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Tests of Fibrous and Nonfibrous Reinforced Concrete Continuous Deep Beams with Web Openings

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Abstract:

Test results of twenty four two-span reinforced concrete deep beams, with or without web openings and with or without steel fibers are reported. All test specimens had the same cross-section, main longitudinal top and bottom reinforcement, and web reinforcement. The main parameters considered were the shear span-to-total beam depth ratio (a/h), position of the web openings, and the amount of steel fibers. Test results indicated that the presence of web openings within exterior or interior shear spans had great effects on the beam capacity and its behavior, with the diagonal cracking between loads and supports being dominant. In these beams, the crack patterns revealed the fact that the contribution of the top reinforcement was not significant. However, the top reinforcement showed better contribution in solid beams and beams with openings within midspan region especially when the shear span-to-depth ratio was increased. The crack patterns were less affected by the addition of steel fibers, however, an increase in the ultimate load capacity was obtained. The amount of increase in the ultimate load was about 10% in solid beams and beams having openings within midspan region, while the amount of increase was dependent on the shear span/depth ratio and location of the openings in the other beams. Also the fibrous beams showed better degree of serviceability requirements.

Keywords: deep beams; non-flexural members; shear strength; web openings; plasticity; strut-and-tie models.

Introduction:

In various forms of construction, openings in the web area of deep beams are frequently provided for essential services and accessibility, for example door openings, windows, ventilating ducts, or heating pipes. Reinforced concrete deep beams are fairly common structural elements. They are used as load distribution elements such as transfer girders, pile caps, tanks, folded plates, building diaphragms (floors or walls), and foundation walls, often receiving many small loads and transferring them to a small number of reaction points [1,2]. The main loads and reactions act in the plane of the member, and a state of plane stress is approximated [3]. Numerous definitions of deep beams exist. These definitions are mostly based on the ratio between the (shear) span and the depth of the beam. They can be defined, according to the ACI Code [4], as members with clear span, ℓ_n, equal to or less than four times the overall member depth or regions of beams loaded with concentrated loads within twice the member depth from the support that are loaded on one face and supported on the opposite face so that compression struts can develop between the loads and the supports.

Reinforced concrete deep beam behavior is influenced by many factors such as span-to-depth ratio, shear span-to-depth ratio, type of loading, position of load, percentage of tension and compression steel, location and amount of web reinforcement, width of the support zone, anchorage of the main reinforcements, concrete strength, and yield stress of the reinforcement [5]. Introducing an opening into the web area of reinforced concrete deep beams, however, leads to more complicated behavior [6,7,8]. To improve special properties of the concrete like the tensile strength, resistance to crack propagation, and to change the brittle mode of failure to a ductile one, short discrete fibers will be added to the concrete, and the addition of such fibers will add an extra factor which affect the behavior of deep beams [9,10,11].

Continuous deep beams differ from either simply supported deep beams or continuous shallow beams. In continuous deep beams, the regions of high shear and high moment coincide and failure usually occurs in these regions. In simple deep beams, the region of high shear coincides with the region of low moment. Failure mechanisms for continuous deep beams are therefore significantly different from failure mechanisms in simply supported beams [1]. The great number of parameters affecting reinforced concrete (continuous) deep beams strength has led to a limited understanding of shear failure.

There have been extensive experimental investigations of simply supported deep beams with web openings, [6-13] but very few tests of continuous reinforced concrete deep beams with web openings have been published. Ashour and Rishi [14] tested sixteen reinforced concrete continuous deep beams with web openings. The main variables were the size and position of web openings and web reinforcement arrangements. On the other hand, no steel fiber reinforced concrete continuous deep beam tests with web openings have been published. Therefore, an experimental program was undertaken to improve the understanding of the structural behavior of fibrous and nonfibrous reinforced concrete continuous deep beams with web openings.

Failure of reinforced concrete deep beams may be either [15,16]: Flexural failure, flexural-shear failure, diagonal splitting failure, diagonal compression failure, bearing failure, or anchorage failure.

Shear strength of deep beams may be as much as 2 or 3 times greater than that predicted using expressions developed for members of normal properties [17]. The 1973 ASCE-ACI Committee 426 [18] report identified the following four mechanisms of shear transfer in a diagonally cracked concrete beam of normal proportions:

1-Shear stress in uncracked concrete. 2-Interface shear transfer, often called “aggregate interlock” or “crack friction”. 3-Dowel action of the longitudinal reinforcing bars. 4-Arch action in which a significant part of the load is transferred directly from the point of application to the support by diagonal compression struts. Since that report was issued, a new mechanism has been identified [19], namely:

5-Residual tensile stresses transmitted directly across cracks, which is called “tension stiffening”. And, if the member contains web steel, a part of the shear force can be transmitted through it.

Objective and Scope of the Present Investigation:

There are extensive experimental investigations on simply supported deep beams (with or without openings and with or without fibers), but few tests of continuous reinforced concrete deep beams with or without openings in the web are available. To the author's knowledge, no continuous reinforced concrete deep beams containing openings in the web and reinforced with steel fibers has been tested. Therefore, this research work was made to supplement the very limited experimental information available on the behavior of continuous reinforced concrete deep beams with or without openings and with or without steel fibers.

Material Properties:

The same concrete mix, which was produced in the laboratory, was used throughout the whole investigation. It consisted of ordinary Portland cement, locally available river sand, and ordinary river gravel of maximum size 12.5 mm. The aggregates were conforming to limits given by ASTM C-33 [20].

A mix proportion of 1:3:2 (Cement: Sand: Gravel, based on dry weights) was selected to be suitable and workable with steel fibers and was adopted for all the specimens. A constant water/cement ratio of 0.55 by weight was used in all mixes.

Only one type of steel fibers (Duoform) with diameter of 0.25 mm and length of 25 mm (aspect ratio=ℓ_f/d_f=100) was used. Three 150 mm cubes and three 150 mm x 300 mm cylinders were cast with each beam to determine respectively the compressive strength and the splitting tensile strength of the concrete.

All main longitudinal top and bottom reinforcement was deformed steel bars of 12 mm (f_y=380 MPa) and 10 mm (f_y=348 MPa) diameter, while the web reinforcement was 6 mm (f_y=380 MPa) diameter plain round bars.

Test Specimens:

A total of twenty four reinforced concrete continuous deep beams with or without openings were tested to failure under static loading. The beams had a rectangular cross section with width of 100 mm and total depth of 350 mm. The beam length was varied to obtain the desired span-to-depth ratio. The test specimens were divided into three groups of similar shear span-to-total depth ratio (a/h). Each group consisted of eight beams. In each group, two specimens were solid which were included in the program to provide basis for comparisons of the strength and behavior of the beams with openings. An overview of the overall dimensions together with the layout of the reinforcement and web openings within each group is given in Table (1) and typically shown for group 2 beams (B9-B16) in Fig. (1). One size (140 x 90 mm) and three locations of web openings were investigated, while the fiber volume fraction was either 0% or 0.8%. Two locations of web openings were selected to interrupt the load path to either the central or end supports, while the other location was within the region of maximum positive moment.

All longitudinal top and bottom reinforcements were extended the full length of the beam straightly without bent or cut, besides the bottom steel was extended about 250 mm through the beam depth at 90^o to provide sufficient anchorage at supports.

