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DUCTILITY BEHAVIOUR OF A REINFORCED CONCRETE FRAME

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Introduction

The behaviour of structures during a strong motion earthquake is not linear and a large amount of energy is absorbed by the structure through its nonlinear deformation before failure. Therefore, an important consideration in the design of earthquake resistant structures is provision of ductility in addition to strength. It is extremely important to ensure that in the extreme event of a structure being loaded near to failure, it has a capacity to dissipate energy through its ductile deformations.

Several codes (1, 3, 4) recommend deflection ductility factor of the order of 3 to 5 for ductile reinforced concrete structures. However, very few attempts have so far been made to determine whether such structures can actually achieve this ductility and whether the strains in steel and concrete in the section of the members are within the allowable limits at this value of ductility.

There are several definitions of ductility based on strain, deflection or curvature. Even among the various definitions, deflection ductility has been interpreted differently by different investigators. In the present study, the deflection ductility factor is defined as the ratio of the lateral deflection of frame, Δ_u just prior to the formation of a mechanism to its yield deflection, Δ_y. The yield deflection is arbitrarily chosen as the intersection point of tangents drawn from the origin and ultimate load point of the lateral load deflection curve (Fig. 1).

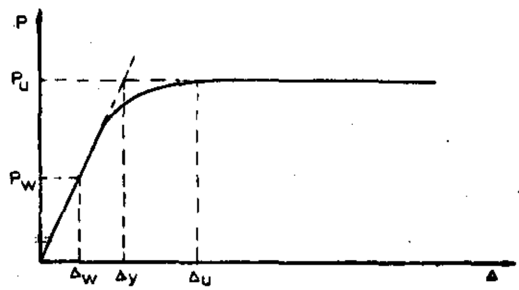

Fig. 1 Lateral load deflection curve

Test Frame

A reinforced concrete strong column weak beam frame designed for vertical load only is chosen for the experimental study. The overall sizes of columns and beam sections are 10 cm × 15 cm and 10 cm × 10 cm respectivectively. Overall height and effective span of frames are 99 cm and 91.45 cm respectively. The details are shown in Fig. 2. The properties of concrete and steel used in the frame are as follows :

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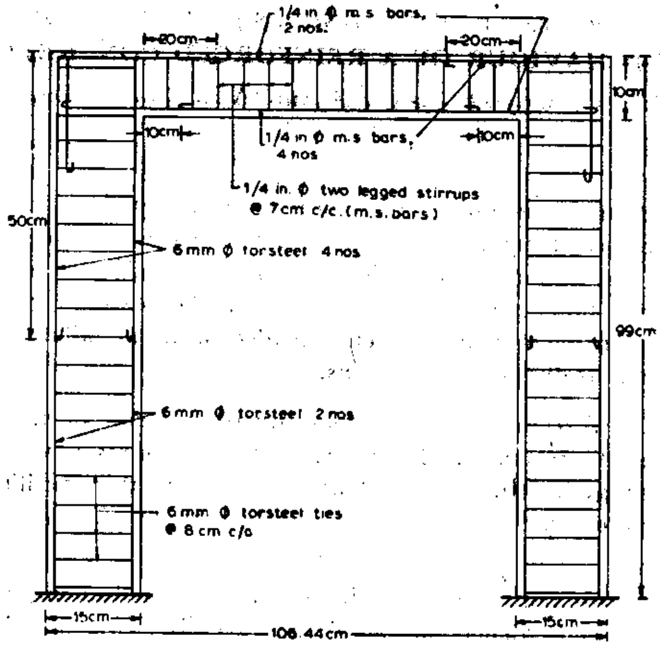

Fig. 2 Details of reinforcement in the frame

Unit weight of concrete	= 2323 kg/m^3
Cube strength of concrete	= 165.3 kg/cm^2
Cylinder strength of concrete	= 137.2 kg/cm^2
Modulus of elasticity of concrete	= 123975 kg/cm^2
Modulus of elasticity of mild steel	= 2.18 $\times$ 10^6 kg/cm^2
Yield strength of mild steel	= 3208 kg/cm^2
Ultimate tensile slrength of mild steel	= 4750 kg/cm^2
Strain at the commencement of strain hardening	= .011
Percentage elongation in mild steel	= 22.8
Modulus of elasticity of tor-steel	= 2.128 $\times$ 10^6 kg/cm^2
Yield strength of tor-steel	= 4570 kg/cm^2
Ultimate tensile strength of tor-steel	= 5280 kg/cm^2
Percentage elongation in tor-steel	= 20

The reinforcement of both the columns in the frame is welded to two base plates each being 30 cm $\times$ 30 cm and 16 mm thick. Each of these base plates are firmly anchored to a reinforced concrete reaction floor through four mild steel bolts. This arrangement simulated the fixed base foundation for the test frame.

