Shear Transmission in Reinforced Grouted Cavity Brickwork Beams

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ABSTRACT

The paper describes a series of tests carried out with the object of assessing the contributions of compression zone transmission, dowel effect and aggregate interlock to the shear resistance of grouted cavity brickwork beams. Methods originally devised for reinforced concrete are applied and it is shown that compression zone transmission predominates with dowel effect playing an almost equally important part as the ultimate load is approached.

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INTRODUCTION

In recent years, reinforced brickwork has received renewed attention as a structural system. The basic ways of introducing reinforcement are by placing steel bars within the mortar joints or in grouted cavity between brickwork leaves. Previous research workers have indicated that the rules of reinforced concrete can be applied to the design of reinforced brickwork beams provided that suitable adjustments are made for differences in materials properties. This paper gives an account of an investigation in which methods originally developed for calculating the relative contributions of various shear transmission mechanisms in reinforced concrete from experimental results are applied to reinforced brickwork of grouted cavity construction. In such elements shear is always accompanied by bending moment and interaction between these effects is complex. For this reason no general theory has been found and previous research has attempted to fomulate design rules by varying the main parameters influencing shear resistance. In the present work tests have been carried out to assess the contribution to shear resistance in a typical section of compression zone transmission, aggregate interlock and dowel effect.

MATERIALS FOR TEST BEAMS

Tests were carried out on grouted cavity brickwork beams having an overall cross section 450 x 295mm and span of 5.34m, as shown in fig. (1). Two types of brick were used for the beams, as shown in Table 1.

Tests on prisms (213 x 100 x 440mm) gave the compressive strength of the masonry, stressed as in the test beams, as 12.24 N/mm^2 and 22.63 N/mm^2 for the two brick types. Young's modulus for the two types of brickwork compressed in this direction were 11.97 kN/mm^2 and 18.50 kN/mm^2 respectively.

The reinforcing steel was hot rolled, high yield deformed bars having the 2% proof stress and ultimate stresses shown in Table 1. Two steel ratios were used for the beams tests namely 0.90% and 1.42%.

The bricks were laid in $1:\frac{1}{3}:4$ cement:lime:sand mortar which had a 100mm cube strength of 21.4 N/mm^2.

The grout mix was 1:1/10:3:2 cement:lime:pea gravel (10mm maximum diameter) with 0.75 water. cement ratio.

Tensile strength tests were carried out on the bricks and grout using a splitting method with the results shown in Table 2.

CONSTRUCTION OF BEAMS:

The beams were built in the laboratory on top of level, wooden planks covered with polythene sheets. The reinforcing bars were placed in position over the planks and then the brickwork leaves were built up to six courses. Galvanized fishtail steel wall ties, were placed in the brickwork as indicated in fig. 1. After one day, the grout was poured into the clean cavity. Beams and control specimens were covered with polythene sheets for seven days. Prior to testing, one face of each beam was white-washed to facilitate detection of cracks.

TEST ARRANGEMENTS

In all tests, the beams were supported on rollers on a span of 5.34m. Loads were symmetrically placed about mid span 760mm apart which gave a shear span to depth ratio of 6:1.

Strains were measured by Demec gauge, the points for which were disposed (a) to measure longitudinal strains on a 150mm gauge length and (b) as rosettes to determine movements across cracks using 50mm gauge length. For the first purpose the Demec points were attached at different depths from the top of the beam in order that the neutral axis depth could be found and the compression zone shear estimated. The estimation of aggregate interlock and dowel effect required the measurement of vertical and horizontal displacements across cracks. The application of a small load sufficient to initiate tensile cracking made it possible to anticipate the position of the subsequent crack pattern, and thus to locate the position of the Demec rosettes necessary for these measurements. Fig. 2 shows the disposition of the gauge points in a typical test.

Loads were applied by two hydraulic jacks each of which had an electrical resistance type load cell between the ram and the top of the beams.