Testing Procedure:

The beam specimens were tested on three support reactions as shown in Figs.(1 and 2). Special arrangements were made through flat steel plates (100 x 100 x 20 mm) at the points of load applications and at the reactions to avoid local bearing failures during testing. The two end supports were of roller type, while packed steel plates were used at the central support. Before testing, one vertical face of each beam was white painted and grid lines of 50 x 50 mm were drawn on this face to facilitate the observation and reconstruction of the cracks. A thin layer of felt (plaster of Paris) was placed between the steel plates and the beam surface at loading and supporting points.

Two Baty – type dial gages of 0.01 mm accuracy were used to measure the midspan deflections (one in each span) during testing procedure. The concrete and steel strains were measured using 100 mm Demec mechanical extensometer measuring between targets (Demec button) on the surface of the concrete or mounted on 6 mm diameter pins extending from the bar through about 12 mm diameter hole to the concrete surface. Close observations were made by naked eye to locate the first crack (flexural and inclined shear cracks). The positions, load magnitude, and extents of the first and other consequent cracks were marked till failure occurred.

Test Results and Discussions:

Control Specimens:

Table (2) summarizes the test results of the control specimens. It was shown by tests that the relation between the cube compressive strength f_{cu} and the cylinder compressive strength f'_c for fibrous [21] and nonfibrous [1,22] concrete has the form: $f'_c \approx 0.85\ f_{cu}$. This relation has been used for the purposes of this study.

The table indicated that an average increase in the compressive strength of about 10% was obtained by providing steel fiber content of about 0.8% by volume, while an average increase of more than about 25% was obtained in the splitting tensile strength for the same fiber content. This reflects the usefulness of steel fibers in improving the tensile (rather than the compressive) strength of the concrete. This behavior is important in delaying (or even preventing) the diagonal splitting failure (the commonest type) in deep beams. The increase in the unit weight due to the inclusion of 0.8% by volume of fibers was negligible (only about 1%).

Specimens Behavior:

In general, two main types of behavior were observed. Solid beams or beams with openings within the midspan region behaved, essentially, in a similar manner. While beams having openings within exterior or interior shear spans behaved differently from solid beams. The effect of fiber content on the crack patterns was almost insignificant; however it affected the mode of failure in some cases. All fibrous beams failed at loads higher than that of the companion ordinary beams. Beams with fibers showed somewhat higher ductility, less damage at failure, and smaller observed crack widths than beams without fibers. The crack patterns, at failure, at one face of all the beams were reconstructed and the failure crack(s) (or the failed region) was identified by the letter **F**, as shown in Fig. (3). The two spans of each tested beam showed nearly the same patterns of cracking before failure.

Solid Beams or Beams with Openings within Midspan Region:

Following an uncracked elastic phase, cracking began in the tension zone near the midspan section (contrary to predictions by slender beam theory). The same behavior was observed by Al-Najjim [23], Asin [24], and Saeed [25]. With increasing load the number of flexural cracks increased and shear cracks formed between the loads and each support. At higher loads the dominant pattern of cracking was in the direction from the supports to the loads especially for beams in Groups 1 and 2 (with a/h of 0.8 and 1.2, respectively), while flexural cracks in beams of Group 3 (a/h = 1.65) were as important as shear cracks.

The number and extension of visible flexural cracks near the top of the middle support were very limited, and even such cracks were not seen as in the case of Beam B2 (a/h = 0.8) which indicated that the negative reinforcement did not contribute very much to the beams strength. With increasing shear span-to-total depth ratio (a/h), the number and extension of such cracks were increased as can be seen from the crack patterns. This means that the contribution of the negative reinforcement to the beam strength increases with increasing shear span-to-total depth ratio. However, these cracks were not seemed to be dangerous in comparison to the bottom flexural cracks or inclined shear cracks, and they happened at late stages of loading.

In general, the crack patterns were not affected by the presence of openings within the midspan region; however such openings reduced the flexural rigidity of the beams at midspan region and enabled the flexural cracks to occur earlier especially when the shear span-to-total depth ratio was increased.

For the fibrous beams in Groups 2 and 3 (a/h of 1.2 and 1.65, respectively), it was well obvious that the steel fibers delayed the formation and widening of cracks (both flexural and inclined cracks), while this was not the case in shorter beams (Group 1 with a/h = 0.8). Steel fibers were effective in increasing the ultimate load capacity of all the beams. The amount of increase was in the order of about 10% except that the solid fibrous beam B2 supported about 40% more load than the companion beam B1 and the mode of failure was changed from diagonal splitting to almost shear-compression type of failure.

First flexural cracks were observed at load of about 30 – 35 % of the span load (total failure load = 2 * span load) in nonfibrous beams B1 (solid beam with a/h = 0.8), B7 (with opening and a/h = 0.8), and B9 (solid beam with a/h = 1.2). While this flexural cracking load was only about 10% of the span load in beams B15 (with opening and a/h = 1.2), B17 (solid beam with a/h = 1.65), and B23 (with opening and a/h = 1.65). The first flexural cracking load was about 20 – 25% of the span load in fibrous beams B2 (solid beam with a/h = 0.8), B8 (with opening and a/h = 0.8), B10 (solid beam with a/h = 1.2), and B16 (with opening and a/h = 1.2), while this load was decreased to about 10 – 15% in beams B18 and B24 (beams of Group 3 with a/h = 1.65).

Table (2) shows that the inclined cracking load for nonfibrous solid beams decreases with increasing shear span-to-total depth ratio (as a fraction of the span load: about 50% in B1, 40% in B9, and about 20% in B17). While for solid fibrous beams the same fraction was about 30% in B2, 55% in B10, and about 50% in B18. It appears from the results that for beams with midspan openings the final mode of failure will affect the level of load at which the first inclined crack will appear, e.g. inclined cracks appeared at early stages of loading in case of diagonal splitting mode of failure (as in beam B15).

In general, openings within the midspan region of deep beams had negligible influence on the ultimate shear strength of these beams.

Beams with Openings within Exterior or Interior Shear Spans:

The first visible diagonal cracks generally appeared at the top and bottom corners of web openings towards the load points and supports at different load levels. For beams in Groups 1 and 2, and with few exceptions (as in beams B6 and B12), at the same or higher loading, flexural cracks at midspans developed. While for beams in group 3 (a/h = 1.65 and ℓ/h = 3.3), the flexural cracks preceded the inclined cracks or occurred at the same load level (as in beam B19), as shown in Table (2).

It is interesting to note that the presence of openings within exterior or interior shear spans of the beams affected the behavior very much. The dominant cracks were inclined shear cracks from the supports to the loads. The flexural bottom cracks were not as important as those in the solid beams and their extensions were also limited (except for beams with high a/h ratio: beams of group 3 with a/h = 1.65). The top flexural cracks were minor and they were very limited in number and extension, and occurred at late stages of loading.

Although the inclusion of steel fibers caused an increase in the ultimate failure load of all the beams in comparison with nonfibrous beams, but still the diagonal splitting mode of failure was not prevented. All the beams with openings within exterior or interior shear spans failed in diagonal splitting mode of failure. The amount of fiber content (0.8% by volume) may be not sufficient to help in this regard.

Openings within exterior or interior shear spans caused a considerable decrease in the ultimate strength capacity of the beams. Beams having web openings within exterior shear spans had a higher capacity than those having web openings within interior shear spans (beams in Groups 2 and 3 (except beam B21)). While similar beams in Group 1 showed contradictory behavior which was very obvious for nonfibrous beam B3. This may be attributed to the fact that these beams had a very low value of shear span-to-total depth ratio (a/h = 0.8) and the loads were very close to the openings which cause premature failure of this highly stressed region. Beam B3 had a value of compressive strength less than that of beam B1, the value which affects the resistance of the beam.

