AN EXPERIMENTAL STUDY ON PILE CAPS IN FLEXURE AND SHEAR

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ABSTRACT

Pile caps are essential structural elements between the stanchions and group of foundation piles. Though the design of pile caps for tensile forces in the bottom of pile cap either by flexure theory or by truss analogy are established and present no problems. Similarly two way (punching) shear on pile caps is also designed routinely. But bending shear occurring on pile caps presents problems. National design codes also have been changing provisions for shear. Present IS 456-2000 has specifications for identification of shear force on pile caps that are different from those of predecessor code IS 456-1978, The present investigation examines by tests the shear provisions of pile cap beams and slabs, of the present IS code. The test results confirm the IS 456-2000 provisions.

Key words: crack width, deflection, flexure, shear, beams

I. INTRODUCTION

In deep foundations, pile cap constitutes a principal structural item, transferring stanchion load to the piles below it. Pile cap covers generally a single pile, two piles, three piles, four piles or a cluster of piles. The structural element, pile cap has to be proportioned for flexure, beam shear, punching shear. Piles are used in adverse situations such as marine clays, river beds, coastal stretches in sea beds. High water tables, surface water, deep water depths present problems in casting pile caps. Pile caps have to be designed for punch shear, beam shear and bending moment or tensile force. To counter design problems encountered with two way shear (punching shear), pile cap depth may be encased or a pedestal between the stanchion and pile cap may be provided as stanchion dimensions are predetermined and remain unaltered. The tensile forces generated at the bottom of pile cap are resisted by provision of longitudinal reinforcement at the bottom of pile cap. This reinforcement can be proportioned by the two methods available. These are truss analogy or standard bending theory.

These two methods present no problems and are straight forward, differing only in the detailing of reinforcement. The third and final item for design is beam shear which presents some problems in design. To suppress shear problem, shear stress can be kept under control by encasing pile cap depth. But size increase presents problems in the management of large quantities of concrete not only in normal circumstances but more so in the presence of water. Incorporation of shear reinforcement helps in the reduction of pile cap size on one hand but becomes problematic in the fabrication of shear reinforcement.

Codal specifications for shear design of pile caps vary in different national codes. IS 456-2000 specifies in 34.2.42 that in computing the external shear, on any section through a footing supported in piles, the entire reaction from any pile of diameter D_p whose centre is located $D_p/2$ or more outside the critical section shall be assumed as producing shear on the section, the section from any pile whose centre is located $D_p/2$ or more inside the section shall be assumed as producing no shear on the section. For intermediate positions of the pile centre, the portion of the pile reaction to be assumed as producing shear on the section shall be based on straight line interpolation between the full at $D_p/2$ outside the section and zero value at $D_p/2$ inside the section. Specification 32.2.4 defines the critical section referred above. The footing acting essentially as a wide beam with a potential diagonal crack extending in a critical section further condition shall be assumed as a vertical section located from the face of the column or pedestal shall be at a distance equal to the effective depth of footing or pile cap for footings on piles.

But the earlier code IS 456-1978 differs from the current code in defining the critical section from the face of column. Contrary to the present code, earlier code defines that this critical section from the face of column, pedestal or wall is at a distance equal to the effective depth of footing in case of footings on soils, and a distance equal to half the effective depth of footing for footings on piles.

ACI 318-08 specifies computation of shear on piles in 15.5.4.1 and 15.5.4.2

Entire reaction from any pile with is center located $d_p/2$ or more outside the section shall be considered as producing shear on that section. Reaction from any pile with its center located $d_p/2$ or more inside the section shall be considered as producing no shear on that section.

II. LITERATURE REVIEW

Perry Adebar and Luke Zhou (1996) in their paper Design of Deep pile cap by Strut and Tie Method comparisons with results from 48 pile cap tests demonstrate that the one way shear design provisions of the present ACI Building Code are excessively conservative for deep pile cap and that the traditional flexural design procedures for beams and two-way slabs are unconservative for pile caps. Flexural design can best be accomplished using a simple strut and tie model and test results demonstrate that the longitudinal reinforcement should be concentrated over the piles as suggested by strut and tie models. A simple shear design procedure is proposed in which maximum bearing stress is considered the best indicator of “shear strength” for deep pile caps. The maximum bearing stress that can be applied without causing splitting of compression struts within pile caps depends on the amount of confinement, as well as the aspect ratio of compression struts. The influence of confinement is more gradual than suggested by the ACI code bearing strength provisions.

Eswara Rao (1997) in his thesis Behaviour of R.C.C Pile caps with steel Fibres studied the behavior of reinforced concrete pile caps with and without fibres. He concluded from his experimental work that pile cap with fibres failed at higher ultimate load. The crack width and deflections are also found to be reduced with fibres in pile caps. He also concludes that when shear span to depth ratio is around 1.68, both bending theory and truss theory gave similar results. He observes that steel reinforcement required from truss theory is more than that required from beam theory.

