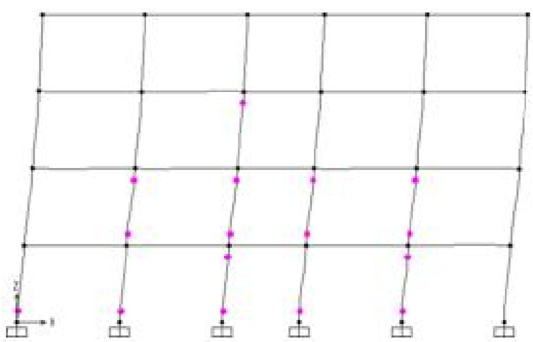
Seismic Evaluation of R/C Framed Building Using Shear Failure Model

D.Sudhakar[1], V.Raj kumar[2]
[1]Dept of Civil Engg
[2]Asst. Professor, Dept of Civil Engg
[1, 2] Newton's Institute of Science & Technology,Macherla,India

Abstract- *Prediction of nonlinear shear hinge parameters in RC members is difficult because it involves a number of parameters like shear capacity, shear displacement, shear stiffness. As shear failure are brittle in nature, designer must ensure that shear failure can never occur. 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. 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.*

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.



II. SHEAR CAPACITY MODEL

Shear Capacity

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 (fc), 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.

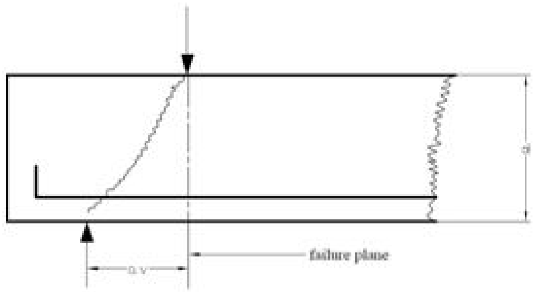
Factors affecting shear capacity of beam

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:

- Shear span to depth ratio (a/d)
- Tension steel ratio (ρ)
- Compressive strength of Concrete (fc)
- Size of coarse aggregate
- Density of concrete
- Size of beam
- Tensile strength of concrete
- Support conditions
- Clear span to depth ratio (L/d)
- Number of layers of tension reinforcement
- Grade of tension reinforcement
- End anchorage of tension reinforcement.

Shear capacity near support

BS-8110:1997 Part 1 (clause 3.4.5.8) states that shear failure in beam sections without shear reinforcement normally occurs at about 30° to the horizontal. Shear capacity increases if the angle is steeper due to the load causing shear or because the section where the shear is to be checked is close to the support.



Modes Of Failure In Shear

Modes of shear failure for beam without web reinforcement depend on the shear span. Shear failure is generally classified based on shear span into three types as follows:

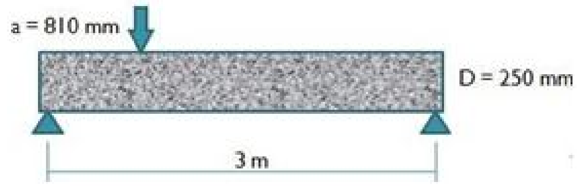
Diagonal tension failure($a > 2d$)
Diagonal compression failure($d \leq a \leq 2d$)
Splitting or true shear failure($a < d$)

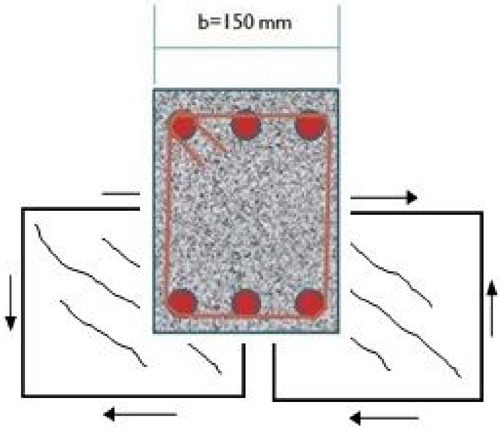
Example Of Shear Strength Estimation

To compare the shear capacity equations available in literature a test beam section is considered and shear capacity for this beam section is calculated using all the equation presented above. The details of the test section are given below. Fig. 3.2 presents a sketch of the test beam considered for the comparison.