Load–deflection Relationships:

The midspan deflections of all beams tested in the present study against the total applied load are shown in Fig. (4). All deflection curves shown are those reported for the failed span only. In general two major stages in behavior are observed. First the plots are nearly linear for the initial stage of loading indicating elastic behavior of the beams prior to the occurrence of cracks, and second, at the later stage of loading deflection increases at higher rate as more cracks are formed indicating nonlinear behavior.

It is clear from the load–deflection plots that the deflections were decreased by inclusion of the steel fibers, while the presence of openings within exterior or interior shear spans resulted in a decrease in the beam stiffness and so larger deflections. Beams with midspan openings showed almost similar behavior to the companion solid beams.

In general the load-deflection response was brittle for most of the beams with the flexibility response being increased with increasing the shear span-to-total depth ratio.

Development of Reinforcement Strains:

Abrupt change in the steel strain occurred when the concrete surrounding the steel bar was cracked. A large amount of data were obtained during testing, however, some of these measurements are shown here as can be seen from Figs. (5). The steel strain (stress) is an indicator for the limit to which a steel bar contributes in resisting the tensile force.

Concrete Strain:

Prior to cracking the strains were small along the depth. As cracks formed and propagated, the concrete strain increased rapidly. The main objective from concrete strain measurements was obtaining an idea about the maximum concrete compressive strain (at the top of the midspan section and at the bottom of the midsupport section). On one hand, the crack patterns revealed that the midspan sections experienced considerable cracking and high values of concrete compressive strain was expected especially in solid beams. The measured concrete compressive strain at 20 mm below the top of the midspan section before failure ranged from a minimum of about $220\text{x}10^{-6}$ mm/mm in beam B13 to a maximum of about $4060\text{x}10^{-6}$ in beam B24. On the other hand, concrete compressive strain (at 20 mm above the bottom of the mid-support section) measurements at the mid-support section were very small (crack patterns support this criteria) and insignificant except in solid beams and this strain ranged from about zero (as in beams B11 and B13) to a maximum of about $780\text{x}10^{-6}$ mm/mm (as in beam B16).

The concrete strain measurements support the fact that the positive moment at midspan section and the negative moment at the mid-support section do not follow the results obtained from the elastic analysis.

Experimental Ultimate Failure Load:

The experimental ultimate failure loads (failure load = 2 * span load) and related data are summarized in Table (2). Except for beams having web openings within exterior shear spans, the critical shear force for all the beams in groups 1 and 2 (a/h = 0.8, and 1.2, respectively) occurred in the inner shear spans. The exterior shear spans were critical for beams having web openings within those regions. All the beams in these two groups failed in shear.

Beams in Group 3 (a/h = 1.65), which have web openings within shear spans, showed similar behavior to those in Groups 1 and 2, while the solid beams or the beams with midspan openings showed somewhat different mode of failure. Such beams almost showed a flexural type of failure, where the failure occurred by crushing of the concrete in the very limited compression zone near the load points after yielding of the bottom tensile reinforcement.

Fig. (6) shows the dimensionless failure load (λ) in each span of the continuous beams as a function of the shear span-to-total depth ratio (a/h). As for simply supported reinforced concrete deep beams, the ultimate failure load of the continuous deep beam decreases with increasing a/h ratio, except that beams B11 and B12, which had web openings within exterior shear spans, have failure loads at a/h = 1.2 higher than that at a/h = 0.8. Almost similar beams showed similar trends.

Conclusions:

Based on the results obtained from the experiments, the following conclusions may be drawn:

1- Existence of web openings within exterior or interior shear spans caused a high reduction in the shear capacity of the beams. Therefore and whenever possible, web openings should be kept clear of the natural load path joining the loading and reaction points.

2- If the openings were clear of the natural load path e.g. within midspan region, the test results showed that these beams behaved almost in a manner similar to the companion solid beams. Therefore, these regions are suitable for providing openings when required.

3- Solid continuous deep beams showed more distributed cracks than beams with openings within exterior or interior shear spans, where dangerous cracks would be situated above and below the openings. Therefore, the regions above and below the openings should be well protected; the conclusion which was also made by Kong et al.[6] for simply supported deep beams.

4- The crack patterns and concrete strain measurements revealed the fact that the moment distribution in continuous deep beams did not follow those obtained from the elastic analysis. The test evidences showed that the positive moment in the midspan region was larger than the negative moment over the mid-support (contrary to the elastic analysis).

5- The crack patterns were less affected by the presence of steel fibers. However, an increase in the beam capacity was obtained by adding steel fibers. The amount of steel fiber used (0.8% by volume) was not able to prevent the diagonal shear failure especially in beams containing openings in the shear spans, however, fibrous beams behaved very well in comparison with companion nonfibrous beams. On the other hand, steel fibers were useful in serviceability and other requirements.

6- In the design of the majority of solid deep beams, it is usually necessary to consider shear for the ultimate state only. In the design of deep beams with openings, however, shear may also be an important consideration for the serviceability limit state of cracking. Continuous deep beams of the present study showed severe cracks before failure, therefore, serviceability limits should be considered in the design.

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Table 1: Properties of test beams.

Group No.	Beam No.	ℓ/h*	a/h$	$V_{f,\ \%}$	Opening size+ Width * height	Opening location	Notes
1	B1	1.6	0.8	0.0	------	------	Solid
	B2	1.6	0.8	0.8	------	------	Solid
	B3	1.6	0.8	0.0	140 * 90+	Ext. load path	With opening
	B4	1.6	0.8	0.8	140 * 90	Ext. load path	With opening
	B5	1.6	0.8	0.0	140 * 90	Int. load path	With opening
	B6	1.6	0.8	0.8	140 * 90	Int. load path	With opening
	B7	1.6	0.8	0.0	140 * 90	Midspan	With opening
	B8	1.6	0.8	0.8	140 * 90	Midspan	With opening
2	B9	2.4	1.2	0.0	------	------	Solid
	B10	2.4	1.2	0.8	------	------	Solid
	B11	2.4	1.2	0.0	140 * 90	Ext. load path	With opening
	B12	2.4	1.2	0.8	140 * 90	Ext. load path	With opening
	B13	2.4	1.2	0.0	140 * 90	Int. load path	With opening
	B14	2.4	1.2	0.8	140 * 90	Int. load path	With opening
	B15	2.4	1.2	0.0	140 * 90	Midspan	With opening
	B16	2.4	1.2	0.8	140 * 90	Midspan	With opening
3	B17	3.3	1.65	0.0	------	------	Solid
	B18	3.3	1.65	0.8	------	------	Solid
	B19	3.3	1.65	0.0	140 * 90	Ext. load path	With opening
	B20	3.3	1.65	0.8	140 * 90	Ext. load path	With opening
	B21	3.3	1.65	0.0	140 * 90	Int. load path	With opening
	B22	3.3	1.65	0.8	140 * 90	Int. load path	With opening
	B23	3.3	1.65	0.0	140 * 90	Midspan	With opening
	B24	3.3	1.65	0.8	140 * 90	Midspan	With opening

* ℓ = span length measured center to center of supports.

$ a = shear span measured from center of load to center of support.

\+ Opening size is in mm.

Notes:

1- Beam cross section, b x h = 100 x 350 mm, with effective depth d= 310 mm.

