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NUMERICAL STUDY OF R.C. BRIDGE BEAMS UNDER STATIC AND CYCLIC LOADING

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Abstract

ECP 203[1] recommended two values for the compression steel ratio in rectangular R.C. section. The first ratio is 10 % of main reinforcement steel as a minimum value to contribute in reducing deflection, however the second ratio is 40 % of main reinforcement steel as a maximum value in an attempt to make the section is under reinforced section, however there is no specific definition for these ratios with the different grade of concrete. In this paper the effect of compression steel ratio on the behavior of a simple span R.C. beam such as bridge girder has been studied. Numerical study of R.C bridge girders under static and dynamic loads has been performed taking the effect of changing compression steel ratio with different concrete grades. Moreover the effect of increasing the steel compression ratios on the failure mode and ductility of concrete has been investigated. It is concluded that using high ratio of compression steel has no influence in case of high strength concrete beams compared with the normal strength concrete beams.

1. INTRODUCTION

Compression steel has an importance to use in concrete beams as stirrup hunger or increasing resistance of section to carry the internal forces.

There are four primary reasons for using compression reinforcement in beams [2]:

1. Reduces sustained-load deflections. First and most important, the addition of compression reinforcement reduces the long-term deflections of a beam subjected to sustained loads.
2. Increases ductility. The addition of compression reinforcement causes a reduction in the depth of the compression stress block, the strain in the tension reinforcement at failure increases.
3. Changes of mode of failure from compression to tension. When enough compression steel is added to such a beam, the compression zone is strengthened sufficiently to allow the tension steel to yield before the concrete crushes.
4. Fabrication ease. When assembling the reinforcing cage for a beam, it is customary to provide small bars in the corners of the stirrups to hold the stirrups in place in the form and also to help anchor the stirrups.

The ratios of compression steel affect the failure mode of section since, the failure produces crushing in compression concrete zone in case of lower grade concrete with low compression steel ratio or failure of tensile steel when the compression zone is strong enough. The ECP 203[1] recommended two values for the compression steel ratio first value must not decrease 10% and 40% for the second value. Different methods are used to ensure confinement of the compression zone for R.C. rectangular section.The simplest of these methods is using compression steel [4] and [5]; the other methods to confine compression zone of the beams are using either ties or fibers [6] and [7].

In this study, two types of loading have been studied; the first type is the static load and the other type is the incremental cyclic loading which flow the time load curve as shown in Fig.(1). Beams of 9 m span has been selected for this study. The cross section of this beam is 25 x 90 cm .

