DETERMINATION OF SEISMIC EVALUATION IN R/C FRAMED BUILDING USING SHEAR FAILURE MODEL

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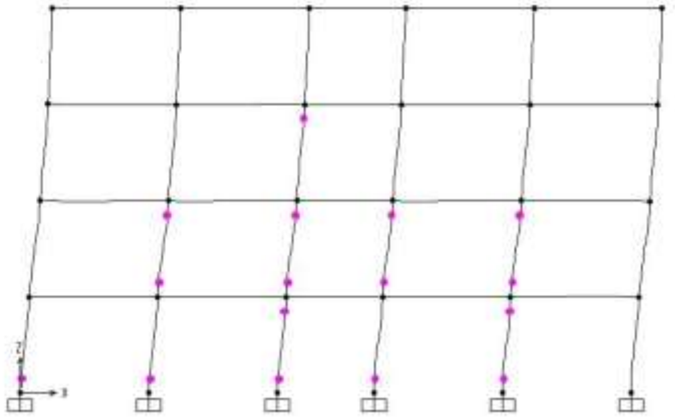
ABSTRACT

This paper summarizes various aspects of the 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. A thorough literature review does not reveal any information about the nonlinear modelling of RC sections in Shear. The current industry practice is to do nonlinear analysis for flexure only. Therefore, 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.

Keywords: Shear Hinges, Shear Strength, Shear Displacement, Nonlinear Static Pushover Analysis, Hinge Property, Reinforced Concrete

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. Fig. 1. represents deformed shape of a building model under lateral load. Failure through formation of hinges in the columns is also shown in this figure. A nonlinear analysis like this can predict the failure mode, maximum force and deformation capacity of the structure. But to do an accurate analysis nonlinear modelling of frame sections for flexure and shear is very important. However, the nonlinear modelling of RC sections in shear is not well understood. A thorough literature review does not reveal any information about the nonlinear modelling of RC sections in Shear. The current industry practice is to do nonlinear analysis for flexure only.



Figure; 1 Deformed Shape of a Nonlinear Building Model Under Lateral Load

II. OVERVIEW

This chapter reviews major international design codes with regard to the shear provision in RC section. This includes Indian Standard IS 456: 2000, British standard BS 8110: 1997 (Part 1), American Standard ACI 318: 2008 and FEMA 356: 2000. The shear capacity of a section is the maximum amount of shear the beam can withstand before failure. In a RC member without shear reinforcement, shear force generally resisted by:

i) Shear resistance V_{cz} of the uncracked portion of concrete.

ii) Vertical component V_{ay} of the 'interface shear' (*aggregate interlock*) force V_a.

iii) Dowel force V_d in the tension reinforcement (due to dowel action).

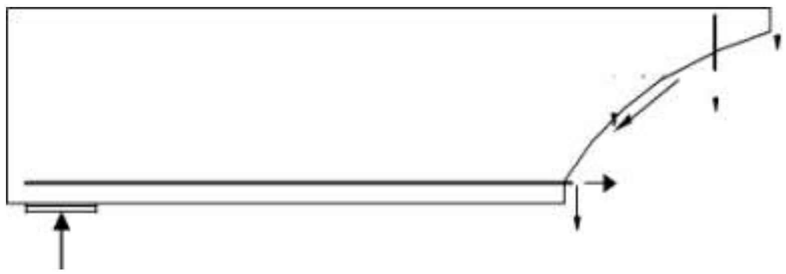


Fig.2 Shear Transfer Mechanism

Member with shear reinforcement, shear force is mainly carried by uncracked portion of concrete (V_{cz}) and transverse reinforcement (V_s). Shear carried by aggregate interlock (V_a) and dowel force in the tension reinforcement (V_d) are very small hence their effects are considered negligible.

International design codes except British Standard recommend procedures to calculate shear strength of rectangular and circular RC sections with transverse reinforcement. However, all the design codes are silent about the maximum shear displacement capacity of RC sections. Shear strength estimation procedures as per few major international codes are discussed as follows.