2- Uniform Φ6mm vertical stirrups were used, giving $\rho_v = A_v/bs = 0.56$ %.

3- two Φ6mm closed horizontal stirrups were used, giving $\rho_{vh} = A_{vh}/bs = 0.49$ %.

4- The stirrups, which interrupted the opening, were added at the nearest sides of the opening.

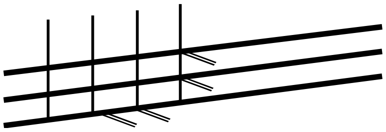
5- $\rho = A_s / bd = 0.73$ % and $\rho` = A_s` / bd = 0.98$ %, for all the beams.

Table 2: Test results of the tested beams.

Beam No.	a/h (ℓ/h)	Fiber content, V_f, %	Cube comp. strength, f_{cu}, MPa	Equiv. cylinder comp. strength, f'_c, MPa*	Splitt. tensile strength, f_{sp}, MPa	First bottom flexural cracking load, kN	First Shear cracking load or cracking load at web opening corners, kN	Total failure loads, P_t, kN	Dimensionless Failure load in each span, λ*	Type of failure
B1	0.8 (1.6)	0.0	41.80	**35.5**	**4.00**	107.9	172.6	**647.3**	0.260	**Diagonal splitting**
B2		0.8	46.53	**39.6**	**5.30**	117.7	137.3	**902.2**	0.325	**Shear-compression**
B3		0.0	36.50	**31.0**	**4.13**	78.5	73.6	**211.8**	0.098	**Diagonal splitting**
B4		0.8	44.00	**37.4**	**5.45**	117.7	78.5	**514.9**	0.197	**Diagonal splitting**
B5		0.0	42.70	**36.3**	**4.43**	78.5	78.5	**480.5**	0.189	**Diagonal splitting**
B6		0.8	41.81	**35.5**	**5.24**	78.5	176.5	**524.7**	0.211	**Diagonal splitting**
B7		0.0	43.24	**36.8**	**3.96**	117.7	215.8	**666.9**	0.259	**Shear-compression**
B8		0.8	44.02	**37.4**	**5.23**	78.5	117.7	**755.1**	0.288	**Shear-compression**
B9	1.2 (2.4)	0.0	40.43	**34.4**	**4.20**	98.1	117.7	**588.4**	0.244	**Shear-compression**
B10		0.8	47.20	**40.1**	**4.82**	88.3	176.5	**644.3**	0.230	**Shear-compression**
B11		0.0	40.08	**34.1**	**4.00**	58.8	58.8	**313.8**	0.131	**Diagonal splitting**
B12		0.8	43.20	**36.7**	**5.10**	117.7	137.3	**549.2**	0.214	**Diagonal splitting**
B13		0.0	41.10	**34.9**	**3.95**	78.5	78.5	**250.1**	0.102	**Diagonal splitting**
B14		0.8	45.86	**39.0**	**5.35**	78.5	78.5	**387.4**	0.142	**Diagonal splitting**
B15		0.0	43.37	**36.9**	**3.87**	39.2	49.0	**647.3**	0.251	**Diagonal splitting**
B16		0.8	47.60	**40.5**	**5.18**	78.5	176.5	**681.6**	0.240	**Shear-compression**
B17	1.65 (3.3)	0.0	45.23	**38.4**	**4.52**	27.0	58.8	**529.6**	0.197	**Flexure-shear**
B18		0.8	50.10	**42.6**	**5.58**	39.2	137.3	**568.8**	0.191	**Flexure-shear**
B19		0.0	46.80	**39.8**	**4.38**	39.2	39.2	**301.1**	0.108	**Diagonal splitting**
B20		0.8	50.52	**42.9**	**5.53**	49.0	58.8	**419.7**	0.140	**Diagonal splitting**
B21		0.0	43.28	**36.8**	**4.48**	44.1	78.5	**333.4**	0.129	**Diagonal splitting**
B22		0.8	51.46	**43.7**	**5.39**	53.9	93.2	**367.8**	0.120	**Diagonal splitting**
B23		0.0	43.72	**37.2**	**4.24**	19.6	78.5	**456.0**	0.175	**Flexure-shear$**
B24		0.8	50.81	**43.2**	**5.45**	29.4	137.3	**514.9**	0.170	**Flexure-shear**

* Calculated as P/bhf'_c [P = midspan load = $P_t/2$], P_t = total applied loads.

$ Crushing of the concrete at the top of the flexural crack and opening of the inclined crack between load and interior support.



How steel strains were measured

6 mm diameter pins extending from the bar through about 12 mm diameter hole to the concrete surface for strain readings in

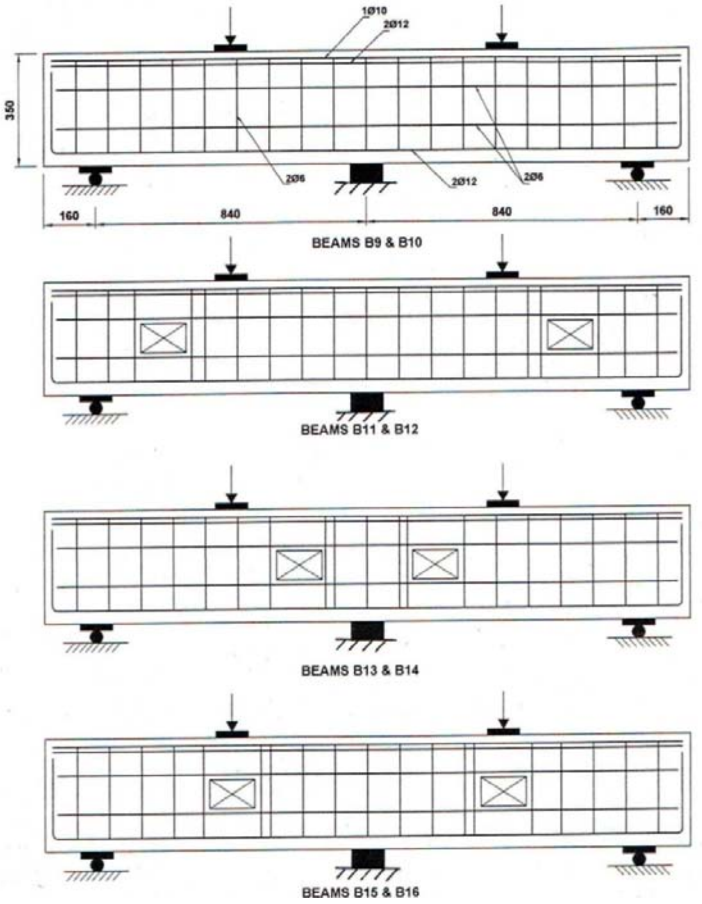
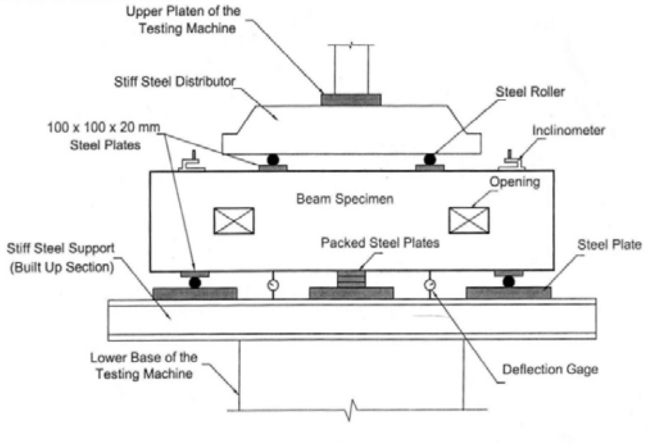


Fig.(1): Geometrical dimensions and reinforcement details for beams B9-B16.