Murty et al (1997) in their paper on Reinforced Cement Concrete Pile cap in shear discussed the design of a pile cap for flexure and shear. The general features and related aspects are discussed in their paper. Various Codal provisions are discussed with reference to shear.

Masahiro Shirato et al (2002) in their paper proposed a design methodology for ultimate shear strength of pile caps subject to various stresses, based on experiments and numerical analyses. First, they determined an evaluation equation for shear strength of pile caps with compressive piles. Second, they clarified the shear resistance mechanism of pile caps with pull-out piles, and confirmed to be able to apply the determined evaluation equation to those with pull-out piles by modifying the setting of shear span. The proposed methodology was introduced into the current version of the Japanese specifications for Highway Bridges (March 2002).

Gupta (2003) he studied on the Analysis and Design of Piles in a group. Most of the methods available for analysis of piles as given in standard books and Indian codes are for single pile. The behavior of pile under combined axial and lateral loads is not defined in codes and in general literature. Most of the design engineers are designing piles based on length of fixity charts given in IS2911 part-1.The method of calculation of bending moment of piles is discussed in detail in their paper and results are supported by finite element analysis on computers.

Saeed Ahmad et al (2009) in their paper Evaluation of the Shear strength of four pile caps using Strut and Tie Model (STM). Strut and Tie model has been widely used for the design of distributed region and non flexural members in RC structures. Pile cap is typically a distributed region with small length to depth ratio, hence ordinary flexural theory for beams cannot be applied to it. In this research, six pile caps were designed for certain theoretical ultimate loads on the basis of STM. These pile caps were tested on four simply supporting piles. Loads were applied at the centre of pile cap. The experimental values were compared with the theoretical capacities of the pile caps on the basis of STM. It has been observed that STM has provided a reliable solution for predicting the shear strength of the four pile caps and the experimental values full very close to the theoretical values based on STM.

III. METHODOLOGY

3.1 Fabrication of Test Specimens

The form work for casting the specimens was made with masonry with concrete blocks .The steel grills were placed in the form work with the concrete designed for M30 grade. The concrete was prepared with concrete mixer available in the laboratory. The concrete was poured in the forms and vibrated with a needle vibrator. After 24 hours, the specimens were demoulded and curing started. At the termination of curing the specimens were prepared for testing. The pile supports were 17 cm and 20 cm circular in section . The specimens were loaded by a hydraulic jack of 1000kN capacity and the load was measured by a 1000kN proving ring. The deformation response of the member was recorded by a dial gauge and a crack width meter. A dial gauge with a least count of 0.01mm was used for measuring transverse deflections. A crack width meter with a least count of 0.01mm was utilised. At each load increment, transverse load was noted. The crack formation was noticed and was noted on the pile cap. Maximum crack was measured and noted. Transverse deflection at the mid spam of the specimen was noted. About 20 load increments were needed to reach ultimate strength of the member loading continued beyond the ultimate load. Pile cap beam PB1 failed in shear. Pile cap beam PB2 failed in flexure. Principal test results are tabulated in Table 7. Comparison of test results and theoretical results are shown in Table 8. The photographs of tested specimens PB1 and PB2 are given in plates 1, through 4.

3.2 Pile Cap

Pile cap is defined as a concrete block cast on the head of a pile, or a group of piles, to transmit the load from the structure to the pile or group of piles. The individual piles are spaced and connected to the pile cap. The pile cap distributes the applied load to the individual piles which, in turn, transfer the load to the bearing ground.

External pressures on a pile are likely to be greatest near the ground surface. Ground stability increases with depth and pressure. The top of the pile therefore, is more vulnerable tomovement and stress than the base of the pile. Pile caps are thus incorporated in order totie the pile heads together so that individual pile movement and settlement is greatlyreduced. Thus stability of the pile group is greatly increased.The functions of a pile cap are

1. To distribute a single load equally over the pile group and thus over a greater area of bearing potential.
2. To laterally stabilize individual piles thus increasing overall stability of the group.
3. To provide the necessary combined resistance to stresses set up by the super structure and/or ground movement. Little or no test results are reported on pile caps to date. However, several hand booksand codes of practice provide guidance for design of pile caps.