DOWEL TESTS

A number of tests were carried out on beams of the lower strength masonry in which an artificial crack had been built, as indicated in fig. 3, as a means of measuring shear transmission due to dowel effect. The central part of the beam was built first and the crack surface was coated with P.T.F.E. material in order to reduce friction across it.

The load was applied centrally to the lower part of the beam through a steel plate passing through the brickwork.

TEST RESULTS

A summary of the test beam results is given in Table 3. Fig. 4 shows typical compressive zone at a section 2.0m from one of the supports. Corresponding shear stresses were calculated from these strains according to the following formula (5):

$$V_{cy} = E_b \int_0^y \frac{\partial \varepsilon_x}{\partial M} \cdot \frac{\partial M}{\partial X}\, dy = V\, E_b \int_0^y \frac{\partial \varepsilon_x}{\partial M}\, dy$$

$$V_c = V \cdot B \cdot E_b \int_0^{d_n} \int_0^{d_n} \frac{\partial \varepsilon_x}{\partial M}\, dy \cdot dy$$

where

V_{cy}	=	shear stress at depth y from the top of the beam
E_b	=	Young's modulus of brickwork
V	=	Total shear force across section
V_c	=	Shear force transmitted through compression zone
B	=	Breadth of the section
ε_x	=	Longitudinal strains at depth y from the top of the beam
M	=	Bending moment at the section
d_n	=	Depth of neutral axis

A computer programme was written to evaluate these expressions.

Shear transmission by aggregate interlock has been assumed to take place only in the grouted section of the beam as the relatively smooth brick-mortar interface would be ineffective in shear transfer by this mechanism. The shear force transmitted in this way have been estimated from measurements of vertical displacements across shear cracks and from crack width using the following formula (8):

$$V_g = k \frac{\delta v}{a_{cr}} b_g \, (d - d_n)$$

where

δv	=	vertical displacement across the crack
a_{cr}	=	crack width
k	=	constant, taken as 1.2
b_g	=	width of grout core
d	=	effective depth
dn	=	depth of neutral axis
V_g	=	total shear force carried by interlock of grout core

In the tests on dowel effect, the shear force (V_d) to cause failure by cracking parallel to the reinforcing bar was calculated from the following expression:

$$V_d = 0.10 \, F_{tg} \, [K \, b_b + b_g - \Sigma \phi] \, I_c$$

$$V_d' = 1.50 \, \Delta^{0.30} \, V_d$$

where

V_d	=	total shear carried by dowel action
V_d'	=	applied shear force carried by dowel action
F_{tg}	=	tensile strength of the grout in N/mm^2
K	=	a constant, depend on the ratio F_{tb}/F_{tg}, where F_{tb} is the tensile strength of the brickwork and taken as 0.175 in the present tests
b_b, b_g	=	width of brickwork and grout core respectively
$\Sigma \phi$	=	bar diameters in one layer - (mm)
I_c	=	moment of intria of the composite section indicated in fig (5a) in cm^4
Δ	=	vertical displacement of dowel force in (mm)

A comparison between this relationship and experimental results is shown in (fig 5b)

On the basis of the above, estimates have been made of the contributions to shear transfer of compression zone transmission, dowel effect and aggregate interlock at a section in the beams tested. Some typical results are shown in fig 6.

Observed crack patterns in typical beams are shown in fig. 7.

DISCUSSION OF RESULTS

None of test beams failed in flexure, this mode having been preceded by shear failure.

In all cases, failure was sudden after progression of a major diagonal crack across the shear span spreading upwards to the neutral axis level. Final failure took place by splitting along the line of the reinforcement.

As will be observed from fig 6, total shear force calculated from the component values falls short of the actual shear. This was found in all the beam tests and is possibly due to an underestimate of aggregate interlock which omits any contribution from the masonry. In fact, there may be some shear transmission across cracks in the masonry as the bricks tended to rotate and to become wedged across the cracks as the deformation of the beams increased. On consideration of all the test results, it would appear that compression zone transmission accounted for about 40% of the shear resistance with dowel effect and aggregate interlock each accounting for rather lower proportions.

CONCLUSION

No significant difference was found in the shear resistance of the beams tested as between those built of strong and of weak brickwork.

