EXPERIMENTAL INVESTIGATION OF THE EFFECT OF ASPECT RATIO ON COLLAPSE OF THIN SLABS UNDER POINT LOADS

by

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ABSTRACT

Three groups of thin slabs with varying end conditions and aspect ratios were cast, cured and tested in the laboratory in order to investigate the effect of aspect ratio on the failure mechanism as well as the ultimate failure load of thin slabs when subjected to concentrated point loads.

Three types of slab edge conditions were considered viz: (i) All the four edges have monolithic edge beams, (ii) All the four edges have non-monolithic edge beams, and (iii) two opposite longer sides have non-monolithic edge beams, the other two edges being free. For all these cases, the aspect ratios were varied between 0.33 and 2.67.

All the thin slabs tested developed fan mechanisms at failure. The aspect ratio of the slabs has a linear relationship with the circumference of the fan developed. The ultimate load at failure of the slab had a non-linear relationship with the circumference of the fan developed.

INTRODUCTION

The analysis of reinforced concrete slabs under concentrated point loads was first carried out by Westergaard (1), who established critical load stress relations for top and bottom fibres. However, tests have verified the authenticity of yield-line theory for the analysis of reinforced concrete slabs. The basis of the theory is that the

energy expended by the external loads at collapse will be equal to the internal energy absorbed on all yield lines. Thus, once a yield line mechanism has been determined the work equation is then used to determine the ultimate moment and the failure load.

Johnharry (2) proposed an equilibrium version of the yield line method for strength analysis of reinforced concrete slabs. He derived a single equation, which simultaneously represented both the yield line and also met a particular solution of the strip method.

Hossain and Famiyesin (3,4) reported the finite element simulation and parametric studies of fully clamped slabs tested by Powell (5) and Park (6). Four isotropically reinforced slabs of Powell and four anisotropically reinforced slabs of Park were used as basis for the finite element simulation and parametric studies, to identify a set of fixed values for the model parameters involved in the finite element model. The reliability of the model for prediction purposes was verified using the identified fixed values for a further direct simulation of a total of forty-two (42) fully clamped slabs (7) tested by various researchers.

Many researchers had shown that yield line pattern is affected by the strength or stiffness of the supporting beams. Variation of the size of supporting beams also affects the yield line pattern. In their work, Gamble et al (8) showed that in multiple panels of two way slabs, a positive moment yield line develops near mid-span in the exterior panels to the outside edges and the failure extends across the interior and spandrel beams that framed perpendicular to the outside edge. It was also shown that reinforced concrete slabs under point load tend to yield around the point load with the shear plane slightly inclined to the horizontal. The load thus induced stresses, which spread out from the loaded face to the underside face. It was also observed that the point loads contact area affects the fan shape developed.

Hatcher et al (9) demonstrated that the shear plane corresponded more accurately to the sides of a truncated cone, with the fan perimeter more pronounced and

measurable on the underside of the slab. They proposed a more classical relationship between the load applied, moment of resistance and the radius of the fan developed. However, effect of the aspect ratio was not studied.

The aim of this study was to investigate the effect of the aspect ratio, $^{Ly}/_{Lx}$ (the ratio of longer span L_y to shorter span, L_x) on the ultimate failure load and failure mechanism of thin slabs with different edge condition when subjected to concentrated point load.

EXPERIMENTAL PROCEDURES

The tests involved casting of thin slabs of varying dimensions. Coarse aggregate used was crushed granite, with maximum diameter of 12mm and a density of 2650kgm^{-3}. The fine aggregate, with a density of 2570kgm^{-3}, was made of sharp sand from Ogun River in Ogun State of Nigeria. The grading curves of sand and granite are as shown in Fig. 1. The concrete mix adopted was 1:2:4 (cement: sand: granite) with water/cement ratio of 0.60 by weight.

In order to ascertain batch-to-batch variation in the mix uniformity as well as determination of measure of stability and mobility of the concrete used, slump tests were carried out for all the freshly made concrete.

There were five different sets of slabs of the same shorter span of 300mm but longer longer spans of 100mm, 500mm, 600mm, 700mm and 800mm. For each of these sets, three end conditions were considered:

i) Type A – Slabs with all edges cast monolitically with edge beam.
ii) Type B – Slabs with all the edge resting on non-monolithic edge beams. The beams were cast separately.
iii) Type C – Slabs with longer span (ly) simply supported (non-monolithic) while the shorter sides are free.

Figures 2 to 4 show the typical types of the thin slabs, which were reinforced with wire mesh, with their dimensions and supports connections.

After curing for 28 days, 60 No. 150mm cubes, three from each slab panel as well as 20 No. 50mm thick rectangular thin slabs were tested to determine the average compressive strength. The average compressive strength of the concrete used varied between 20.50N/mm^2 and 26.76N/mm^2.

The slab panels were cured continuously for 28 days by wetting of the sack used in covering the panels. The testing of the thin slabs were carried out by point loading under the universal testing machine. The load from the testing machine was transferred through the roller point at a pre-marked central point of the rectangular slab at the rate of 5kN/second so as to observe the development of yield lines and ascertain the point of yielding of the wire mesh.

At failure of reinforcement, further loading was discontinued and the thin slab panel reversed carefully to enable its removal from the loading bay. The yield lines developed were then carefully marked out and traced into tracing paper for further analysis.

DISCUSSIONS OF RESULTS

Failure Loads of the Thin Slab

The failure of the reinforcement, which indicated also the point of yielding of the wire mesh, was determined by the sudden snap of the wire strand. The collapse loads for the different aspect ratio and end conditions are presented in Table 1, while Figure 5 shows the relationship of failure loads to the aspect ratio of the slabs.

