The Structural Behavior of Indirectly Loaded Flanged Deep Reinforced Concrete Beams.

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Abstract:

The study is aimed to investigate the structural behavior of indirectly loaded flanged deep reinforced concrete beams. Twenty one flanged deep beams were tested. The behavior of beams under loading was observed. Cracking and ultimate loads were recorded.

Key words: Flanged deep beams, indirectly loaded, shear span-to effective depth

التصرف الإنشائي للعتبات الخرسانية المسلحة العميقة ذات الشفاه المحملة تحميلا غير مباشر.

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الخلاصة:

يهدف البحث الحالي لدراسة التصرف الأنشائي للعتبات الخرسانيه المسلحة العميقة ذات الشفاه المحملة تحميل غير مباشر. الدراسة تضمنت عمل مختبري لفحص احدى وعشرون عتبة خرسانيه مسلحة ذات شفاه. تمت مراقبة تصرف العتبات تحت تأثير التحميل و تسجيل الحمل عند حدوث التشقق المائل و الحمل المسبب للفشل.

Introduction:

Some reinforced concrete members have depth much greater than normal flexural members, in relation to their span, while the thickness in the perpendicular direction is much smaller than either span or depth. Members of this type are called deep beams in which the shear span /effective depth ratio is less than 2 for simply supported beams [1, 2] or less than 2.5 for any span of continuous beam [2]. According to the ACI Building Code 318-05[3], beams with clear spans less than or equal to 4 times the total member depth or with concentrated loads placed within twice the member depth from the face of 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, are classified as deep beams.

Reinforced concrete deep beams have many useful applications in building structures such as transfer girders, wall footing, foundation pile caps, floor diaphragms, shear walls and offshore structures[4]. The stronger compression zone provided by flanges in T-sections precludes shear compression failure in T-beams and as a result improves the shear strength capacity [5, 6].

Details of Test Beams:

The test beams were divided into three groups of similar shear span/effective depth ratios 1, 1.4 and 1.8 respectively. All beams were of T-cross section, had web thickness of (120mm) and had central intersecting member with the same overall depth of the beam. The details and dimensions of the beams are shown in Table (1). Each group consists of six beams, they had overall depth of 300mm, two of six had flange width of 360mm and flange thickness of 90mm, and 60mm respectively the other two had flange width of 300mm and flange thickness of 90mm, 60mm respectively. The last two of them had both flange width of 240mm and flange thickness of 90mm, 60mm respectively as shown in Figures (1 and 2). All beams were single span and without shear reinforcement.

The beams were designed to fail in shear, to satisfy this type of failure a suitable reinforcement was provided to avoid premature flexural failure. The design compressive strength of about 25 MPa after 28 days and slump of about 120 mm [7], [8] The main reinforcement was 12mm diameter deformed steel bars with yield strength of 420 MPa and anchored at the ends with 90 degree bent. Bearing plates of (100mm width, 10mm thickness and 120mm length) were seat at loading and supporting points in order to avoid local bearing failure as shown in Figure(3).

Table (1): Details of Tested Beams

Beam No.	a/d	l/h	f_{cu} N/mm²	f'_c N/mm²	f_t N/mm²
Series 1					
TB1Gr1	1.0	1.67	37.00	30.0	4.20
TB2Gr1	1.0	1.67	34.00	27.5	5.00
TB3Gr1	1.0	1.67	37.00	30.0	4.40
TB4Gr1	1.0	1.67	31.00	25.0	4.40
TB5Gr1	1.0	1.67	38.00	30.9	5.00
TB6Gr1	1.0	1.67	36.00	27.5	5.30
TB7Gr1	1.0	1.75	36.00	28.9	4.50
Series 2					
TB1Gr2	1.4	2.30	36.00	29.0	3.00
TB2Gr2	1.4	2.30	37.00	30.0	4.58
TB3Gr2	1.4	2.30	31.00	25.0	3.30
TB4Gr2	1.4	2.30	34.00	27.5	4.00
TB5Gr2	1.4	2.30	37.00	30.0	3.60
TB6Gr2	1.4	2.30	34.00	27.5	4.00
TB7Gr2	1.4	2.45	36.00	28.9	3.90
Series 3					
TB1Gr3	1.8	3.00	31.00	25.0	2.60
TB2Gr3	1.8	3.00	33.00	26.5	2.80
TB3Gr3	1.8	3.00	33.00	26.5	2.70
TB4Gr3	1.8	3.00	33.00	26.5	3.00
TB5Gr3	1.8	3.00	31.00	25.0	2.80
TB6Gr3	1.8	3.00	33.75	27.2	3.00
TB7Gr3	1.8	3.15	31.00	25.0	3.30