The shear strength of the beams is accounted for by the three main factors of compression zone transmission, dowel effect and aggregate interlock. The contribution of each of these factors, which varied as the load on the beam was increased, has been assessed experimentally by methods originally devised for reinforced concrete. The results give an approximate indication of the relative magnitude of these mechanisms, and suggest that compression zone transfer provided the largest single contribution to shear resistance.

ACKNOWEDGEMENT

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TABLE 1 BRICK AND STEEL STRENGTHS

(a) Brick compressive strengths

(i) 23.86 N/mm^2 (ii) 88.28 N/mm^2

(b) Steel properties

Diameter mm	16mm	20mm	25mm
Young's modulus N/mm^2	206.0	213.3	215.5
2% proof stress N/mm^2	562.0	572.0	580.0
Ultimate stress N/mm^2	575.0	636.7	649.3

TABLE 2 SPLITTING TENSILE STRENGTHS OF BRICKS AND GROUT

Brick Type	Beam Series	average Splitting tensile strength of grout F_{tg} N/mm^2	average Splitting tensile strength of brick F_{tb} N/mm^2
A	1.1	1.990	0.274
		2.179	0.383
	1.2	2.341	0.383
		2.637	0.574
B	2.1	2.799	0.967
		2.351	0.981
	2.2	2.164	0.774
		1.890	1.184

A : Common clay bricks manufactured from London clay

B : Perforated (three 25mm dia.holes) bricks

F_{tb} : Tensile strength of brickwork = $\frac{2 \times \text{SPLITTING FORCE}}{\pi \times H \times L}$

where H and L height and length of brick units respectively

TABLE 3 SUMMARY OF BEAM TEST RESULTS

Beam Series	Beam No.	P%	Mortar Strength N/mm^2	Grout Strength N/mm^2	Brick Pier Strength N/mm^2	Ult. Shear V (kN)
1.1	1.1.1	0.905	21.40	17.36	10.55	62.508
	1.1.2	0.905	21.40	18.27	11.91	62.984
1.2	1.2.1	1.47	22.90	18.54	14.26	73.855
	1.2.2	1.47	22.90	19.13	14.26	78.815
2.1	2.1.1	0.905	19.20	21.12	22.44	60.072
	2.1.2	0.905	22.20	18.94	22.50	63.392
2.2	2.2.1	1.47	19.50	18.50	24.30	66.392
	2.2.2	1.47	21.50	16.90	22.54	62.718

