastic hinge zones. In this building the amount of transverse reinforcements provided in the plastic hinge zone is 8 @ 300mm c/c and 8 @ 250mm c/c as required by IS 456:1978 whereas ties required in that region is 8 @ 100mm c/c as per IS13920:1993 [6].

Third most concern is the joint shear reinforcement detail. As per SP34 (S&T):1987, clause 7.6 the column ties are extended through the joints if, beams do not frame into the column on all four sides or the beams do not frame into the column by approximately the full width of the column. Considering the spacing of ties in the columns, the transverse reinforcement provided may not be adequate to resist the shear developed in the joint, which makes them vulnerable under seismic loads. Another feature is the splicing of column reinforcements near the floor levels just above the joints. The code requires closer spacing of ties in splicing regions to provide better confinement which will avoid splice failure. Other feature is intended to the failure mechanism associated with the practice. Generally the failure mechanism resulting from a gravity load designed building is often a column side sway mechanism (soft storey) or combination of mechanisms. These mechanisms are highly undesirable. For seismic loads, the mechanism most desirable for a good seismic detailing is a beam side sway mechanism.

MODELING ASPECTS

Computational Tool: SAP2000 NL

The computer program SAP2000NL [7] is used for pushover analysis. The nonlinear static procedure of ATC 40 is implemented in SAP2000 NL which feature is in the present analysis. The unique capability of the program is the definition of plastic hinge properties and the nonlinear static analysis tool. It allows for the direct input of moment rotation properties characteristic of sections. SAP2000 NL uses the moment rotation backbone curve from ATC40.

Modeling of Structural Elements

The primary structural elements of the RC MRF such as beams and columns are modeled as three dimensional frame elements with point plasticity at the end faces of beam and column. The contribution of infill stiffness is disregarded in this particular study but their weight is included in mass computations. The effective moment of inertia of 0.7 I_g (I_g is the gross moment of inertia) is considered for modeling the beams and columns. The foundation is treated to be fixed and the building is assumed to be in Zone V as per IS1893 (Part 1):2002 [8].

Modeling of Confinement

The moment rotation properties for beams and columns are obtained from Table 9.6 and 9.7 of ATC-40 depending on the level of transverse reinforcement provided in the sections. Generally flexural hinge (M3) is assigned for beams and axial moment hinge (PMM) for columns. The PMM hinge properties include moment theta relations as well as the interaction curve given as per ACI 318 [9]. The building was verified for the possibility of shear failures in the flexural components and it was found to be safe against such failures.

EVALUATION METHODOLOGY

Nonlinear Static Analysis Procedure(Pushover Analysis)

The analysis is performed using the tool SAP2000 NL. The pushover analysis follows the nonlinear static procedure. It essentially adopts the capacity spectrum method proposed by ATC-40. This method of evaluation considers two aspects, the performance of a structure during seismic event, and the strength/capacity of the structure. The structure has been idealized as a 3D finite element model constructed with elastic frame elements having point plasticity at the possible plastic hinge locations. A lateral force distribution in accordance with IS 1893:2002 is applied to the analytical model. The force deformation relationship is defined as per the ATC-40 guidelines which follows the convention below:

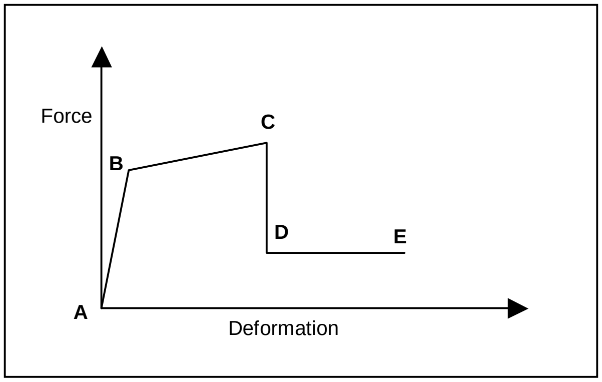

Fig 4 Typical Force Deformation relationship

Three different pushover cases have been performed in sequence as follows:

1. Gravity push, which is to apply gravity load (DL+0.25 LL)
2. Lateral push in the X-direction
3. Lateral push in the Y-direction

In general, the gravity load push is force controlled while the lateral push is deformation control. The displacements are monitored at the roof level. This includes the effect of secondary moments due to large deflections (P-Δ effect). The responses of the structure are the capacity curve representing the base shear versus roof displacement, the sequence of hinge formation and the capacity spectrum curve in ADRS format. Building performance can be described by the extent of damage sustained by the building, which influences the safety of the building occupants during and after the event. In this study, the performance objectives have been imposed to satisfy the code compliance and to insists favorable failure pattern preferably a strong column-weak beam mechanism.