Details:

- Type of the beam: Simply supported beam subjected to one pointload.
- Beam size = 150 × 250 mm with cover 25 mm.
- Span = 3 m.
- Shear span-to-depth ratio = 3.6
- Top reinforcement = 3 number of 12 mm bars (3Y12)
- Bottom reinforcement = 3 number 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





the shear capacity as carried out by the concrete and transverse reinforcement separately for different approaches available in literature.

III. SHEAR DISPLACEMENT MODEL

Shear Displacement

Consider the reinforced concrete element shown in Fig.. The shear forces are represented by V. The Application Of Forces In Such A Manner

SAP 2000.

Developing computational model is an important part on which linear or nonlinear, static or dynamic 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.

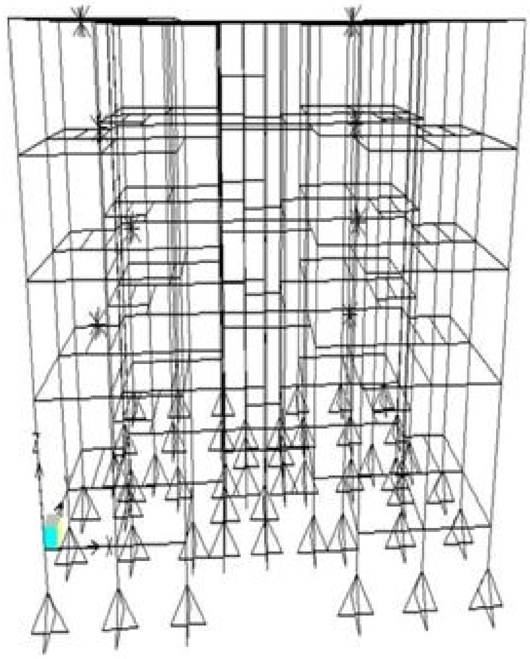
The effect of the shear forces translates into tension along the diagonal, which can be visualized by resolving the shear forces along the principal direction. As the concrete is weak in tension, it is susceptible to cracks in the direction perpendi cular to the tensile load, which creates diagonal cracking well known to be associated with shear. The corresponding displacement is known as shear displacement (δ).

Calculations For Yield And Ultimate Shear Displacement

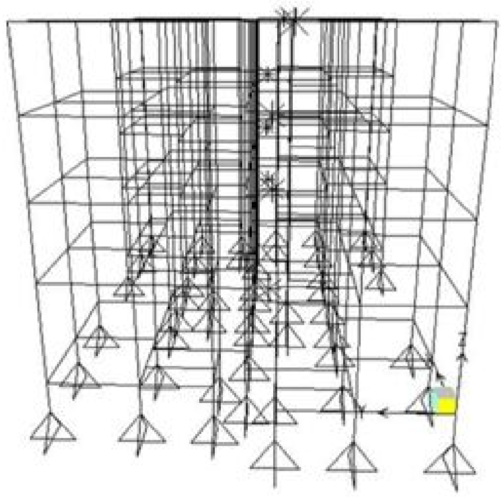
To compare equations available in literature for estimation of shear displacement at yield and ultimate point, a test beam section is considered and shear displacement for this beam section is calculated using all the equation presented above. The details of the test section are given below. A sketch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