3.3 Design of Pile Cap

Pile caps are used to transmit column loads to the pile foundation. The dimension of the pile cap is based on the fact that the actual final position of piles can be in construction upto 10 cm out of line from the theoretical center lines should be made very large to accommodate this deviation. In practice, pile cap are extended as much as 15 cm beyond the outer face of the piles. The important parameters in design of pile caps are:

- ❖ Shape of pile cap
- ❖ Depth of pile cap
- ❖ Amount of steel to be provided
- ❖ Arrangement of reinforcement

3.4 Modes of Cracking

3.4.1. Flexural Cracks

In reinforced concrete beams of usual proportions, subjected to relatively high flexural stresses f_y and low shear stresses ح , the maximum principal tensile stress is invariably given by the flexural stress f_y max in the outer fiber at the peak moment locations, the resulting cracks are termed flexural cracks. These are controlled by the tension bars.

3.4.2. Web - Shear Cracks or Diagonal Tension Cracks:

In short span beams which are relatively deep and have thin webs and are subjected to high shear stresses ح and relatively low flexural stresses f_y , it is located at the neutral axis level at an inclination $\theta = 45°$, the resulting cracks are termed web shear cracks ordiagonal tension cracks. Shear reinforcement is required to prevent the propagation of these cracks.

3.4.3. Flexure – Shear Cracks

When a flexural crack occurs in combination with a diagonal tension crack, the crack is referred to as flexure-shear crack. In such a case, it is the flexural crack that usually forms first, and due to the increased shear stresses at the tip of the crack, this flexural crack extends into a diagonal tension crack.

3.4.4. Secondary Cracks

When the inclined crack propagates along the tension reinforcement towards the support, such cracks are referred to as secondary cracks or splittingcracks.

3.4.5. Dowel Forces in Bars

When cracks are attributed to the wedging action of the tension bar deformations and to the transverse 'dowel forces' introduced by the tension bars functioning as dowels across the crack, resisting relative transverse displacements between the two segments of the beam.

3.5 Modes of Failure for a Pile Cap

The modes of failure for a pile cap include

- Crushing of the concrete under the column or over the pile.
- Bursting of the side cover where the pile transfers its load to the pile cap.
- Yielding of the tension reinforcement.
- Anchorage failure of the tension reinforcement.
- Two-way shear failure where the cone of material inside the piles punches downward.

IV. EXPERIMENTAL INVESTIGATION

4.1 General

This chapter deals with the experimental programme particulars. The materials used, concrete mix details, formwork, casting procedure, preparation of specimens, cover details and testing procedure are explained in detail.

4.2 Experimental Programm

To investigate the provisions of IS 456-2000, relative to shear design, an experimental programme has been under taken. The investigation comprises testing of two pile cap beams. Pile cap beams are supported by two piles.

In the two pile cap beams PB1 and PB2, one beam is designed such that pile contributes shear force on the pile cap. In the second pile cap beam, pile does not contribute shear on the pile cap. These designs are made as per the code IS 456-2000 .The details of pile cap beams are furnished in Table1. The preliminary designs of pile cap beams are furnished in Appendix A. Mechanical properties of steel reinforcement are given in Table 3

4.3 Materials

The properties and specifications of various materials used in the preparation of test specimens are as follows.

4.3.1Cement

The cement used for the investigation was ACC Portland slag cement. The cement is fresh and is of uniform color and consistency. It is free from lumps and foreign matter. The results of the tests on cement are listed in Table 1. Initial setting time observed is 140 minutes and final setting time is 318 minutes, specific gravity is 3.13 .

Table 1: Properties of Cement

Properties	Test Values	Standard values (IS 8112:1989)
Specific gravity	3.13	
Standard consistency (percent)	31	
Initial setting time (min)	140	>30

Final setting time (min)	318	<600
Fineness of cement (percent)	10	10

4.3.2 Fine Aggregate

The fine aggregate used in the present experimental programme is river sand confirming to zone-II as per 383:1970. It is clean, inert and free from organic matter, silt and clay. The physical properties of sand are given in Table 2

Table 2: Properties of Fine Aggregate

Properties	Test values
Specific gravity	2.61
Bulk density (gm/cc)	1.46
Fineness modulus	2.53

4.3.3 Coarse Aggregate

The coarse aggregate used, was from an established quarry satisfying the requirements of IS 383:1970. In this experimental programme aggregates of 20 and 10 mm size used. The coarse aggregate used, satisfied the standard values, as per sieve analysis. All the parameters specific gravity, bulk density, water absorption and fineness modulus were determined. The material properties of aggregates are summarized in Table 3.

Table 3: Material Properties of Aggregates

Physical properties	Test values
Specific gravity	2.81
Bulk density (Loose) gm/cc	1.38
Bulk density (Rodded) gm/cc	1.60
Water Absorption percent (%)	0.5
Fineness Modulus	5.96
Impact value (%)	24

4.3.4 Water

The water used for cement mixing was potable water collected from the laboratory taps. Water from same source was used for curing the specimens.

4.3.5 Steel reinforcement

The steel reinforcement was tested in the laboratory for its strength . High strength deformed bars (HYSD) are used. The properties of steel are given in Table 4.

