TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

DEPARTMENT OF CIVIL ENGINEERING

DESIGN OF REINFORCED CONCRETE STRUCTURES

LAB REPORT

(CE-702)

SUBMITTED BY

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DEPARTMENT OF CIVIL ENGINEERING

PULCHOWK CAMPUS

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SLUMP TEST

COMPRESSIVE STRENGTH TEST

BOND AND ANCHORAGE TEST

(OVERLAP)

PURE BENDING TEST

(NON-OVERLAP)

FAILURE IN OVERLAP

SHEAR TEST

(RC BEAM WITH 3-8mm dia. STIRRUPS)

COMBINED SHEAR AND BENDING TEST

(RC BEAM WITH 5-8mm dia. STIRRUPS)

EXPERIMENT NO. 1

Compressive strength test of the concrete

Objective:-

To determine the compressive strength of concrete and to check whether strength based on design is obtained or not.

Materials required:

28 days cured concrete cube

Apparatus required:

Compressive strength testing machine

Theory:

Compressive strength of a concrete is the resistance to withstand the compressive load. The compressive strength of concrete is determined to control the quality of concrete and to specify the grade of concrete.

$$\text{Compressive strength} = \frac{\text{compressive load}}{\text{cross-sectional area}}$$

Details of cube testing:

Grade of concrete = M25

Proportion used = 1 : 1.696 : 2.887 : 0.48

(C : S : CA : W)

Size of cube = 150×150×150mm

Number of cubes = 3

For Pure bending and Bond & Anchorage test:-

Cube	Weight (kg)	Failure load (kN)	Avg. compressive load (kN)
1	8.405	640	
2	8.54	650	633.33
3	8.36	610	

Area of cube = 150× 150

= 0.0225 m^2

Average compressive strength = $\frac{633.33}{0.0225}$ = 28.15 MPa

Slump = 13mm (very low slump) [Range: 0-25 mm]
(True slump)

Cube	Weight (kg)	Failure Load (KN)	Avg. compressive load (KN)
1	8.39	660	
2	8.385	690	656.67
3	8.520	620	

Average compressive strength = $\frac{656.67}{0.0225}$ = 29.18 MPa

slump = 6mm (very low slump/true slump)

Result and conclusion

Hence, average compressive strength for pure bending and bond & anchorage test was found to be 28.15 MPa. and for shear failure and combined bending & shear test was found to be 29.18 MPa.

The cubes were tested for M25 grade of concrete. Thus, both results shows that Average compressive strength exceeded the characteristic strength of cube (i.e. 25MPa).

