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Experimental Study of Self Compacting Reinforced Concrete Deep Beams under Four Point Loads

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ABSTRACT

The results of eight reinforced concrete deep beams tested under four point loading condition are reported. The test beams were simply supported and were made with self compacting concrete (SCC). The variables were; web reinforcement and anchorage of tension reinforcement. The test beams were divided into four groups according to the web reinforcement. Each group consists of two beams, one with the anchorage of tension reinforcement and the other without. The nominal cross section was 100 x 300mm and the clear span length was 1100mm. Deflections of beams and cracking patterns were monitored during the tests at different stages of the monotonic loading until failure. The results showed the significance of the web reinforcement and anchorage of tension bars on the strength and failure behavior of SCC deep beams. The ultimate strength of beam without web reinforcement increased to 39% by adding anchorage to the longitudinal tension reinforcement. While the ultimate strength of the beam increased to 16% by adding anchorage to tension reinforcement for beams having web reinforcement that consists of stirrups with horizontal reinforcement.

Keywords: Self Compacting Concrete, four point loads, anchorage effect, web and longitudinal reinforcement.

ألدراسة العملية للأعتاب ألعميقة للخرسانة ألمسلحة ذاتية ألرص تحت تأثير أربعة أحمال نقطية

الخلاصة

يعرض البحث النتائج التجريبية لفحص ثمان اعتاب خرسانية مسلحة عميقة تحت تاثير اربعة احمال نقطية. طبيعة الاسناد لجميع الاعتاب من نوع الاسناد البسيط و كافة الاعتاب مصنعة من الخرسانة ذاتية الرص. المتغيرات التي تم دراستها هي: تسليح الجذع و طول التثبيت لحديد الشد. قسمت الاعتاب المفحوصة الى اربعة مجاميع استنادا الى طبيعة تسليح الجذع. حيث تضم كل مجموعة عتبتين احداهما ذات تسليح شد مثبت بالنهايتين والاخرى بدون

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تثبيت. ابعاد المقطع 100 x 300ملم و بفضاء صافي 1100ملم. تم مراقبة مقدار الهطول و انتشار الشقوق اثناء مراحل التحميل و لحد الفشل. بينت النتائج اهمية كل من تسليح الجذع و طول تثبيت قضبان الشد على المقاومة و التصرف اثناء الفشل للاعتاب العميقة المصنعة من الخرسانة ذاتية الرص. حيث عند اخذ طول التثبيت لحديد الشد بنظر الاعتبار تزداد المقاومة القصوى للاعتاب الخرسانية الغير مسلحة الجذع بمقدار 39% عن تلك التي بدون طول تثبيت. بينما تزداد المقاومة القصوى للاعتاب المسلحة بالاتاري و التسليح الافقي بنسبة 16% باخذ طول التثبيت بنظر الاعتبار عن تلك التي بدون طول تثبيت.

INTRODUCTION

A deep beam can be defined as a beam having a ratio of span to depth of about 4 or less or having a shear span less than about twice the depth and which are loaded at the top or compression face only [1]. Reinforced concrete deep beams are used in structures as load distributed elements such as transfer girders, pile caps, shear walls and foundations.

Shear resistance of reinforced concrete deep beams has been studied extensively over the last few decades. Only few studies take the effect of four points load on the behavior of shear strength [2, 3 and 4]. The main reason is the mechanism of shear failure was difficult to be found, so most of the research has concentrated on the simpler case of two point loading. Zararis, and Zararis [4] provided that the shear strength of beams under four point load is considerably higher than the strength under one or two points loading arrangements. The results of simple deep beams tested by Tan et. al. [5] and Smith and Vantsiotis [6] showed that the relative effectiveness of horizontal and vertical shear reinforcement on controlling diagonal cracks and enhancing load capacity reversed for deep beams having an a/h less than 1.0, that is horizontal shear reinforcement was more effective for an a/h below 1.0, where the vertical shear reinforcement was more effective for an a/h larger than 1.0. On the other hand tests by Russo et. al. [7] included the effect of both horizontal and vertical web reinforcements in predicting the ultimate shear strength of deep beams but ignored the contribution of flexural steel. The current ACI code [1] and several researches [8 to 12] have recommended the design of deep beams using the strut and tie-model. In these strut and tie models, the main functions of shear reinforcement is to restrain diagonal crack near the ends of bottle-shaped struts and to give some ductility to struts. ACI318M-08 [1] requires that at supports of simply supported deep beams "positive tension moment reinforcement be anchored to develop yield stress of bars at the face of the support or at the end of the extended nodal zone if the deep beam is designed using Appendix A. This implies that the assumed force transfer mechanism for deep beams in ACI318M-08 corresponds to that of a tied arch on the other hand suggesting that beams with a/d of approximately 0.5 or less be designed using a tied arch model , and those with an a/d of 2.0 or above be designed using truss model. The results of behavior of deep beams with short longitudinal bar anchorages [11] showed that shorter anchorage lengths than required by ACI 318-