Table 4: Properties of Steel

Grade of steel Reinforcement	Diameter of Bar (mm)	Yield stress (N/mm^2)	Ultimate stress (N/mm^2)
Fe 500	8	500	630
Fe 500	12	520	650
Fe 500	16	550	680

4.4 Test Specimen

There are two pile caps in this investigation. The two pile caps are provided with 20 mm cover. The two pile caps are designated as PB1 & PB2

A measure of the compressive strength and split tensile strength of concrete was obtained by testing 150×150×150 mm cubes, 150 mm diameter and 300 mm height cylinders respectively.

4.5 Cover Details

Cover of 20 mm is provided for all four pile caps. Mortar briquettes of (70mm ×40mm×20mm) were cast and used as cover blocks. They were cast with 1:3 cement mortar and cured before being used.

4.6 Concrete Mix Design

The nominal grade of concrete used in this experimental program are M20 & M30. The mix design is based on strength criteria and durability criterion suitable for severe environment. The mix design procedure is adopted according to IS 10262-1982. M30 mix design procedure was adopted for all the pile caps and M20 mix design was adopted for circular beams. The mix proportions by weight were finalized after some trial mixes. The water cement ratio were kept as 0.55 & 0.43 for M20 & M30 respectively.

4.6.1 Mix Design Procedure for M20 Grade Concrete

(As per IS 10262:1982)

(a)	Characteristic compressive strength required in the field at 28 days (MPa)	20
(b)	Maximum size of aggregate (mm)	20
(c)	Degree of Workability (specified) mm (slump)	50 to 75
(d)	Degree of quality control	good
(e)	Type of exposure	Moderate

4.6.2 Test Data for Materials

(a)	Cement used	ACC Portland slag

(b)	Specific gravity of cement	3.13
(c)	Specific gravity of Coarse aggregate – 20 mm Coarse aggregate – 10 mm Fine aggregate	 2.81 2.78 2.61
(d)	Sand corresponds to zone	II
(e)	Target mean strength of concrete	20+1.65×4 = 26.6MPa
(f)	Selection of W/C ratio corresponding to the above strength requirement	0.55
(g)	Selection of water per cubic m	175
(h)	Fine aggregate percentage selected in total aggregate.	37%

Adjustment in water and sand change in condition	Adjustment required in water percent	0% sand in total aggregate
For decrease in W/C ratio by	-	- 1.0 %
For sand conforming to zone – II	-	
Total	-	- 1.0 %
Therefore required sand content as percentage of total aggregate by absolute volume	37 – 1= 36 %	
Required water content	175 liters	

4.6.3 Determination of Cement Content

Water-cement ratio = 0.55

Water = 175 liters

Cement = 318 Kgs

This cement is adequate for Severe exposure conditions.

4.6.4 Determination of Fine Aggregate

$$V = [W + (C/S_c) + (1/p) \times (f_a / S_{fa}] \times 1/1000$$

$$0.98 = (175 + (318/3.13) + (1/0.36) (fa/2.61) \times (1/1000)$$

$$f_a = 661 \text{ Kgs}$$

4.6.5 Determination of coarse Aggregate

$$V= [W + (C/S_c) + (1/(1\text{-}p))(C_a/S_a)] \times 1/1000$$

$$0.98 = [(175 + (318/3.13) + (1/0.64) (C_a/2.80)] \times 1/1000$$

$$C_a = 1260 \text{ Kgs}$$

4.6.6 Mix proportions by weight (with ACC Portland slag cement)

Water	:	Cement	:	F.A	:	C.A (20+10)
175	:	318	:	661	:	1260
0.55	:	1.00	:	2.08	:	3.96

4.7 Mix Design Procedure for M30 Grade Concrete

(As per IS 10262:1982)

(a)	Characteristic compressive strength required in the field at 28 days (MPa)	30
(b)	Maximum size of aggregate (mm)	20

(c)	Degree of Workability (specified) mm (slump)	50 to 75
(d)	Degree of quality control	good
(e)	Type of exposure	Moderate

4.7.1 Test data for Materials

(a)	Cement used	ACC Portland slag
(b)	Specific gravity of cement	3.13
(c)	Specific gravity of Coarse aggregate – 20 mm Coarse aggregate – 10 mm Fine aggregate	 2.81 2.78 2.61
(d)	Sand corresponds to zone	II
(e)	Target mean strength of concrete	30+1.65×4 = 36.6MPa
(f)	Selection of W/C ratio corresponding to the above strength requirement	0.43
(g)	Selection of water per cubic m	170
(h)	Fine aggregate percentage selected in total aggregate.	37.4%

Adjustment in water and sand change in condition	Adjustment required in water percent	0% sand in total aggregate
For decrease in W/C ratio by	-	- 3.4 %
For sand conforming to zone – II	-	
Total	-	- 3.4 %
Therefore required sand content as percentage of total aggregate by absolute volume	37.4 – 3.4 = 34 %	
Required water content	170 liters	

4.8 Determination of Cement Content

Water-cement ratio = 0.43

Water = 170 liters

Cement = 395 Kgs

This cement is adequate for Severe exposure conditions.