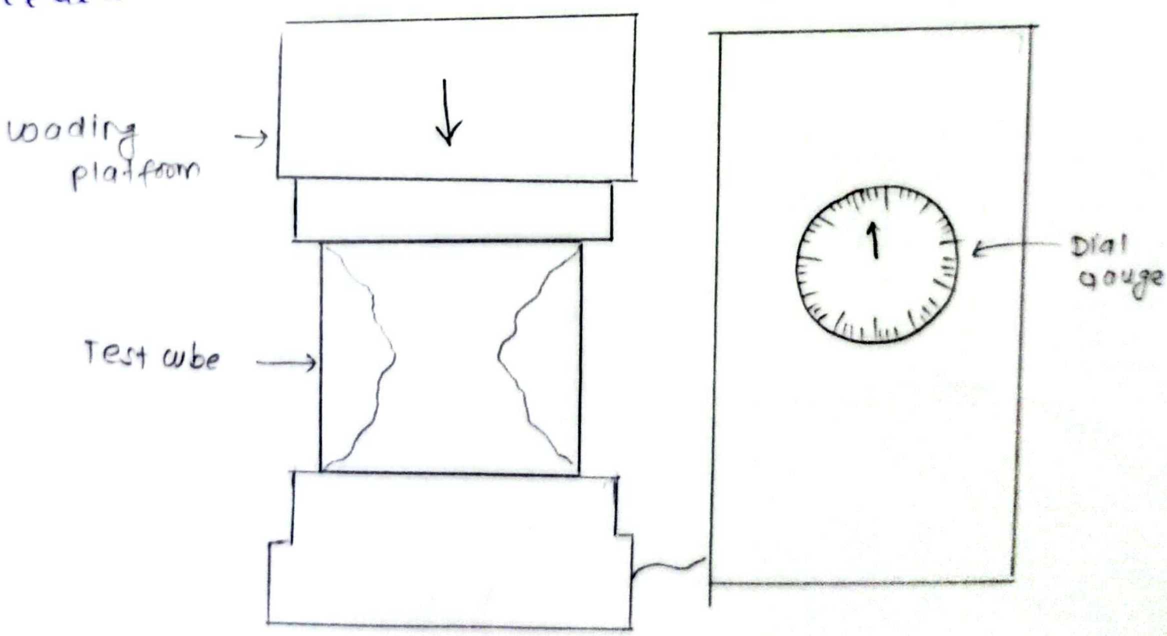


Fig: compressive strength test

EXPERIMENT NO. 2

Mix design of Concrete

OBJECTIVES

To determine the required portion for the ingredient of concrete mix, with adequate workability.

AGGREGATES PROPERTIES USED FOR MIX:

Sand:

Bulk sp. gravity (OD) = 2.631
Bulk sp. gravity (SSD) = 2.692
Sp (Apparant) = 2.804
% water absorption @ SSD = 2.341%
Bulk density = 1650 kg/m^3
% voids = 39%
FM = 2.475
Sand zone = IS zone II
(58% passing 600μ sieve)

Coarse aggregates:

Bulk sp. gravity (OD) = 2.742
Bulk sp gravity (SSD) = 2.756
Sp (apparant) = 2.782
Bulk density = 1630 kg/m^3
% voids = 40%
FM = 7.236

Nominal size = 20mm graded

43 grade cement and 75mm slump used.

IS Mix Design

From mix design, 1 : 1.693 : 2.887 : 0.48

Density = 2425.14 kg/m^3
Sand = 37.14 kg
Cement = 21.94 kg
Coarse aggregate = 63.34 kg
Water = 10.53 litres

Mix Design for M25 Grade concrete. [F.M = 7.236; % void = 40%]

(1) Target Mean strength (f_m) = $f_{ck} + k\sigma$ ← (σ for M25)
= 25 + 1.65 × 4
= 31.6 N/mm²

(2) W/C ratio

- cement grade → 43 → curve 2

From curve (28 days compressive strength vs free w/c ratio) free w/c ratio → 0.48 [& C_{min} = 300 kg/m³]

- Durability
considering ~~severe~~ Moderate exposure] $(w/c)_{max}$ = 0.45

Adopt, w/c = 0.48

(3) 75 mm slump ⇒ Medium workability [Cl. 7.1 IS456:2000]

(4) Water content,

- Nominal max. size of aggregate = 20 mm
Water content = 186 kg/m³

$(P_s)_i$ = IS Zone II (58% passing thr. 600 micron sieve)

Adjustment,
Actual water content, W = 186 + (3% of 186)
[increase water content by 3% for each increase of 25mm slump above 50mm]
= 191.58 kg/m³
≈ 192 kg/m³

(5) Cement content
[Nominal size = 20mm & Zone II] → $\frac{\text{Vol. C.A}}{\text{Total Vol. of Agg.}}$ = 0.62
[Table 5].

$$\text{cement} = \frac{\text{water}}{w/c} = \frac{192}{0.48} = 400 \text{ kg/m}^3 > C_{min} = 300 \text{ kg/m}^3$$

So, C = 400 kg/m³

(6) Volume of entrapped air, For 20 mm down

$\% a = 1.0\%$ [Table 3].
[IS 10262:2019]
$= 0.01 m^3$

(7) Volume of Aggregate,

Total vol^m of concrete = $1 m^3$

$$V_{cement} = \frac{400}{3.15 * 1000} = 0.127 m^3$$

$$V_{water} = \frac{192}{1000} = 0.192 m^3$$

$V_{air} = 0.01 m^3$

$$V_{Total\ Agg.} = 1 - (0.127 + 0.192 + 0.01) = 0.671 m^3$$

Thus,

$Vol_{CA} = 0.624 * V_{TA} = 0.624 * 0.671 = 0.419 m^3$

[Actual, $\frac{V_{CA}}{V_{TA}} = 0.62 + 0.01 * \frac{(0.50 - 0.48)}{0.05}$]

$= 0.624$ ~~0.63~~.

