STRENGTH AND BEHAVIOUR OF THE JOINTS IN TIED-FRAME

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ABSTRACT

The present investigation was aimed at studying the behaviour and strength of joint of three concrete members; namely a rafter, a tie and a column, with various anchor shapes of the end of the tie bars. Practically such joint is of great interest since it is encountered in tied frames and arches. The test program included testing of twelve reinforced concrete frames. The tested frames had variable amount and type of reinforcement and different details for the tie reinforcement anchorage. The behaviour of different types and steel arrangements for the tie-end anchorage and different types of a tied-frame joint were studied experimentally at different stages of loading up to failure. Based on the results of this study the most efficient steel arrangement and joint type were recommended for design purposes.

INTRODUCTION

Tied structures such as tied arches and gable and polygonal frames having tie connected to the column rafter connection are in common use in industrial buildings. Such structures owe their stability to the tie anchorage. If the anchorage fails the bars slip and the tie force is reduced dramatically. The moment in the frame member or in the arch jumps up to several times the original value. Collapse of the frame is inevitable if the tie anchorage fails. The available information in literature about the behaviour of such joint is scarce. The object of the present investigation was to study the behaviour and the strength of the joint of three concrete members; namely a rafter, a tie and a column to obtain data useful for design purposes. Various anchor types of reinforcement and different shapes of joint were considered. Both the ordinary mild steel and high strength steel were used throughout the investigation.

TEST PROGRAM

Twelve reinforced concrete test frames of width 15 cm and different dimensions were studied. Figure 1 and Table 1 give the overall dimensions and the reinforcement details of all frames tested in this study. The main variables studied were:

1- The details of anchoring the tie reinforcement.
2- The shape of the anchor joint.
3- The amount and grade of steel used for the tie reinforcement.

The test frames were arranged in three groups, as given in Table (1). The test frames included in the first group, S-o through S-3, served as pilot tests, where different frame systems, dimensions and reinforcement were tried. S-3 proved to be the most suitable one. Its dimensions were chosen for frames in the subsequent test groups. The allowance of the rotation at the top joint served to bring the test frame to be statically determinate. The tie force was computed by equilibrium equations and presented as a ratio of the applied load.

LOAD MEASUREMENT AND TEST PROCEDURE:

The tests were conducted in the reinforced concrete laboratory, Alexandria University. A hydraulic compression machine of 300 tons capacity was used. The load was applied directly at the top joint of the test frame through a spreader beam and two movable rollers supports were arranged to allo any displacement through a roller bearing and rotation through a fixed cylindrical bearing. The tensi n force in the tie were measured indirectly through measuring the strains in the tie bars by means of four electric strain gauges. For this purpose the