IV. STRUCTURAL MODELLING

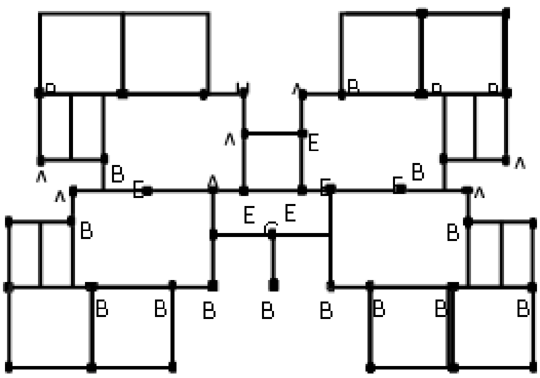
In the present study an existing building is selected for seismic evaluation case study. This building is analyzed considering nonlinear flexural and shear failure of the frame elements. Shear failure model is developed from the existing literature presented in the previous chapters. The building is also analyzed ignoring the shear failure of the frame elements for demonstrating the importance of shear failure model in seismic evaluation study. All the analyses are carried out in commercial software analysis performed. First part of this chapter explains the details of computational model. Also, details of the selected building model are described in this section. Accurate modeling of the nonlinear properties of various structural elements is very important in nonlinear analysis. Frame elements in this study are modelled with inelastic flexural hinges and shear hinges. The procedure to generate these hinge properties and its related assumptions are briefly explained in the second part of this chapter.



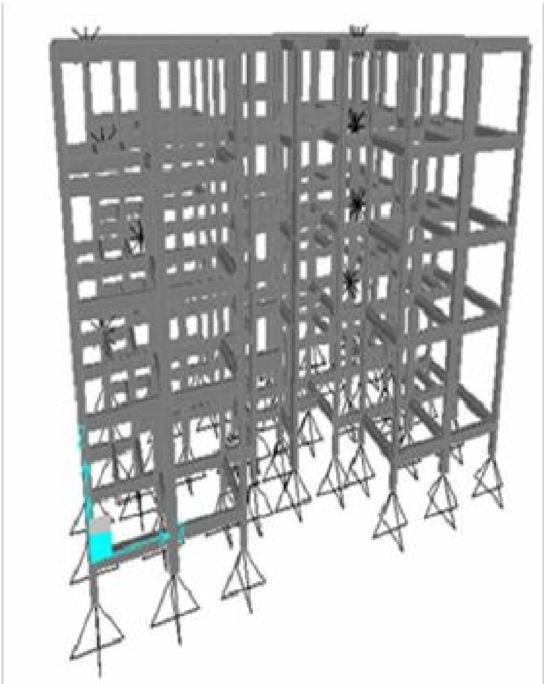
ELEVATION-FRONT VIEW



ELEVATION-SIDE VIEW



COLUMN LOCATION



3D COMPUTER MODEL OF A BUILDING

V. NONLINEAR STATIC (PUSHOVER) ANALYSIS

A nonlinear pushover analysis of the selected building is carried out as per FEMA 356 for evaluating the structural seismic response. In this analysis gravity loads and a representative lateral load pattern are applied to frame structure. The lateral loads were applied monotonically in a step- by-step manner. The applied lateral loads in X- direction representing the forces that would be experienced by the structures when subjected to ground shaking. The applied lateral forces were the product of mass and the first mode shape amplitude at each story level under consideration. P–Delta effects were also considered in account. At each stage, structural elements experience a stiffness change as shown in Fig. 6.1, where IO, LS and CP stand for immediate occupancy, life safety and collapse prevention respectively.

Capacity Curve

In pushover analysis, the behaviour of the structure is depends upon the capacity curve that represents the relationship between the base shear force and the roof displacement. Due to this convenient representation in practice engineer can be visualized easily. It is observed that roof displacement was used for the capacity curve because it is widely accepted in practice. Two models of the selected building one with shear hinges and other without shear hinges are analysed in the present study.

1. Considering Flexural Hinges only.
2. Considering both Flexural and Shear Hinges

Capacity Curves For Push X And For Push Y

The two resulting capacity curves for Push X and for Push Y analysis are plotted in Figs. 6.2 and 6.3, respectively. Two building models with and without shear are considered. They are initially linear but start to deviate from linearity as the beams and the columns undergo inelastic deformation. When the buildings are pushed well into the inelastic range, the curves become linear again but with a smaller slope. The two curves could be approximated by a bilinear relationship. Tables 6.3 and 6.4 presents the numerical data for capacity curves obtained from pushover analysis in X- and Y-directions respectively

Plastic Hinge Mechanism

Sequences of plastic hinge formation are presented in Figs. 6.4 to 6.7. 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.