Mass of C.A. = $0.419 * 2.756 * 1000 = 1154.76$ kg/m³.

Mass of fine A. = $(0.671 - 0.419) * 2.692 * 1000 = 678.38$ kg/m³

[Agg. at SSD] ⇒

~~400 : 1154.76~~ :

400 : 678.38 : 1154.76 : 0.48

[1 : 1.696 : 2.887 : 0.48] ✓

(8) Moisture correction,

Water absorbed,

Total density
$= 400 + 1154.76 + 678.38 + 192$
$= 2425.14$ kg/m³

Total vol^m
$= 2 * 750 * 150 * 150 +$
$+ 3 * 150 * 150 * 150$
$= 43.875 * 10^{-3} m^3$

25% extra $= 54.84375 * 10^{-3} m^3$

Mass $= 54.84375 * 10^{-3} * 2425.14$
$= 133.004$ kg

Wt of cem
$= \frac{133.004}{6.063}$
$= 21.94$ kg

2 * [750 x 150 x 150]
↳ beam

3 * [150 * 150 * 150]
↳ cube

(25% excess)

[8mm rebar (B) → 2 nos.
8mm rebar (B) → lapping

M25 (lap length = 49ϕ)
M30 = 45ϕ (≈ 200mm)

(Fe500, M25)

EXPERIMENT NO. 3

PURE BENDING RC RESPONSE TEST

OBJECTIVE:

1. To observe the cracking load and yielding load, ultimate load as well as crack propagation and crushing of concrete at ultimate state.
2. To understand the ductile response of RCC under monolithic loading.

APPARATUS:

(i) 28 days cured RC beam specimen, (M25 concrete & Fe500 steel)
(ii) Universal testing machine (UTM) with two-point loading to create a constant moment region (pure bending)
(iii) Measuring tape
(iv) Chalk to mark crack propagation.

THEORY

For singly reinforced beam in ultimate limit state (under-reinforced): steel yields before concrete crushes. Equilibrium of internal forces gives

compressive force in concrete = tensile force in steel

In limit state method:

$$0.36 * f_{ck} * b * x_u = 0.87 * f_y * A_{st}$$

$$x_u = \frac{0.87 f_y A_{st}}{0.36 f_{ck} b}$$

$x_u \rightarrow$ Neutral axis depth.

For Fe500, critical NA depth, $x_c = 0.46d$.

For under-reinforced section:

Moment of Resistance:

$$(MOR) = 0.87 f_y A_{st} (d - 0.42 x_u)$$

PROCEDURE

1. Formwork was cleaned, prepared & greased.
2. 2-8mm⌀ bars were cut to length of 800mm was bent up to 100mm. (800mm → considering stretching during bar bending)
3. The calculated quantity of materials were weighed and dry mixed first.

4. After water was mixed wet mix of concrete was made.
5. Bottom of formwork was filled with concrete upto 25mm and reinforcement was kept and again the formwork was filled with concrete through vibration & compaction.
6. After 24 hours, formwork were removed and curing was done for 28 days
7. Testing was done after 28 days.

Testing of RC beam:

The center of beam was marked. And from center, 300 mm was marked on either side. The marked positions were placed in supports of UTM. A point load was applied at the center of beam as marked before. Failure load was obtained in the UTM which was noted.

OBSERVATION & CALCULATION:

Length of beam $(l) = 750mm$

width $(b) = 150mm$

depth/height $(D) = 150mm$

Effective depth(d): $150 - 25 - 8/2 = 121\,mm$

Area of tensile steel $(A_{st}) = 2 * \pi * \frac{8^2}{4} = 100.53mm^2$

$f_{ck} = 25MPa$

$f_y = 500MPa$

$$x_a = \frac{0.87 f_y A_{st}}{0.36 f_{ck} b}$$

$$= \frac{0.87 * 500 * 100.53}{0.36 * 25 * 150}$$

$= 32.39mm$

$x_c = 0.46 * 121 = 55.66mm$

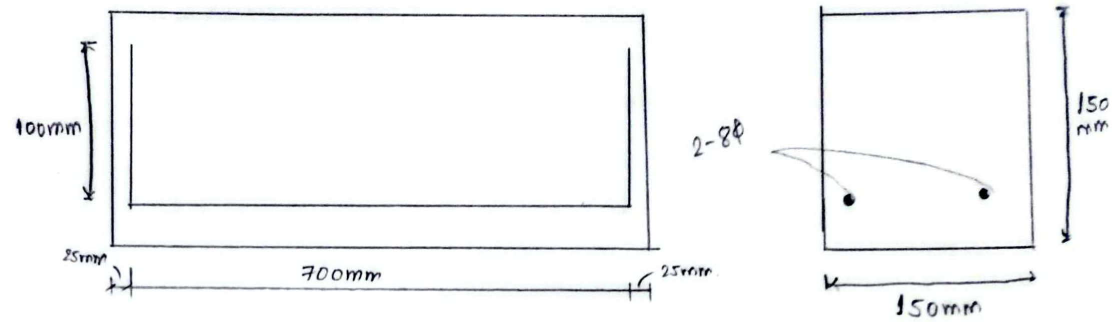
$x_a < x_c \rightarrow$ Section is under reinforced

Thus,

MOR $= 0.87 f_y A_{st} (d - 0.42 x_u)$

$= 0.87 * 500 * 100.53 * (121 - 0.42 * 32.39)$

$= 4.696\,KNm$



L-section X-section

OBSERVATION DATA

Load at Failure = 47.7KN

The UTM had calibration equation of $y = 0.98771X + 1.59353$

Thus, correct load = 0.98771 * 47.7 + 1.59353
= 48.71KN

Clear span length = 0.6m (kept at 300mm either side from centre)

Moment at Midspan = $\frac{48.71 \times 0.6}{4}$ = 7.31KNm $\left[M = \frac{Wab}{l}\right]$

[a = b = 300mm & l = 600mm]

RESULTS AND CONCLUSION

Initially, at the midspan ... of beam nearly vertical cracks were developed. With continued application of load, the cracks propagated diagonally. This indicates that beam initially exhibited flexural behaviour indicated by vertical cracks at mid-span. With increased loading, the beam showed diagonal shear cracks near the supports. It demonstrates the combined effect of bending & shear in RCC beams.

Since, there was no shear stirrups (transverse reinforcement) improper execution of detailing may have caused the beam to exhibit shear failure along with bending.

The observed value of moment at midspan i.e. 7.31KNm which is greater than resistance value 4.696KNm thus the failure of beam take place.

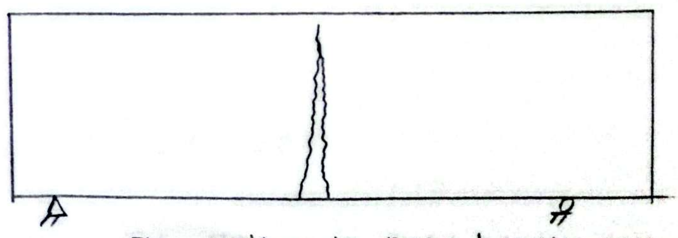


Fig: Failure in pure bending test

EXPERIMENT NO. 4

COMBINED BENDING & SHEAR TEST

OBJECTIVE

To investigate behaviour of beams under combined bending and shear, observe crack development (flexural v/s diagonal shear), and determine mode of failure and shear.

APPARATUS

(i) Same as Exp. no 3

(ii) Steel rods:

2 - 8mm φ top bars
2 - 10mm φ bottom bars
5 - 8mm φ stirrups @ 175mm c/c

THEORY

→ Real beam experience both bending moment (M) and shear force (V); shear causes diagonal tension crack.

• Nominal shear stress, $\tau_v = \frac{V}{bd}$

b = width & d = effective depth

→ Shear resistance of concrete (without shear reinforcement) τ_c is given by code.

→ Shear strength in RC section is given by,

$$V_c = V_{cz} + V_a + V_d$$

V_{cz} = Uncracked concrete (V_{cz}) → 20-40%

V_a = Due to aggregate interlocking → 35-50%

V_d = Dowel action due to longitudinal rebar → 15-30%

→ Flexure and shear interact: for a given high shear, flexural cracks may propagate and join to form diagonal shear failure.