4.9 Determination of Fine Aggregate

$$V = [W + (C/S_c) + (1/p) \times (f_a / S_{fa}] \times 1/1000$$

$$0.98 = (170 + (395/3.13) + (1/0.34) (fa/2.61) \times (1/1000)$$

$$f_a = 607 \text{ Kgs}$$

4.10 Determination of coarse Aggregate

$$V= [W + (C/S_c) + (1/(1-p))(C_a/S_a)] \times 1/1000$$

$$0.98 = [(170 + (395/3.13) + (1/0.66) (C_a/2,8)] \times 1/1000$$

$$C_a = 1264 \text{ Kgs}$$

4.11 Mix proportions by weight (with ACC Portland slag cement)

Water	Cement	F.A	C.A (20+10)
170	395	607	1264
0.43	1.00	1.54	3.2

4.12 Casting of Pile Cap

4.12.1 Formwork:

The bed for casting pile caps was prepared with lean concrete mix and the surface was made smooth without any undulations. Masonry moulds were used for casting the pile caps. The moulds were made of bricks and plastered with mortar. The inner dimensions of the moulds were equal to the dimensions of the four pile caps.

4.12.2 Preparation of Specimen

The moulds were oiled before casting the pile caps. Reinforcement cage was placed in position in the mould and then cover blocks were placed to maintain a cover of 20 mm. The materials are weigh batched. Concrete mixer was used for mixing concrete. After placing concrete in the moulds, needle vibrator was used for vibration. The top surface was smoothened with a trowel. Simultaneously from each pile cap mix corresponding cubes and cylinders were casted.

4.12.3 Curing

The beams were cured for 28 days uniformly by wet gunny bags. Cubes and cylinders were also cured for 28 days in a water tank.

4.12.4 Demoulding

After 28 days, the brick moulds were manually broken and the pile caps were separated.

4.13 Test Details

Testing of four pile caps and three circular beams were done at 28 days..The fig shows a general view of typical specimen and loading arrangements.

4.13.1 Measurement of Deflection

The deflections were measured at pile cap mid span by a dial gauge whose least count was 0.01 mm. It could record a maximum deflection of 50 mm. The dial gauge was mounted on a frame firmly, touching the bottom face of the pile cap.

4.13.2 Measurement of Crack Width

Crack widths were measured for all pile caps using a hand-held microscope. The instrument could measure a maximum width of 10 mm and a minimum width of 0.05 mm.

4.14 Procedure for Testing

The pile caps and circular beams were placed in position in the loading frame manually. Prior to testing glass pieces of size 2 cm × 2 cm were fixed at the center of the bottom surface of the pile cap where deflections are measured. Each pile cap and circular beam was tested to failure by applying loads in a series of increments. It took about a quarter minute for increasing the load after which it was held constant, while deflections and crack widths were measured and cracks marked. The holding period after each increment varied for two to four minutes. Smaller increments of loads were used as cracking and failure loads were approached. In all instances load application was continued well beyond the stage at which peak values of strength were observed. Usually 25 to 30 increments were usedto failure and the entire test took about 1½ hrs.