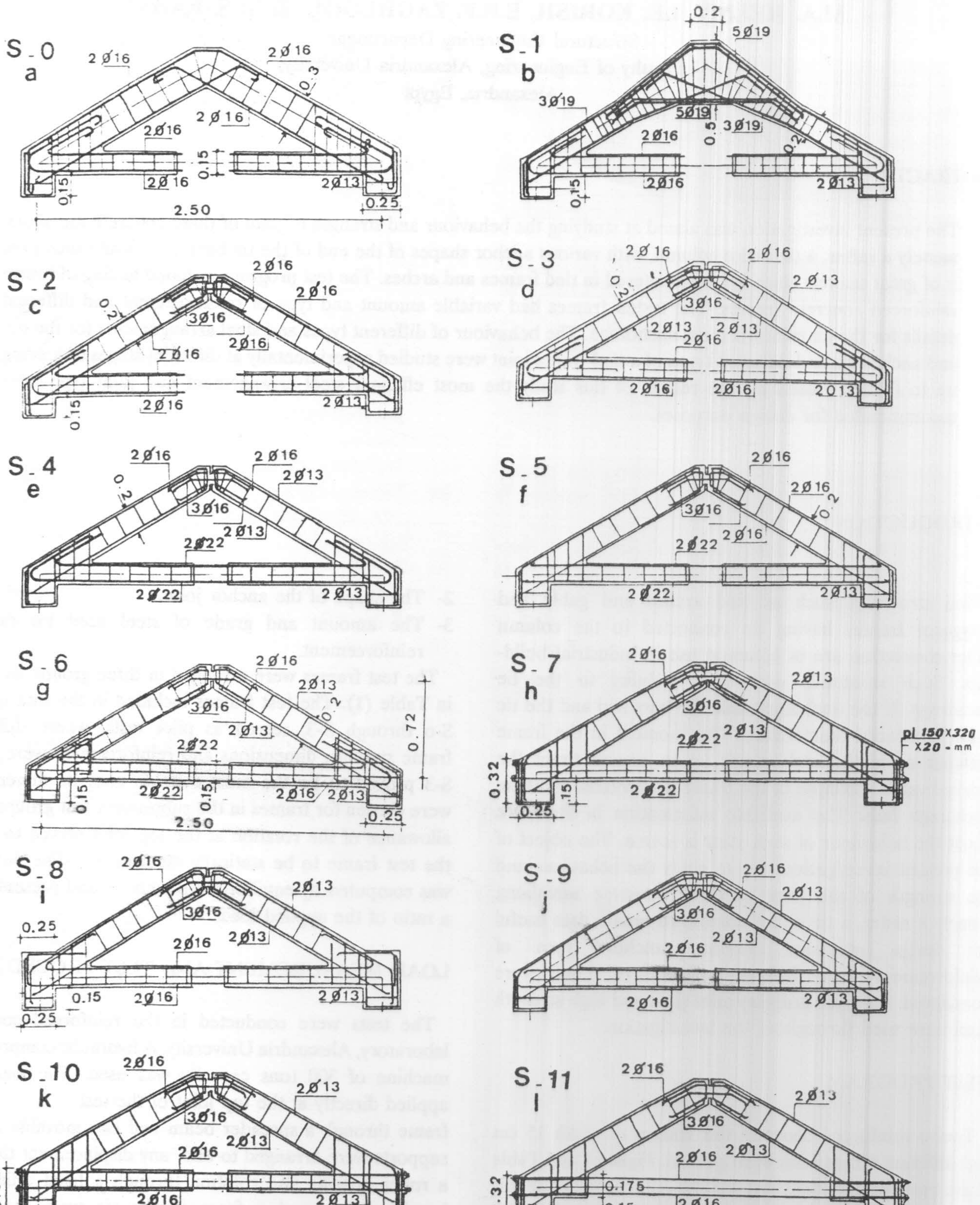

S-0
a
2Ø16
0.3
0.15
2.50
0.25
2Ø13
S-1
b
0.2
5Ø19
3Ø19
0.5
2Ø16
2Ø13
S-2
c
3Ø16
0.2
2Ø16
2Ø13
0.15
S-3
d
2Ø16
2Ø13
3Ø16
S-4
e
2Ø22
3Ø16
2Ø13
S-5
f
2Ø16
3Ø16
2Ø22
2Ø13
S-6
g
2Ø16
2Ø13
3Ø16
0.72
2Ø22
0.15
2.50
0.25
S-7
h
2Ø16
2Ø13
3Ø16
2Ø22
pl 150X320
X20 - mm
0.32
0.25
S-8
i
2Ø16
2Ø13
3Ø16
0.25
0.15
S-9
j
2Ø16
2Ø13
3Ø16
S-10
k
2Ø16
3Ø16
2Ø13
0.32
S-11
l
2Ø16
2Ø13
3Ø16
0.175
0.15
0.32
0.50
plastic pipe

Table 1. Details of Test Frames.

Group No	Frame No	Dimensions# cm Tie	Rafter	Column	Joint	Reinforcement * Tie	Rafter	Column
G-1	S-0	15	30	25	Connected	4ø16	4ø16	4ø13
	S-1	15	Var.	25	Connected	4ø16	4ø19	4ø13
	S-2	15	30	25	Hinged	4ø16	4ø16	4ø13
	S-3	15	20	25	Hinged	4ø16	4ø13	4ø13
G-2	S-4	15	20	25	Hinged	4Φ22	4Φ13	4Φ13
	S-5	15	20	25	Hinged	4Φ22	4Φ13	4Φ13
	S-6	15	20	25	Hinged	4Φ22	4Φ13	4Φ13
	S-7	15	20	25	Hinged	4Φ22	4Φ13	4Φ13
G-3	S-8	15	20	25	Hinged	4ø16	4ø13	4ø13
	S-9	15	20	25	Hinged	4ø16	4ø13	4ø13
	S-10	15	20	25	Hinged	4ø16	4ø13	4ø13
	S-11	15	20	25	Hinged	4ø16	4ø13	4ø13

