CARRYING CAPACITY AND CRACKING RESISTANCE AT THE SUPPORT ZONE OF HALVING JOINTS IN REINFORCED CONCRETE BEAMS - Part 2.

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SYNOPSIS

Results are presented from tests on 3 beams having discontinuous support zones.All of them had web and diagonal shear reinforcement. Two out of the three represented beams, their test results have been analysed in a paper designated Part 1 which appeared in the **Uhandisi Journal**,Vol. 13 No. 1 December 1989.They have been presented in this paper for comparison purposes. The third beam has been made to investigate the effect of anchoring diagonal shear reinforcement by spot welding method.

The third beam was tested with two concentrated loads in the span.In all beams several diagonal tension cracks formed in the regions of maximum shear.All beams failed in shear. The magnitude of the cracking load was found to depend primarily on the dimensions of the cross-section and strength of concrete.All beams were able to support substantially loads than the cracking loads.The final shear failure occurred by destruction of the compression zone of concrete at the support or load bearing block. The magnitude of the failure load was clearly a function of the amount, configuration and type of web reinforcement.

INTRODUCTION

Experimental studies were made on simply supported beams with diagonal mild steel reinforcement acting as web reinforcement to determine the carrying capacity and cracking resistance at the support zones of halving joints in reinforced concrete beams.The results of the tests of simply supported beams with and without web reinforcement were reported in Part 1 of this series[1]. The results for the beam with improved diagonally anchored steel bars at the support zones as web reinforcement are presented in this paper.

SPECIMENS, EQUIPMENT AND TEST PROCEDURES

Test program and Specimens

A beam type E, series V was made to study the influence of the configuration and intensity of the reinforcement on the loading capacity, bending and shearing of the support zones of the halving joints. Tension reinforcement and diagonal reinforcement were anchored with welded steel bars across their ends. The details of the specimen are given in Fig.(1), Tables [1] and [2]; beams in Figs.(2) and (3), series III and IV respectively from the first research program have been added for comparison purposes.

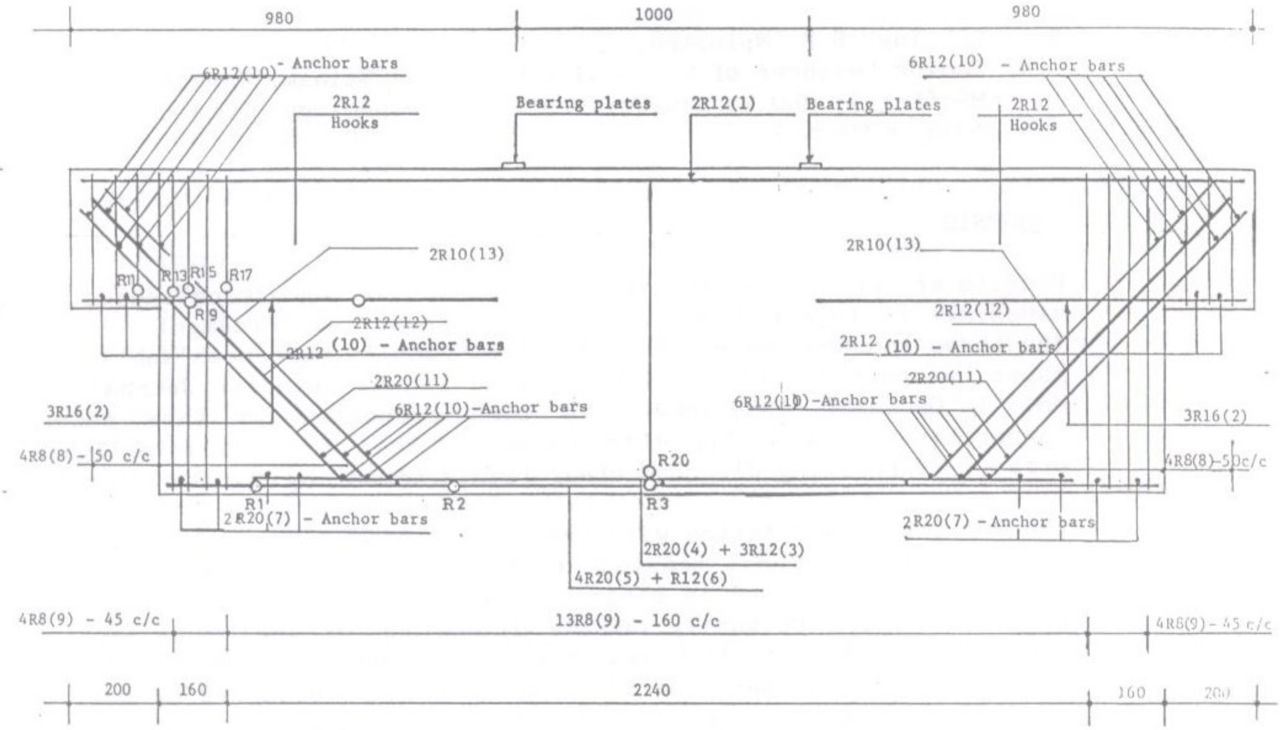

Fig.(1) Details of beam type E, Series V.

Note:- R1, R2, R3, R9, R11, R13, R15, R17, R20, R78, R79, R80 and R81- refers to strain gauges.

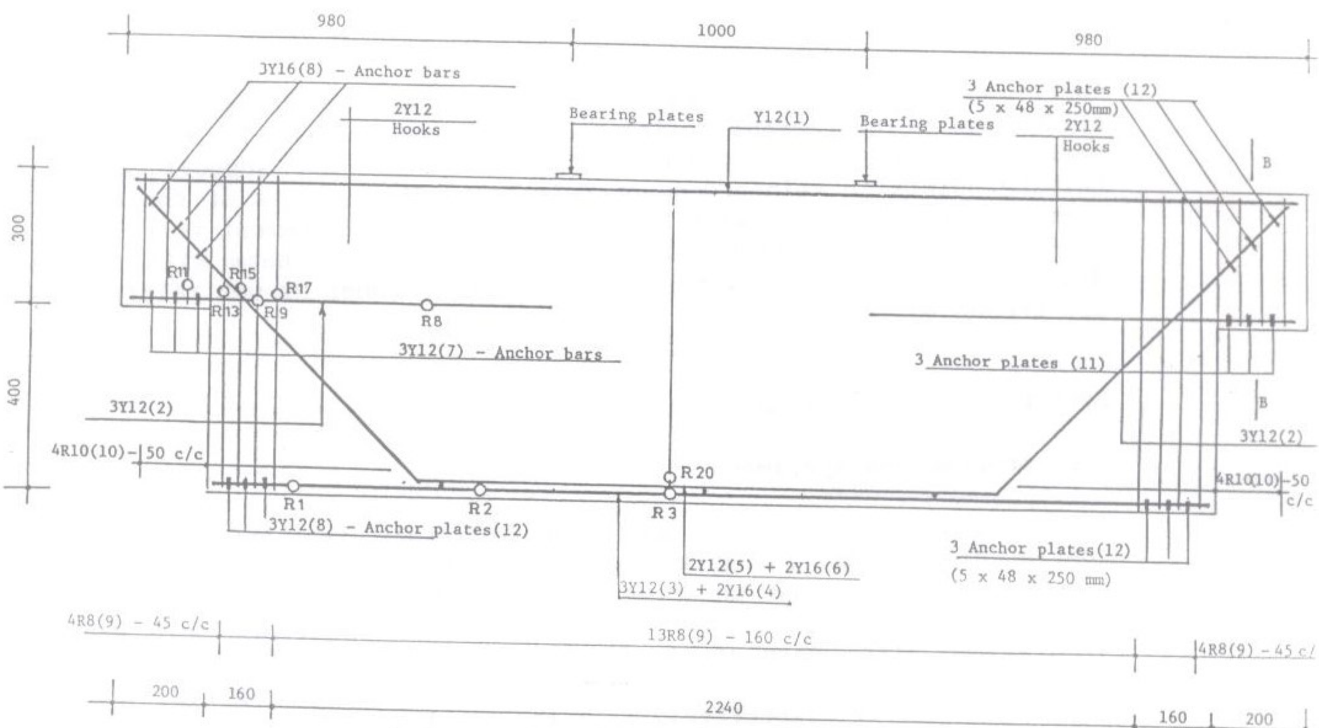

Fig. (2) Details of beam type C, Series III.