It was observed that for the type A slabs, with monolithic edge beams, decrease in the aspect ratio, ($^{L_y}/_{L_x}$) led to increase in the failure load. In this case, as $^{L_y}/_{L_x}$ was reduced the monolithic supported beams tended to move closer to the point of loading, thus

transferring stresses, through membrane action, unto the support beams. This thus resulted in a combination of failure of the slab through yielding and failure of the support beams through shear rupture. This is in agreement with the findings of Mattock et al (10).

In view of the non-monolithic connection of the edges to the supporting beams for slabs of types B edge connections, the increase in failure load with increase in the aspect ratio was not as rapid as for type A connection. Slab with type C support connection showed decrease in the failure load with decrease in the aspect ratio. In this case, reduction in the aspect ratio brought closer the free opposite edges such that at an aspect ratio of 0.33 the failure was by a single straight yield line linking and perpendicular to the two opposite free edges (shorter spans).

At low aspect ratio, of less than 1.0, the failure loads differ substantially for different end conditions. However, at aspect ratio of greater than 2.0, there seems to exist an asymptotic collapse load of 400kN for all the cases investigated.

Yield Pattern of the Thin Slabs

The fan perimeters were more pronounced and measurable on the underside of the slabs tested. This confirms the findings of Hatcher et al (9).

The study showed that for majority of the cases investigated, the slab panel failure was by fan mechanism with the circumference ranging between 504mm and 820mm. Analysis also showed that for slab panel of type A with monolithic edge beams, decrease in the aspect ratio was accompanied by a decrease in the circumference of the fan developed. Same also was the case for slabs, which were simply supported on the four sides (Type B).

Plates 1 to 4 show the patterns of the thin slab with yield with respect to their aspect ratio and type.

For slab panels with monolithic built-in end beams, the positive yield lines numbering

four or five and propagating from the epicentre with varying radii, gave the mechanism an oblique shape.

However, for slab, simple supported along the longer sides only (Type C) only two panels corresponding to aspect ratios of 2.67 and 2.33 (that is with high aspect ratios) failed by fan mechanism with corresponding circumference of 629mm and 724mm and failure load reducing from 325kN to 290kN, respectively. All the other samples with lower aspect ratios failed by simple - beam action. This was due mainly to simple support condition and with low aspect ratio. The failure is similar to that of a beam with uplifting. It was also observed that there exists a linear relationship between the fan circumference developed at failure and the aspect ratio of the slabs.

Figure 6 shows the relationship between the aspect ratio of the slab panels and the circumference of the fans developed at failure while their relative values are also presented in Table 1.

Fan Circumference with Yield Load

Hitherto considered not as relevant as the radius of the fan developed in all theoretical relations, Johansen (11), the results of the investigation showed an unprecedented relationship that exists between the failure load at collapse and the fan circumference developed. Figure 7 relates the values of the failure load at collapse to the fan circumference for all various samples tested while the values are presented in Table 1. It showed that, within the test range, there exists asymptotic relationship between the load and the circumference of the fan developed for all the investigated boundary conditions.

For example, samples of type A, with monolithic edge beams and an aspect ratio of 2.67, the measured circumference of the developed fan was 820mm with a failure load of 359kN; at an aspect ratio of 2.00, the measured circumference had gradually reduced to 76mm with failure load increasing to 389kN; while at an aspect ratio of 0.33 the measured circumference of the developed fan had reduced to 542mm with failure load increasing to 840kN.

CONCLUSIONS & RECOMMENDATIONS FOR FUTURE WORK

The effect of aspect ratio of thin slab with different boundary conditions subjected to concentrated loading and circumference of the fan developed at failure had been investigated and the results of the experiments showed the following:

1. The collapse of the thin slab was due to the failure of the reinforcement, which occurred with sudden snap of the wire mesh. The slab was under-reinforced.

2. Supporting beams increased the load carrying capacity of the thin slab. For monolithically supported slab in all the four sides, there was increase in failure loads with reduction in the aspect ratio. For simply supported slab, on only opposite longer side, the failure load decreased with reduction in the aspect ratio

3. The failure of thin slabs subjected to concentrated loads was by fan mechanism especially for aspect ratio greater than 2. There exists linear relationship between the aspect ratio and the circumference of the fan developed, independent of the boundary conditions.

4. There also exists an asymptotic relationship (non-linear) between the collapse load and the developed fan for all the investigated boundary conditions.

The experimental Investigation was carried out into the effect of the aspect ratio on the collapse load and fan circumference of a thin slab loaded with central point load. It is recommended that failure work should concentrate on ascertaining, experimentally, the effect of other factors such as thickness of slab, closeness of point load to the edge of the fan circumference, reinforcement of the slab, etc.

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Table 1: **Collapse Load and Fan Circumference for Slab Panels**

Type	Longer Span (Ly)	Aspect Ratio Ly/Lx	Collapse Load kN	Fan Circumference (mm)
A	800	2.67	359	820
	700	2.33	370	802
	600	2.00	389	761
	500	1.67	404	705
	100	0.33	840	542
B	800	2.67	330	740
	700	2.33	335	702
	600	2.00	344	671
	500	1.67	349	633
	100	0.33	410	525
C	800	2.67	325	629
	700	2.33	290	724
	600	2.00	275	- *
	500	1.67	265	- *
	100	0.33	152	- *

* No fan circumference, failure by simple-beam action.