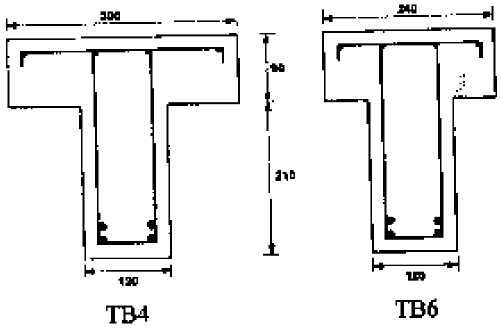

Fig. (1): Details of tested beams

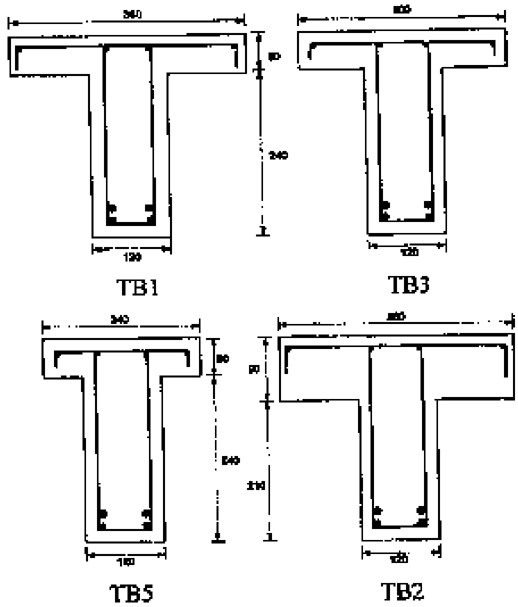

Fig. (2): Detail of tested beams

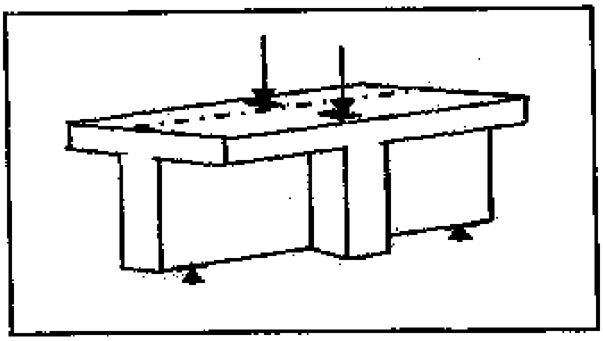

Fig (3) loading Type

Test program:

Twenty one simply supported reinforce concrete deep beams were tested, subjected to mid span one-point indirect load. The loading arrangement of the test specimens are shown in Figure (3).

Test Setup and Instrument:

Torsee's Universal Testing Machine with capacity Of 2000kN was used to apply the load. The beam was loaded from top at the centers of the spans. Load was applied gradually in equal increments. At each load increment, the total applied load on the beam mid-span deflection, and crack width were measured. The cracks were then plotted and marked .A test was terminated when the total load on the specimens started to drop off. The total time to failure in a test was approximately two hours. Figure (4) and Plate (1) shows the test setup.