Note:- R1, R2, R3, R9, R11, R13, R15, R17, R20- refers to strain gauges.

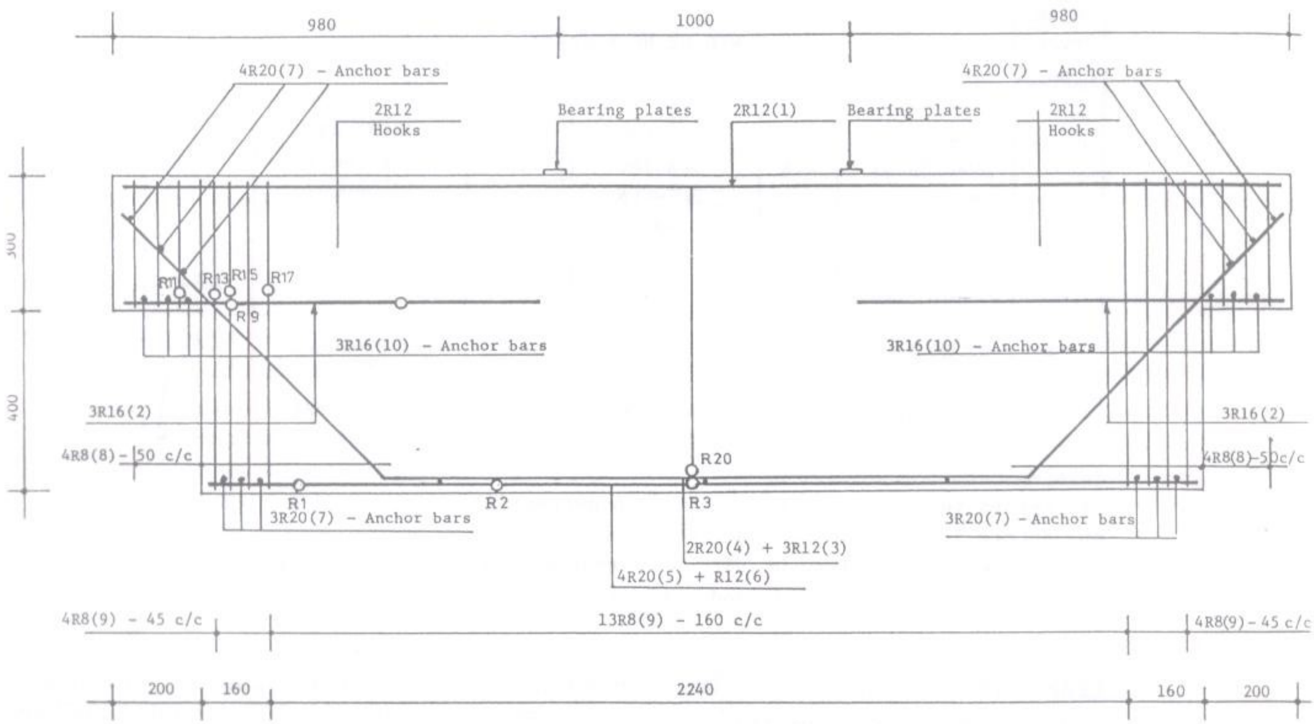

Fig.(3) Details of beam type D, series IV.
Note:- R1, R2, R3, R8, R9, R11, R13, R15, R17, R20- refers to strain gauges.

TABLE [1] DETAILS OF SPECIMENS-SERIES III , IV AND V.

BEAM TYPE No.	LONGITUDINAL REINFORCEMENT			
	NUMBER AND SIZE OF BARS AT MIDSPAN +	p * %	NUMBER AND SIZE OF BARS AT SUPPORT REGION ++	p * %
C#	4Y16.10 + 3Y12.19	0.775	3Y12.19	0.434
D#	6R18.90 + 4R11.89	1.283	3R15.97	0.744
E	6R18.90 + 4R11.89	1.283	3R15.97	0.744

Note:-
- beam taken for comparison purposes,
+ - cross section of beam = 300 x 700mm,
++ - cross section of beam = 300 x 300mm,
* - refers to tension reinforcement.

TABLE [2] DETAILS OF SPECIMENS-SERIES III, IV AND V.

BEAM TYPE No.	WEB REINFORCEMENT					
	SIZE AND SPACING AT MIDSPAN	r,%	SIZE AND SPACING BETWEEN DE AND CL	r,%	SIZE AND SPACING AT SUPPORT	r,%
E	R7.83-160c/c	0.2	R7.87-80c/c	0.2	R7.87-50c/c	0.645
C#	R7.83-160c/c	0.2	R7.87-80c/c	0.4	R7.87-50c/c	0.645
D#	R7.83-160c/c	0.2	R7.87-160c/c	0.2	R7.87-50c/c	0.645

Note:-

#- refers to beam taken for comparison purposes,

MS- refers to mid-span part of the beam,

DE- refers to discontinuous part and concentrated load part of the beam,

CL- refers to concentrated load part of the beam.

BEAM TYPE E SERIES V:- The specimen of this series was a rectangular beam 2.46m long with variable cross sections of 300x300mm and 300x700mm at support zones and between the halving joints respectively as shown in Fig.(1). The specimen had the same amount of tension and compression reinforcement as in specimen D,series IV except that the arrangement of diagonal bars deferred from one another.The specimen was also supplied with shear reinforcement which were distributed as shown in Fig.(1). Percentages of reinforcement and bar sizes were varied as shown in Tables [1] and [2]. The concrete mix used in this series was the same as those used in the first research program as shown in Table[3]

MATERIALS

The concrete for this specimen was the same as that used in the previous specimens of the first research program[2].It was made with ordinary portland cement, crushed fines and gravels from granite mined stones. The maximum size of gravel was 20mm. All aggregates passed the usual BS 882 sieve analysis tests. The composition of concrete and significant technological data are summarized in TABLE [3].

The cube strength was determined from twelve test cubes of 150mm in size, flexural strength was determined on two prisms measuring 100x100x100mm while the modulus of elasticity was determined from two cylindrical tubes measuring 100x300mm.The concrete for these specimens was taken from the batches used to prefabricate the beam specimen.

Mild steel bars was used as tension and shear reinforcement as in beam specimen type D, series IV tested in the first research program [1]. The physical properties of the reinforcement were the same as those for beam type D and are shown in TABLE [4].

TABLE [3] PROPERTIES OF CONCRETE MIXES

SERIES	BEAMS	MIX RATIO BY WEIGHT	c/w BY WEIGHT	DEN + [kg/m^3]	CS + [N/mm^2]	FS + [N/mm^2]	SME + [kN/mm^2]
III	C#	1:2.8:3.2	0.74	2310.00	27.56	4.12	23.50
IV	D*	1:2.8:3.2	0.74	2308.00	29.50	3.43	-
V	E	1:2.8:3.2	0.74	2308.00	29.50	3.43	-

Note:-

- beam taken for comparison purposes,

+ - strength and density on the day of testing,

DEN - density of the cube,

CS - Cube strength,

FS - flexural strength,

SME - static modulus of elasticity,

C/W - cement water ratio by weight.