PROCEDURE

1. Formwork was cleaned, assembled and greased.
2. Steel bars & stirrups were cut and bent as per requirements. & fixed accordingly.
3. Wet mixing of materials was done.
4. Concrete and reinforcements were arranged and filled in formwork accordingly.

⑤ After 24 hours it was taken out of mould and cured for 28 days and testing was done.

OBSERVATION AND CALCULATION

Dimension of the beam: 750mm × 150mm × 150mm

Effective depth (d): $150 - 25 - 8 - \frac{10}{2} = 112$ mm

Area of tension reinforcements, $A_{st} = 2 \times \pi/4 \times 10^2 = 157.08 mm^2$

Area of compression bar, $A_{sc} = 2 \times \pi/4 \times 8^2 = 100.53 mm^2$

$f_y = 500 MPa$

$f_{ck} = 25 MPa$.

% tensile reinforcement $= \frac{A_{st} \times 100}{bd} = \frac{157.08 \times 100}{150 \times 112}$

$= 0.935\%$

From table 19 (IS456) → M25

$0.75 \rightarrow 0.57$
$1.0 \rightarrow 0.64$] $0.935 \Rightarrow \tau_c = 0.622 N/mm^2$

Permissible shear force $= \tau_c \times b \times d = 10.45 kN$

Due to verticle stirrups, $V_{us} = \frac{0.87 f_y A_{sv} \times d}{S_v}$
(Cl. 40.4)

[stirrups kept at 165mm c/c spacing] $= \frac{0.87 \times 500 \times 2\pi \times 4^2 \times 112}{15}$

$= 29.68 kN$

Thus, Total shear force, $V_u = 10.45 + 29.68 = 40.13 kN$

From experiment,

Load at which crack started = 57.6 kN

$d' = 25 + 8 + 8/2 = 37 mm$

$d = 112 mm$

$b = 150 mm$

$f_{ck} = 25 MPa$ & $f_y = 500 MPa$

$x_u = x_{u,l} = 0.46 \times d = 0.46 \times 112 = 51.52 mm$

$d'/d = 37/112 = 0.3304$

$\varepsilon_{sc} = 0.0035(1 - d'/x_u) = 0.0035(1 - 37/51.52) = 0.000986$

$\varepsilon_{st} = 0.0035\left(\frac{d}{x_u} - 1\right) = 0.0035\left(\frac{112}{51.52} - 1\right) = 0.00411$

$$f_{sc} = 0 + \frac{288.7}{(0.00144-0)} * (0.000986 - 0) = 197.68 N/mm^2$$

$$x_u = \frac{0.87*500 * 157.08 - (197.68 - 25) * 100.53}{0.36 * 25 * 150}$$

$= 37.8 mm$

2nd trial,

$x_u = 44.5 mm$

$\varepsilon_{sc} = 0.000589$

$f_{sc} = 118.262 N/mm^2$

$x_{u,new} = 43.671 mm$

3rd trial

$x_u = 44.1 mm$

$\varepsilon_{sc} = 0.000563$

$f_{sc} = 112.97 N/mm^2$

$x_{u,new} = 44.1 mm$

Thus,

$x_u = 44.1 mm$

Moment of resistance, MOR $= 0.36 * f_{ck} * x_u\, b(d - 0.42 x_u) + (f_{sc} - f_{ck})\, A_{sc}(d-d')$

$= 0.36 * 25 * 44.1 * 150(112 - 0.42 * 44.1) + (112.97 - 25) * 100.53 * (112 - 37)$

MOR $= 6.221 kNm$

From experiment

Load developed at the crack $= 57.6 kN$

Shear force at support at which crack started $= \frac{57.60}{2} = 28.8 kN$

Actual Moment of resistance (practical) $= \frac{Wab}{l}$

$= \frac{57.60 * 300 * 300}{600} * \frac{1}{1000}$

$= 8.64 kNm >$ Theoretical moment ($= 6.22 kNm$)