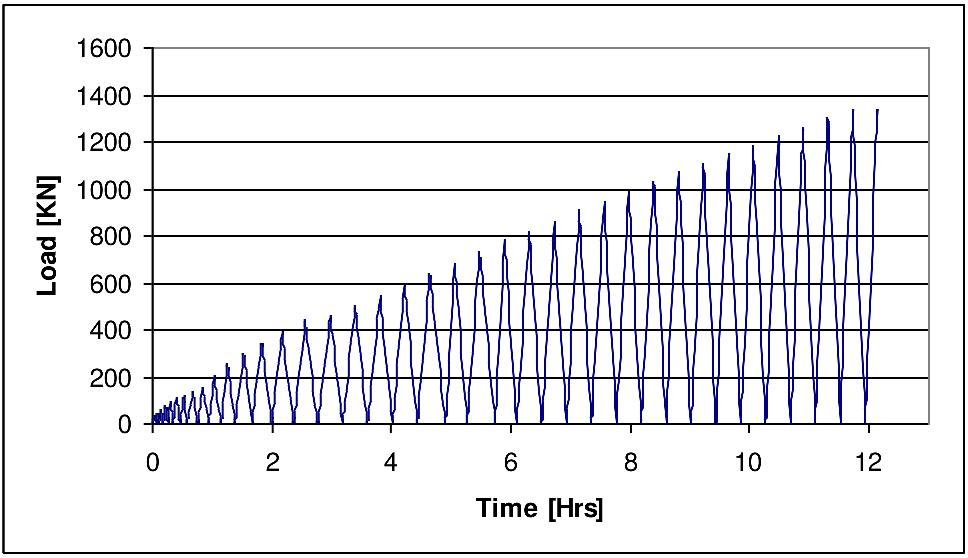

Figure 1 Load time curve for cyclic loading

Finite element method has been applied to analyze these girders. The concrete of the beam has been divided to small solid elements and the steel bars have been divided into small bar elements. ANSYS program [8] is used in the analysis. This study include the effect of compression steel ratios 10% , 25%, 40% and 60% with different concrete grades C250 , C350 , C600 and C800 . The study covers the effect of these different parameters on ductility and failure mode of the analyzed beams.

2. Verification of ANSYS computer program

The goal of the verification of the finite element program is to ensure that the proposed elements, material properties, real constants and convergence criteria are adequate to model the response of the beam. In order to verify the model, the control beam (LL3) tested by R. Vidya Sagar. [3] was analyzed. The tested beam has a 150 mm x 450 mm cross section, and 3200 mm length. The beam was designed to be simply supported over a span of 3000 mm and loaded at the two-third points. The longitudinal reinforcement of the beam consisted of three bars 22 mm. diameter with yield and ultimate strengths 360 MPa and 520 MPa respectively, and two bars 8 mm. diameter with yield and ultimate strengths 240 MPa and 350 MPa compression bars. The spacing for the stirrups with 8 mm. diameter is 200 mm. Figure (2) shows the geometry, reinforcement details, and loading of the analyzed beam.

The steel had an average yield stress of 360 MPa, and the concrete had an average compressive strength 58 MPa and the strength was determined by testing concrete cubes of dimension 150 mm x 150 mm x 150 mm made in laboratory and tensile strength of concrete mix was 3.56 MPa and the same was determined by conducting split cylinder (300 mm length, 150 mm diameter) tests.

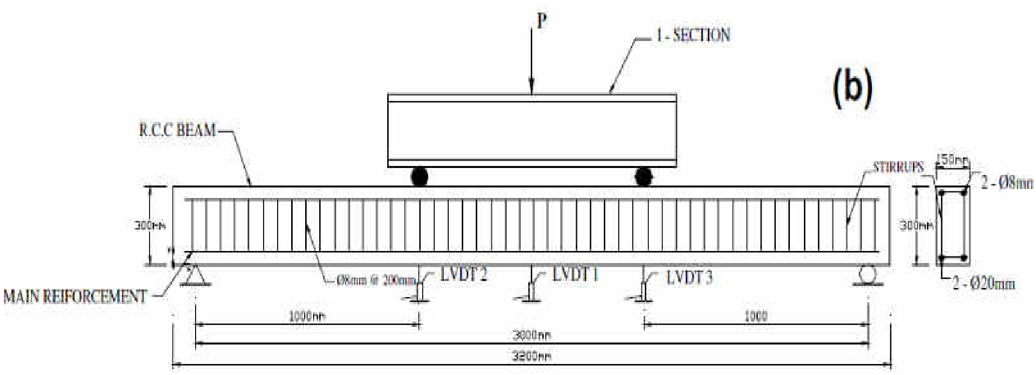

Figure 2 Geometry, Loading, and Reinforcement of Beam (LL3)
Tested by R. Vidya Sagar [3]

The finite element [9] adopted by ANSYS program was used as described previously. A quarter of the full beam was modeled by taking advantage of the symmetry of the beam and loadings. The load versus mid span deflection plots obtained from finite element study along with the experimental plots reported by R. Vidya Sagar, [3]are presented and compared as in Figure (3).
As shown in the figure, the given result of the numerical models for load versus mid span deflection are in good agreement with the experimental one.