Note : For Group 3 beams , the loads where applied by means of two hydraulic jacks in a self-suporting steel frame with the same details of supports.

Fig. (2): Test Setup

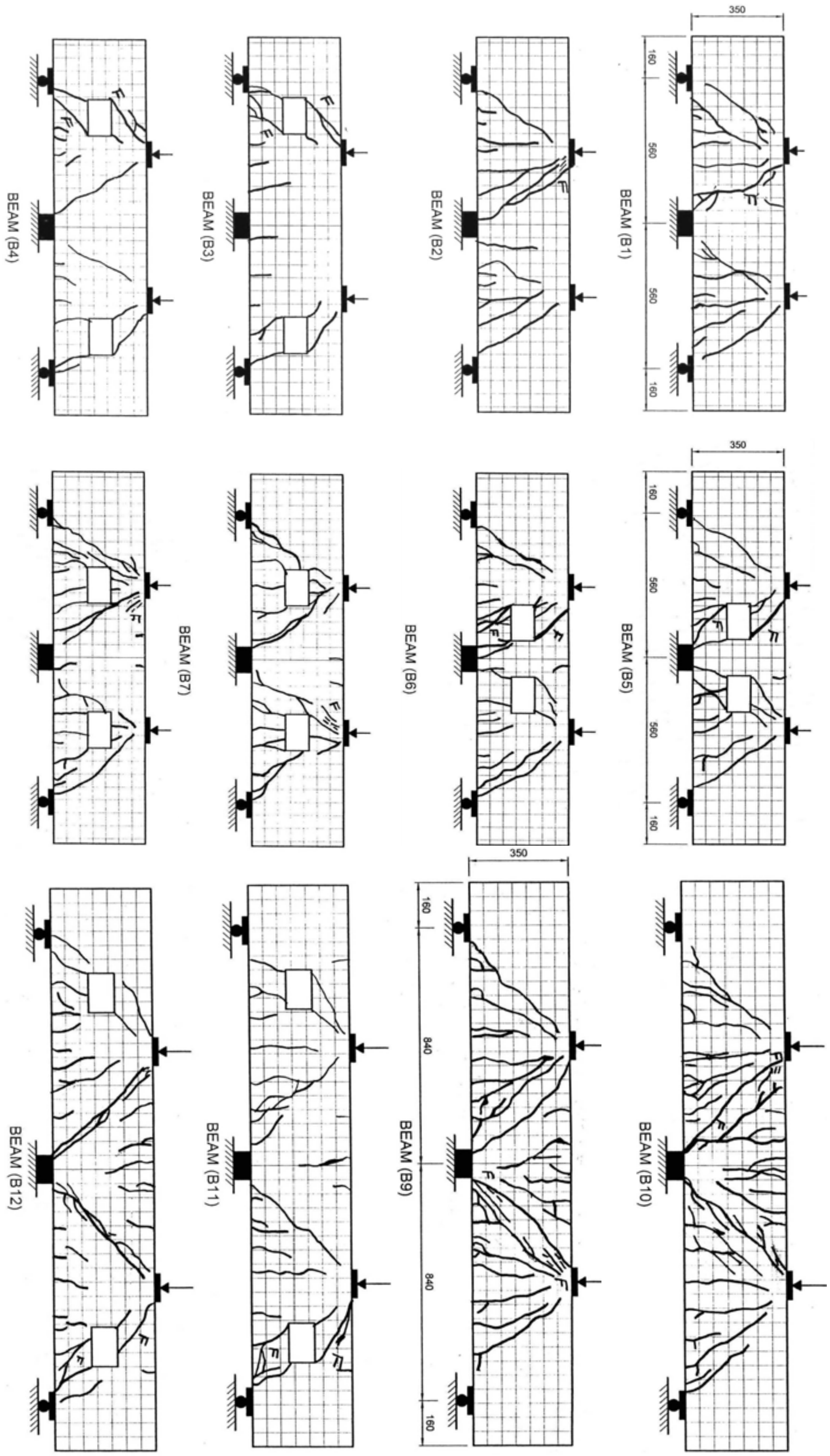


Fig.(3): Reconstructed crack patterns.