VI. CONCLUSIONS

Followings are the salient conclusions from the present study:

Shear strength

i) FEMA-356 does not consider contribution of concrete in shear strength calculation for beam under earthquake loading for moderate to high ductility.
ii) Contribution of web reinforcement in shear strength given in IS-456: 2000 and ACI-318: 2008 represent ultimate strength.
iii) FEMA-356 consider ultimate shear strength carried by the web reinforcement (= strength of the beam) as 1.05 times the yield strength. But there is no engineering background for this consideration.
iv) No clarity is found in yield strength from the literature.

Shear displacement at yield

i) The model by Sezen (2002) is based on regression analysis of test data

ii) Model by Panagiotakos and Fardis (2001) is simple but it is reported to be overestimating the shear displacement.
iii) Model proposed by Gerin and Adebar (2004) is reported to be underestimating the shear displacements at yield.
iv) Priestley et al. (1996) is reported to be most effective for calculating shear displacement at yield for beams and columns.

Ultimate Shear displacement

i) Model of Park and Paulay (1975) is reported to be most effective in predicting the ultimate shear displacements for beams and columns.
ii) CEB (1985) is also reported to be effective in predicting the ultimate shear displacements of beam.
iii) Model by Gerin and Adebar (2004) is reported to be not suitable for predicting the ultimate shear displacements.

REFERENCES

[1] A. Kadid and A. Boumrkik, "Pushover analysis of reinforced concrete frame structures", Asian journal of civil engineering (building and housing) Vol. 9, No.1, pp. 75-83, 2008.
[2] A.Ghaffar, A.Javed, H.Rehman, K.Ahmed and M hyas, "Development of shear capacity equations for rectangular reinforced beams", Park J Eng. & appl.Sci.Vol.6, pp.
[3] ACI 318, Building Code Requirements for Reinforced Concrete, American Concrete Institute, Detroit, Michigan, 2002.
[4] Alexander Placas and Paul E. Regan and A.L.L Baker, "Shear failure of reinforced concrete beams," ACI journal, title No.68-67, pp.763- 773, October 1971.
[5] Applied Technology Council (ATC-40), "Seismic evaluation and retrofit of concrete buildings", Vol.1& 2, California, 1996.
[6] ASCE-ACI Task Committee 426, "The Shear Strength of Reinforced Concrete Members," ASCE Journal of Structural Div., Vol. 99, pp. 1091-1187, June 1973.
[7] Bazant Z P and Kazemi M T, "Size effect on diagonal shear failure of beams without stirrups", ACI Structural Journal, 88(3), pp.268–276, 1991.
[8] Bazant Z P and Sun H H, "Size effect in diagonal shear failure: influence of aggregate size and stirrups", ACI Materials Journal, 84(4) pp. 259–272, 1987.
[9] Bazant, Z. P., Yu and Qiang, "Design Against Size Effect on Shear Strength of Reinforced Concrete Beams without Stirrups". Structural Engineering Report No.03-02/A466s, Northwestern University, Evanston, Illions, 2003.
[10] BS 8110-1, Structural use of concrete, Part 1: Code of Practice for Design and Construction, British Standards Institution, London, 1997.
[11] C.G.Karayannis, C.E.Chalioris and P.D.Mavroeidis, "Shear capacity of RC rectangular beam with continuous spiral transverse reinforcement", proceedings of Twelfth International Conference on Computational Methods and Experimental Measurements, Malta, pp.379-386, 2005.
[12] Chaitanya Patwardhan (2005), "Shear strength and deformation modeling of reinforced Concrete columns", Department of Civil Engineering, Ohio State University, 2005.