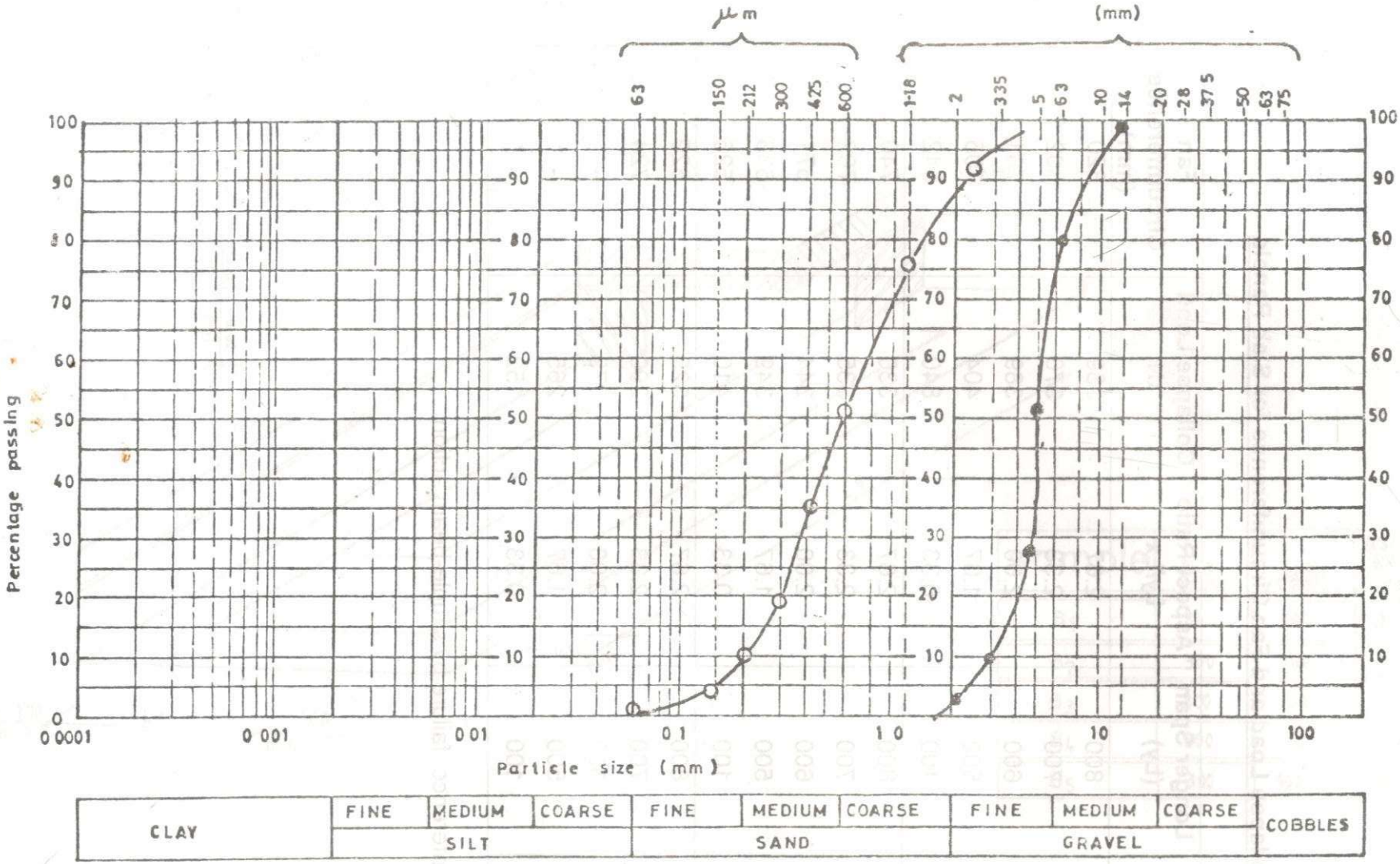
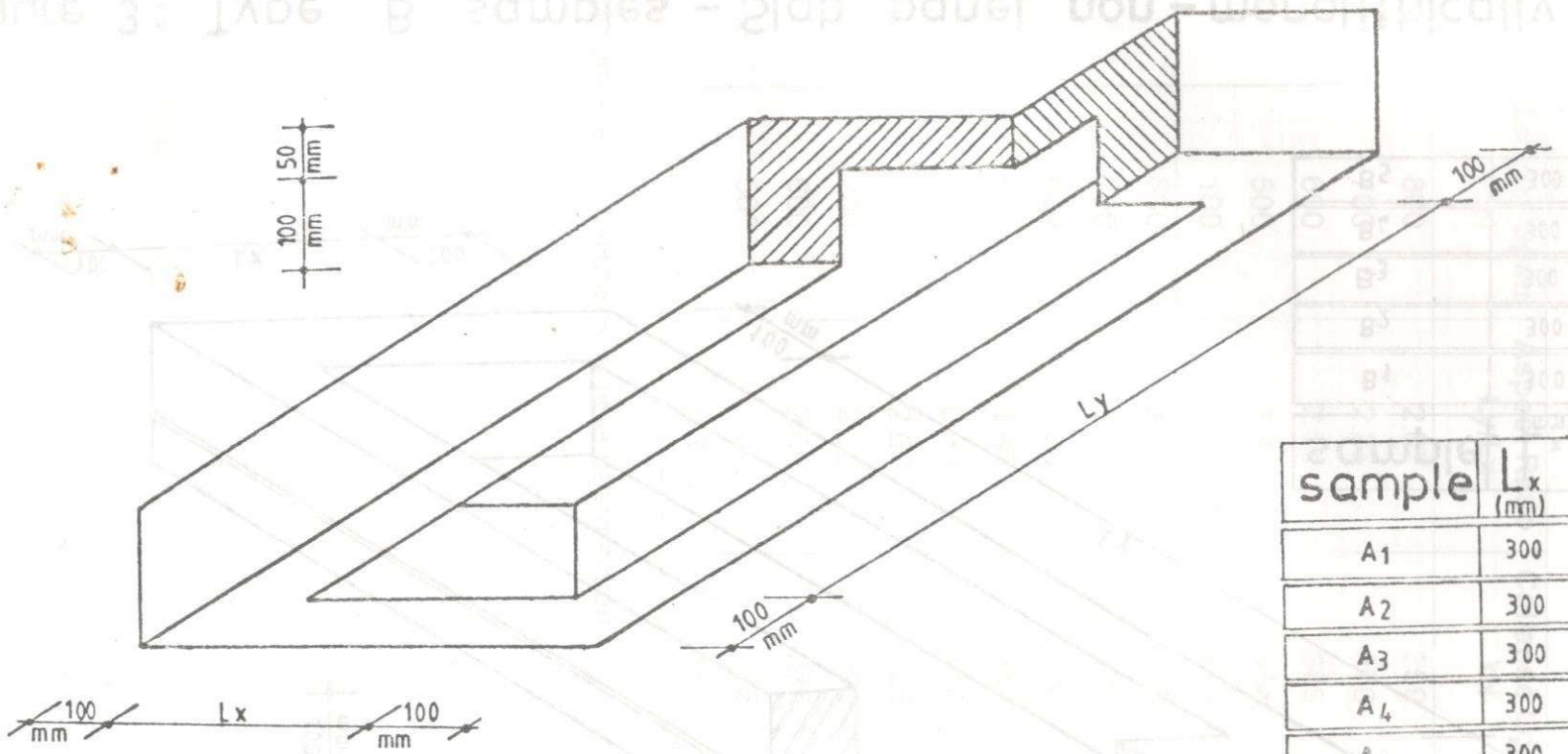