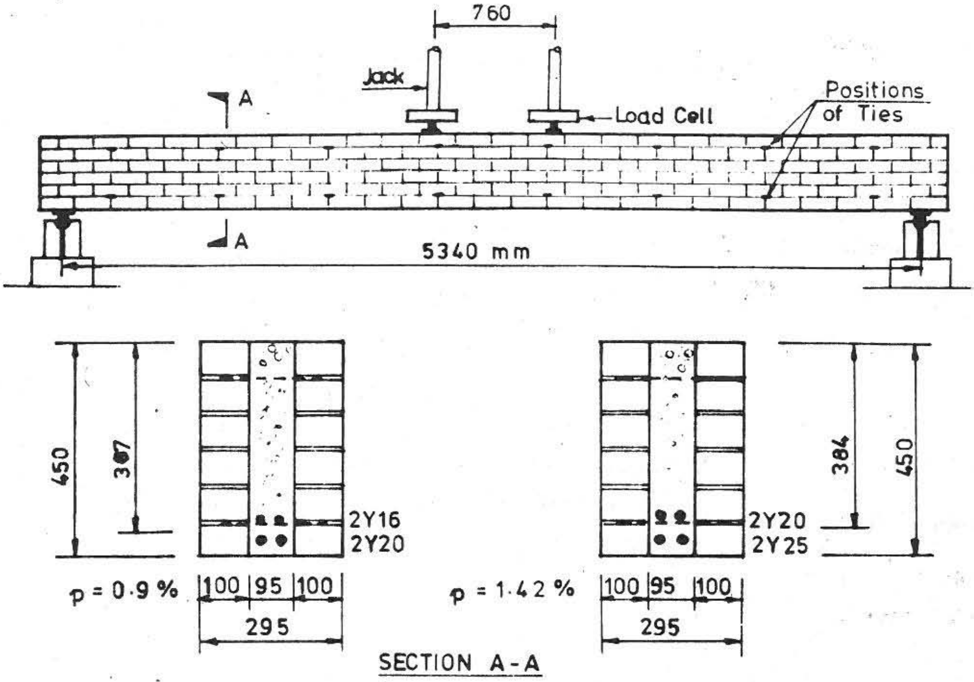


FIG. 1 _ BEAM CROSS SECTION AND BRICK BONDING ARRANGEMENT

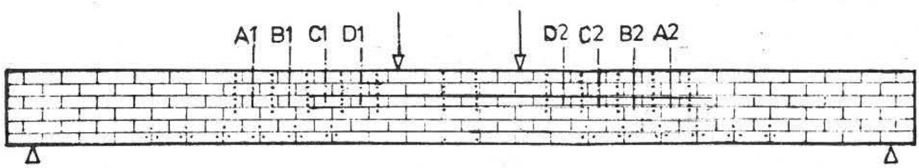