08, chapter 12, are effective in developing the yield stress of bars at the end of the extended model zone.

Self-compacting concrete (SCC) was later used to facilitate construction operations and reduce construction time and cost. SCC has been defined by EFNARC [13] as a highly flowable yet stable concrete that can spread readily into place and fill the form work without compaction. The behavior of self compacting reinforced concrete deep beams is expected to differ from those R.C. deep beams [14 to 17]. Hence it is generally felt that studies are needed to understand the behavior of deep beam made with SCC under different conditions of shear reinforcement.

This paper presents laboratory test results of eight reinforced concrete deep beams under four points loading. The main variables included the amount and configuration of shear reinforcement, using SCC and the anchorage of the tension reinforcement. The influence of the steel reinforcement on the ultimate shear strength was compared with that in the corresponding simple ones.

RESEARCH SIGNIFICANCE

A great deal of research has focused on one or two points load with deep beams. Even the few tests on four points load deep beams were carried out on beams having concrete strength less than 35MPa and ignoring the effect of anchorage of tension reinforcement. Test results in this study showed the influence of shear reinforcement and anchorage of tension reinforcement on the structural behavior of high strength SCC deep beams under four point loads. The tests reported herein are used to identify changes in the force transfer mechanism in deep beams as a result of web reinforcement and anchorage of tension bars to incorporate the effect of shear and bond strength of deep beams.

EXPERIMENTAL INVESTIGATION

Specimen preparation

Eight reinforced concrete deep beams were designed, instrumented and tested in displacement control mode under a four point loading system in a simply supported configuration. The 2008 edition of ACI318 design code was adopted for the design of the beams and to determine the amount of flexural reinforcement such that shear failure would occur. The main experimental parameters in the test series were shear reinforcement and anchorage of tension reinforcement. The cross section of the beams (b x h), was 100 x 300mm. All beams were reinforced with three longitudinal reinforcing bars (2#12 and 1#16mm), which corresponds to a steel ratio of 0.01743. Top reinforcement for all beams consisted of 2#6mm bars used for constructability of the beam reinforcing cage. Web reinforcement consisted of vertical stirrups formed using #6mm @100mm and horizontal bars formed using 2#12mm and 4#12mm. The beams were divided into four groups depending on the shear reinforcements. The first group without web reinforcement, the second group reinforced by vertical stirrups only, the third group reinforced by vertical stirrups and 2#12mm horizontal bars while the last group reinforced by vertical stirrups and 4#12mm horizontal bars. Each group consists of two beams one without anchorage and the other with hook anchorage. The details of reinforcement of test specimens are shown in Fig. (1).

MATERIAL PROPERTIES

Only one SCC mix was used in this investigation. The concrete was designed for an average 28 day concrete strength of 56 N/mm^2 (f'c). The design mix is shown in table (1). Ordinary Portland cement types I (conforming with the requirements of the ASTM C150 standards), fine aggregate and crushed river gravel from natural resource with maximum size of 14 mm are used (Both types of aggregate conformed to ASTM C33 requirements. The self compacting is obtained by using super plastiliciser which is Glenium 51 (This superplasticizer conformed to the requirements of types A and F of the ASTM C494 standard) and limestone powder with a fineness of 3100 cm^2/gm [18].