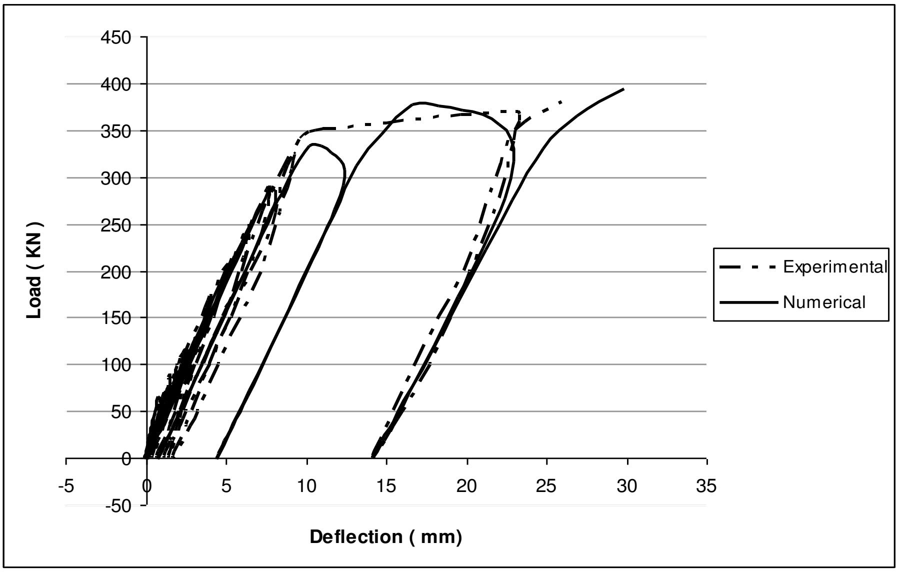

Figure 3 Experimental and numerical load versus mid span deflection plots of beam (LL3) tested by R. Vidya Sagar [3]

3. NUMERICAL STUDY AND RESULTS

3.1. Description of the Analyzed Beams

All the analyzed beams were simply supported over a span of 9000 mm with the same rectangular cross-section dimensions 250mm wide, and 900mm total depth and loaded by two concentrated loads. The distance between the load and support is equal to 3600 mm { a/d = 4.00 }

where a/d is shear span to beam depth ratio. The longitudinal reinforcement of the beam consisted of eight bars 22 mm. diameter with yield and ultimate strengths of 360 MPa and 520 MPa respectively for tensile steel. This means that the steel ratio in the beam (μact) equals approximately (0.0145). Number and cross section of stirrups are calculated for different grade of concrete in order to prevent shear failure. The compression steel is taken as a ratio of tension steel. These ratios are 10%, 25%, 40% and 60%. The meshing of the finite element of the beam and loading of typical beam are shown in Figure (4).