FIGURE 1: PARTICE SIZE DISTRIBUTION FOR FINE AND COARSE AGGREGATE

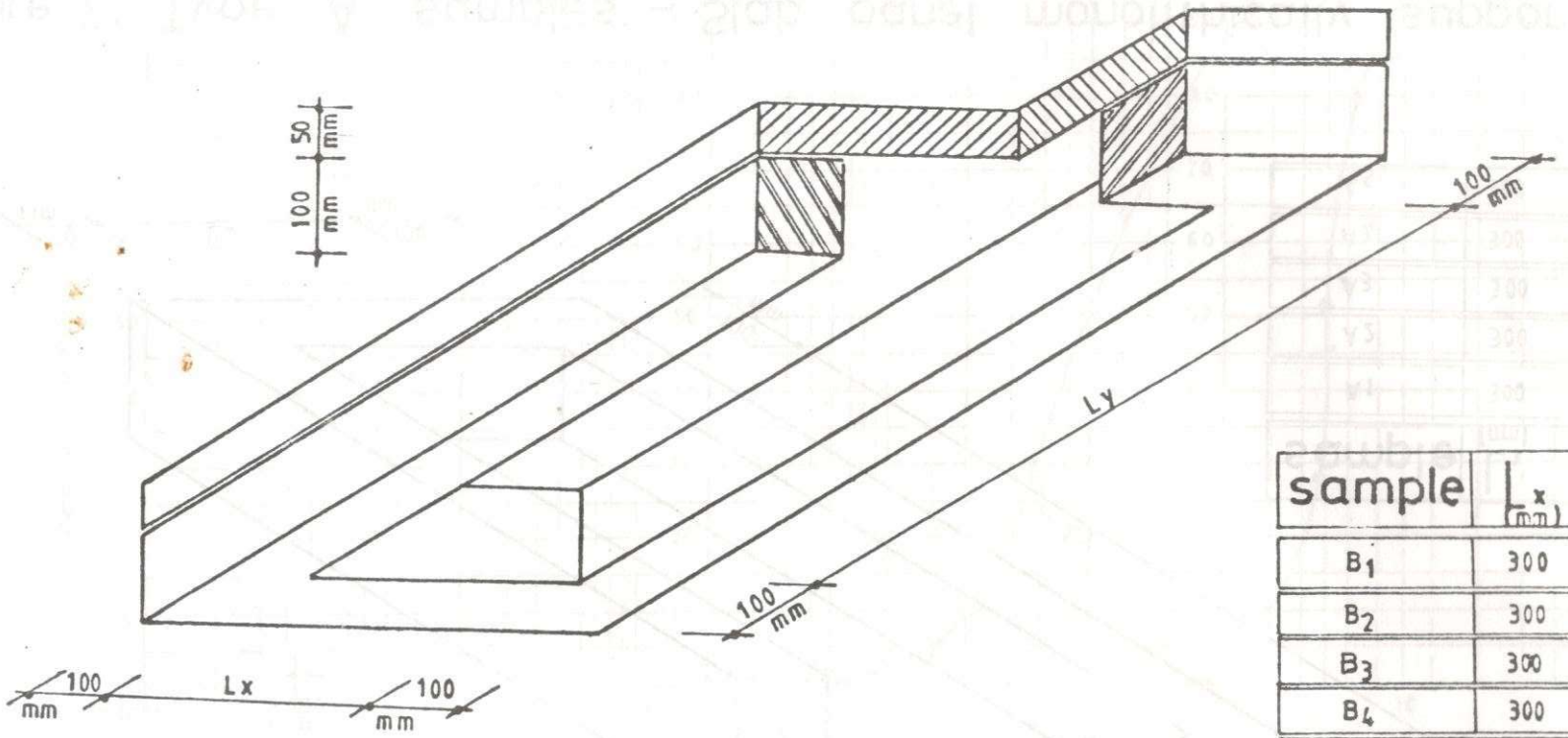
—o—o— Fine Aggregate (sand)

—·—•— Coarse Aggregate (crushed Granite)