III. INDIAN STANDARD (IS 456: 2000)

Indian standard IS 456: 2000 as per Clause 40.1, specify the nominal shear stress by following equations.

$$\tau_v = \frac{V_u}{bd} \quad (.1)$$

Shear carried by concrete is given by

$$V_u = \delta \, \tau_c \, bd \quad (.2)$$

$$\text{Where } \delta = 1 + \frac{3P_u}{A_g f_{ck}} \leq 1.5 \text{ and } \tau_c = \frac{0.85 \sqrt{0.8 f_{ck}} \left(\sqrt{1+5\beta} - 1\right)}{6\beta}$$

$$\text{Here } \beta = \frac{0.116 f_{ck} bd}{100 A_{st}} \geq 1.0$$

As per clause *40.2.2*, for member subjected to axial compression P_u, the design shear strength of concrete, given in Table 19 shall be multiplied by the following factor :

$$\delta = 1 + \frac{3P_u}{A_g f_{ck}} \leq 1.5 \quad (3)$$

The design shear strength of concrete (τ_c) in beam without shear reinforcements is given in Table 19. τ_c depend upon percentage of steel p_t which is given by

$$p_t = \frac{100 A_{st}}{bd} \quad (4)$$

If τ_v exceeds τ_c given in Table *19* , Shear reinforcement shall be provided in any of the following forms:

- Vertical stirrups
- Bent-up bars along with stirrups
- Inclined stirrups

IV. BRITISH STANDARD (BS 8110: 1997, PART 1)

British standard BS 8110: PART 1 as per clause *3.4.5.2*, specify the nominal shear stress by following equations.

$$v = \frac{V}{b\,d} \quad (2.6)$$

v

Where b_v is the breadth of the section. For a flanged beam width is taken as the width of the rib below the flange. V is the design shear force due to ultimate loads and d is the effective depth. The code gives in Table *3.9* the design concrete shear stress v_c which is
used to determine the shear capacity of the concrete alone. Values of v_c depend on the
percentage of steel in the member, the depth and the concrete grade. The design concrete shear stress is given by

$$V_c = \frac{0.79}{\gamma_m} \times \left(\frac{100A_s}{bd}\right)^{\frac{1}{3}} \times \left(\frac{400}{d}\right)^{\frac{1}{4}} \times \left(\frac{f_{cu}}{25}\right)^{\frac{1}{3}} \quad for \ \frac{a}{d} > 2 \qquad (2.7)$$

where $\frac{100A_s}{bd} \le 3, \ \frac{400}{d} \ge 1, \ \gamma_m = 1.25 \ \& \ f_{cu} \le 40MPa$.

V. 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 ($f_c^{'}$), 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.

VI. 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.

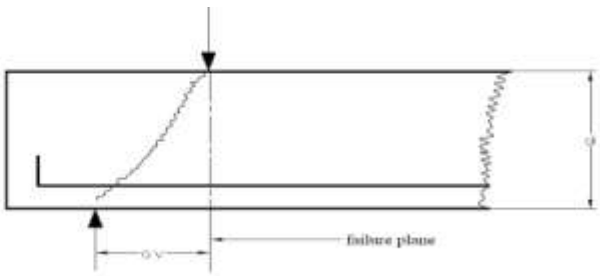


Fig.3. Shear Capacity Near Support

VII. 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:

i) Diagonal tension failure ($a > 2d$)

ii) Diagonal compression failure ($d \leq a \leq 2d$)

iii) Splitting or true shear failure ($a < d$)

VIII. 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 point load.
- 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