Mix proportioning of SCC must satisfy the criteria on filling ability, flowability, passability and segregation resistance. The mix design method used in the present study is according to EFNARC [13]. Numerous trial mixes were prepared to obtain both the fresh concrete properties as well as the target concrete compressive strength. The main characteristics of SCC are the properties in the fresh state. Production of SCC is focused on its ability to flow under its own weight without vibration and the ability to obtain the homogeneity without segregation of aggregate. The slump table flow, V-funnel and L-box are used for assessment of fresh properties of SCC in this study. The tests results of the fresh properties of the SCC mix are shown in Table (2).

The physical properties of reinforcement are given in table (3). All longitudinal and shear reinforcing bars were deformed bars.

CASTING OF BEAM SPECIMENS

A horizontal rotary mixer of 0.19 m^3 capacity is used to produce SCC. Immediately after concrete mixing, tests on fresh properties of concrete mixtures as well as casting of beams in prepared wooden forms were carried out. SCC was cast without consolidation; the concrete was poured in the formwork from one end and easily flowed until it reached the other end. Visual observation showed that the SCC properly filled the forms with ease of movement around reinforcing bars. Formworks were removed after 24h of casting and beams were cured moist until the date of testing (after the age of 28 days).

TEST SETUP

The test beams were subjected to four concentrated loads applied at the top compression surface of beams in a (3000kN) capacity Universal Testing Machine (hydraulic type) of the Structures Laboratory in the department of Civil Engineering, College Of Engineering, Al-Mustansireyah University, as shown in Fig. (2).

Two series of steel I joists with rollers and steel plates were employed as load transfer devices for all beams. Details of the test setup are shown in Fig.(3). Beam surfaces were white washed on all sides to facilitate visual observation of the propagation of cracks. Two deflectometers having the smallest division of 0.01 mm were employed to measure the deflection of test beams at each load increment. One of these was set at midspan and another at the quarter of the span. The cracking and ultimate loads and the observed deflections of test beams are given in Table (4). The observed crack patterns of test beams are shown in Fig. (4).

RESULTS AND DISCUSSIONS

Load Cracking Observation

The first flexural cracks occurred at midspan, diagonal cracks formed in the general direction between supports and load point on the test and far ends of the beams. Intermediate cracks between the midspan flexural cracks and these diagonal cracks formed subsequently, as shown in Fig. (4). All SCC beams failed after the occurrence of only one large diagonal crack at one of the beam sides (while normal concrete beams failed after the occurrence of two big diagonal cracks in both sides of beams [17]). The failure of all beams was noisy and accompanied by huge explosions.

Failure loads and Mode of Failure

All tested beams were designed to fail in shear. The failure occurred suddenly, right after the formation of a dominant diagonal crack, which occurred after the formation of flexural and flexural-shear cracks, as shown in Fig. (4).

The dowel action of the longitudinal tension bars contributes up to 39% of the shear capacity for non web reinforcement beam (while for normal concrete up to 25% [19]). This action is reduced by adding web reinforcement to the beam specimens, for stirrup reinforcement the dowel action becomes 19% while for full web reinforcement (stirrups with four horizontal bars) it is 16%

Experimental Load Deflection Response

The load deflection responses for all beams are presented in Figs. (5 and 6). Table (4) also shows the load and deflection at first flexural crack and diagonal crack, as well as the deflection at ultimate load.

Fig.(5) shows the behavior of beams with the different web reinforcement for beams without and with anchorage in tension bars. The test results show increasing deflection of the beams with the use of horizontal bars in addition to the stirrup reinforcement.

The load deflection behavior for beams with anchorage in tension bars gives deflection larger than beams without anchorage for beams without web reinforcement and for beams with stirrups. While the deflection is decreased for beams with anchorage in tension and web reinforcement, consisting of stirrups and horizontal bars, as shown in Fig. (6).

Post Cracking Shear Resistance and Ductility

The load at first flexural crack was observed visually and confirmed by marking the first step or slope change in the load central deflection curve. The load at the first diagonal crack was also observed visually. The ratio of failure load to the load at the first diagonal (P_u/P_d) is presented in Table (4), the ratio is increased by adding stirrups and stirrups with two longitudinal bars, but the ratio is decreased by adding stirrups and four longitudinal bars.

The post cracking shear ductility, expressed as the ratio of the deflection at failure load to the deflection at first diagonal crack load ($\delta_f/\ \delta_d$) was higher in beams with stirrups and with bond compared to other beams. The ratio of ($\delta_f/\ \delta_d$) was 204%, 311%, 373%, and 380% in beams without bond and with different web reinforcement respectively compared to 280%, 340%, 335%, and 326% in beams with bond and different web reinforcement respectively.