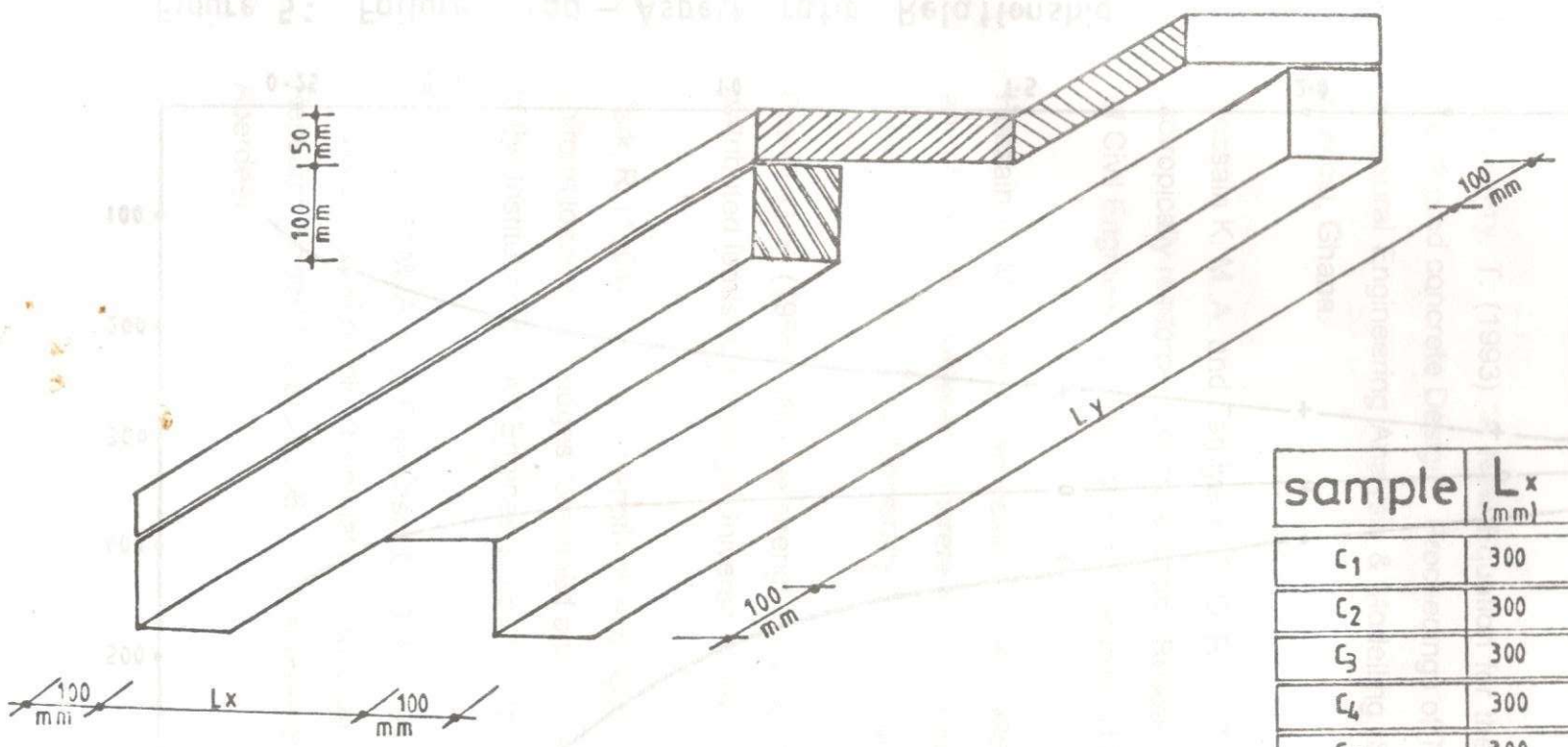
sample	L_x (mm)	L_y (mm)	ASPECT RATIO Ly/Lx
A_1	300	800	2·67
A_2	300	700	2·33
A_3	300	600	2·00
A_4	300	500	1·67
A_5	300	100	0·33

Figure 2: Type A samples – Slab panel monolithically supported along all sides.



sample	L_x (mm)	L_y (mm)	ASPECT RATIO Ly/Lx
B_1	300	800	2·67
B_2	300	700	2·33
B_3	300	600	2·00
B_4	300	500	1·67
B_5	300	100	0·33

Figure 3: Type B samples - Slab panel non-monolithically supported along all sides.



sample	L_x (mm)	L_y (mm)	ASPECT RATIO L_y/L_x
C_1	300	800	2·67
C_2	300	700	2·33
C_3	300	600	2·00
C_4	300	500	1·67
C_5	300	100	0·33

Figure 4: Type A samples – Slab panel non-monolithically supported along Longer sides (Ly).