TABLE [4] PHYSICAL PROPERTIES OF REINFORCEMENT FOR BEAMS C, D AND E.

BEAM TYPE	GRADE OF STEEL	BAR SIZE [mm]	No. OF TESTS	SECTION AREA [N/mm^2]	f_y [N/mm^2]	σ_z [N/mm^2]	E_s [kN/mm^2]
C#	MS	7.83	3.0	48.13	390.00	405.00	195.00
	HTS	12.18	3.0	116.46	390.00	405.00	210.00
	HTS	16.10	3.0	203.00	416.00	640.00	208.00
D#	MS	7.83	3.0	48.13	390.00	405.00	195.00
	MS	11.89	3.0	111.03	390.00	405.00	195.00
	MS	15.97	3.0	200.21	396.00	465.00	208.00
	MS	18.90	3.0	280.41	375.00	445.00	195.00
E	MS	7.83	3.0	48.13	390.00	405.00	195.00
	MS	11.89	3.0	111.03	390.00	405.00	195.00
	MS	15.97	3.0	200.21	396.00	465.00	208.00
	MS	18.90	3.0	280.41	375.00	445.00	195.00

Note:-

- beam taken for comparison purposes,

f_y - average yield strength,

σ_z - average ultimate strength,

E_s - Young Modulus of Elasticity,

MS - mild steel,

HTS - high tensile steel.

Fabrication of specimens and curing.

The beam was cast in wood forms.The bottom bars were supported from the base of the forms on concrete cover blocks. Since the beam had web reinforcement, the reinforcement was tied into a rigid cage before it were placed in the forms.Enough strain gauges were installed on the tension and web reinforcement before concreting for later investigations of stresses and strains in the reinforcement.

The concrete was mixed in a nontilting horizontal drum mixer of 0.22 cu.m capacity. All batching was done by weight. The concrete was placed in the forms with the aid of internal vibrator. Forms were removed one day after casting.The beam was subject to wet curing for 4 days followed by storage in the curing room with 100% humidity content at a temperature of $27^{0} \pm 2^{0}C$ for 16 days and thereafter stored in the air of the laboratory until tested at the age of 28 days.

Twelve cubes of 150mm in sizes, 2 prisms measuring 100 x 100 x 500mm as well as 2 cylindrical tubes measuring 100 x 300mm were taken for measuring the cube strength, flexural strength and modulus of elasticity of concrete respectively.The concrete for the specimens was taken from the batches used to prefabricate each beam specimen.All of them were cured in an identical manner and tested on the same day as corresponding beams.

Test Equipment and Procedures

The beam under two point loads was tested in a 100kN capacity testing machines type **"WOLPERT AMSLER"**. This machine was calibrated prior to and satified the requirements of **BS 1610-Part 1**. The load was applied through two hydraulic jacks seated on 18x150x300mm steel bearing block which were set on the beam with leveling plaster. Each jack was able to supply a safe load of 500kN. The beam was supported through 18x 150x300mm steel blocks having centre's-7x40x300mm grooves attached with plaster to their ends. The grooved portions of the bearing steel blocks were the resting positions of the hinged rollers. The hinged roller systems were welded at a distance 2.8m apart on top of two long transversely stiffened I beams. The distance between the steel hinged rollers was the effective span length of the beam specimen.The two I beams were fixed into the ground floor by steel bolts. Some main features of the equipment are shown in Fig.(4).
The load was usually in 20kN increments until failure. After each increment the machine was operated intermittently to maintain the load constant while cracking and creeping of the concrete procceeded. After the load was stabilized, strains in the tension and web reinforcement on the surface of the beam, displacements and rotations were measured. The crack patterns were observed through a low-power illuminating magnifying glass and mapped on the white washed beam surfaces. Particular attention was directed to find as close as possible, the location of the first diagonal cracks and the loads under which these cracks started. Displacements approximately at the quarter points of 2.80m span length and rotations at the support bearings were measured by the **Linear Velocity Displacement Transducers (LVDTs) and electro-levels** respectively. **The linear Velocity Displacement Transducers (LVDTs)** were attached on the bottom wedges of the beam by magnets and held in the vertical positions by steel stands clamped on the I-beams which were part of the foundation system of the main testing equipment. The electro-levels were fixed firmly by applying epoxy resin on the top

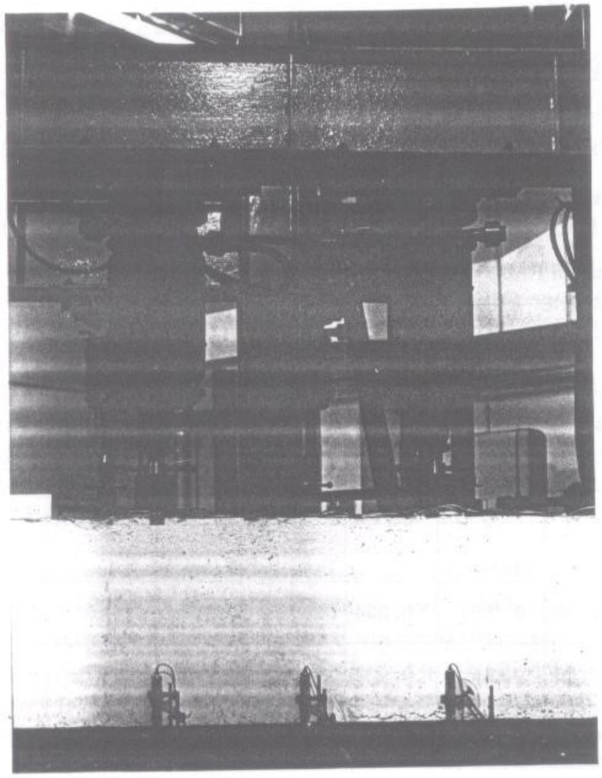

Fig.(4) Testing arrangement.

surface of the specimens at the support levels. Strains in mild steel reinforcement as well as on the surface of the concrete were measured with **WF LA-6, FLK-6 and PI-60 electric resistance strain gauges** connected to **"DORIC DATA LOGGER"**, strain recorder. The time required for testing was about 6hrs. Photographs of the tested beam were taken at important stages of loading and after failure.

TEST RESULTS.

Results of the tests are summarized in Table [5] which includes cube strength f_{cu} ,the load at the formation of the initial diagonal tension crack P_c,the failure loads P_u and the critical steel stress at failure f_{st}.In addition, the table includes the nominal shearing stress, τ_c at initial cracking loads,the ultimate shearing stresses, ν_u at failure loads and their ratios to the concrete strengths, f_{cu}.

Concrete strengths given in TABLE [5] are values determined from the tests of all 12 control cubes for each specimen in every series.Cracking loads P_c were determined from the load-deflection curves and load-strain curves.

These were compared with those obtained basing on visual observations of cracking by using a low power illuminating magnifying glasses. The failure loads, P_u were measured by the testing machine and recorded by "DORIC DATA LOGGER". The critical steel stresses were obtained from steel strain measured by the strain gauge types **WFLA-6 and FKA-6** attached on the tension reinforcement at the level of initial cracking position.Nominal shearing stresses, τ_u and υ_u were computed from the equation $\upsilon = 8V/7bd$ in which V is the maximum shear corresponding to the appropriate value of the load P and b and d are the width and effective depth of the beam respectively.