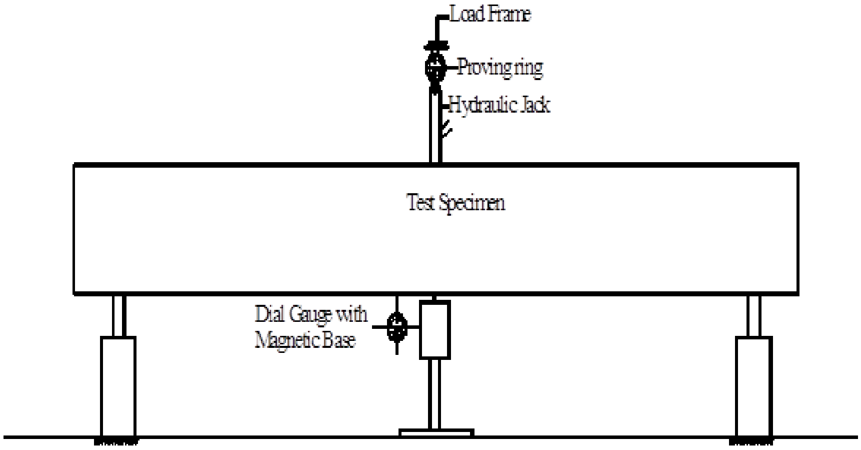

Fig. 1: Test Set Up

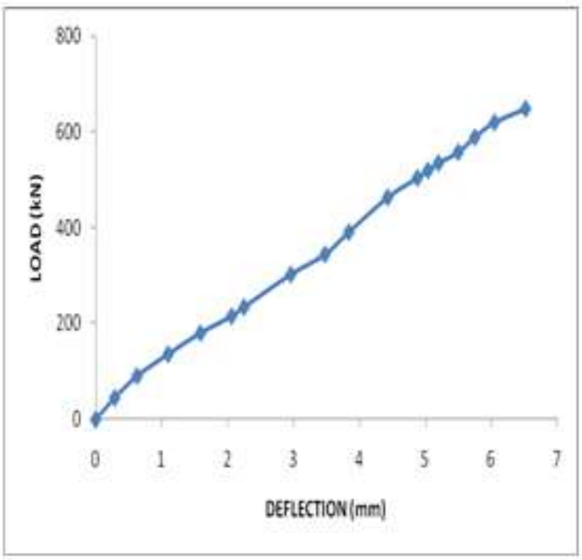

Fig. 2: Load-deflection curve of beam PB1

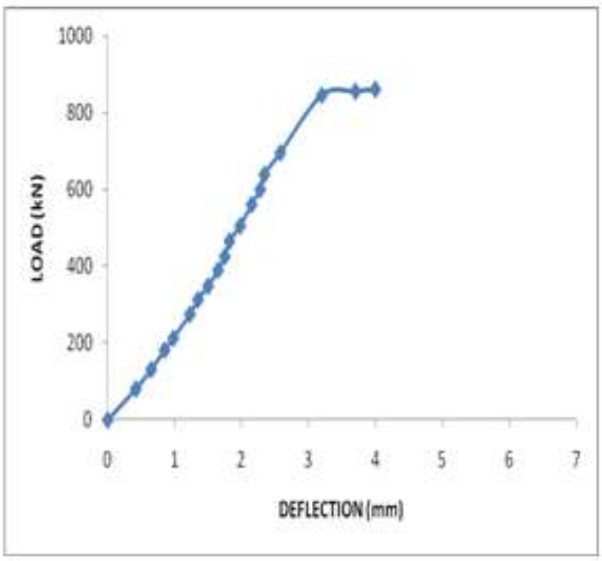

Fig. 3: Load-deflection curve of beam PB2

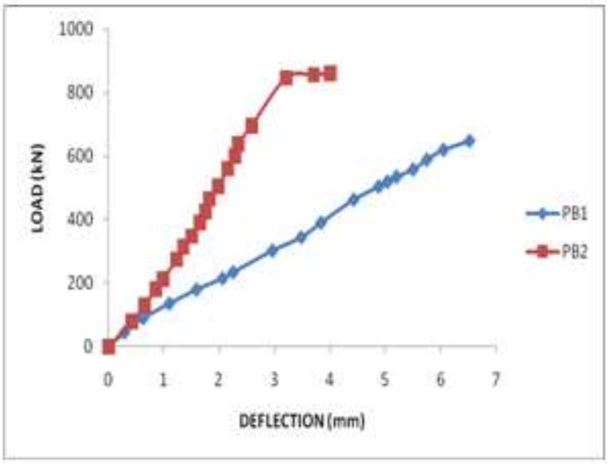

Fig. 4: Load-deflection curve of beams PB1, PB2

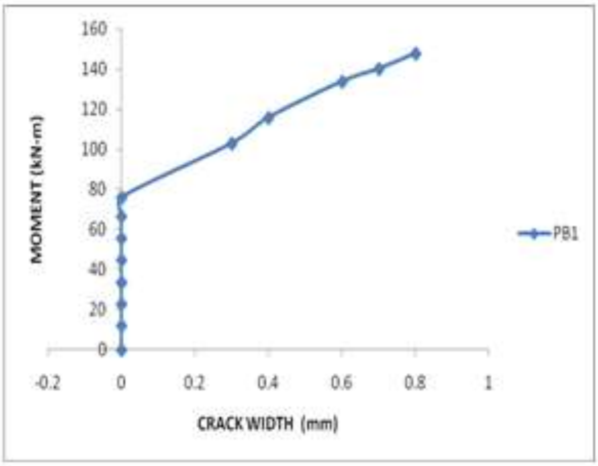

Fig. 5: Moment Crack width curve of beam PB1

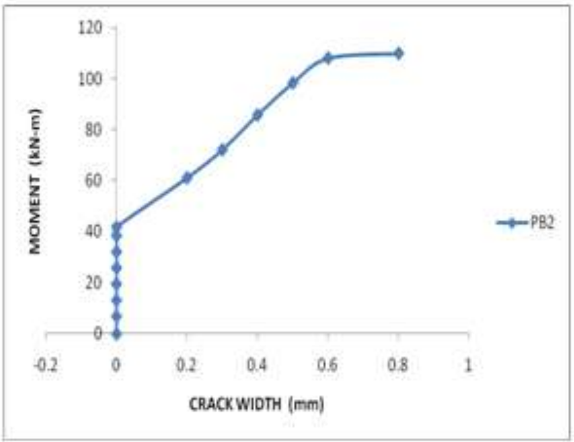

Fig. 6: Moment Crack width curve of beam PB2

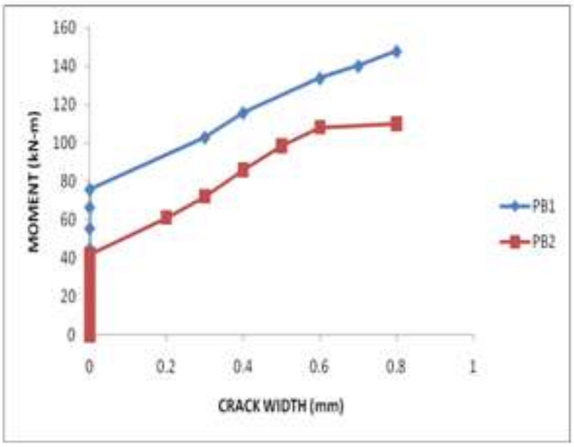

Fig. 7: Moment Crack width curve of beams PB1, PB2

Fig. 8: Plate 1: Front view of PB1

Fig. 9: Plate 2: Front view of PB1

Fig. 10: Plate 3: Front view of PB2

Fig. 11: Plate 4: Reinforcement cage of PB2

V. PRELIMINARY DESIGNS

5.1 Size of Pile Cap

PB1:- 122 x 50 x 33.6cm

Grade of concrete = M30

Grade of steel = Fe 500 grade

Theoretical stanchion load = 350kN

Shear force (V) = 350/2 =175 kN

Maximum Bending Moment = 175 × 39.5

= 69.1kNm

$M/bd^2 = (69.1 \times 1.5 \times 10^3) / (50 \times (31)^2) = 2.16$

From Table 56 of SP 16

$= (0.544 / 100) \times 50 \times 31$

$= 8.43 cm^2$

= 8 – 12mm Ø are used

Shear force (V) = 175kN

Shear stress $= (175000) / (500 \times 310) = 1.12\ N / mm^2$

PB2:- 86 x 55 x 33.6cm

Grade of concrete = M30

Grade of steel = Fe 500 grade

Theoretical load = 550kN

Shear force (V) = 550/2 =275 kN

Maximum Bending Moment = 275 × 0.1965

= 54kNm

$M/bd^2 = (54 \times 1.5 \times 10^3) / (50 \times (31)^2) = 1.69$