Loading Arrangement

The experimental loading arrangemet is as shown in Fig. 4. The vertical load applied by a vertical hydraulic jack of 50 tonne capacity distributed equally on the tops of the two columns of the frame. Horizontal force is applied by a hydraulic jack of 20 tonne capacity, which is fixed on the supporting frame. Curved surfaces of mild steel are used to transfer the load vertically on each column throughout the test period. Rollers assembly is placed between central vertical jack and the top reaction girders in order to allow the test frame to move horizontally and to maintain the vertical loads to remain vertical all the time.

Instrumentation

The vertical load applied to the columns is measured by a proving ring of capacity 25 tonne attached between vertical hydraulic jack and the test frame. The lateral load is also measured by another proving ring of capacity 5 tonne placed between the hydraulic jack and the test frame. The lateral deflection of the frame at the top of column along the centre line of beam is recorded by means of long travel dial gauges with 0.01 mm least count.

Strain gauges are pasted on steel and concrete, and strains are recorded with the help of SR-4 type Baldwin-Lime-Hamilton Strain Indicator. Cube and cylinder tests of concrete and tensile tests of steel bars used in the frame are conducted on Universal testing machine along with the strain Indicator.

Frame Test

The vertical load is set to an assigned value and thus transferring net load of 5.13 tonne on each column of the frame. At this vertical load, strains on column concrete face and in beam steel are recorded by strain indicator and the lateral deflection of the frame by dial gauges.

Lateral load is applied in steps of 100 kg upto 1 tonne and 50 kg beyond 1 tonne upto failure. At each step of lateral load, the lateral deflection of the frame at column top and the strains at all significant points are measured simultaneouly.

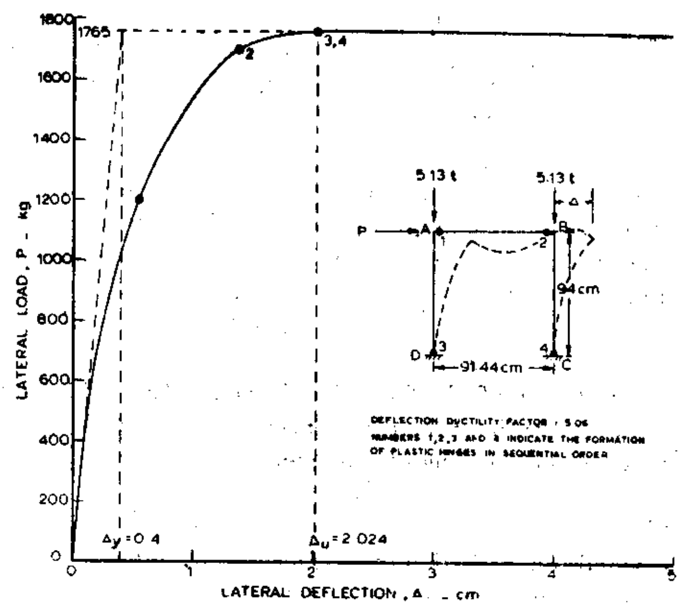

Fig. 3 Lateral load deflection curve of a reinforced concrete frame

Experimental Observations

The behaviour of the frame is shown in Fig. 3. Lateral load is taken for the ordinate and the lateral deflection for the abscissa. The first plastic hinge is formed in beam on the lateral load side and the last hinge is formed at the base of columns. Plastic hinges formed are shown by numbers 1, 2, 3 & 4 in sequential order. Fig. 5 and 6 indicate the deformed shape of the frame after collapse.

Results and Discussions

Figure 3 represents the lateral load-deflection curve of the strong oolumn weak beam frame under the loading condition as shown in the figure. The vertical load on the top of each column corresponds to the safe working load. The tangents have been drawn to locate an arbitrary yield deflection.

The definition of deflection ductility factor based on the yield deflection (as given in this paper) may be easily employed by a stuctural designer as it is easier for a structural analyst to find the yield deflection by determining

(i) the lateral deflection Δ_w at safe lateral working load P_w by using elastic analysis, and

(ii) the collapse load P_u by using ultimate load theory.