CONCLUSIONS

The first cracking load, midspan deflection, failure load, mode of failure, and ductility of SCC deep beams subjected to four concentrated loads were studied. Although the experimental test in this study was limited to testing only eight beams, the paper brings valuable information on the structural behavior of the deep beams. Based on the experimental investigations, the following conclusions were derived.

1) The first diagonal cracks in SCC beams occurred at around 77% of the failure load for beams without web reinforcement and without anchorage in tension bars. While this was at 50% of the failure load for beams with anchorage in tension bars (as calculated in Ref [5]), and occurred around 30% of the failure load for beams with full web reinforcement and anchorage tension bars.

2) The SCC failed after the occurrence of only one large diagonal crack at one of the beam sides. The failure occurred suddenly with loud noise and accompanied by huge explosions.

3) The dowel action of the tension bars contributes up to around 39% of the beam shear capacity for beams without web reinforcement while this percentage is down to 16% for beams with full web reinforcement (stirrups and horizontal bars).

4) Shear ductility (expressed as the ratio of the deflection at failure load to the deflection at first diagonal crack load $\delta_f/\ \delta_d$) was increased by adding web reinforcement and tension bars with anchorage. The ratio of ductility ($\delta_f/\ \delta_d$) was 204% for beams without web and without anchorage, these ratio increased to 280% and 311% for beams with anchorage and stirrup reinforcement respectively. The ductility increased by increasing web reinforcement for beams without anchorage in tension bars, the ratio of ($\delta_f/\ \delta_d$) was 311%, 378% and 380% with stirrups, stirrups with two horizontal bars and stirrups with four horizontal bars respectively. While the ductility decreased by increasing web reinforcement for beams with anchorage in tension bars, the ratio of ($\delta_f/\ \delta_d$) was 340%, 335% and 326% with stirrups, stirrups with two horizontal bars and stirrups with four horizontal bars respectively.

5) For all beams with and without anchorage in tension bars, the test results show increasing of the deflection of the beams by adding horizontal bars to the stirrups reinforcement.

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Table (1): Details of SCC mix

Cement (kg/m^3)	Limestone powder (kg/m^3)	Sand (kg/m^3)	Coarse Aggregate (kg/m^3)	Water ($liter/m^3$)	Superplastisizer ($liter/m^3$)	W/P
350	150	770	890	185	6	0.37

Table (2): Fresh Properties of SCC Mixes.

Mix	Diameter Table Flow (mm)	T_{500mm} (sec)	V-Funnel		L-Box		
			T_V (sec)	T_{V5} (sec)	Blocking H_2/H_1 Ratio	T20 (sec)	T40 (sec)
SCC	745	1.85	5.67	7.08	0.90	0.98	2.043
Criteria	500-800	< 2	< 6	< Tv+3	≥ 0.80	1±0.5	2±0.5

Table (3): Physical properties of reinforcements

Nominal Diameter (mm)	Actual Diameter (mm)	Area (mm^2)	f_y (MPa)	f_u (MPa)
6	5.9	27.2	382	545
12	12	113.1	476	566
16	15.9	197.8	518	632

Table (4): Load-deflection results

Beam	Load (kN)			P_u/P_d (%)	Deflection (mm)		δ_f/δ_d (%)
	First flexural crack (P_f)	First diagonal crack (P_d)	Ultimate (P_u)		First diagonal Crack load (δ_d)	Failure load (δ_f)	
B1	99	120	158	132	0.93	1.90	204
B2	97	110	220	200	1.00	2.80	280
B3	105	130	275	211	0.82	2.55	311
B4	100	130	325	250	0.88	3.00	340
B5	104	130	376	289	1.25	4.66	373
B6	100	130	435	335	1.45	4.86	335
B7	95	130	363	279	1.48	5.63	380
B8	98	130	418	322	1.84	6.00	326