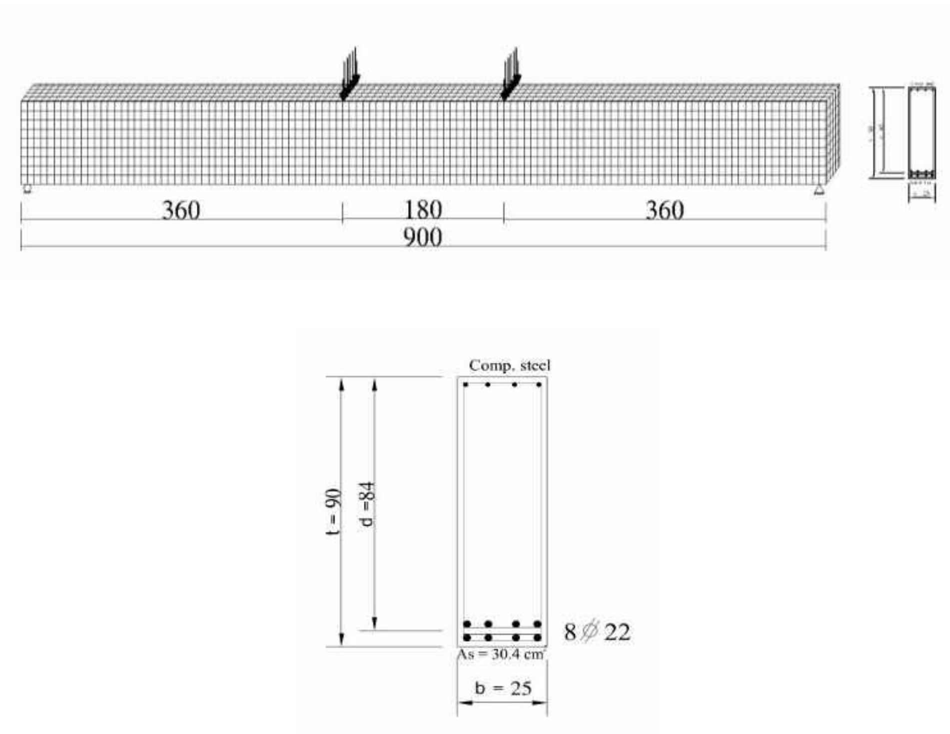

Figure 4 Details and Reinforcement of Analyzed Beams &Cross Sections

The concrete for the studied cases was assumed to have a characteristic strength of fcu= 25 MPa , 35 MPa , 60 MPa and 80 MPa where fcu is the compression strength of concrete, while its ultimate rupture tensile strength (fctr) was taken equal to $0.6\sqrt{fcu}$ MPa as recommended by ECP-203 [1]. Also, the longitudinal reinforcement and the stirrups were assumed to behave as an elastic - perfectly plastic material with yield stresses equal to 360 MPa and 240 MPa respectively.

The concrete beams sections can be divided to over reinforcement sections, balanced reinforced sections and under reinforcement sections these three types give impression for failure mode. Brittle failure occur when the beams have balance or over reinforcement sections. Ductile failures occur when the beams have under reinforcement sections, this type of failure given prior notice before the failure occur so this type of cross section used in design to obtain the preferred type of flexural behavior. The meaning of an under-reinforced beam section is that, when the section is loaded in bending beyond its elastic range, the tension zone steel will yield before the concrete in the compression zone reaches its maximum useable strain, εcu.

The type of section can be identified by knowing the maximum steel ratio (μmax) which equals to 0.0005 fcu for steel 36/52 According to ECP-203 [1]. Table (1) shows the types of sections for beams under study.

Table 1 Types of sections for beams under study

fcu	Mmax	μact	Type of sec.	Effect of increasing compression steel
250	0.0125	0.0145	Over rein.	Change the section from brittle to ductile
350	0.0175	0.0145	Under rein.	Increase ductility for the section
600	0.03	0.0145	Under rein.	Increase ductility for the section
800	0.04	0.0145	Under rein.	Increase ductility for the section

In order to investigate the effect of ratio of the compression to tension reinforcement ratio {α = As' / As } on the behaviour of beams, the beams are classified into four groups, each with a particular parameter. These groups can be described as follows:

Group A, contains four beams having compression strength of concrete fcu =25 MPa. Each beam is analyzed with two load cases first case static loading and the second case incremental cyclic loading

Group B, contains four beams having compression strength of concrete fcu =35 MPa. Each beam is analyzed with both loading types as previously mentioned in Group A.

Group C, contains four beams having compression strength of concrete fcu =60 MPa. Each beam is analyzed with both loading types as previously mentioned in Group B.

Group D, contains four beams having compression strength of concrete fcu =80 MPa. Each beam has analyzed with both loading types.