Load-deflection and load strain (stirrup) curves for tested specimen including those for beams C, and D from the first research program are shown in Figs.(5) to (10) and a few representative specimens before and after failure are shown in Figs.(11) to (16).

TABLE [5] TEST RESULTS FOR TESTED BEAMS.

BEAM No	CONCRETE STRENGTH	INITAL DIAGONAL TENSION CRACKING			FAILURE			P_u/P_c
	f_{cu} [N/mm^2]	P_c [kN]	τ_υ [N/mm^2]	τ_c/f_{cu}	P_u [kN]	f^*_{st} [kN/mm^2]	υ_u/f_{cu}	
C	27.56	60.00	0.85	0.024	30.00	420.00	0.158	6.3
D#	29.51	60.00	0.85	0.022	35.00	375.00	0.173	5.9
E#	28.30	60.00	0.85	0.024	20.00	375.00	0.140	4.7

Note:

\# - beam taken for comparision purpose,

f^*_{st} - critical steel stress.

The beam behaved elastically until the cracks formed. The critical diagonal cracks in the specimen appeared first and later followed by other tension cracks. Tension cracks developed on the bottom surface of the beam and spread vertically upwards. With further increase of load, tension cracks located between the discontinuous zones of the halving joints and the nearest load points curved towards the load points.

The diagonal reinforcement near the support zones had a remarkable influence on the behaviour of the beam.(Fig.(10).The stirrups along the beam other than those at discontinuous edges of the beam showed no influence on the behaviour indicating that they carried practically no stresses.

Initial diagonal tension cracking

At some load the strains in the stirrups began to increase rapidly and at a load 15 to 40 percent higher one or more inclined cracks were observed. These cracks were similar to those defined in Part 1 [1] as diagonal tension cracks but were shorter and more difficult to detect visually.It is believed that these cracks began to form at the load at which the strains in the stirrups began to increase rapidly; however, the stirrups prevented the cracks from opening to a width susceptible to visual observations until the loads increased as indicated above.Thus for beams with web reinforcement the loads corresponding to the first sharp breaks in the load-stirrups strain curves are called the initial diagonal tension cracking loads.

The initial cracking loads are listed in Table [5], in which the specimens are divided into the same groups as in Tables [1] and [2]. The major variable in these tests, the percentage of web reinforcement between the discontinuous part and the concentrated load part of the beam, was the only variable in each group. It can be seen that cracking loads are constant for all groups including beam type A, series I that is the beam without web reinforcement [1] Thus it may be concluded that the web reinforcement has no significant effect on the magnitude of the cracking load.

In addition to the percentage of web reinforcement, the tests in both Parts 1 and 2 included diagonal reinforcement, percentage of the longitudinal reinforcement,length of shear span, strength of the concrete and depth of the beam as minor variables.Of these, the first three had no significant effect on the cracking load but increase in strength of concrete, and depth of beams resulted in higher cracking loads. However, on the basis of these tests alone no definite conclusions can be reached since the test data for the minor variables are limited both in number and scope.

Ordinarily, the occurrence of diagonal tension cracks at working loads is not objectionable in beams with web reinforcement, since in such beams diagonal cracks are narrow and well distributed. However, diagonal cracking could become objectionable if the arrangement of longitudinal reinforcement permitted failure at or slight above the cracking load. Such failure, termed failure by separation, were observed in beam type A, series 1 without web reinforcement [1].

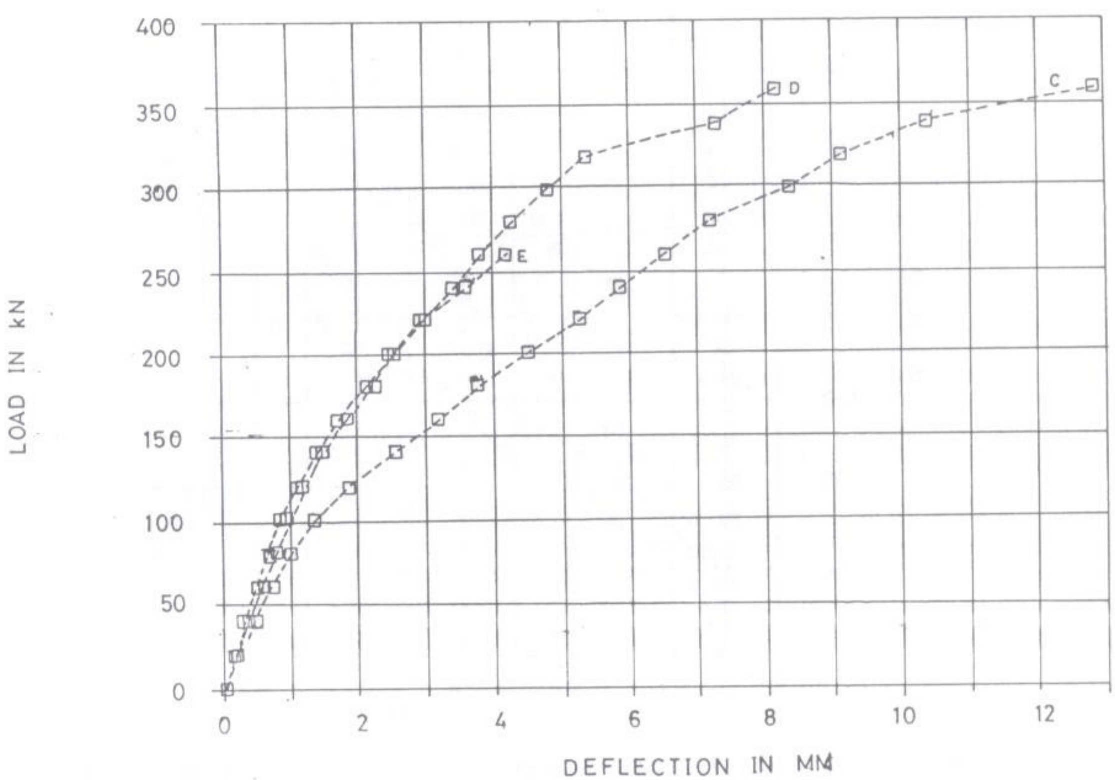

Fig.(5) Load Deflection curves for beams type C,D and E.

