Seismic Evaluation of R/C Framed Building Using Shear Failure Model

Vinod Kumar Kardam, R. S. Ojha

Abstract— **Since a number of parameters like shear capacity, shear displacement, shear stiffness etc. are involved in calculation of nonlinear shear hinge parameters; therefore it is very difficult to predict the same.**

As shear failure are brittle in nature, designer must ensure that shear failure can never occur, otherwise the concerned building is going to collapse suddenly without giving any warning. Designer has to design the sections such that flexural failure (ductile mode of failure) precedes the shear failure. Also design code does not permit shear failure. However, past earthquakes reveal that majority of the reinforced concrete (RC) structures failed due to shear.

It is unfortunate that the Indian construction practice does not guaranty safety against shear. Therefore accurate modelling of shear failure is almost certain for seismic evaluation of RC framed building.

The primary objective of the present work is to develop nonlinear force-deformation model for reinforced concrete section for shear and demonstrate the importance of modelling shear hinge in seismic evaluation of RC framed building. From the existing literature it is found that equations given in Indian Standard IS-456: 2000 and American Standard ACI-318: 2008 represent good estimate of ultimate strength. However, FEMA-356 recommends ignoring concrete contribution in shear strength calculation for ductile beam under earthquake loading. No clarity is found regarding yield strength from the literature. Priestley et al. (1996) is reported to be most effective for calculating shear displacement yield whereas model proposed by Park and Paulay (1975) is most effective in predicting the ultimate shear displacements for beams and columns. Combining these models shear hinge properties can be calculated.

To demonstrate the importance of modelling shear hinges, an existing RC framed building is selected. Two building models, one with shear hinge and other without shear hinges, have been analysed using nonlinear static (pushover) analysis.

This study found that modelling shear hinges is necessary to correctly evaluate strength and ductility of the building. When analysis ignores shear failure model it overestimates the base shear and roof displacement capacity of the building. The results obtained here show that the presence of shear hinge can correctly reveal the non-ductile failure mode of the building

Index Terms—**FEMA-356, Reinforced Concrete, RC.**

I. INTRODUCTION

The problem of shear is not yet fully understood due to involvement of number of parameters. In earthquake resistance structure heavy emphasis is placed on ductility. Hence designer must ensure that shear failure can never occur as it is a brittle mode of failure. Designer has to design the sections such that flexural failure (ductile mode of failure) antedates the shear failure. Also, shear design is major important factor in concrete structure since strength of concrete in tension is lower than its strength in compressions. However, past earthquakes reveal that majority of the reinforced concrete (RC) structures failed due to shear. Indian construction practice does not guaranty safety against shear.

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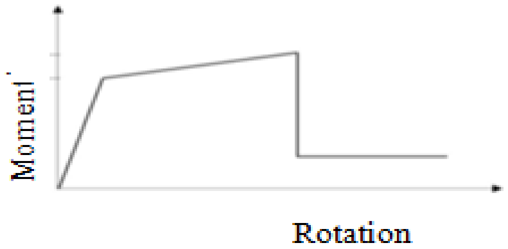

Fig.1.: Nonlinear models for Moment *v/s* Rotations

Fig. 1. presents a typical nonlinear moment rotation curve for RC member. Alternative methods are available in literature to calculate the important points required to define the nonlinear moment rotation curve for any section. In the conventional analysis the sections are generally considered to be elastic in shear although this not true. Therefore, the primary objective of the present work is to develop nonlinear force-deformation model for RC rectangular section for shear

II. SHEAR CAPACITY MODEL

The shear capacity of a section is the maximum amount of shear the section can withstand before failure. Based on theoretical concept and experimental data researchers developed many equations to predict shear capacity but no unique solutions are available. Several equations are available to determine shear capacity of RC section, *i.e*., ACI 318:2005 equations, Zsutty's equation (1968,1971) and Kim and White equation (1991) etc. To verify the applicability of these equations experimental study was carried out by several researchers on rectangular RC beam with and without web reinforcement. Three parameters: cylindrical compressive strength (f_c'), longitudinal reinforcement ratio (ρ) and shear span-to-depth ratio (*a/d*) are considered for developing equations for estimating shear strength of RC section without web reinforcement.