FIG. 2 _ DISPOSITION OF DEMEC POINTS IN TYPICAL TEST

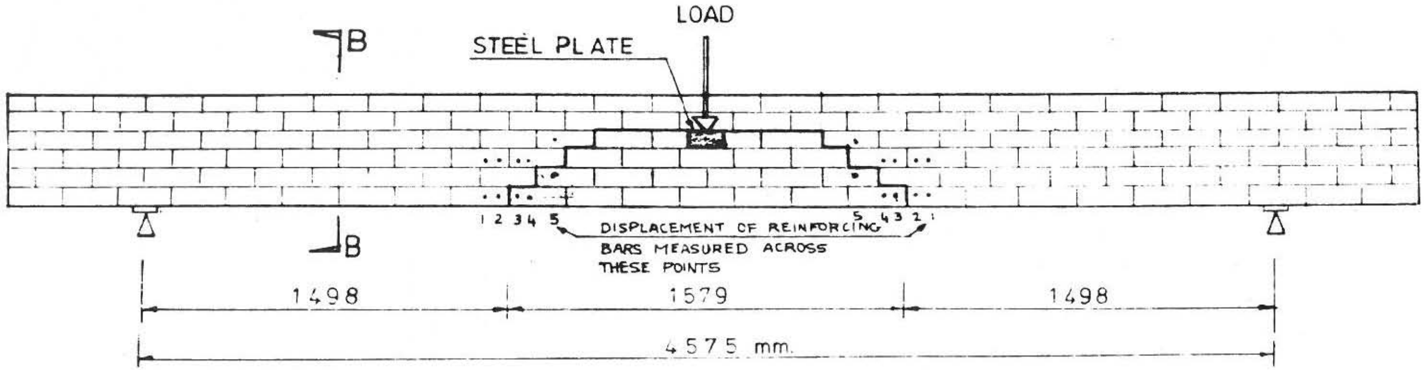
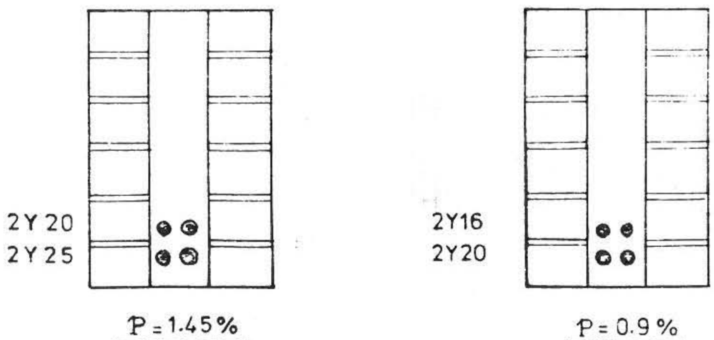
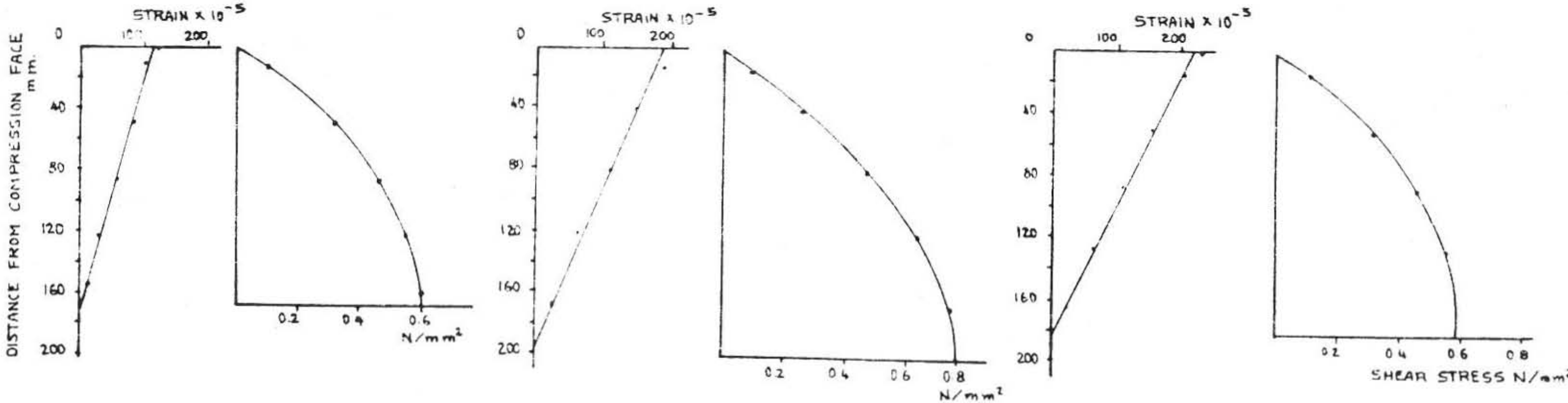