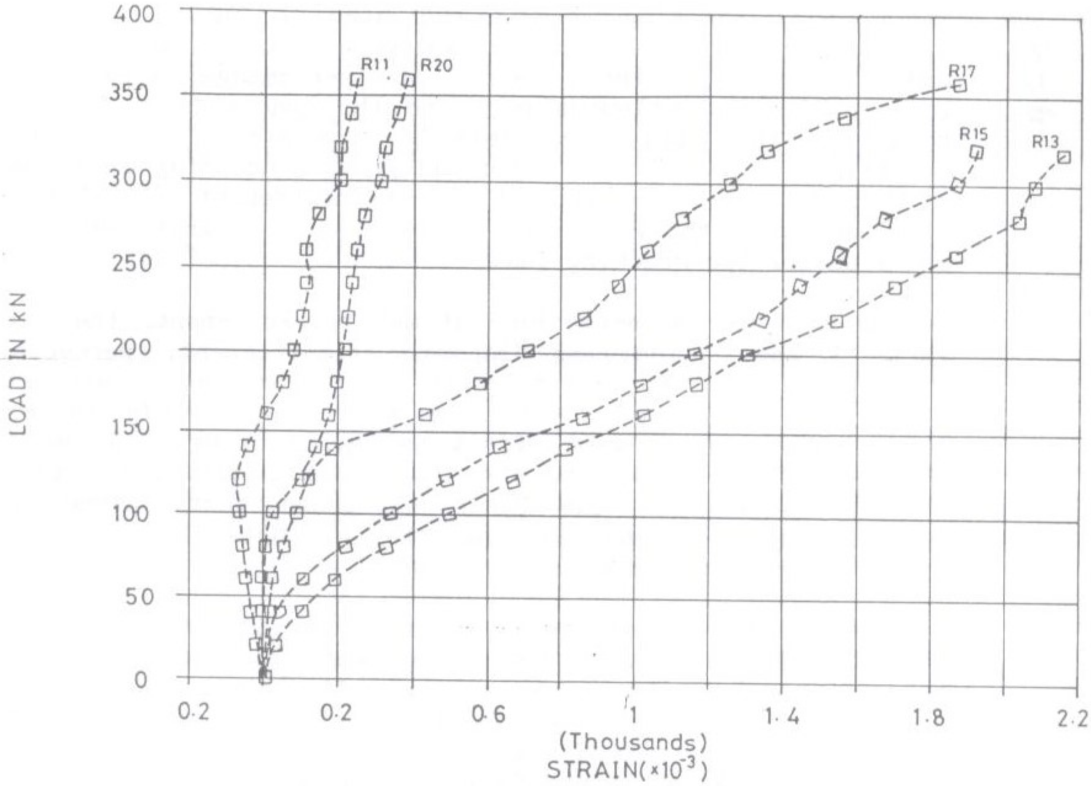

Fig.(6) Load stirrup strain curves for beam type C.
Note:- R11, R13, R15, R17, R20 - refers to strain gauges on the stirrups.

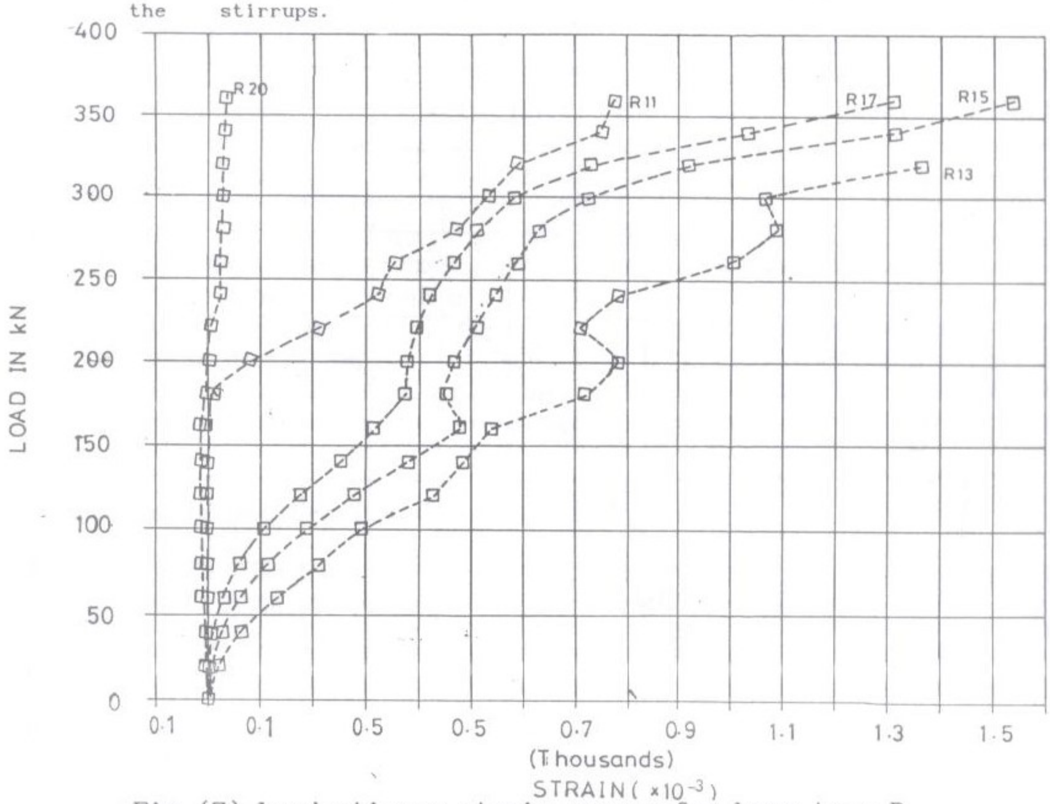

Fig.(7) Load stirrup strain curves for beam type D.
Note:-R11, R13, R15, R17, R10- refers to strain gauges on the stirrups.

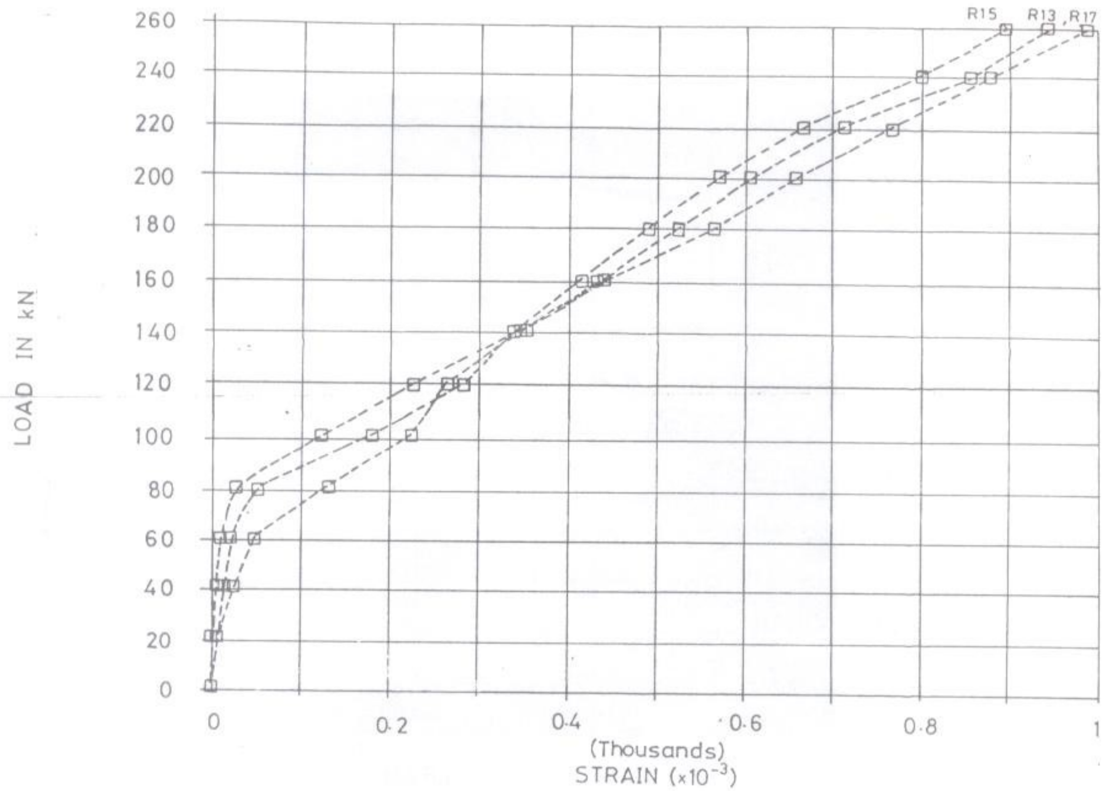

Fig.(8) Load stirrup strain curves beam type E.
Note:-R13, R15,R17- refers to strain gauges on the stirrups.