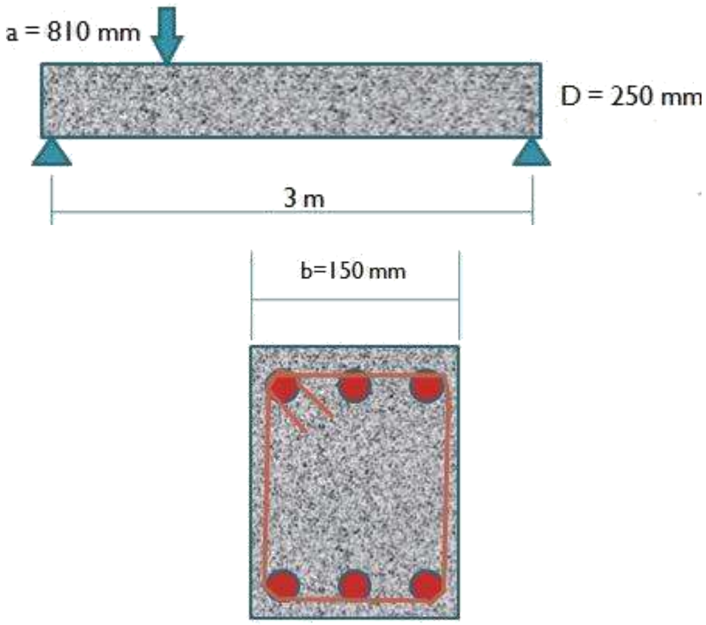


Fig. 4 Test Beam Section Considered for the Comparison

Table 1 presents the shear capacity as carried out by the concrete and transverse reinforcement separately for different approaches available in literature.

Table 1. Ultimate Shear Strength (KN) of beam

Methods	V_c (kN)	V_s (kN)	V_y (kN)	V_u (kN)
Zsutty's T.C	32.87	-	-	-
Mphonde & Frantz	47.29	-	-	-
Bazant & Kim	34.56	-	-	-
Bazant & Sun	30.60	-	-	-
BS 8110 : 1997	27.71	--	-	-
IS 456:2000	30.10	54.42	-	84.52
ACI 318: 2008	22.95	62.55	-	85.50
FEMA - 356	0	Vs,y	Vy=Vs,y	$1.05V_y$

*For seismic loading.

IX. SHEAR DISPLACEMENT

Consider the reinforced concrete element shown in Fig.4.1. 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).

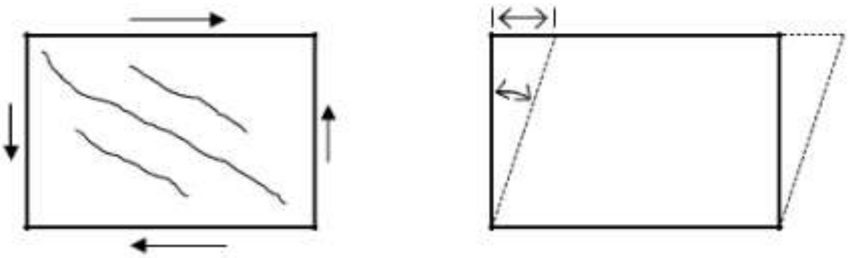


Fig 5 Shear Displacement of Concrete Member

Deflections due to flexure and bond-slip are relatively easy to model with adequate accuracy whereas calculating shear displacement accurately has not been investigated thoroughly. The accuracy of the few existing models is not known. This chapter presents various methodologies available in literature to estimate shear displacement of RC section for un-cracked phase, at yield and at collapse.

X. MATERIAL PROPERTIES

The material properties of any member consists of its mass, unit weight ,modulus of elasticity, poisson's ratio, shear modulus and coefficient of thermal expansions.The material grades used for frame model are presented in Table

Table 2 Materials Grades

Material	Grade
Concrete	M 20
Reinforcing steel	Fe 415

Elastic material properties of these materials are taken as per Indian Standard IS 456: 2000. The short-term modulus of elasticity (E_c) of concrete is taken as:

$$E\ 5000 \qquad 5.1$$

f_{ck} is the characteristic compressive strength of concrete cube in MPa at 28-day (25 MPa in this case). For the steel rebar, yield stress (f_y) and modulus of elasticity (E_s) is taken as per IS 456 (2000).

XI. BUILDING GEOMETRY

The selected building is a three storey residential apartment building located in Seismic Zone III designed with IS 1893:2002 and IS 456:2000. Table 5.2 presents a summary of the building parameters. The building is almost symmetric in both the directions. The concrete slab is 150 mm thick at every floor level. The wall thickness is 230mm for the exterior and 120mm for interior walls.