Width of all frames = 15 cm

* Yield stress for O.M.S. = 2800 Kg/cm² and for H.T.S. = 3800 Kg/cm²

ø For O.M.S , Φ for H.T.S

middle part of the tie was left without concrete to expose the tie bars, on which the strain gauges were mounted in the test frames S-4 through S-11. This arrangement was found to be simpler and more efficient than the arrangement used in frames S-1 through S-3 where special tension load cell fixed to the tie bars through two steel heads centrally bolted to the tie bars. The load was applied in increments of five tons up to failure. With every stage of loading, the strain readings in the tie bars, the applied load, as read on the compression machine loading panel, and the demec gauge readings on the surface of the joint were recorded. Also the cracks development were also marked.

BEHAVIOUR OF TEST FRAMES

Table 2 was prepared to demonstrate clearly the effect of the parameters studied on the behaviour, strength and the mode of failure of the connections. Figures 2-a through 2-I clarify in a self explained way the patterns of cracks and the developed modes of failure. Test frame S-o failed by crushing of concrete at the top section of the rafter, Figure 2-f and 2-g. This section was subjected to the maximum moment due to loading and end conditions of the test frame. The stress in the tie steel, at failure, reached 2583 Kg/cm², which is about 92% of the yield stress of the tie steel. As it is clear from the test results presented in Table 2 and the modes of failure indicated in Figures 2-a, 2-d and 2-e, the anchorage type encountered in frames S-1,S-4 and S-5 was not sufficient to develop the full tension capacity of the tie. The tie reinforcement lost its bond in the region at the tie frame connection, and the anchorage zone suffered heavy cracking causing the movement of the hooks. Subsequently the tie force was reduced except in S-1, where the steel stress in the bars had reached about 99 % of their yield strength. The other anchorages proved to be efficient in developing the tie capacity. In the test frames S-0, S-3, S-6 and S-7 premature failures occurred away from anchorage region