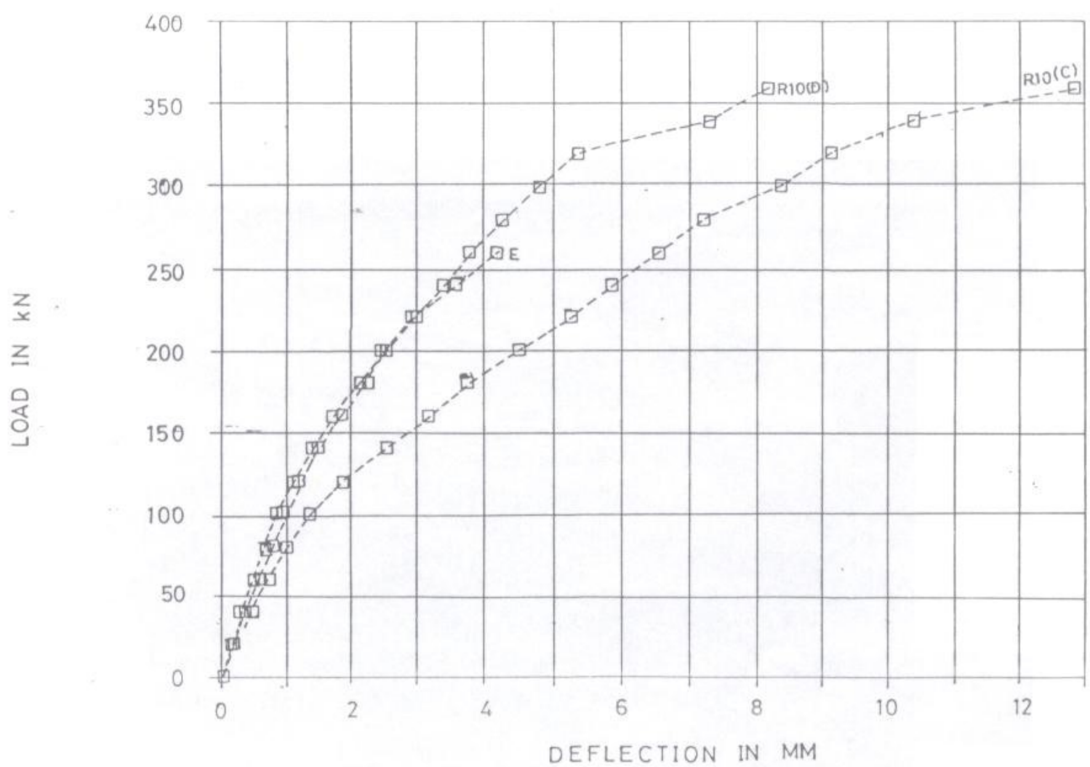

Fig.(9) Load diagonal strain curves for beams type C and D.
Note:- R10(C), R10(D)- refers to strain gauges on diagonal reiforcement.

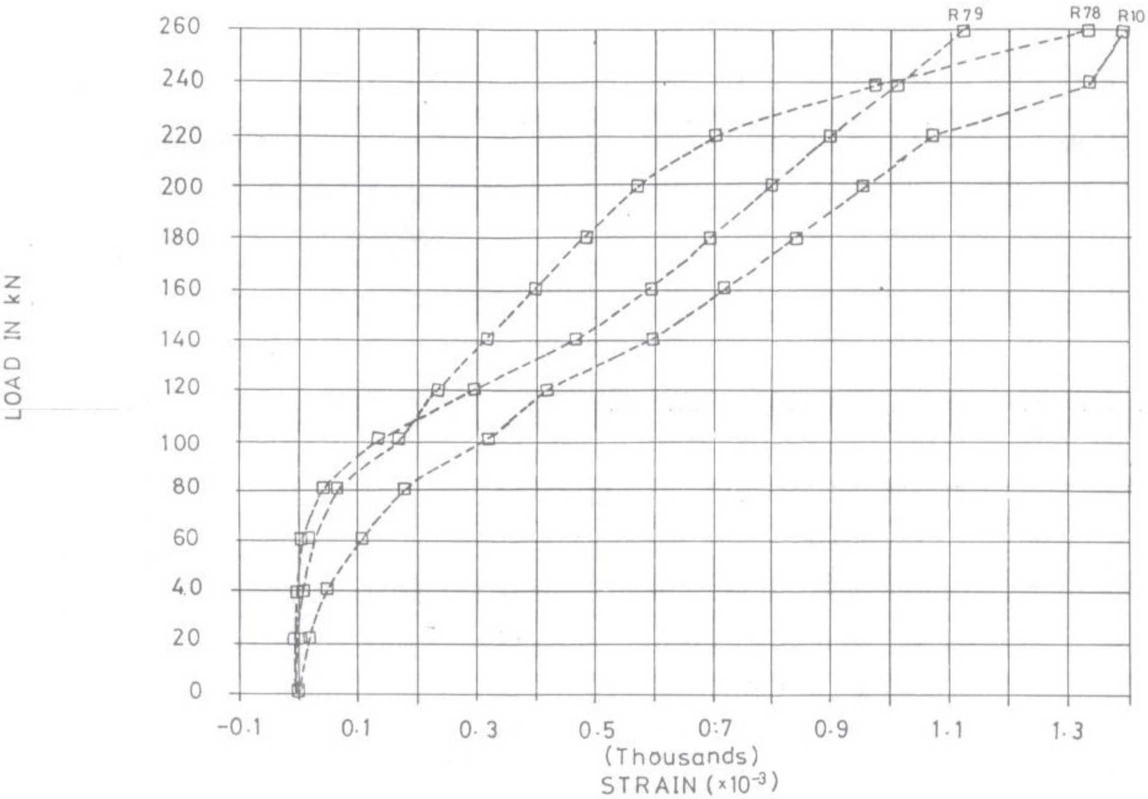

Fig.(10) Load diagonal strain curves for beam type E.
Note:-R10, R78, R79 -refers to strain gauges on diagonal reinforcement.

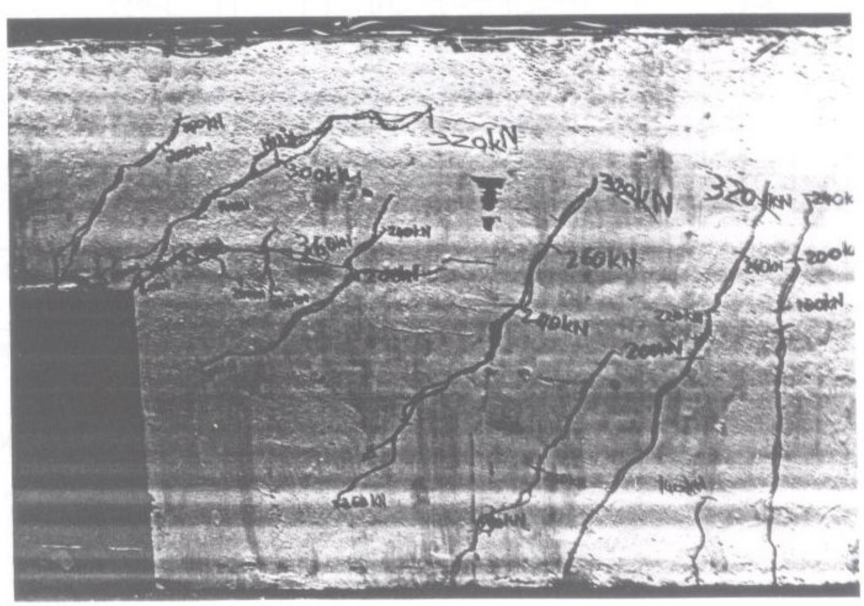

Fig.(11) Cracks pattern at the left hand portion of beam type C near failure.