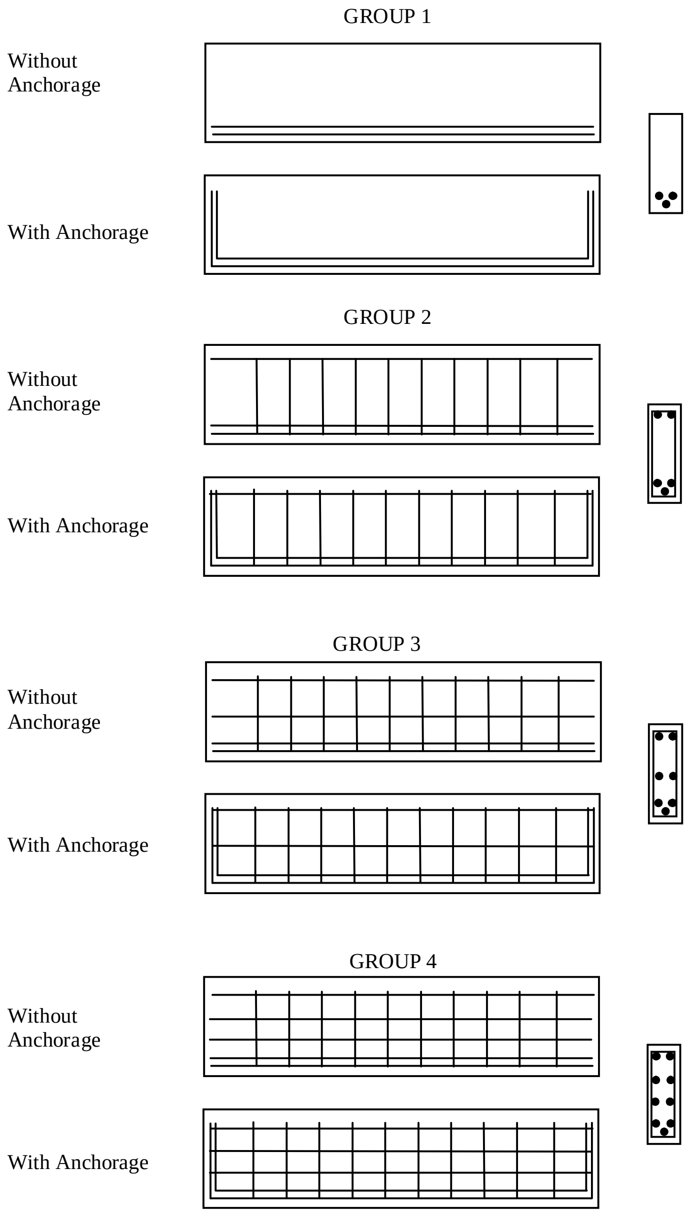


Figure (1): Details of specimen's reinforcements

Figure (2): Test setup