Results and Discussions

The building time period is estimated as 1.162s from the Eigen value analysis with the code estimated period being 0.554s. The building base shear capacity from pushover analysis is 1276 kN (0.2W where W is the total seismic weight of the building) and a maximum displacement of 0.24m. The plot of the base shear versus the displacement is shown in Fig 4. The capacity curve and the demand curve for the building is represented in the ADRS format and the intersection of the curves resulting in the performance point is shown in Fig 5. The possible failure mechanism of the building and in specific column hinging at the ground level and beam hinging in the floor levels is clearly depicted in Fig 6. Column hinging in between the storeys is another feature representative in this building. The performance point is obtained at a base shear level of 1148 kN and a displacement of 0.121m which lies below the performance objective required for Life safety of 2% of building height (0.288m). The building fails to satisfy the required performance objective of life safety under a maximum credible earthquake.

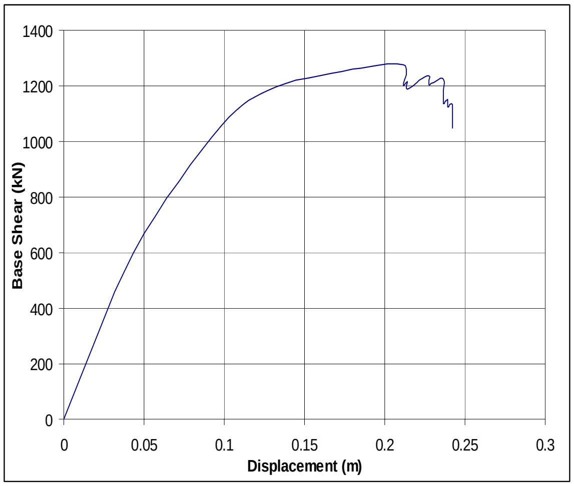

Fig 4 Capacity curve for four storey building

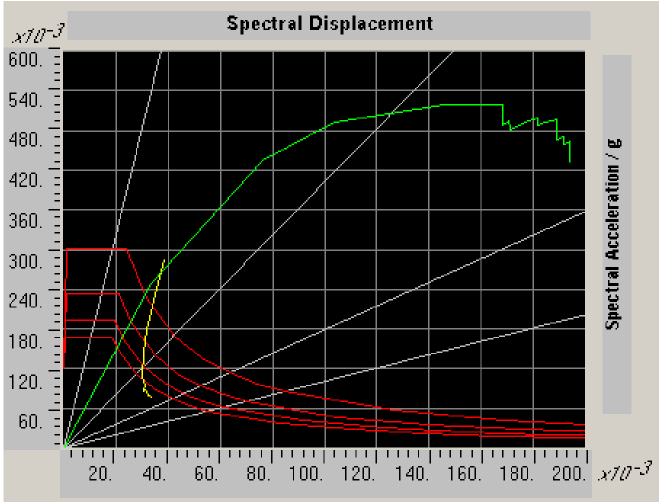

Fig 5 Capacity and demand curve in the ADRS plot

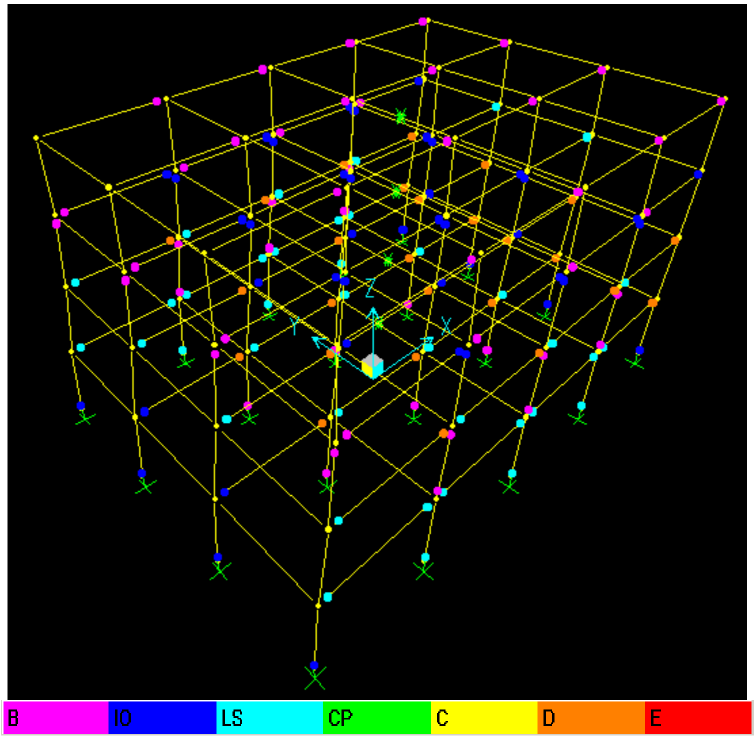

Fig 6 Failure mechanism for the four storey RC MRF building

CONCLUSIONS

In this paper a rational procedure for seismic evaluation of Indian RC MRF buildings is presented with a detailed pushover analysis of a typical four storey building. The inadequacies in detailing are incorporated in the model in the form of moment rotation properties for the structural elements. This procedure gives a quick estimate of the base shear and the desirable performance of the building in its existing condition. Also this methodology is efficient in determining the deficient members and the performance of the building as a whole. The performance of the building is finally checked for code compliance and for the probable failure mechanisms. This evaluation is a prerequisite for the retrofit of the existing RC MRF buildings in India.

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