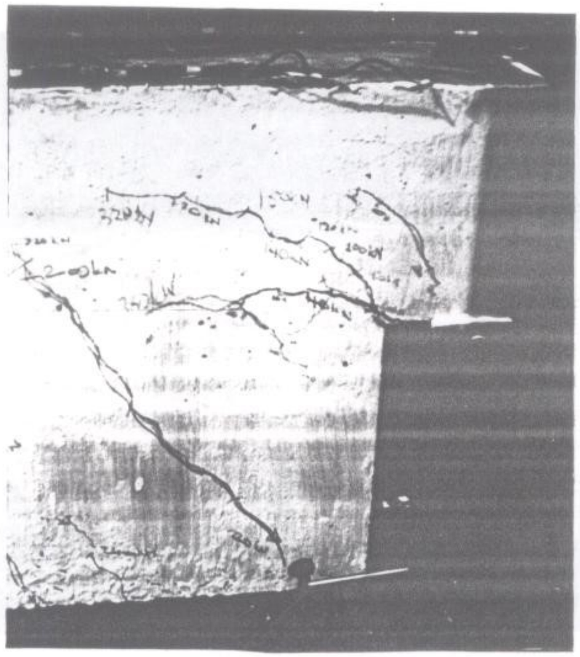

Fig.(12) Cracks propagations at the right hand support zone as the load was increased-beam type D.

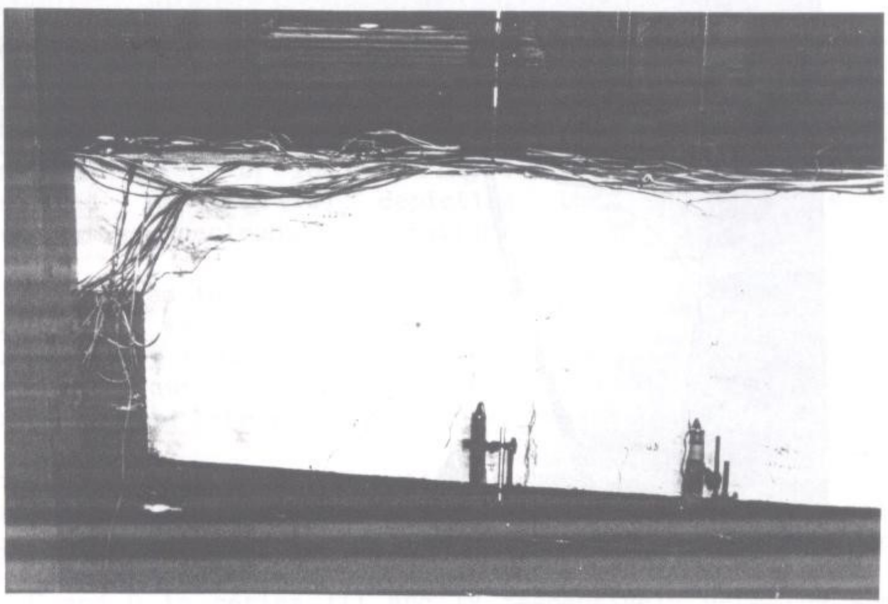

Fig.(13) Cracks propagation at the left hand support zone as the load was increased- beam type E.

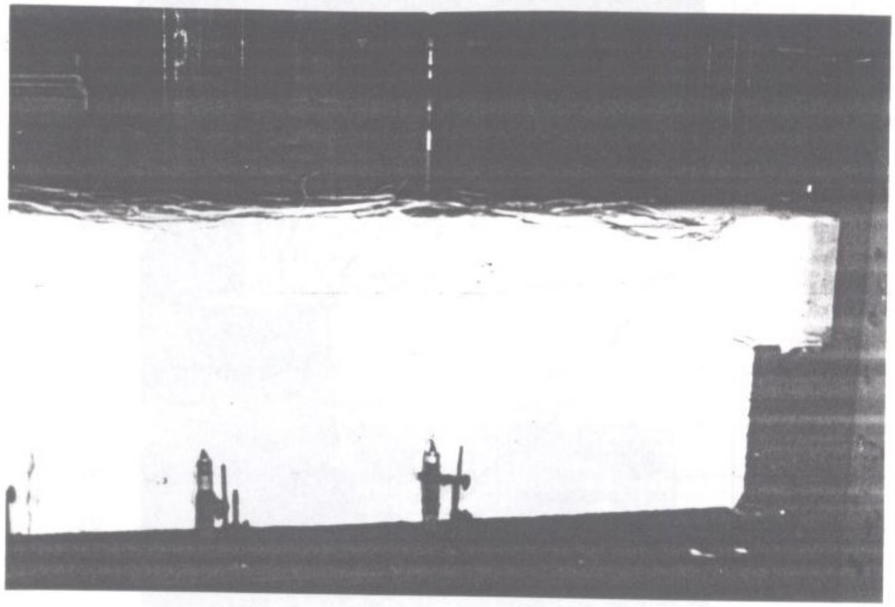

Fig.(14) Cracks propagation at the right hand support zone as the load was increased -beam type E.

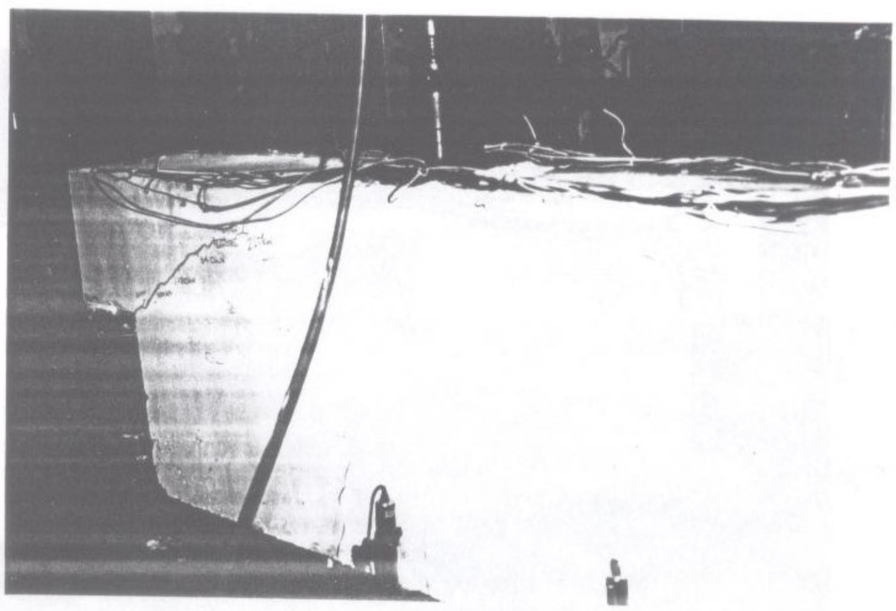

Fig.(15) View of the initial diagonal crack generating towards the load block-beam type E.