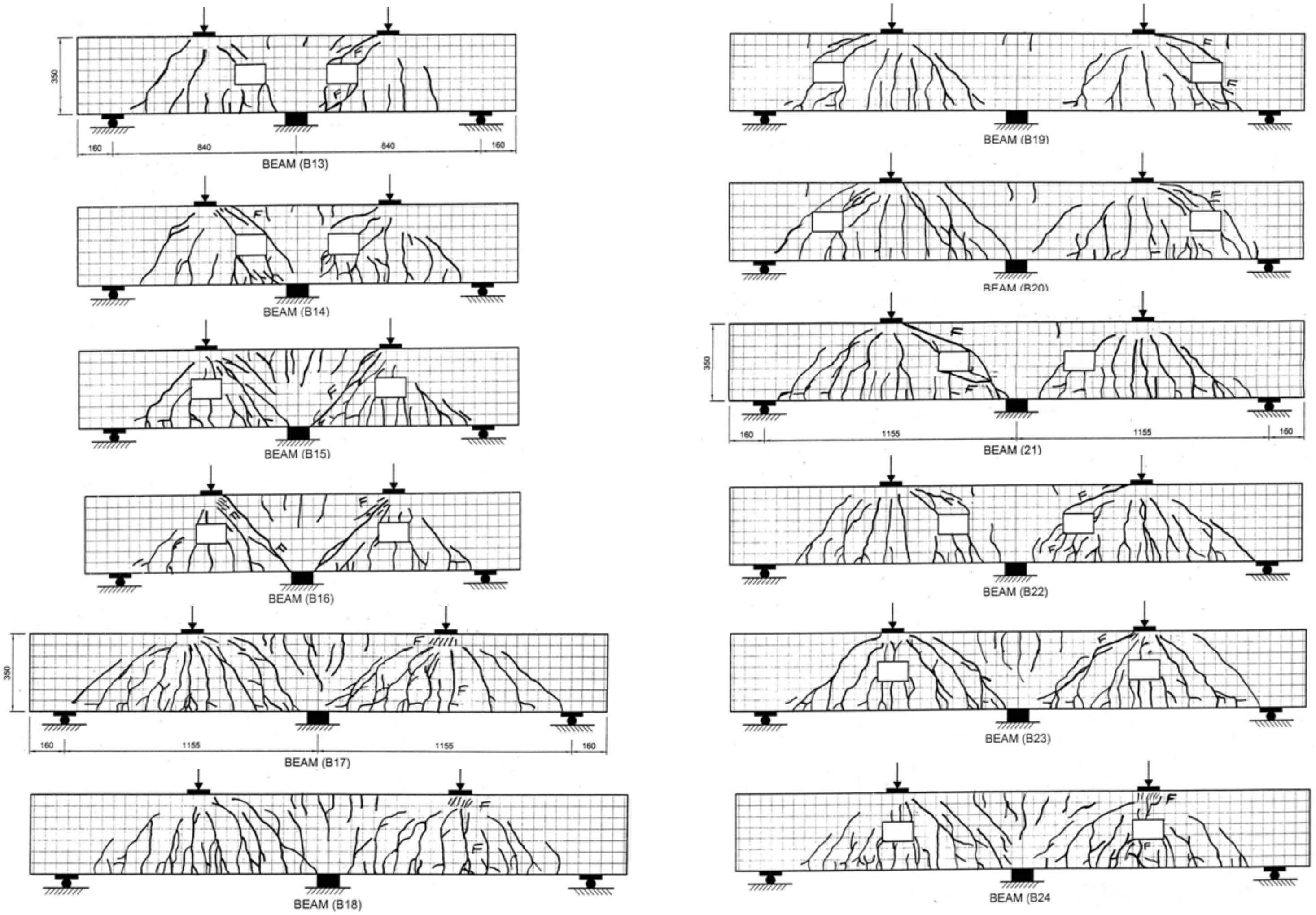
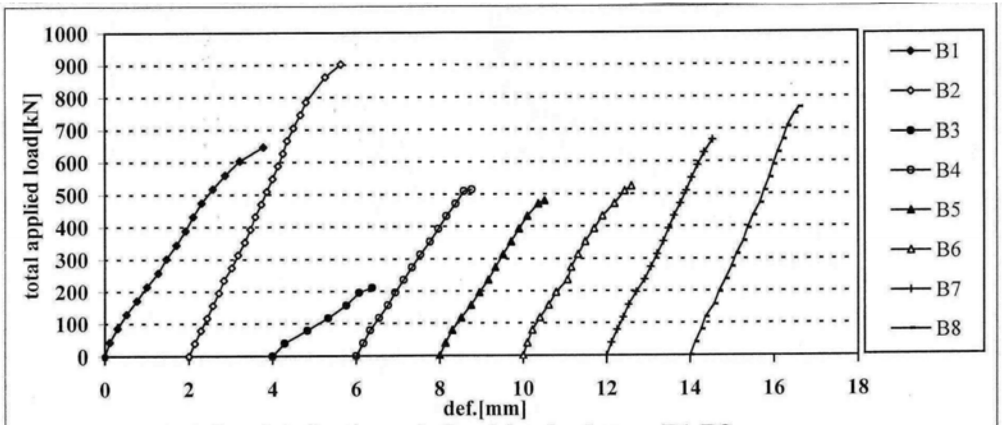
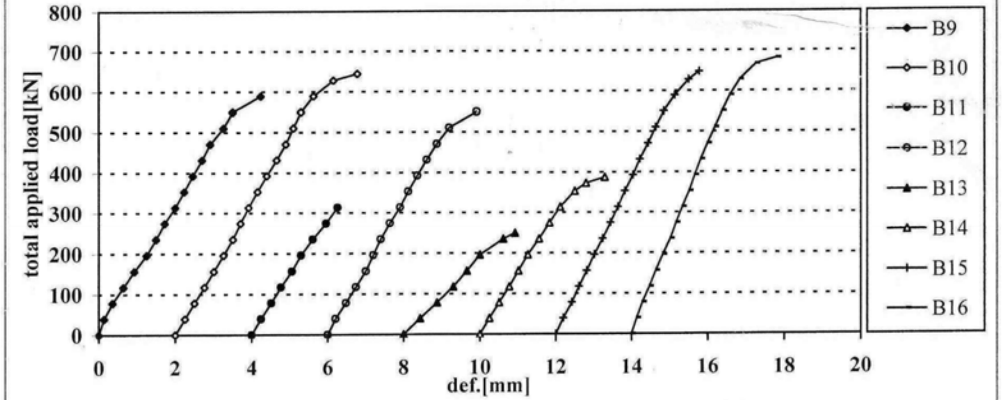

350
160
840
840
160
BEAM (B13)
BEAM (B14)
BEAM (B15)
BEAM (B16)
350
160
1155
1155
160
BEAM (B17)
BEAM (B18)
BEAM (B19)
BEAM (B20)
350
160
1155
1155
160
BEAM (21)
BEAM (B22)
BEAM (B23)
BEAM (B24
F

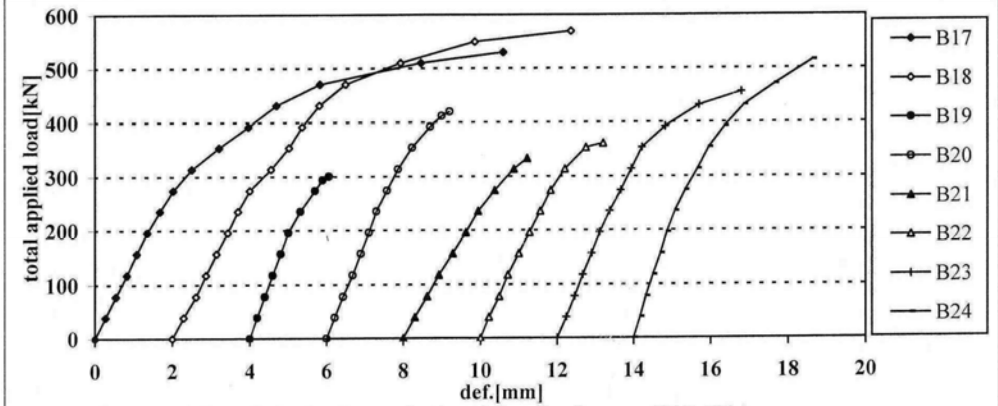
Fig.(3): Cont'd.



Load-deflection relationships for beams B1-B8

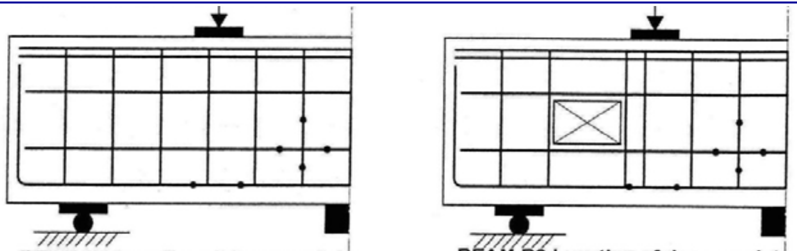


Load-deflection relationships for beams B9-B16



Load-deflection relationships for beams B17-B24

Fig.(4): Load-Deflection relationships for beams B1-B24.



BEAM B1-Location of demec points

BEAM B3-Location of demec points

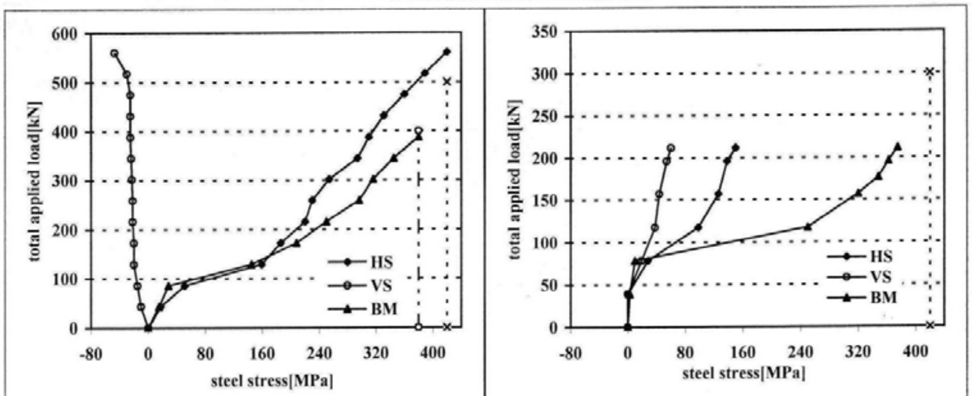
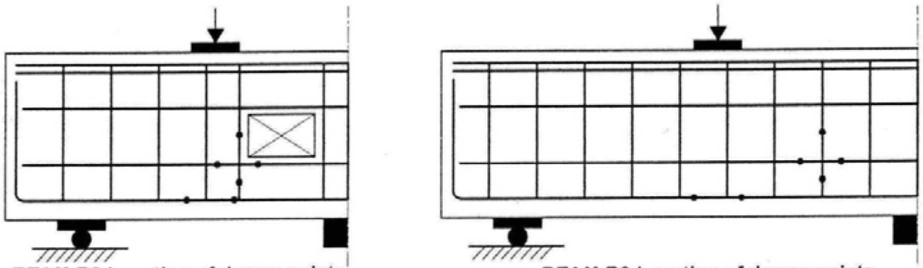