FIG. 3 - BEAMS FOR TESTS ON DOWEL EFFECT



SECTION B-B



A - BEAMS SERIES 2.1 & 2.2   B - BEAMS SERIES 1.2   C - BEAMS SERIES 1.1

FIG. 4 - TYPICAL STRAIN & SHEAR STRESS IN COMPRESSION ZONE AT LAST LOAD STAGE FOR SECTION AT 2000 FROM SUPPORT

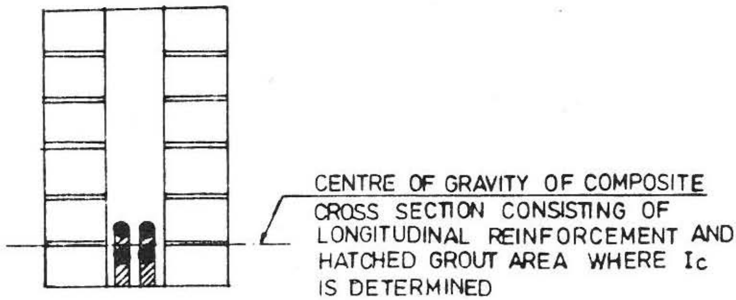


Fig. 5A – DETERMINATION OF Ic

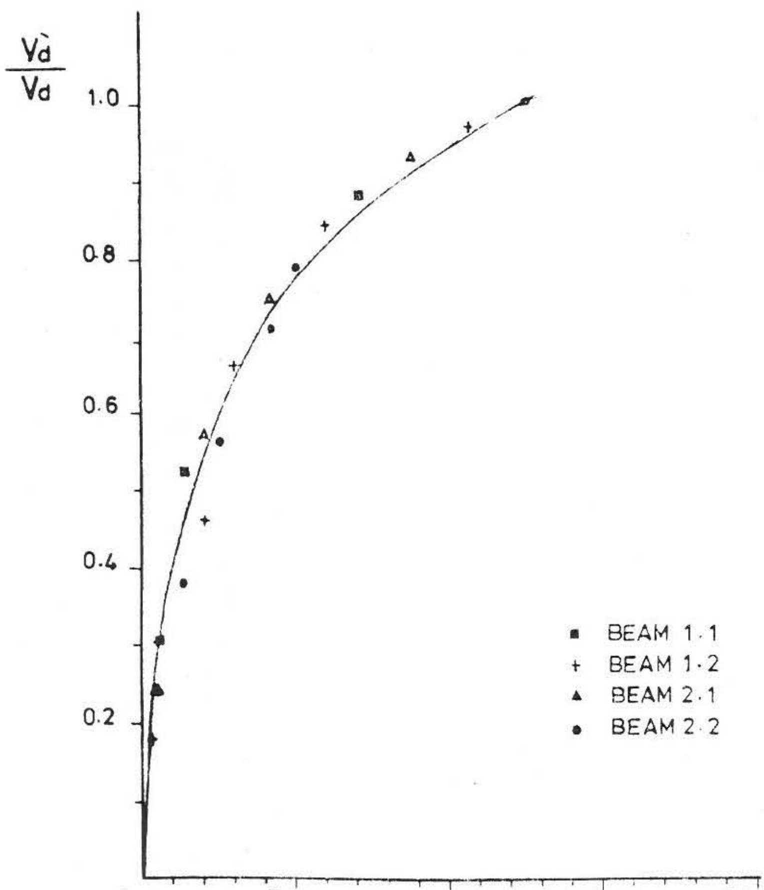