Table. 3 Building Summary

Building Type	RC frame with un-reinforced brick infill
Year of construction	2001
Number of stories	Ground + 3 Storey
Plan dimensions	20.50m × 13.30m
Building height	13.1 m above plinth level

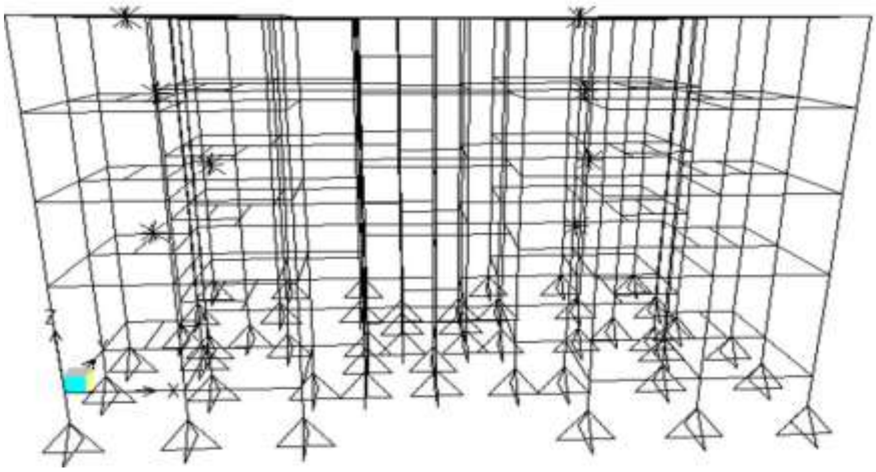


Fig 6 Elevation of The Building - Front View

The main objective of the present study is to demonstrate the importance of shear hinges in seismic evaluation of RC framed building. A detailed literature review is carried out as part of the present study on shear strength and displacement capacity of rectangular RC sections and seismic evaluation based on nonlinear static pushover analysis. Different methods to estimate shear strength and displacement capacity are studied. These calculation procedures are discussed through example calculations in Chapters 3 and 4.

There is no published literature found on the nonlinear force-deformation model of RC rectangular section for shear. A model for nonlinear shear force versus shear deformation relation is developed using FEMA 356, IS 456:2000, Priestley et al. (1996) and Park and Paulay (1975). To demonstrate the importance of shear hinges in seismic evaluation of RC framed building an existing framed residential apartment building is selected. This building is analyzed for two different cases: (a) considering flexural and shear hinges (b) considering only flexural hinges (*i.e.*, without considering shear hinges). The structures are analyzed for pushover analysis in X and Y directions.

Beams and columns in the present study were modelled as frame elements with the centrelines joined at nodes using commercial software SAP2000 (v14). The rigid beam-column joints were modelled by using end offsets at the joints. The floor slabs were assumed to act as diaphragms, which ensure integral action of all the vertical lateral load-

resisting elements. The weight of the slab was distributed as triangular and trapezoidal load to the surrounding beams. M 20 grade of concrete and Fe 415 grade of reinforcing steel were used to design the building. The column end at foundation was considered as fixed for all the models in this study.

The flexural hinges in beams are modelled with uncoupled moment (M3) hinges whereas for column elements the flexural hinges are modelled with coupled P-M2-M3 properties based on the interaction of axial force and bi-axial bending moments at the hinge location.

All the building models were then analysed using non-linear static (pushover) analysis. At first, the pushover analysis is done for the gravity loads (DL+0.25LL) incrementally under load control. The lateral pushover analysis (in X- and Y-directions) was followed after the gravity pushover, under displacement control.

Pushover analysis results for two different cases, as mentioned earlier, compared to identify the importance of the shear hinges in seismic evaluation problem

XII. SCOPE FOR FUTURE WORK

i) The nonlinear shear hinge properties of rectangular RC sections developed here can be validated through experimental study.

ii) The present study considers only rectangular sections with rectangular links as web reinforcement. This study can be further extended to spiral web reinforcement in circular section.

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.