Fig.(5.13)-Experimental total applied load versus steel stress for beam B1

Fig.(5.14)-Total applied load versus secondary steel stress for beam B3



BEAM B6-Location of demec points

BEAM B9-Location of demec points

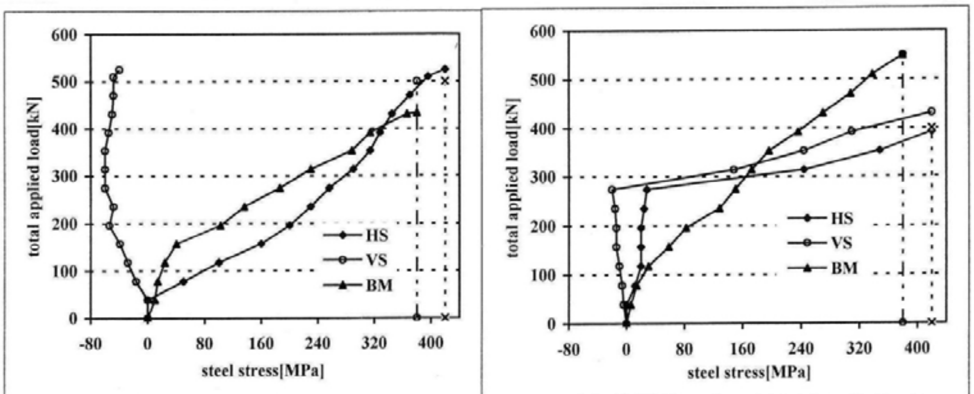
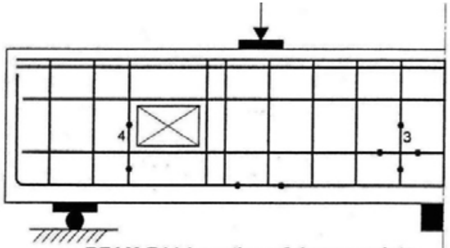


Fig.(5.15)-Experimental total applied load versus steel stress for beam B6

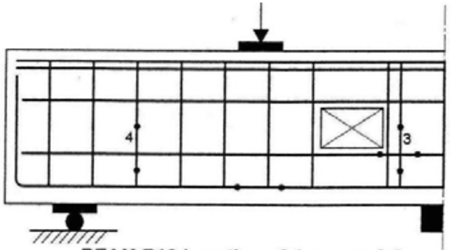
Fig.(5.16)-Experimental total applied load versus secondary steel stress for beam B9

HS=Horizontal Stirrup; VS=Vertical Stirrup; BM=Bottom Main steel

Fig.(5): Load –steel strain relationships.



BEAM B11-Location of demec points



BEAM B13-Location of demec points

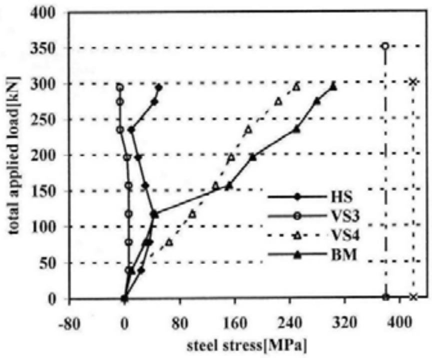


Fig.(5.17)-Experimental total applied load versus steel stress for beam B11

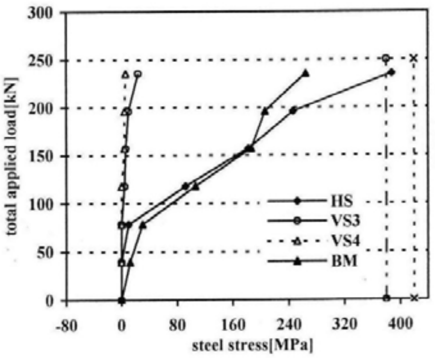
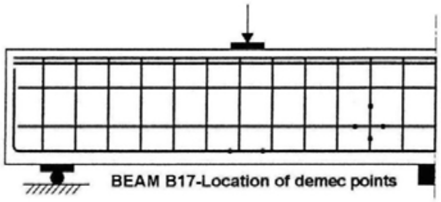
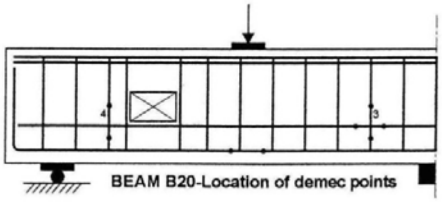