The details of the analyzed beam are presented in table (2)

Table 2 Details of the Analyzed Simply-Supported Beams

Group	Grade of concrete	Beam no.	α = As`/As	As (mm^2)	As' (mm^2)	Stirrup cross sec. (mm^2)	No of stirrups /m
A	C250	A1	0.10	3040	304	50.5	7
		A2	0.25	3040	760	50.5	7
		A3	0.40	3040	1216	50.5	7
		A4	0.60	3040	1826	50.5	7
B	C350	B1	0.10	3040	304	50.5	7
		B2	0.25	3040	760	50.5	7
		B3	0.40	3040	1216	50.5	7
		B4	0.60	3040	1826	50.5	7
C	C600	C1	0.10	3040	304	50.5	5
		C2	0.25	3040	760	50.5	5
		C3	0.40	3040	1216	50.5	5
		C4	0.60	3040	1826	50.5	5
D	C800	D1	0.10	3040	304	28.3	5
		D2	0.25	3040	760	28.3	5
		D3	0.40	3040	1216	28.3	5
		D4	0.60	3040	1826	28.3	5

Where {As} is the summation of tensile bars areas and {As`} is the summation of steel bars area in compression zone.

3.2 Results and Discussions

The outcomes of the numerical study are presented to evaluate the influence of different parameters on the behavior of simply-supported, reinforced-concrete beams.

3.2.1 Load deflection curve for static and cyclic loading

Figure (5) shows the load deflection curve for beams with compression strength of concrete fcu =25 MPa. It is obvious from the figures that the increase deflection values increase with increasing the load values and numbers of cycles. For beam A1 which the compression steel ratio is equal to 10 %, a brittle failure occurs in the beam. This means that the concrete crushing in the compression zone occurs before the steel reaches the yield stage. The ultimate loads are the same for two cases of loading (static and cyclic) as shown in Figure (5-a) with cycles numbers of cyclic load of 15 cycles. For beam A2, although the value of ultimate load increased due to increasing of compression steel ratio to 25% as shown in Figure (5-b), the failure still brittle as beam A1and the numbers of cycles increase to 16 cycles. For beam A3, the steel reaches the yield stage with increasing of compression steel ratio to 40% which convert the failure from brittle to ductile in the case of static load, but for cyclic loading the failure still brittle, the ultimate load increases compared with the previous beams as shown in Figure (5-c) and the numbers of cycles increased to 17 cycles. For beam A4, the increasing of compression steel ratio to 60 % leads to start yielding stage for steel, the ultimate load increases than other cases, the failure became ductile for both cases of loading and numbers of cycles increase to 19 cycles

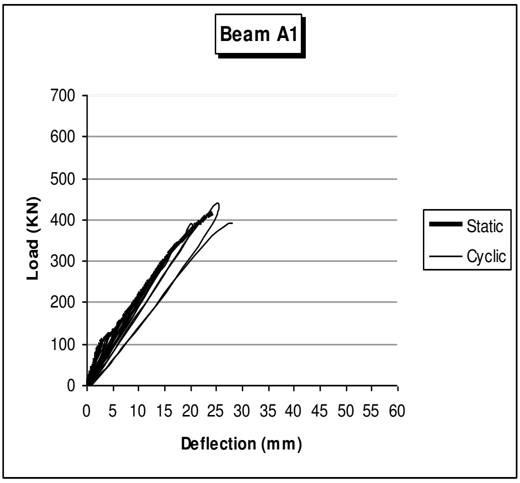

Fig (5-a)

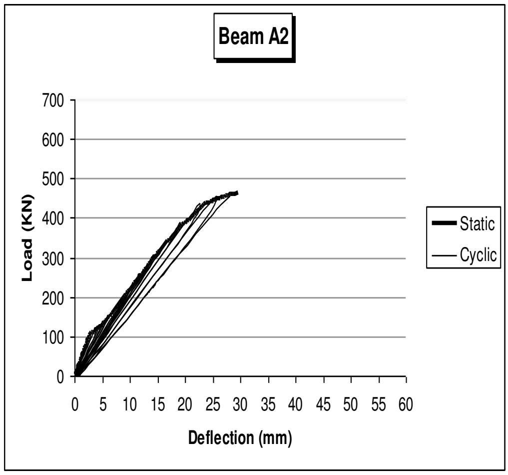

Fig (5-b)