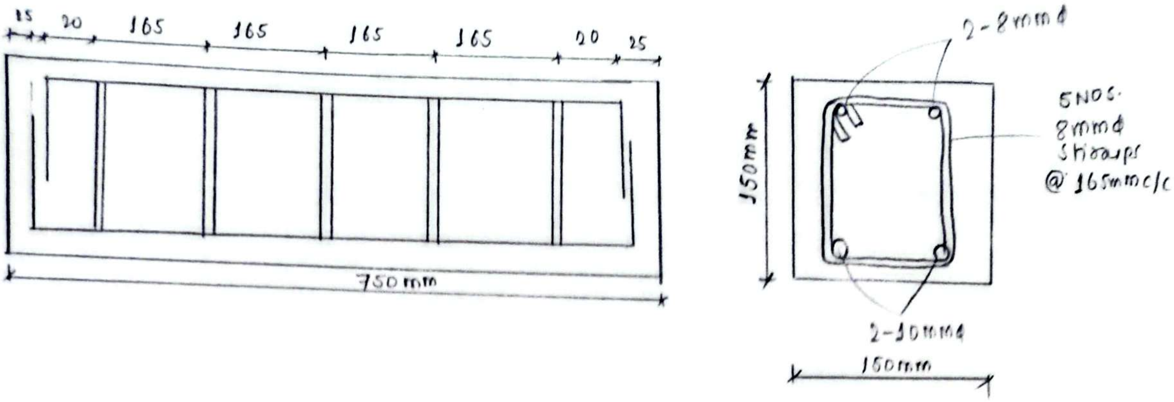


Fig: Bar arrangement for combined shear and Bending test

RESULTS AND CONCLUSION

The tested RC beam under combined bending and shear exhibited inclined cracks beginning near the supports, indicating shear influence and vertical cracks near mid-span, indicating bending influence. Failure occured when the shear capacity was exceeded in the presence of high flexural stresses. The experiment demonstrated that in real-life loading, bending and shear often act simultaneously and shear reinforcement (stirrups) plays a crucial role in preventing brittle diagonal tension failure. The mixed crack pattern and reduced ultimate load compared to pure bending beams validate the need for proper shear design. variations from theoretical capacity can arise from uneven stress distribution due to local defects. or early cracks propagation

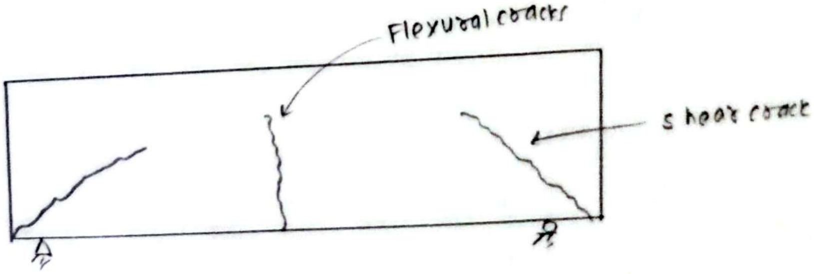


Fig: Failure pattern in combined bending and shear test

EXPERIMENT NO. 5

BOND AND ANCHORAGE TEST

OBJECTIVE

To observe the bond failure pattern in RC Beam, and observe failure modes (slip, splitting) and verify required development/anchorage length.

APPARATUS

① same as exp. no. ③
② 10mmϕ longitudinal rebar lapped

THEORY

Bond in RC beam arises due to adhesion, friction and mechanical interlock (especially for deformed bars). Development length approximate relation is given by,

$$L_d = \frac{\phi \sigma_s}{4 \tau_{bd}} = \frac{\phi \times 0.87 f_y}{4 \tau_{bd}}$$

Lapping is done so that the bar doesn't slip under the design stress. While, Anchorage (Bends/hooks) increases bond by providing mechanical bearing. The force may be transferred from one bar to another by a lapped or mechanically welded joint. The splicing should be done as far as possible away from section of high stress & where several parallel bars are to be joined. Not more than 50% of bars should be spliced at particular section.

PROCEDURE

① Formwork was cleaned, assembled and greased.
② 2-10mmϕ bars were cut to length of 500mm & edges were bent upto 100mm in each bond.
③ The bars were spliced such that they fit within 700mm providing lapping of about 130 mm.
④ The concrete mix was prepared from calculated proportion of cement, sand, aggregate and water.
⑤ The bottom of formwork was filled upto 25mm and reinforcement was kept and again filled full with concrete.