Fig.(5.18)-Experimental total applied load versus steel stress for beam B13



BEAM B17-Location of demec points



BEAM B20-Location of demec points

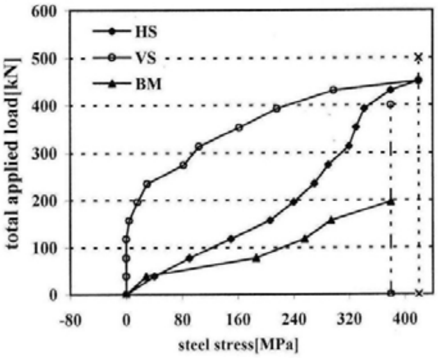


Fig.(5.19)-Experimental total applied load versus steel stress for beam B17

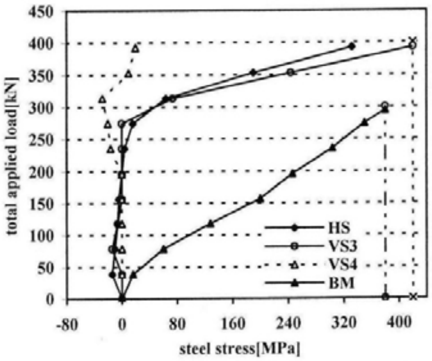
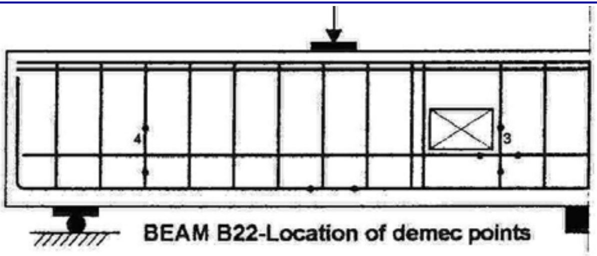
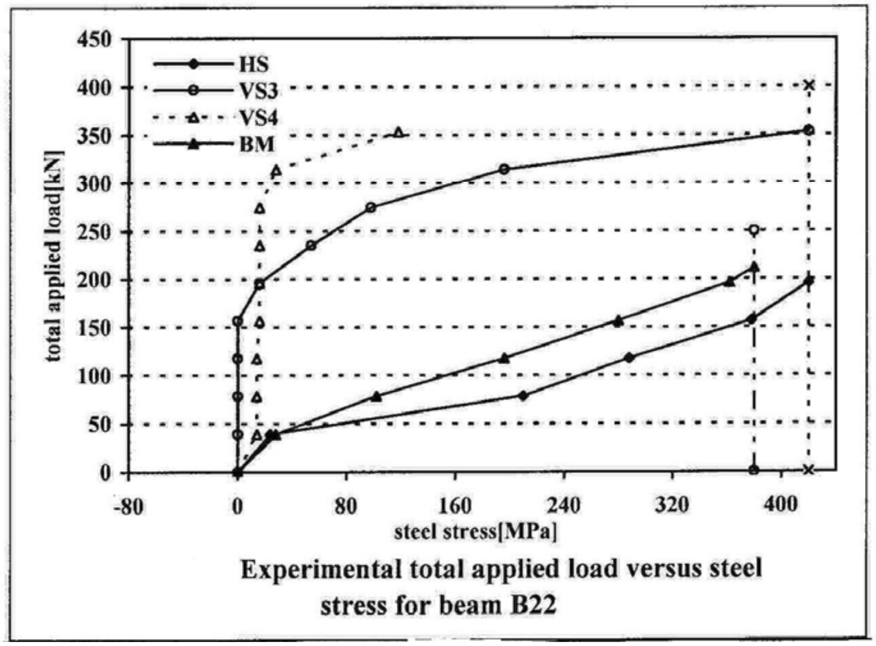


Fig.(5.20)-Experimental total applied load versus steel stress for beam B20

HS=Horizontal Stirrup; VS=Vertical Stirrup; BM=Bottom Main steel

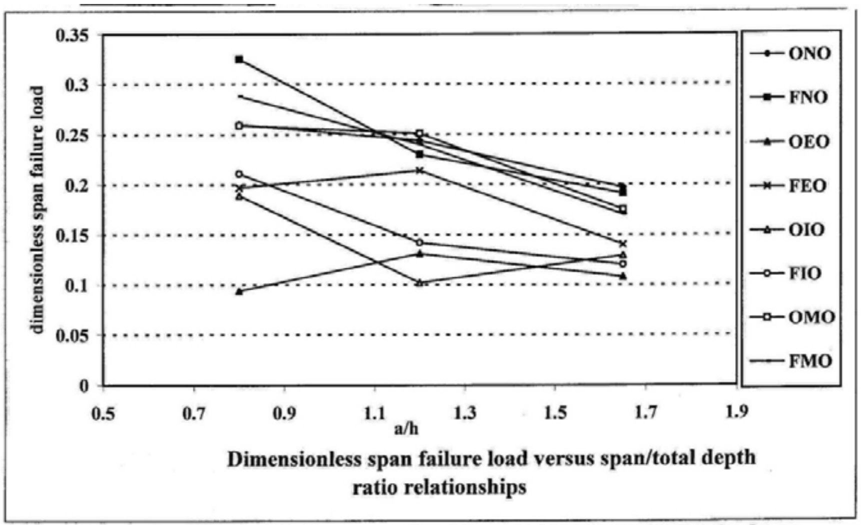
Fig.(5): Cont'd.





Experimental total applied load versus steel stress for beam B22

Fig.(5): Cont'd



Dimensionless span failure load versus span/total depth ratio relationships

ONO=Ordinary without Open.; FNO=Fiber beam without Open.; OEO=Ordinary with Exterior Open.; FEO=Fiber beam with Exterior Open.; OIO=Ordinary with Interior Open.;FIO=Fiber beam with Int. Open. OMO=Ordinary with Mid Open.; FMO=Fiber beam with Mid Open.

پوخته

له شێوەکانی جۆراوجۆری بیناسازی، کون opening **دروست دەکرێت له ڕایەڵەکانی قووڵ بەمەبەستی کارەکانی خزمەت کردن یان گەیشتن وەکو دەرگا، پە نجەرە، دەکتەکانی گۆڕینی باری هەوا و بۆڕیەکانی گەرم کردنەوە. زۆر تاقیکردنەوە ئە نجام دراوە له سەر هەڵسوکەوتی ڕایەڵە قووڵەکانی سادە (له سەر دوو سەکۆ) کە کونیان تێدایە، بەڵام کاری زۆر کەم ئە نجام دراوە لەسەر ڕایەڵە قووڵەکانی بەردەوام کە کونیان تێدایە. له لایەکی ترەوە پشکنینی پراکتیکی له سەر ڕایەڵی کۆنکریتی بەردەوام و کوندار و بەهێزکراو بە ڕیشالی پۆڵایین ئە نجام نەدراوە. له بەر ئەوە پرۆگرامێکی پشکنینی پراکتیکی ئە نجام درا بۆ زیاتر تێگەیشتن له هەڵسوکەوتی ڕایەڵی قووڵی بەردەوام کە کونیان تێدایە و بە ڕیشال یان بێ ڕیشالی پۆڵایین و بە جەخت کردن له سەر بەرگری بڕینی** shear strength **ئەم ڕایەڵانە. پرۆگرامی پراکتیکی بریتی بوو له پشکنینی بیست و چوار ڕایەڵی کۆنکریتی بەردەوام کوندار یان بێ کون. ڕایەڵەکان هەمان پانی و بەرزیان هەبوو،** 100 **مم پانی و** 350 **مم بەرزی، بەلام درێژیەکانیان جیاواز بوو بۆ بەدەست هێنانی سێ ڕێژەی جیاواز له** a/h **کە بریتی بوون له** 0.8 ، 1.2 ، 1.65. **یەك جۆر کون دروست کرا له ڕایەڵەکان بە درێژی** 140 **مم و بەرزی** 90 **مم و له شوێنی جۆراوجۆر. شوێنی کونەکان بریتی بوون له : ناوەڕاستی ناوچەی بڕینی دەرەوە، ناوەڕاست ی ناوچەی بڕینی ناوەوە، و ناوەڕاستی ڕایەڵەکان. تەنها یەك جۆر له ڕیشاڵی پۆڵایین بەکارهات و بە ڕێژەی** 0.8٪ **له قەبارەی کۆنکریت. هەموو ڕایەڵەکان هەمان ڕێژەی ئاسنیان تێدابوو. ئە نجامەکانی پراکتیکی دەریان خست کە بوونی کون له ناوچەی بڕینی دەرەوە یان ناوەوە کاریگەری زۆری هەیە له سەر هەڵسوکەوت و بەرگری ڕایەلی کۆنکریتی بە جۆرێك کە درزی خوار کۆنترۆلی هەڵسوکەوتەکەی کردبوو. درزەکان وایان پێشاندا کە شیشی ئاسن ی سەرەکی سەرەوە ڕۆلێکی گرنگی نەبوو له بەشداربوون، بەلام ئەم ڕۆڵە زیاتر بوو له ڕایەڵەکانی بێ کون یان ئەوانەی کە کونەکان له ناوەڕاستی ڕایەڵەکە بوون بە تایبەتی له گەل زیادبوونی ڕێژەی** a/h .