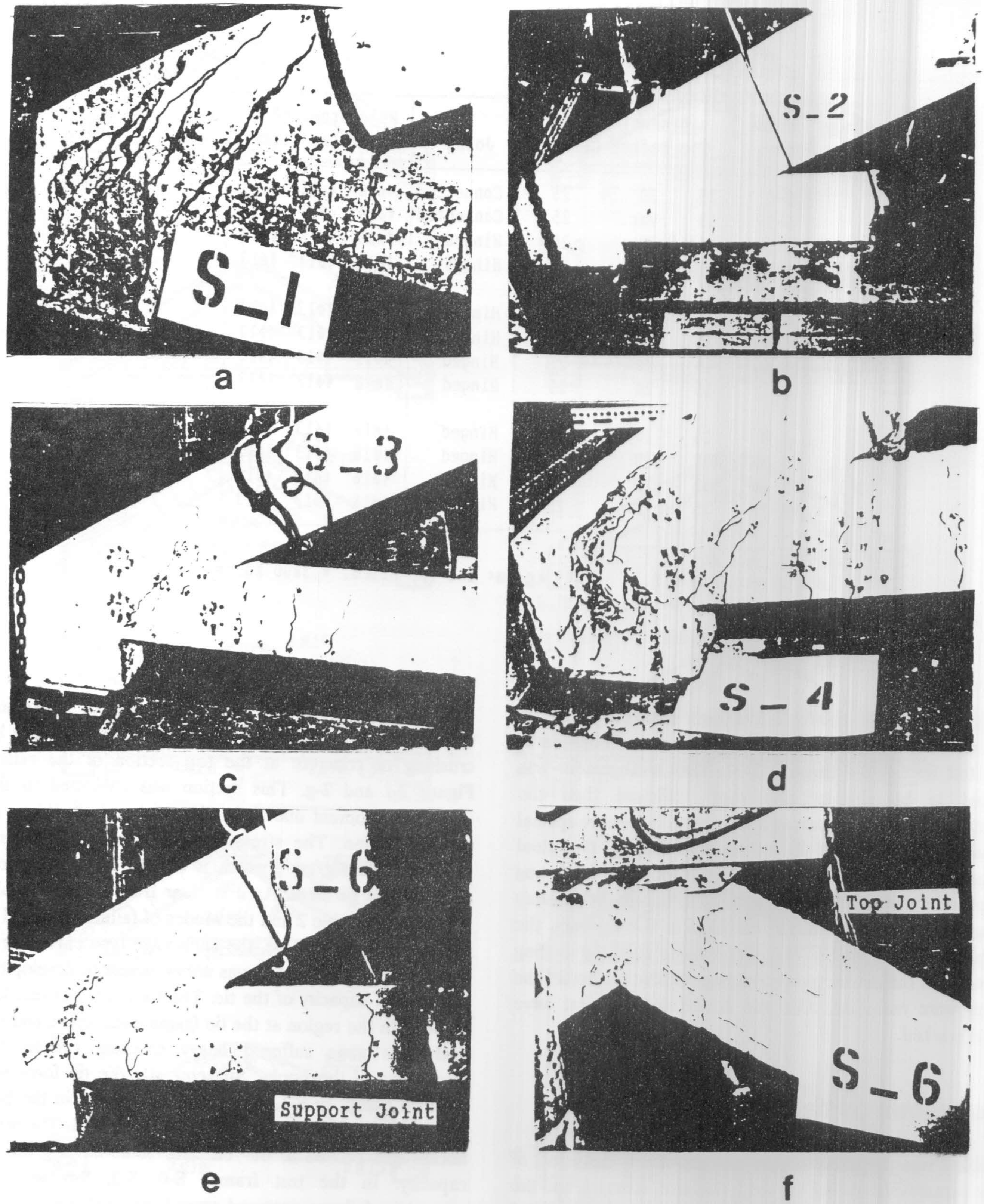


Figure 2. Crack pattern and modes of failure of tested frames.