⑥ Concrete was vibrated and well compacted.
⑦ Formwork was disassembled after 24 hours and kept for 28 days for curing and tested after that.

OBSERVATION AND CALCULATION

L = 750mm , b = 150mm, D = 150mm
d = 150 − 25 − 10/2 = 120 mm

Actual = 52.8KN
Calibrated failure load = 53.74KN

Dead load = $25 \times 0.15^2 = 0.5625$ KN/m

$$L_d = \frac{0.87 f_y \phi}{4 \tau_{bd}} = \frac{0.87 \times 500 \times 10}{4 \times 1.6 \times 1.4} = 485.49mm$$

$[\tau_{bd} = 1.4 \times 1.6]$

Lapping provided = 130mm < Ld

Thus, failure at the lap was be observed at the load of 53.74KN.

RESULT AND CONCLUSION

With the increased load on RC beam, it was failed at the location of lap length as it was insufficient. With increase in load, vertical cracks appeared first near the mid span suggesting flexural, tension failure in the lap region. Additionally, some slightly inclined cracks were observed, indicating localized bond stress failure. The actual failure occured earlier, indicating a bond or anchorage shortage. The results confirm the need for anchorage provisions as per IS456/NBC codes to ensure structural safety.

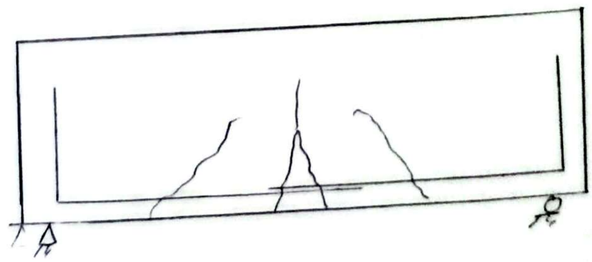


Fig: Failure at the location of lapping
(Bond & Anchorage test)

EXPERIMENT NO. 6
SHEAR FAILURE TEST

OBJECTIVE:
To determine shear behaviour of RC beams, observe the initiation and progression of diagonal shear cracks, and compare experimental shear capacity with theoretical expectations.

APPARATUS
1. same as exp. no ③
2. RC beam with 3-8mm ϕ stirrups.
3. Top reinforcement 2-8mm ϕ
4. Bottom reinforcement 2-10mm ϕ.

THEORY
- Shear in beams is carried by concrete (aggregate interlock, un-cracked compression zone) and shear reinforcement.
- Shear stress, $\tau_v = \frac{V}{bd}$ { τ_v exceeds shear capacity τ_c then diagonal tension cracks form }

- Components of shear resistance
  - Concrete contribution (V_c) (code based)
  - Shear reinforcement contribution $V_s = \frac{0.87 A_{sv} f_y d}{S_v}$
  - Thus, ultimate shear capacity, $V_u = V_c + V_s$

- Failure modes:
  - Shear compression: crushing of concrete in compression zone near support, often at low shear span/depth ratios.
  - Diagonal tension (shear) failure: inclined cracks coalesce and sudden failure (brittle)
  - Flexure-shear: mixture of flexure and shear cracking leading to failure.

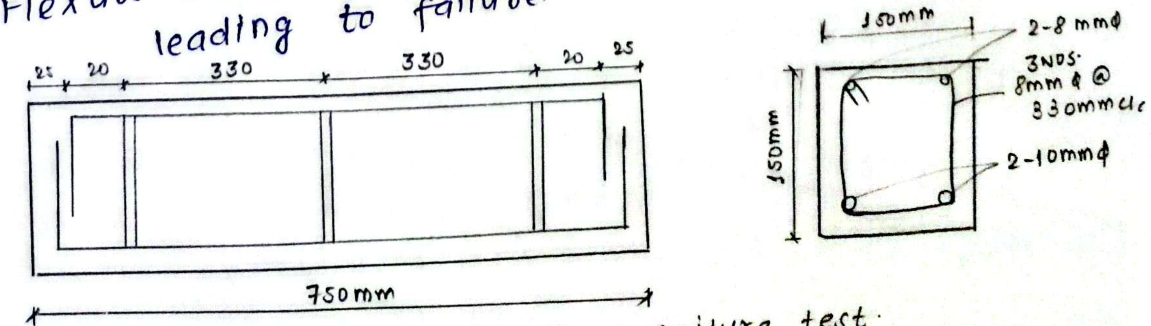


Fig. Bar arrangement for shear failure test.