Referring to Fig. 1 and approximating the load deflection curve to the elastic-plastic plot the yiely deflection is expressed as

$$\Delta_y = \Delta_w \cdot \frac{P_u}{P_w}$$

In the present study deflection ductility factor of the frame is achieved as 5.06 when the volumetric ratio of confinement steel to the confined concrete is kept as .026 in beam and .018 in columns. Here, the pitch of the stirrups in beams and spacing of ties in columns are in accordance with the Indian Standard specifications (2).

It is also observed that the ultimate lateral load carrying capacity of this frame is 1.765 tonne and the maximum tensile strain in steel is .0089 whereas maximum compressive strain in concrete at the outer face of the columns is .00316. This study indicates that the maximum limit of tensile strain in steel remains well below the strain at which strain hardening starts, and the failure is due to the crushing of concrete.

Conclusions

Deflection ductility factor of the frame is achieved as 5.06. Maximum tensile strain in steel remains well below the strain at the commencement of strain hardening. The collapse of the frame takes place at the crushing of concrete.

Acknowledgement

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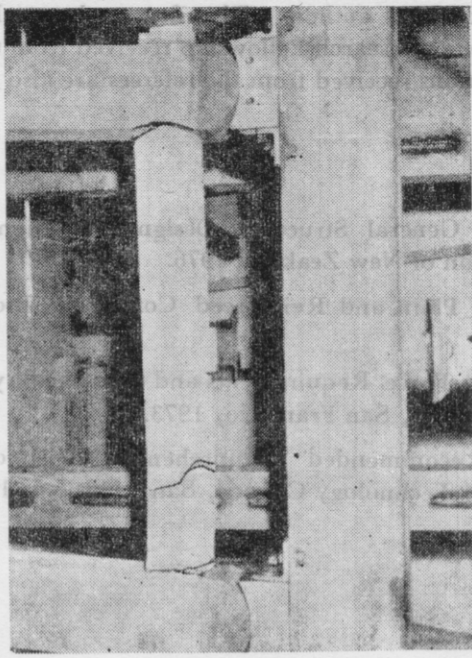

Fig. 4 Experimental Set-up

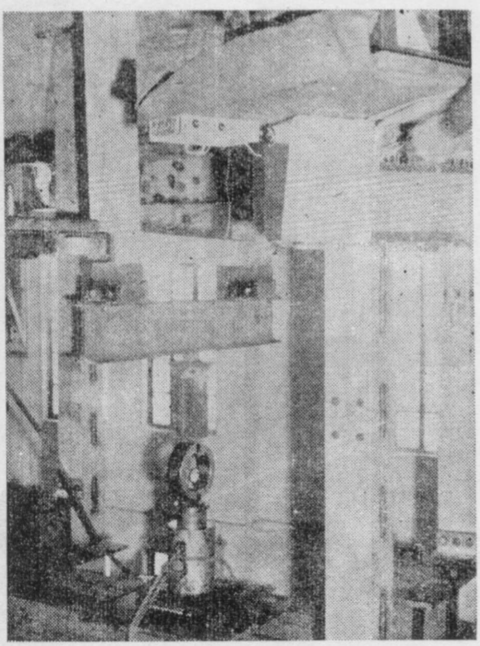

Fig. 5 Deformed shape of the frame after collapse

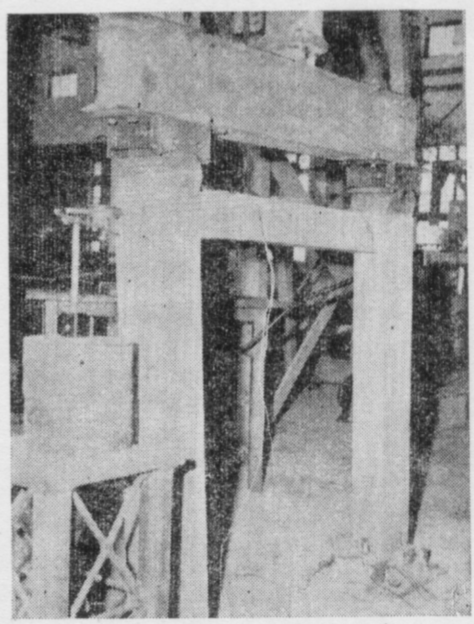

Fig. 6 Close-up of the beam portion

direction of the second and [illegible] authors. [illegible] first author acknowledges the financial assistance in the form of Senior Research Fellowship received from the Department of Earthquake Engineering. Suggestions received from the referees are also gratefully acknowledged.

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