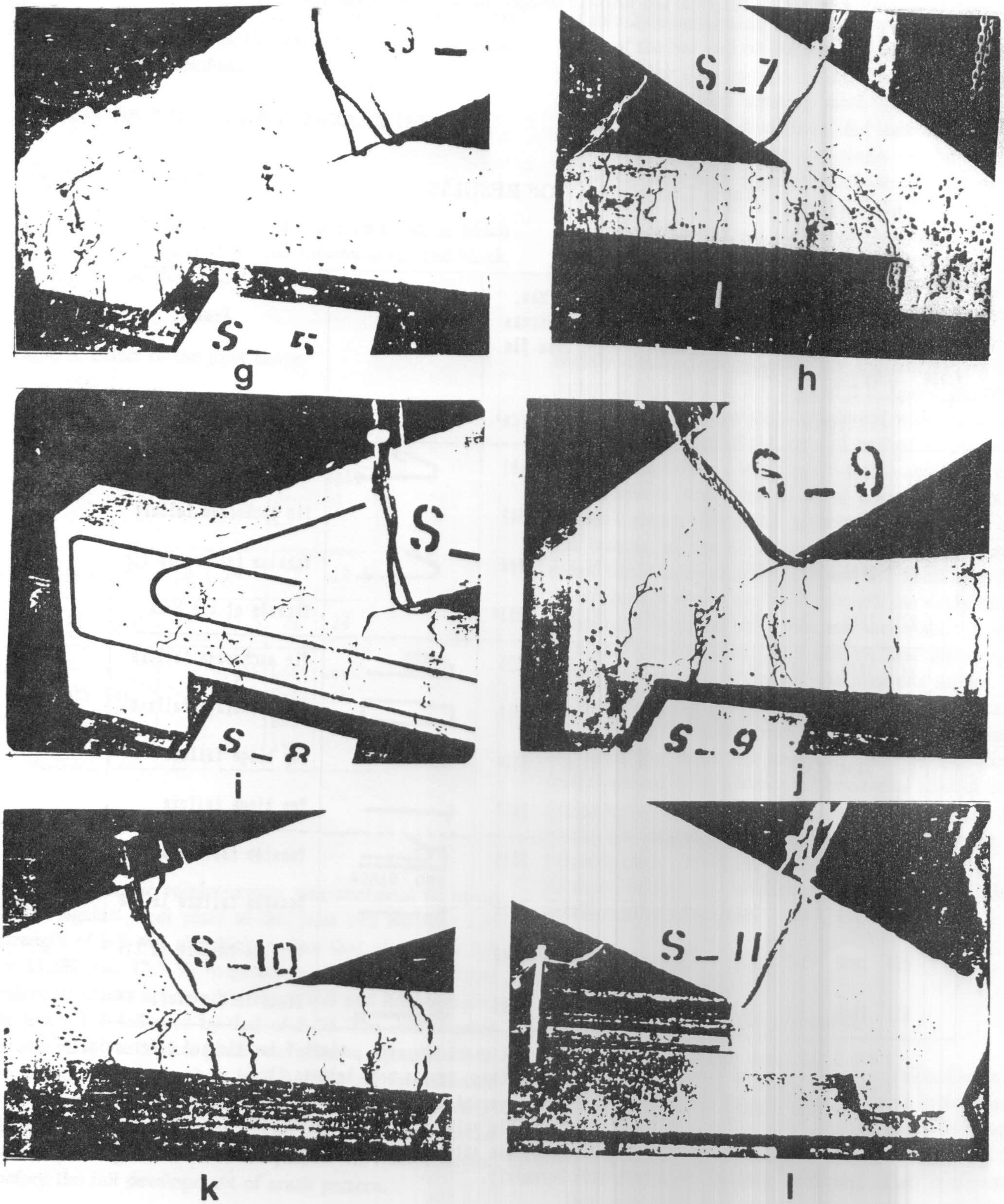
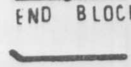


Figure 2. (Contd.) Crack pattern and modes of failure of tested frames.

Table 2. SUMMARY OF RESULTS

Group & Frame No		Material Properties fy (kg/cm²)	fcu (kg/cm²)	fc' (kg/cm²)	Load of 1st Crack at T @ (ton)	J (ton)	Max. Load (ton)	Max. Stress in Tie (kg/cm²)	End type	Remarks
G1	S0	2800	374	330	43	62	36.5	2583		Flexure failure at top
G1	S1	2800	333	259	20	75	40.0	2763		Tie anchorage failure
G1	S2	2800	400	379	31	62	26.0	2800		Tension failure in tie
G1	S3	2800	393	246	35	43	23.0	2325*		Threads of tie bars
G2	S4	3800	340	303	40	53	37.5	2135		Tie anchorage failure
G2	S5	3800	403	380	38	38	53.0	3018		Tie anchorage failure
G2	S6	3800	412	352	23	46	43.0	2448		Top hinge failure
G2	S7	3800	430	386	30	40	50.0	2847		Top hinge failure
G3	S8	2800	334	283	38	38	26.0	2815		Tension failure in tie
G3	S9	2800	318	280	44	44	22.5	2436		Tension failure in tie
G3	S10	2800	342	317	41	41	24.0	2598		Tension failure in tie
G3	S11	2800	306	263	No#	No#	25.0	2706		Yield in tie steel

@ T & J indicates positions at which the first crack appeared , where T for tie and j for joint.
# No crack appeared in this test frame since there was no bond between the tie bars and connection zone as the tie bars passed through a sleeve.
* The stress at the threads is higher than this value since the area at the threads is about 80-85% of the gross area, The actual stress is cpmputed as 2325/.8 or 2325/.85 i.e 2835-2735 kg/cm²=fy.

before the development of the full capacities of the tie force due to the failure of the top hinge. The ties in these frames were over reinforced.

EFFECTS OF THE STUDIED PARAMETERS

i- Effect of Joint Shape

From Table 3 the strength of test frame S-8, in which the joint was enlarged above the column at the end block, was higher than that of S-1 by 8%.