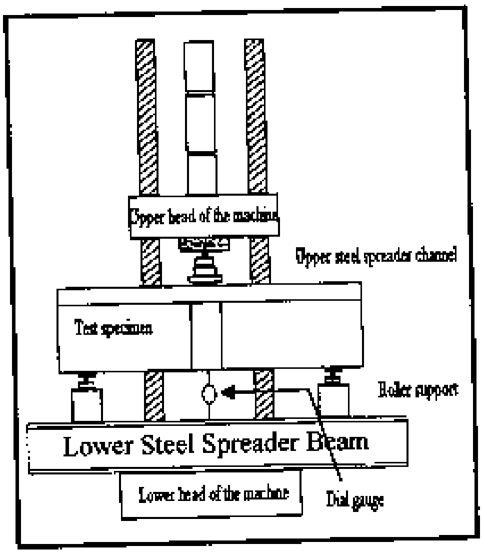

Fig. (4): Test Setup

Plate (1): Test Arrangement

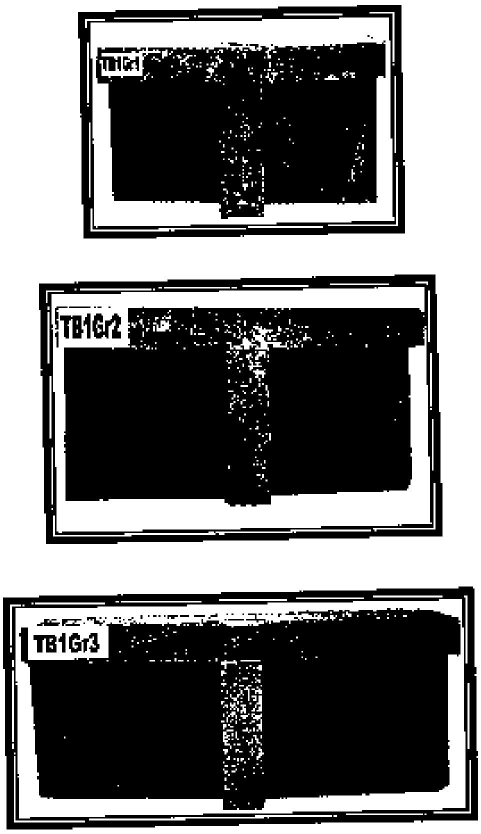

Plate (2): Crack Pattern

Experimental Result:

1. ***Behavior of Beams under Loading and Crack Patterns***:

All tested beams failed in shear. No local failure due to crushing of concrete under the load or over the supports was observed. Enough end anchorage of the main bars was provided; therefore no anchorage failure was noticed during testing. Crack patterns after failure are shown in Plate (2). For beams with shear span-to effective depth (a/d) ratio of 1.0 the first diagonal crack appears with thud at mid-depth between the applied load and support and few fine inclined cracks occurred in the mid-depth between the intersecting member and the support without bridging with each other. At failure load, one major inclined crack was widened. For beams with (a/d) of 1.4 and 1.8 similar behavior was observed except that the formation of inclined cracks was preceded by the development of few inclined crack near the intersecting member at the bottom of the beams. The failure occurred suddenly by extension of diagonal crack through the compression flange.

2. ***Inclined Cracking and Ultimate Loads***:

Inclined cracking and ultimate mid-span loads are listed in Table (2). Inclined cracking load is defined as the load at Which the first major inclined crack Appears in the shear span.

Beams TB2, TB4, and TB6 of group(1) showed 37%, 38%and 10% higher ultimate loads than beams TB1, TB3 and TB5 of group (1); beams TB2, TB4 and TB6 of group (2) showed 10%, 15% and 26% higher ultimate loads than beams TB1, TB3 and TB5 of group (2); beams TB2 and TB4 of group (3) showed 11% and 10% higher ultimate loads than beams TB1 and TB3 of group (3), This up rise in ultimate loads of higher flange depth beams is attributed to the stronger compression zone provided by increasing depth of flanges. Reserve strength of the beams, which is defined as the ratio of the difference of ultimate load and diagonal cracking load to diagonal cracking load expressed as a percentage, seems to decrease as (a/d) ratio increase as shown in Table (2). For beams with (60mm) flange depth and (360mm) flange width, an increase of 67% is obtained by reducing (a/d) ratio from (1.8 to 1), for beams with (90mm) flange depth and (360mm) flange width an increase of 80% is obtained by reducing (a/d) ratio from (1.8 to 1). Also the other beams show the same behavior. This increase in ultimate load is attributed to the higher contribution of arch action shear transfer in beams with lower (a/d) ratio.