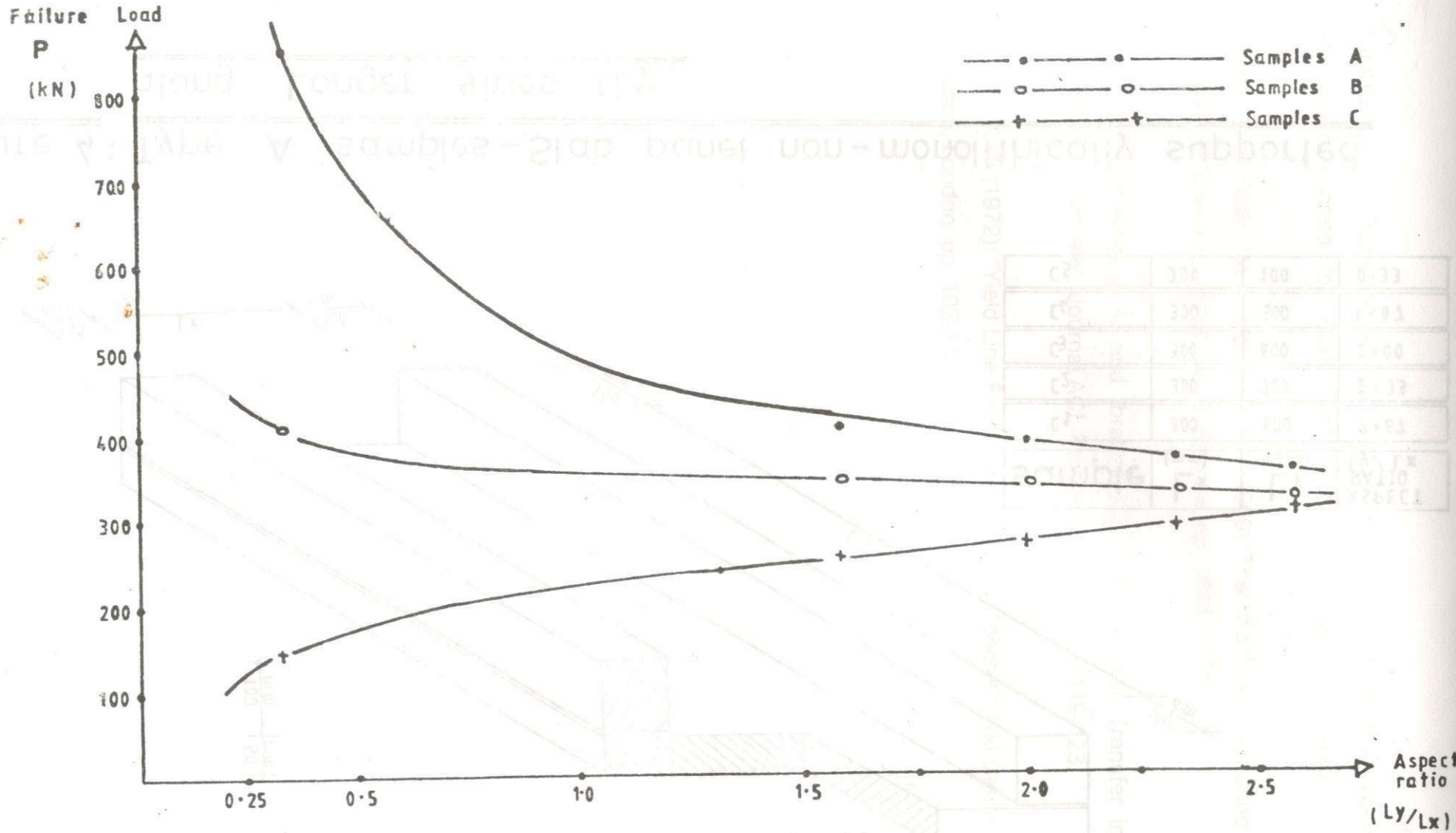


Figure 5: Failure Load – Aspect ratio Relationship

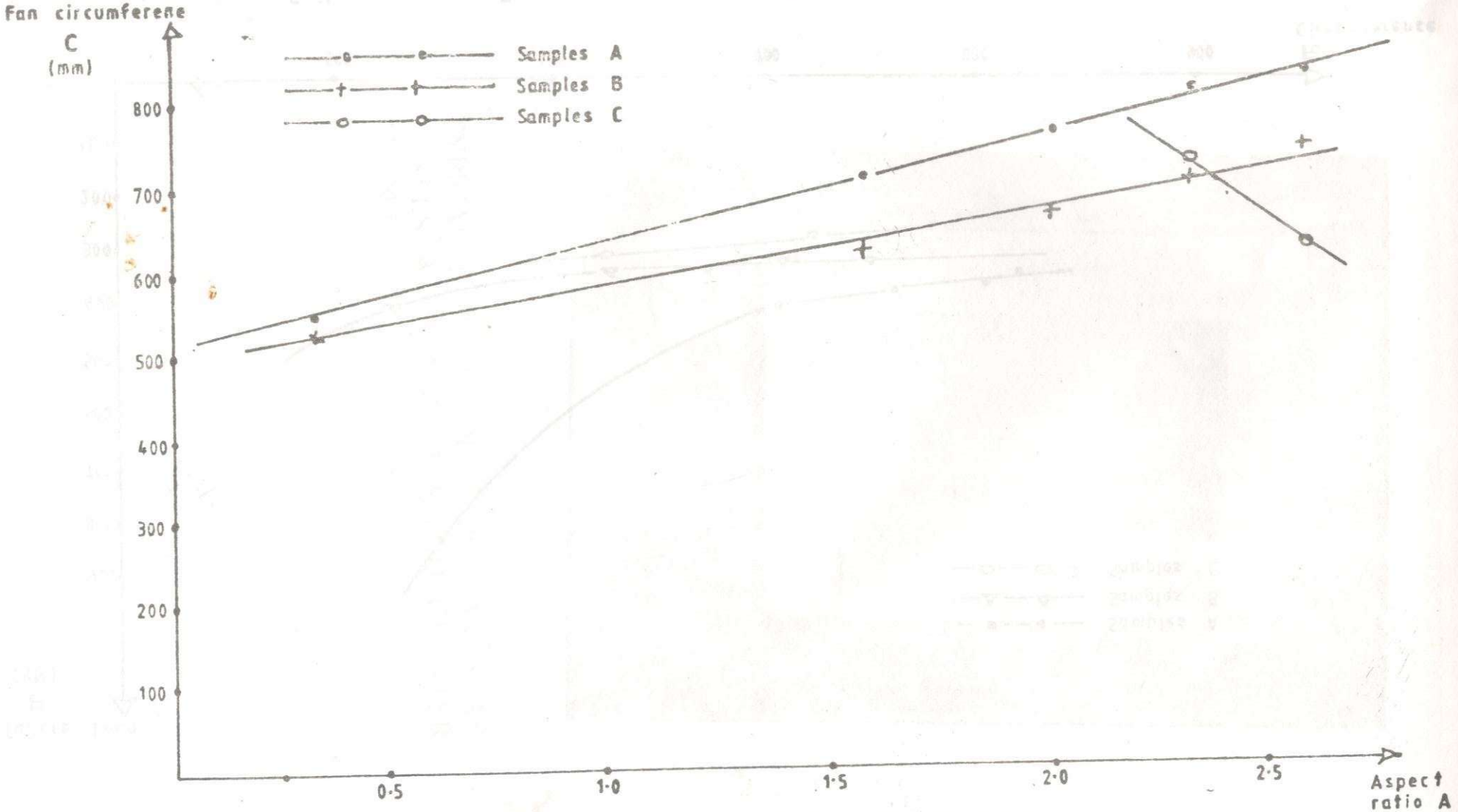


Figure 6: Fan Circumference – Aspect Ratio Relationship

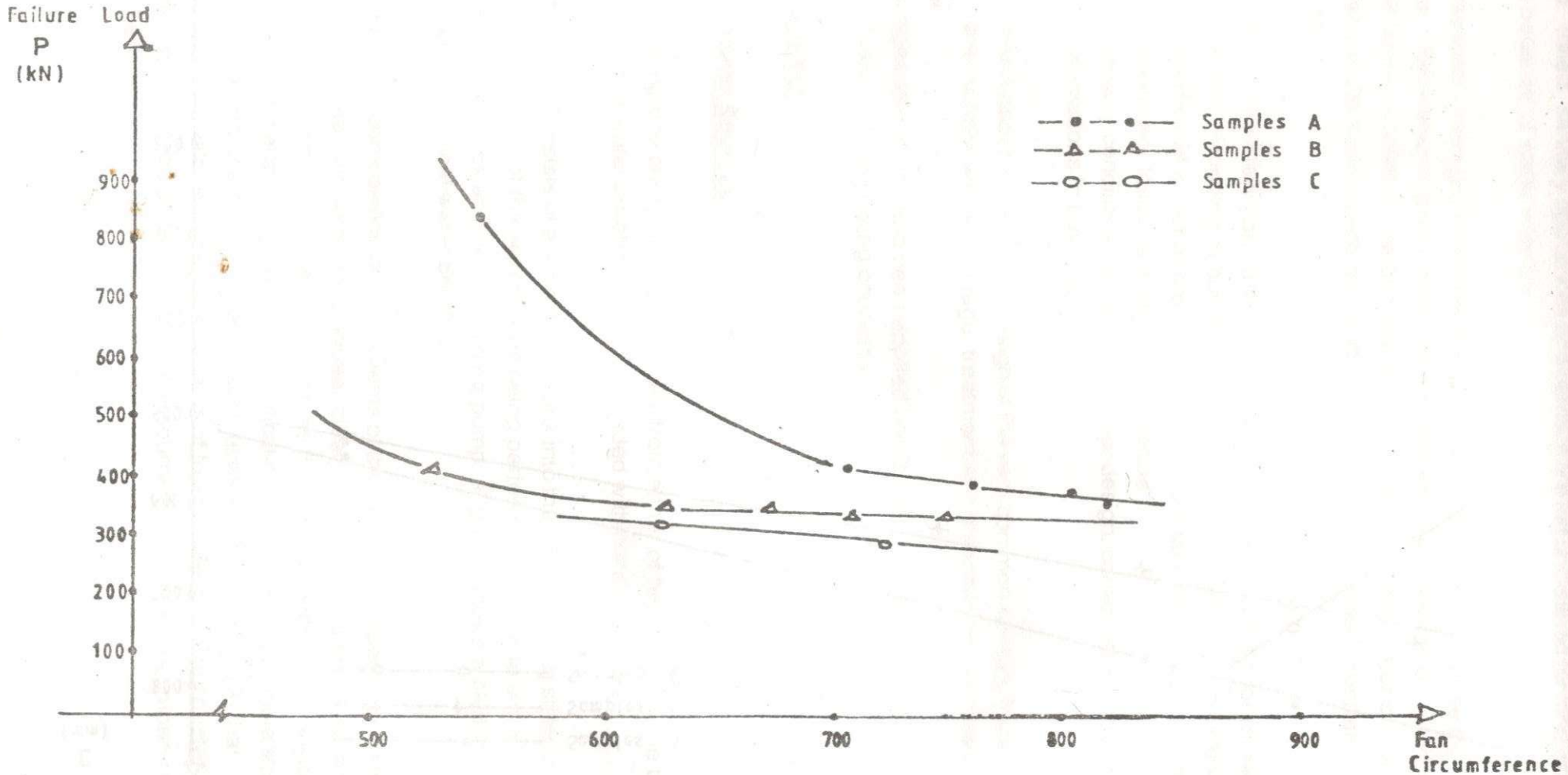


Figure 7: Failure Load – Fan Circumference Relationship.



PLATE 1: TYPICAL FAILURE OF TYPE A SLAB PANELS WITH ASPECT RATIO GREATER THAN 1.50



PLATE 2: TYPICAL FAILURE OF TYPE B SLAB PANELS WITH ASPECT RATIO GREATER THAN 1.50.