From Table 56 of SP 16

$= (0.421 / 100) \times 50 \times 31$

$= 6.53 cm^2$

= 6 – 12mm Ø are used

Shear force (V) = 275kN

Shear stress = (275000) / (500 × 310) = 1.77 N / mm^2

Table5:- Properties of Test Specimens Pile Cap Beams

Specimen label	Depth (mm)	Width (mm)	Span (mm)	Total length (mm)	Compressive Strength of concrete (N/mm^2)		Split tensile strength of concrete (N/mm^2)
					7days	28days	
PB1	336	500	947	1220	32.5	42.6	2.54
PB2	336	500	550	860	32.5	44.4	2.54

Table6:- Mechanical Properties of Steel Reinforcement

S.No.	Diameter (mm)	Yield strength (N/mm^2)	Ultimate strength (N/mm^2)
1	8	500	630
2	12	520	650

Table7:- Principal Test Results of Pile Cap Beams

Specimen label	Load at first crack (kN)	Ultimate load (kN)	Ultimate moment (kN- m)	Service load (kN)	Service moment (kN- m)	Deflection At first crack (mm)	Deflection At service Load (mm)	Deflection at ultimate load (mm)	Crack width at service load (mm)	Crack width at ultimate load (mm)	Failure mode
PB1	462.72	647.26	154.57	431.5	103.04	4.43	4.34	6.52	0.3	0.8	Shear
PB2	405.06	860.76	108.3	573.84	72.2	1.65	2.46	4	0.3	0.8	Flexure

Table8:- Theoretical Load and Experimental Load of Pile Cap Beams

	Experimental results			Theoretical results			Ratio
specimen label	Stanchion load	Bending moment (KN-m)	Shear force (kN)	Stanchion load	Bending moment (KN-m)	Shear force (kN)	Experimental B.M / Theoretical B.M
PB1	350	69.1	175	647.26	127.83	323.63	1.5
PB2	550	46.75	275	860.72	72.72	427.75	1.57