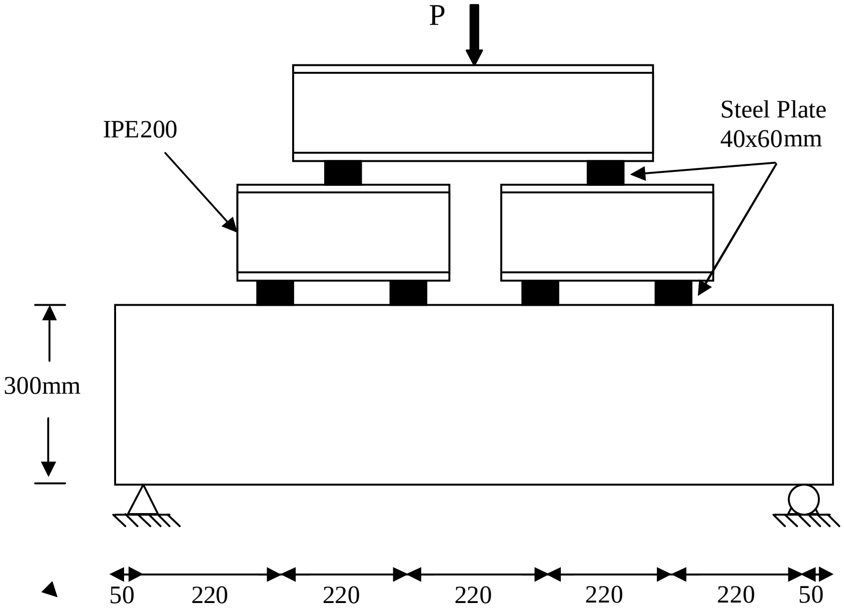


Figure (3): Load arrangement

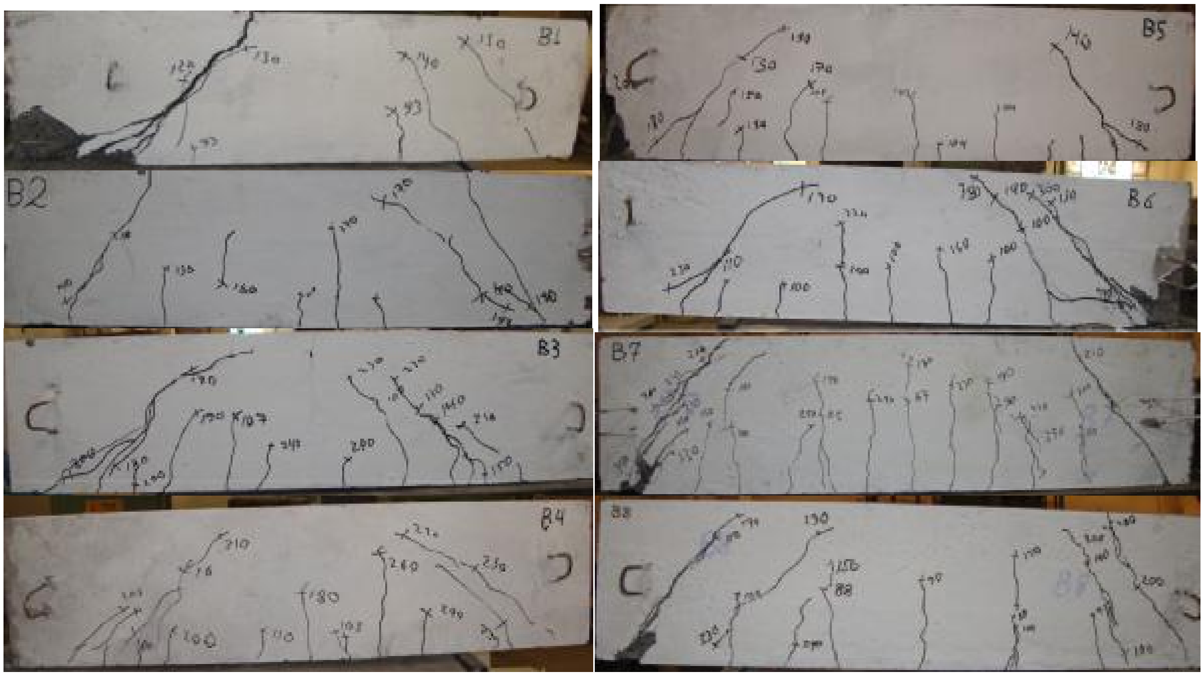
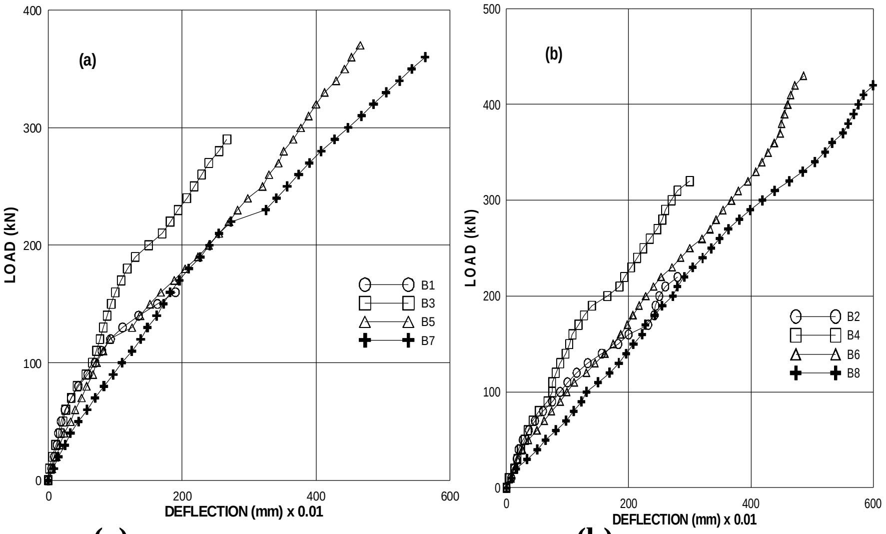