Table 3. Effect of the joint shape

Frame No	S3	S9	S8	S-10
Joint shape	Sloping		Enlarged	Bolted
Crack.load	10	10	10	10.5
Fail. load	23	22.5	26	24
Crack Pat.	-	Highest	Less Extensive	Lowest

In S-10 the tie reinforcement was anchored by being bolted against steel plate at the joint end surface. The strength of S-8 was also higher, than that of S-3 and S-9 by 11.5% and 13.5 % respectively. At failure, the most extensive cracks appeared in frame S-9 and less extensive in frame S-8 followed by that of S-10. The confinement produced by the anchor plate was efficient enough in S-10 to cause less cracks than in S-8 although the ultimate carrying capacity of S-8 was slightly higher than that of S-10, as can be seen in Table 3. The failure of S-3 occurred due to yielding of the threaded part of the reinforcement before the full development of crack pattern.

ii- Effect of the Shape of Bar Ends

Table 2 demonstrates, in a simple way, the effect of the shape of the bar end on the strength and behaviour of the test frame for the two types of the reinforcement; namely, mild steel and high strength steel. The strength of the frames with mild steel bars did not seem to vary significantly when varying the shape of the bar ends. However, with high strength steel the strength did vary significantly. This can be seen in Table 2 specially when the mode of failure was due to the anchorage failure, as for test frames S-4 and S-5. In the joints reinforced with mild steel the anchorage types used for S-3, S-8, S-9 and S-10 proved to be equally efficient, when the strength of the joint was the factor. The behaviour of the joint was slightly changed as indicated by the intensity of crack patterns, Figures 2-c, 2-i, 2-j and 2-k, against the type of end anchorage. In the joints reinforced with high strength steel, the influence of the type of anchorage was noticeable. The failure load of S-5, in which the tie reinforcement was bent to form horizontal hooks and welded together, was much higher than those of the other test frames, as can be seen in Table 2. This concluded result was drawn, although S-6 and S-7 failed away from the anchorage region and their strength can not be directly compared. From the behaviour and serviceability point of view the most efficient arrangement was anchoring by bolting against a steel plate at the joint end surface. This outer anchor plate produced compression in the block and the concrete zone became confined. This confinement improved the bond between the concrete and the tie reinforcement. The addition of horizontal stirrups in the anchorage zone of frame S-6 reduced the amount of cracks and improved the anchorage and subsequently the joint capacity.
Stirrups limits the extension of cracks and induces confinment to concrete.

CONCLUSIONS

The following conclusions are drawn from the test results.

1- The most efficient arrangement was achieved when the tie reinforcement was anchored by being bolted against steel plate at the joint end surface, since this anchor plate produced compression in the block and the concrete zone became confined. This confinement improves the bond between the concrete and the tie reinforcement.
2- The enlargement of the joint depth above the column at the end block and looping the tie steel as in frame

S-8 creates a compression zone above the tie level. This zone was found to be beneficial since the bars can be bent with reasonable radii and have ample anchor length in a compression zone.

3- Anchoring the tie reinforcement by bending within the rafter is sufficient in developing the full force of the tie when the length of the straight part of the tie bars after bending is equal to 25 times the bar diameter. In this context, it is worth reporting that frame S-9 performed to give a good anchorage method as S-3 so long as enough length was available after the tie rafter intersection.

4- Although, traditionally, it was recommended that all bars should be anchored beyond the point of intersection of the center lines of all members common in the joint, yet the experiments proved that this is not strictly necessary. However, bottom bars should be bent beyond the intersection point while top bars may be bent over a reasonable radius if they are sufficiently embedded in concrete.

5- To improve the anchorage and develop the full force in the tie, horizontal stirrups are highly recommended.

6- The tie reinforcement may be laid as horizontal pairs having continuous ends with reasonable radius and welded together as in frame S-5. This type of anchorage made the compression force in the rafter more efficient in preventing any movement of the tie reinforcement until failure.

7- Using deformed bars as reinforcement decreased the amount of cracks in comparison with those of ties reinforced with mild bars at the same load level.

REFERENCES

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