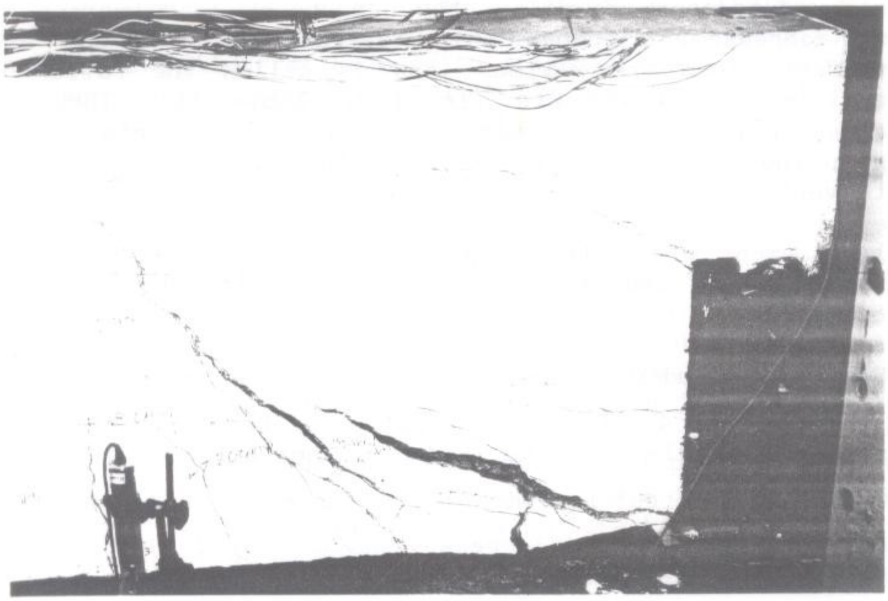

Fig.(16) View of cracks pattern at the right hand support zone near failure-beam type E.

BEHAVIOUR AFTER FORMATION OF DIAGONAL CRACKS.

All beams with web reinforcement were able to sustain large increase of load beyond that causing the formation of initial diagonal tension cracks. After the cracking load had been exceeded, numerous very fine inclined closely spaced parallel cracks formed progressively in both shear spans between the discontinuous support and load bearing blocks but leaving zones of intact concrete around the blocks.The formation of the two major cracks indicates that full redistribution of internal stresses had taken place before failure.The failure occurred at the maximum load by destruction of the compression zones of concrete at either the support or load bearing block. The final crack pattern is illustrated in Fig.(16) depicting the shear spans of other representative specimens after failure.

Strains measured in the tension reinforcement near mid span and over the supports were always smaller than the yield point strain and strain measured on top beam surface at mid span were considerably smaller than those usually associated with failure by crushing of the concrete. Thus the beams failed before their flexural capacities were reached.

Typical load-mid span deflection curves are shown in Fig.(5) for comparable beams with vertical stirrups, with vertical stirrups and diagonal shear reinforcement and vertical stirrups with diagonal shear reinforcement anchored by spot welding method.The failure loads for beams C and D in series III and IV respectively were the same.This is due to the fact that the diagonal shear reinforcement and stirrups arrangements were the same except that types of steel bars used as reinforcement in beam C was high tensile steel bars while in beam D was mild steel bars.

FAILURE LOADS

When the maximum load was reached, the compression zone of concrete was destroyed adjacent to either the support or load bearing block and the load decreased. Although this decrease of load was small, it was permanent; thus the maximum load is called the failure load.Failure loads for all beams are listed in Table [1]. They increase with increasing percentage of web reinforcement, concrete strength and beam depth; they are higher for beams with diagonal reinforcement together with vertical stirrups than for beams with only vertical stirrups, but they do not seem to be affected by the percentage of longitudinal reinforcement or by the length of the shear span. The effect of the percentage of web reinforcement is noticeable in all groups of specimens.

Table [1] includes ratios of ultimate load to cracking load, P_u/P_c, which vary from 4.7 to 6.3. The ratio for beam without web reinforcement was 1.0. Since the cracking load P_c is not affected significantly by the presence of web reinforcement, the increase in P_u/P_c shows clearly that the web reinforcement increase substantially the shear strength of reinforced concrete beams.

ACTION OF STIRRUPS

Information regarding the action of web and diagonal reinforcement were obtained from measurement made by electric resistance strain gauges types WFA-6 and FKA6 attached to each leg of the stirrup in the region of maximum shear near the points of intersection with major diagonal tension cracks.

Since two gauges were attached to each stirrup, data were obtained on the distribution of strain along individual stirrups and some of their strains were very close to the maximum values.Typical load stirrup strain curves are shown in Figs.(6) to (8) respectively.As it has been pointed out, the stirrups and diagonal steel reinforcement remained practically unstressed until diagonal tension cracks occurred; afterward the stirrup strains increased rapidly. The strains were always largest in the stirrups located near the middle of the shear span and decreased toward the support and load points.In the most of the tested beams, one or more stirrups yielded before maximum load was reached.

Typical load maximum diagonal strain curves for beams with diagonal reinforcement are shown in Figs.(1-9) and (1-10) Inclined reinforcing steel bars were stressed from the inception of loading since their inclination was identical with that of the principal stress at mid depth of the beam.

It was observed in these tests of Parts 1 [1] and 2 that the stirrups and diagonal bars delayed the full development of diagonal tension cracks. In beam type A, series I,that is beam without stirrups [1] only two diagonal tension cracks, (one at each discontinous edges of the beam) formed; these cracks then penetrated into the compression zone of concrete and thus precipitated the failure which occurred by destruction of this zone.

In beams [1] with stirrups, however, numerous short diagonal cracks formed since the stirrups distributed the cracks, more load was required for the cracks to develop and to penetrate into the compression zones and thus to cause crushing of the concrete.Diagonal shear reinforcement together with vertical stirrups were more effective in distributing diagonal cracks than were vertical stirrups alone; accordingly, more load was required for failure of beams with diagonal shear reinforcement together with vertical stirrups than for failure of beam [1] with vertical stirrups alone.

CONCLUDING REMARKS

Four full scale rectangular beams having discontinous edges at the support zones were tested with and without web and diagonal shear reinforcement in Part 1 [1] of this research program.In Part 2 of this research program tests were carried out on a full scale rectangular beam with web and diagonal shear reinforcement anchored in the support zone by spot welding method.In both research programmes, the beams were tested with two concentrated loads in the span. In all beams except beam type A, series I where only two initial diagonal crack developed at both discontinous edges, several diagonal tension cracks formed in the regions of maximum shear.No beam failed in flexure but all failed in shear.Prior to the formation of the diagonal tension cracks the behaviour of all beams was the same as that of beams failing in flexure and the stirrups were practically unstressed. Beyond the formation of the diagonal tension cracks the stresses in the stirrups increased rapidly.

The magnitude of the cracking load depended primarily on the dimensions of the cross section and on the strength concrete. It was practically independent of the web reinforcement.

In all beams with web and web together with diagonal reinforcement,considerable increase of load was possible beyond the cracking load. The final failure occurred at the section of maximum moment in the region of maximum shear; the compression zone of concrete was destroyed at this critical section. The magnitude of the ultimate load depended clearly on the amount, type and configuration of web reinforcement. It increased with increasing amount of web reinforcement and was high for beams with vertical stirrups together with diagonal shear reinforcement.

No attempt was made to test T-beams discontinous at support zones although earlier tests [4] shows that they possessed higher shear strengths than the rectangular beams of the same depths, concrete strength and area of reinforcement and of a width equal to the width of the stem of the T-beams.

Analytical expressions for predicting the shear strength of rectangular beams having discontinous edges at the support zones with web reinforcement developed on the basis of these tests will be reported in the future after more tests have been carried out.

ACKNOWLEDGEMENT

The tests reported in this paper were carried out at the Department of Civil and Structural Engineering, University of Hong Kong.The financial assistance from Department of Civil and Structural Engineering as well as the devotion and care contributed by the workers in conducting the testing programs in the Laboratory are gratefully acknowledged.

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