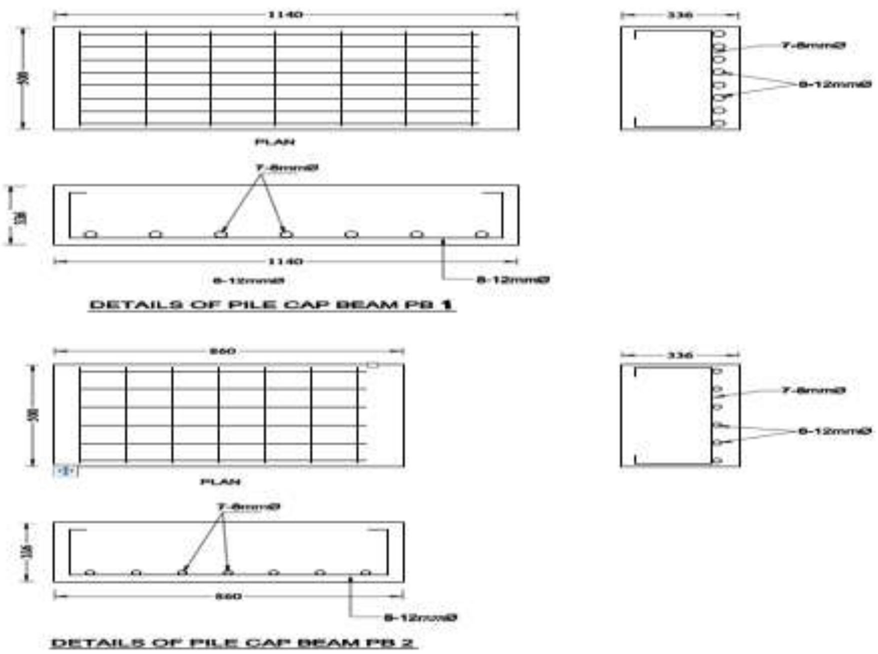

Fig. 12: Detailing Of Pile Cap Beams

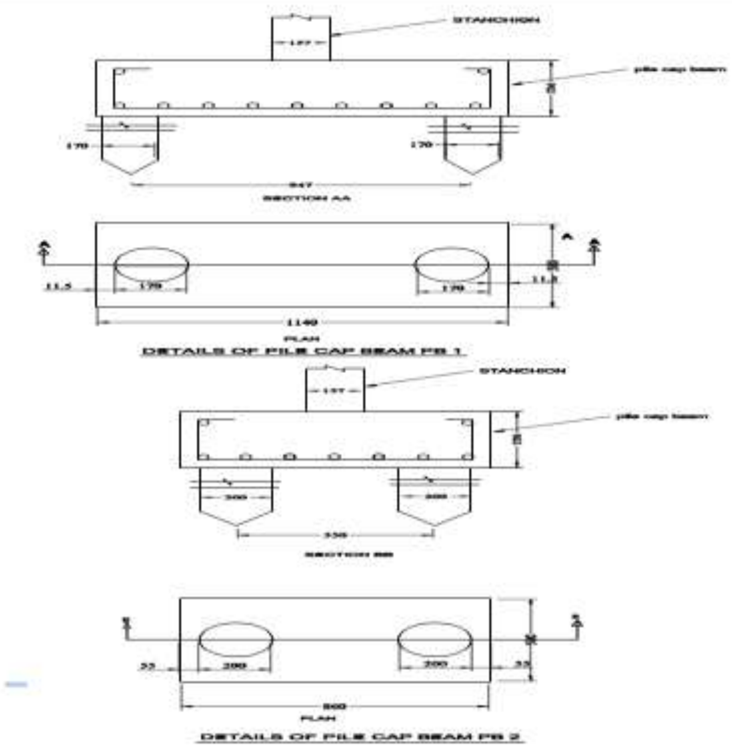

Fig. 13: Pile Cap Setup

VI. DISCUSSION OF TEST RESULTS

The load of first crack for pile cap beam PB1was 462.72kN; this was 71% of ultimate load. PB1 recorded initial crack at 405.6kN which was 47% of ultimate load. The crack width at service load was 0.3mm for PB1 and PB2 respectively. The transverse deflections were 4.34mm and 2.46mm at service load for PB1 and PB2 respectively. The pile cap beam PB1 failed in shear. Pile cap beam failed in flexure as per IS 456-2000.

VII. CONCLUSION

From the test results for pile cap beams it is concluded that the results obtained for shear force are in accordance with IS code provisions

Based on the test results, it can be concluded that circular beams can be designed to fail in bending with the provision rectangular stirrups. The tests conducted are highly preliminary requiring additional tests for adequate information on flexural and shear failures of circular beams with line flexural reinforcement in the tension zone.

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