Figure (4): Failure Modes



(a) **(b)**

Figure (5): Load midspan deflection for beams; a- without anchorage, b- with anchorage

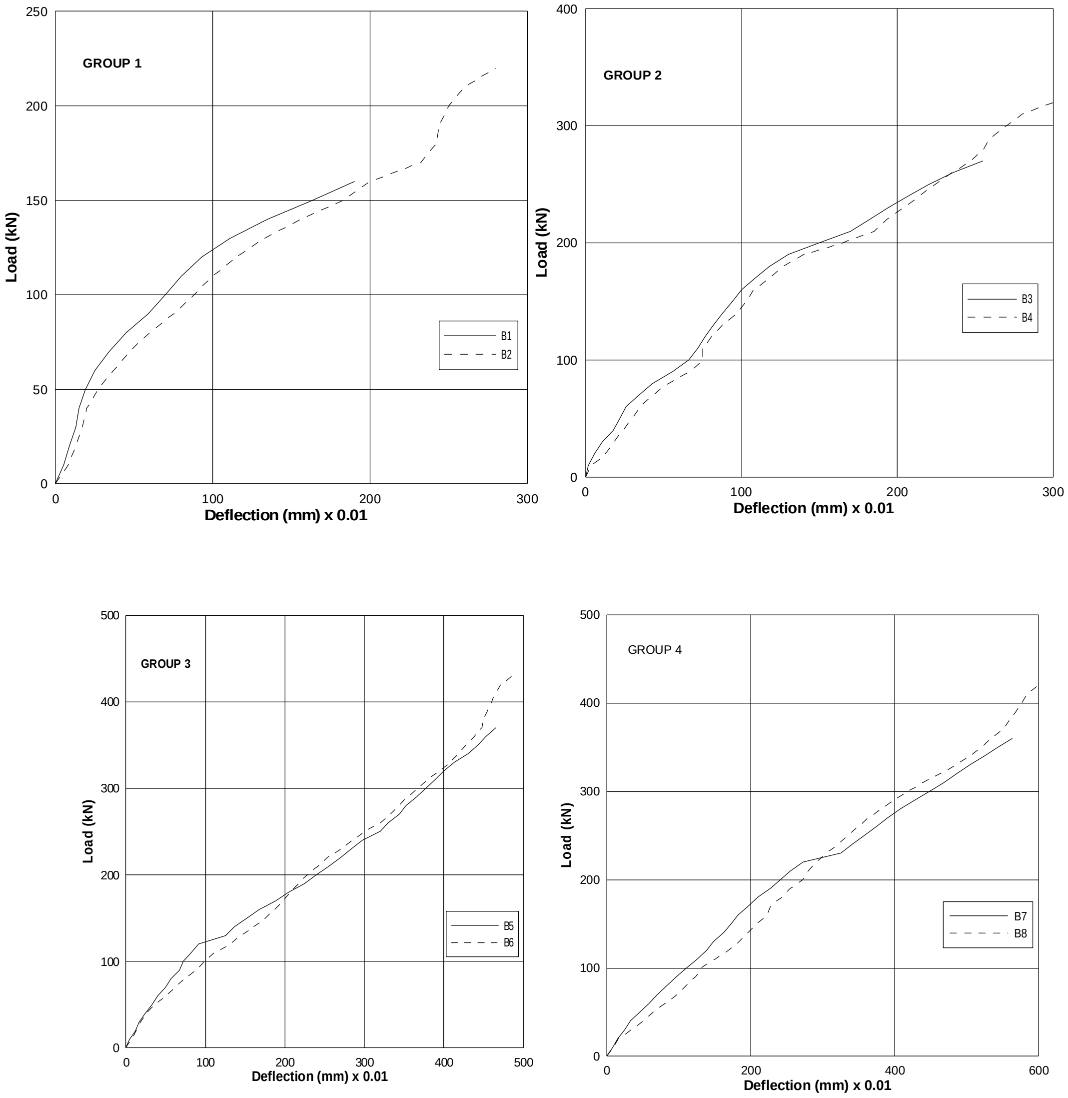


Figure (6): Load midspan deflection for the beams with similar web reinforcement