3. Effect of Flange Depth

It can be seen from Table (2) that maximum loads are increased as the flange depth is increased (with the same a/d ratio). This increase is attributed to the stronger compressive zone provided by increase in the flange depth. Beams TB2Gr1, TB4Gr1, TB6Gr1 Exhibit 34%, 3% and 9% higher first cracking load and 18%, 15% and 20% higher ultimate load compared to corresponding beams TB1Gr1, TB3Gr1 and TB5Gr1. In group 2 and group 3 the variation of flange depth has a significantly effect on the ultimate load but less for cracking loads.

Table (2) Experimental Inclined Cracking and Ultimate Loads.

Beam No.	Span Load (kN) Inclined Cracking P_{cr}	Span Load (kN) Ultimate P_u	P_{cr}/P_u	P_u/bhf'_c R	$\frac{P_U - P_{cr}}{P_{cr}} \times 100$
Grope (1) a/d = 1					
TB1Gr1	117.70	300.00	0.39	0.27	155%
TB2Gr1	156.96	353.00	0.44	0.37	125%
TB3Gr1	156.96	313.90	0.50	0.29	100%
TB4Gr1	160.96	360.00	0.45	0.40	124%
TB5Gr1	161.86	353.00	0.46	0.32	118%
TB6Gr1	176.95	372.78	0.47	0.35	111%
TB7Gr1	196.96	317.80	0.62	0.23	61%
Grope (2) a/d = 1.4					
TB1Gr2	117.70	215.82	0.55	0.21	83%
TB2Gr2	117.70	323.73	0.36	0.23	175%
TB3Gr2	156.60	235.44	0.67	0.26	50%
TB4Gr2	156.96	293.32	0.54	0.30	87%
TB5Gr2	117.70	252.12	0.47	0.23	114%
TB6Gr2	156.60	284.50	0.55	0.29	82%
TB7Gr2	156.96	274.68	0.57	0.26	75%
Grope (3) a/d = 1.8					
TB1Gr3	112.80	180.00	0.63	0.19	60%
TB2Gr3	110.00	196.00	0.56	0.21	78%
TB3Gr3	98.00	193.00	0.51	0.20	97%
TB4Gr3	137.00	213.00	0.64	0.22	55%
TB5Gr3	107.90	198.00	0.54	0.22	84%
TB6Gr3	127.50	215.80	0.59	0.22	69%
TB7Gr3	137.00	230.00	0.59	0.26	68%
		Average		0.53	
		Standard		0.08	

Conclusion:

Based on the test results of the indirectly loaded flanged deep reinforced concrete beams that investigated in this present study, the following main conclusions can be drawn:

1. The crack pattern showed that the webs of all the beams functioned as simple struts between loads and supports.
2. The mid-span deflections of the indirectly loaded flanged deep beams are small and less than the permissible deflections specified by the ACI Building Code (318-05) which is (L/360) and does not cause any problem at service load (P_u/1.5).
3. The increasing of flange depth of the T-beams in the same (a/d) ratio causes an increase in ultimate shear load – carrying capacities. The same tendency is observed for the case of the respective deflections.
4. Both inclined cracking and ultimate loads have a tendency to increase with decreasing the shear span to effective depth ratio below 1.8. An increasing of about (44%) in inclined cracking load and (28%) in ultimate load of beam TB7Gr1 and TB7Gr3 are

obtained by reducing the (a/d) from 1.8 to 1.

General Symbols:

a	Shear span.
b	Web width
f_t	Tensile strength of concrete.
h	Overall depth of beam.
l	Clear span.
P_{cr}	Cracking span load.
P_u	Ultimate span load.
R	Non dimensional ultimate load.
d	Effective depth of beam.
f'_c	Cylindercompressive strength of concrete.
f_{cu}	Cube compressive strength of concrete.

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