Factors affecting shear capacity of beam

There are several parameters that affect the shear capacity of RC sections without web reinforcement. Following is a list of important parameters that can influence shear capacity of RC section considerably:

1-Shear span to depth ratio *(a/d)*

2-Tension steel ratio *(ρ)*

3-Compressive strength of Concrete *(fc)*

4-Size of coarse aggregate

5-Density of concrete

6-Size of beam

7-Tensile strength of concrete

8-Support conditions

III. SHEAR DISPLACEMENT MODEL

Consider the reinforced concrete element shown in Fig. The shear forces are represented by *V*. The application of forces in such a manner causes the top of the element to slide with respect to the bottom. The displaced shape is shown by the dashed lines and the corresponding displacement is known as shear displacement depicted by (δ). Shear displacements over the height of the element are generally expressed in terms of shear strain (γ) which is ratio of shear displacement to height of the element and is a better representation of shear effect. The effect of the shear forces translates into tension along the diagonal, which can be visualized by resolving the shear forces along the principal direction. As the concrete is weak in tension, it is susceptible to cracks in the direction perpendicular to the tensile load, which creates diagonal cracking well known to be associated with shear. The corresponding displacement is known as shear displacement (δ).

IV. MODELS FOR SHEAR DISPLACEMENT AT YIELD

Most of the models available in literature are developed to predict shear displacement at yield point. The reason for concentrating on yield point is mainly because some of the shear strength models use displacement ductility as a measure of shear strength. Displacement ductility is defined as ratio of ultimate displacement to yield displacement. Thus it is necessary to predict displacement at yield more accurately with better knowledge of all its components including flexure, bar-slip and shear displacement. The following models are developed to calculate the shear displacement at yield. These models are applicable for both beam and column with web reinforcement.

V. CALCULATIONS FOR YIELD AND ULTIMATE SHEAR DISPLACEMENT

To compare equations available in literature for estimation of shear displacement at yield and ultimate point, a test beam section is considered and shear displacement for this beam section is calculated using all the equation presented above. The details of the test section are given below.

Details:

- Type of the Section: Simply supported beam subjected to one point load.
- Beam size = 150 × 250 mm with cover 25 mm.
- Span = 3 m.
- Shear span to depth ratio = 3.6
- Top reinforcement = 3 numbers of 12 mm bars (3Y12)
- Bottom reinforcement = 3 numbers of 16 mm bars (3Y16)
- Web reinforcement = 2 legged 8 mm stirrups at 150 mm c/c
- Shear span = 810 mm.
- Maximum aggregate size = 40 mm.
- Grade of materials = M 20 grade of concrete and Fe 415 grade of reinforcing steel.

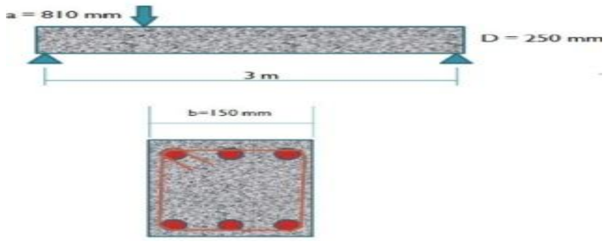

Fig.2 . Test beam section considered for the comparison.

VI. PLASTIC HINGE MECHANISM

Sequences of plastic hinge formation are presented . Performance levels of the plastic hinges are shown using colour code. The global yielding point corresponds to the displacement on the capacity curve where the system starts to soften. The ultimate point is considered at a displacement when lateral load capacity suddenly drops. Plastic hinges formation first occurs in beam ends and columns of lower stories, then extended to upper stories and continue with yielding of interior intermediate columns.

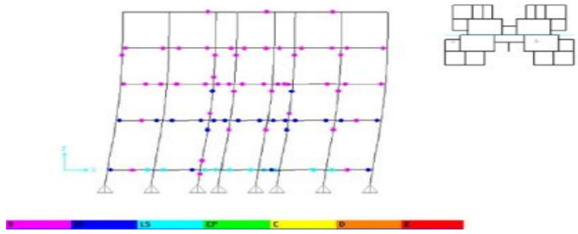

Fig.3 At Step# 4 (973.4 kN, 57.8 mm)

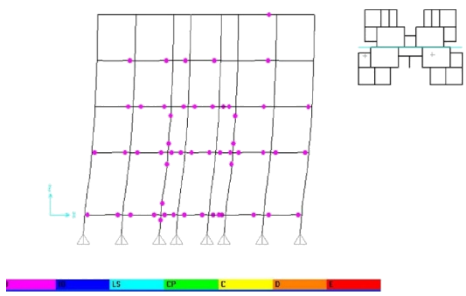

Fig.4 At Step# 2 (757.5 kN, 32.2 mm)

VII. CONCLUSIONS

Shear strength

FEMA-356 does not consider contribution of concrete in shear strength calculation for beam under earthquake loading for moderate to high ductility. Contribution of web reinforcement in shear strength given in IS-456: 2000 and ACI-318: 2008 represent ultimate strength

Shear displacement at yield

The model by Sezen (2002) is based on regression analysis of test data Model by Panagiotakos and Fardis (2001) is simple but it is reported to be overestimating the shear displacement. Model proposed by Gerin and Adebar (2004) is reported to be underestimating the shear displacements at yield. Priestley et al. (1996) is reported to be most effective for calculating shear displacement at yield for beams and columns.

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