PROCEDURE

① Formwork was cleaned, assembled and greased.

② 2-10mm ϕ bars and 2-8mm ϕ bars were cut to the length approximately 850mm and bent upto 10mm in each end.

③ 3-8mm ϕ bars were cut and bent to form stirrups.

④ Stirrups were arranged in longitudinal bars with 2-10mm ϕ bars at bottom and 2-8mm ϕ bars at top.

⑤ Calculated proportion and quantity of cement, sand and aggregates were dry mixed and wet mixed.

⑥ 25mm of concrete was filled in formwork and reinforcement arrangement was placed in it and again concrete was filled.

⑦ It was well vibrated and compacted.

⑧ Formwork disassembled after 24 hours and cured for 28 days and tested.

OBSERVATIONS AND CALCULATIONS

Dimensions of beam = 750mm * 150mm * 150mm

Effective depth(d) = $150 - 25 - 8 - \frac{10}{2}$ = 112mm

Dead load of the beam (w) = 0.15 * 0.15 * 25
= 0.5625 KN/m

Area of tensile reinforcement (A_{st}) = $\frac{2 * \pi * 10^2}{4}$

= 157.08 mm^2

Area of 2-legged vertical reinforcement (A_{sv})
= $\frac{2 * \pi * 8^2}{4}$

= 100.53 mm^2

Spacing of vertical reinforcement (S_v) = 350mm

f_y = Fe500 , f_{ck} = M25 = 25 N/mm^2

% of tensile steel = $\frac{100\, A_{st}}{bd}$ = $\frac{100 * 100.53}{150 * 112}$ = 0.935%.

For M25, Table 19, τ_c = 0.622 N/mm^2

Permissible shear force, $\tau_c * b * d$ = 10.45 KN

Due to verticle stirrups, $V_{us} = \frac{0.87 * f_y A_{sv} d}{S_v}$

$$V_{us} = \frac{0.87 * 500 * 100.53 * 112}{350}$$

$= 13.99\ KN$

Thus, total shear force, $V_u = 10.45 + 13.99$
$= 24.44\ KN$

Actual load = 5 .3 KN
Calibrated failure load = 51.27 KN
Thus Reaction/Shear force at support = $\frac{51.27}{2} = 25.635 > 24.44\ KN$

DISCUSSION AND CONCLUSION:-
With increase in load, initially flexural cracks appeared at mid-span of beam and further increase in load resulted in diagonal cracks near supports. The beam resisted higher shear force than theoretically predicted as shear reinforcement was provided. The results reinforce the necessity of providing minimum shear reinforcement even when calculated shear stresses are below permissible limits, to prevent sudden collapse.

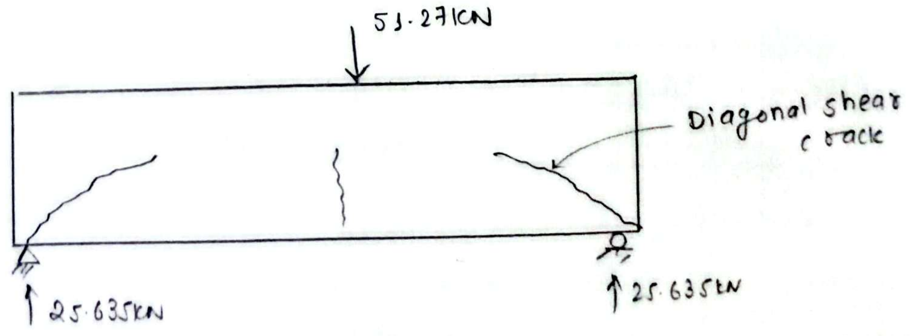


Fig: Failure in shear test.