Fig. 5B – COMPARISION BETWEEN EXPERIMENTAL RESULTS AND THE PROPOSED EQUATION $V\grave{d} = 1.50\ \Delta^{0.3}\ Vd$

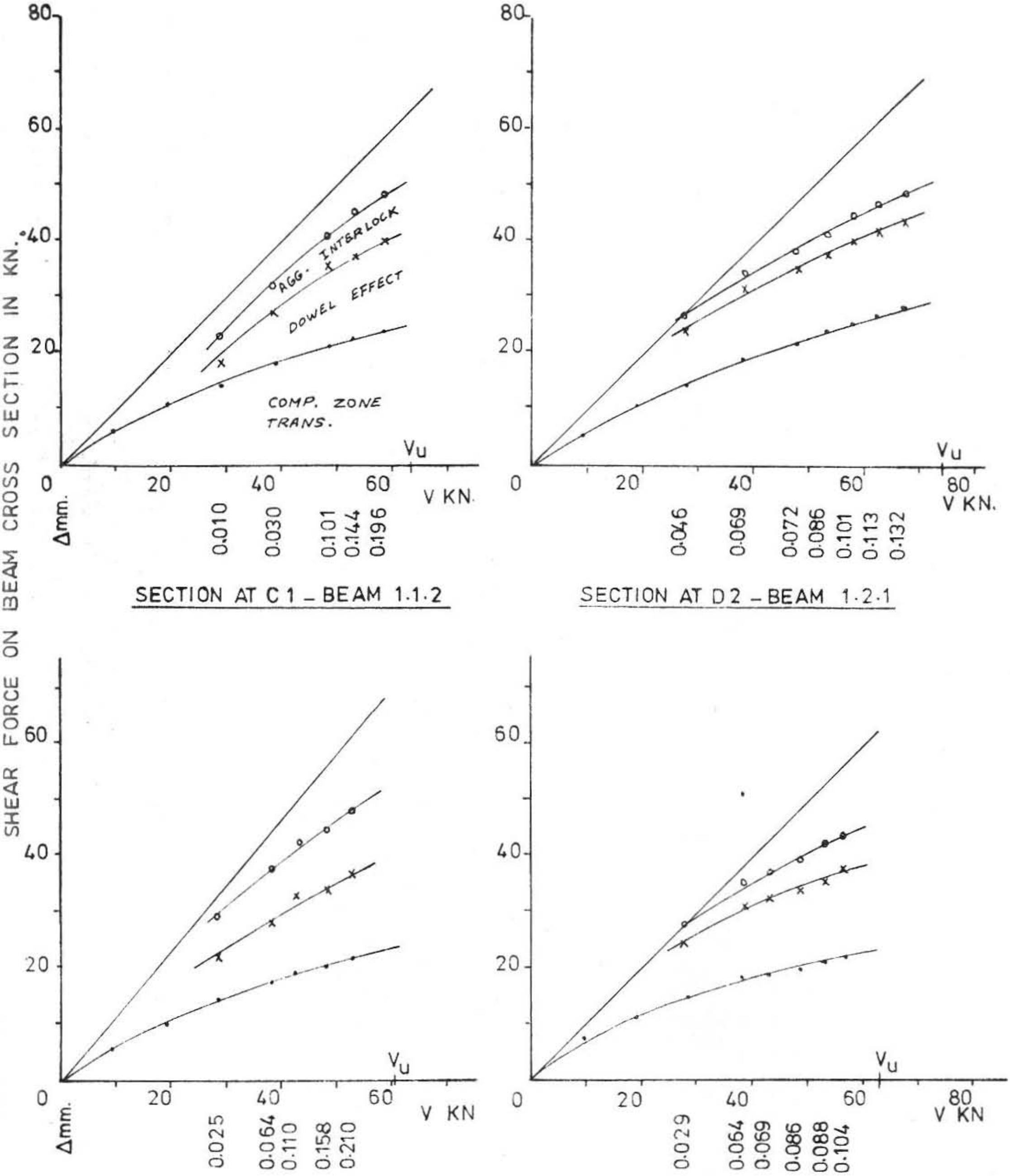
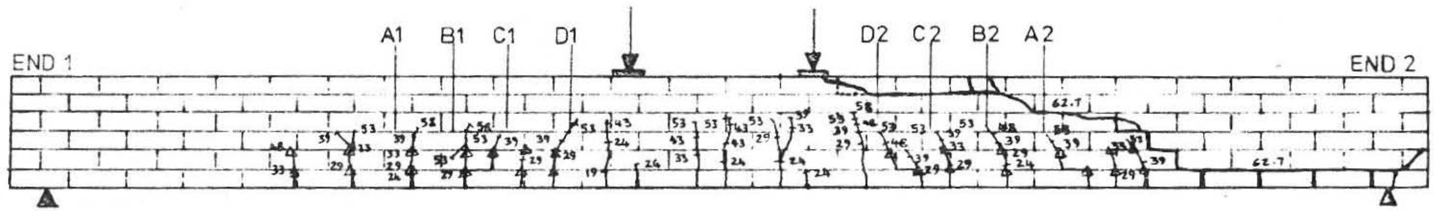
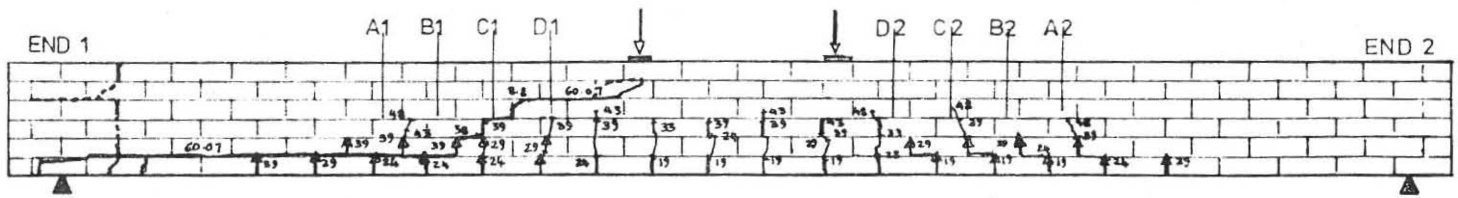


FIG.6 – SHEAR TRANSFER BY VARIOUS MECHANISM



BEAM 1.1.1



BEAM 2.1.1

FIG. 7 – OBSERVED CRACK PATERNS IN TYPICAL BEAMS