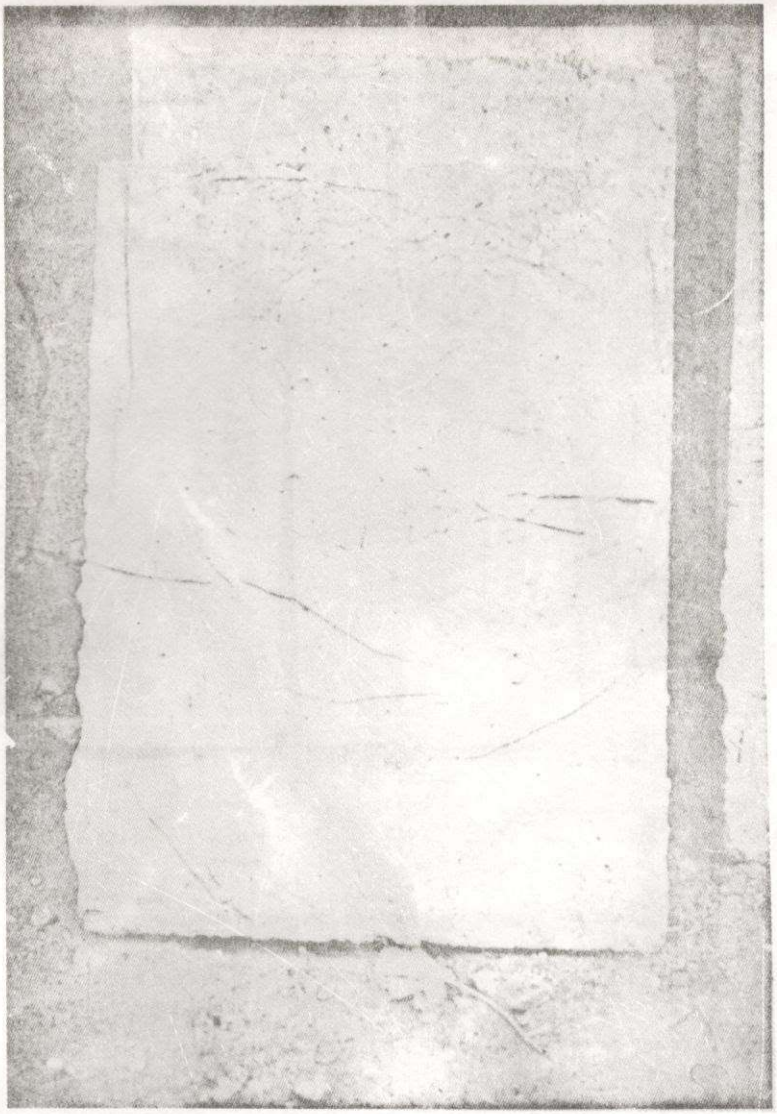


PLATE 3: TYPICAL FAILURE OF TYPE C SLAB PANELS WITH ASPECT RATIO GREATER THAN 1.50

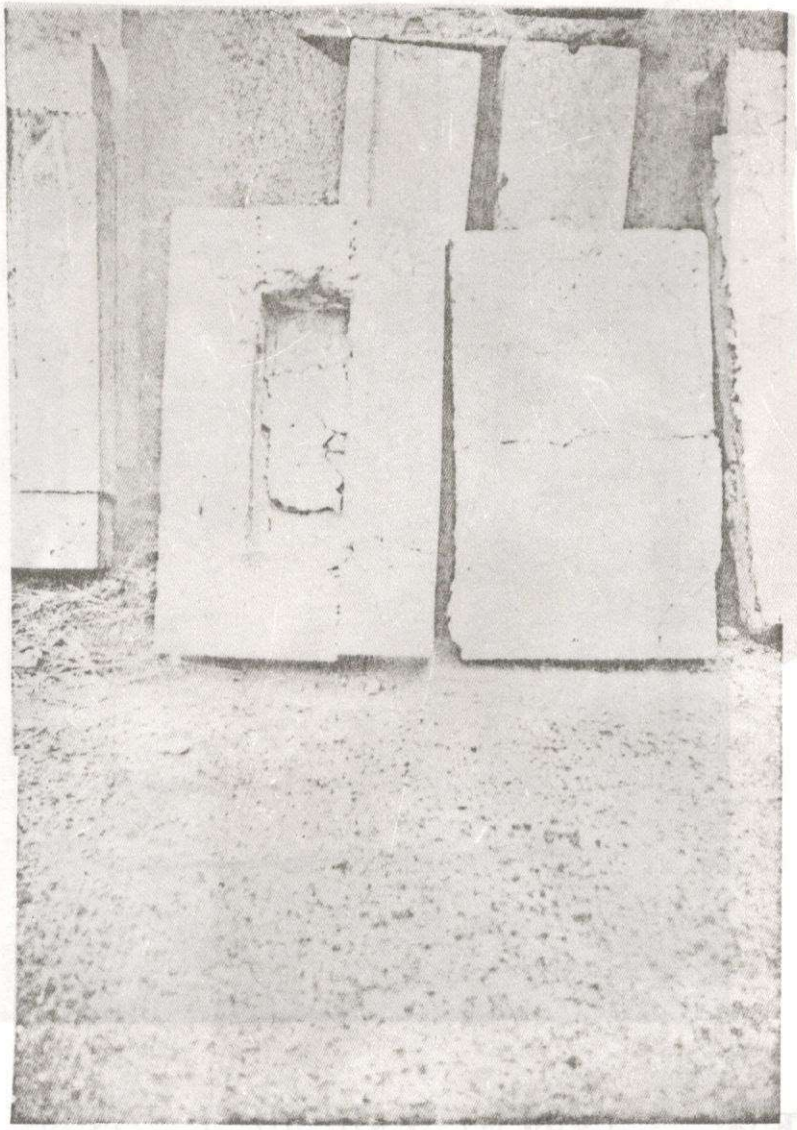


PLATE 4: FAILURES OF TYPE A AND C SLAB PANELS WITH LOW ASPECT RATIO.