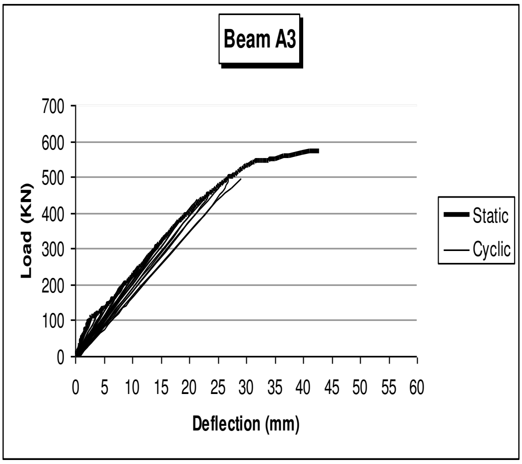

Fig (5-c)

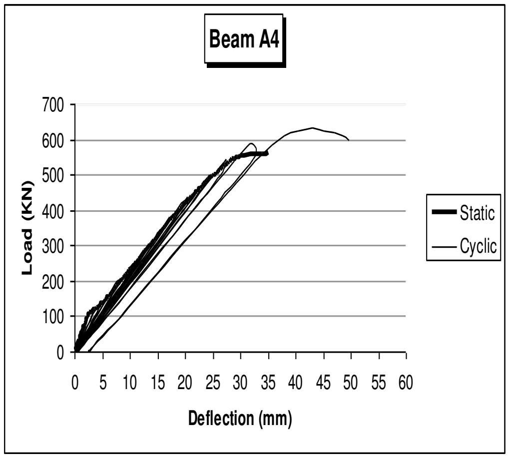

Fig (5-d)

Fig 5 load deflection curve for beams group {A}

Figure (6) shows the load deflection curves for beams with compression strength of concrete fcu =35 MPa. It is obvious from the figure that the ultimate load values required to failure increases with increasing of compression steel ratio the same for the deflection values for static loading case , the ultimate load values required to failure increases with increasing of compression steel ratio for the same deflection values and number of cycles for cyclic loading cases. In general in all cases the failure is ductile. For beam B1, the numbers of cycles are 18 cycles without residual deflection but in B2, the number of cycles increased and become 19 cycles which means that the increasing compression steel ratio 25% produces one new cycle more than B1, with residual deflection equals to 7% of maximum deflection.

For beam B3, the same style of beam B2 with increasing the compression steel ratio about 40 %, the numbers of cycles increased to 20 cycles, with residual deflection equals to 20% of maximum deflection.

For B4, the same style of B2 and B3 the number of cycles generated about 21 cycles by increasing the compression steel ratio 60%, with residual deflection equals to 31% of maximum deflection.

From above it is saying that the ultimate load and deflection are really connected by increasing the compression steel ratio in static loading case and also the ultimate load, deflection and numbers of cycles are connected by increasing the compression steel percentage in cyclic loading case

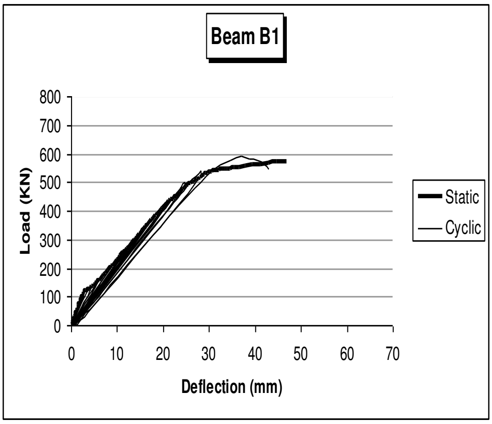

Fig (6-a)

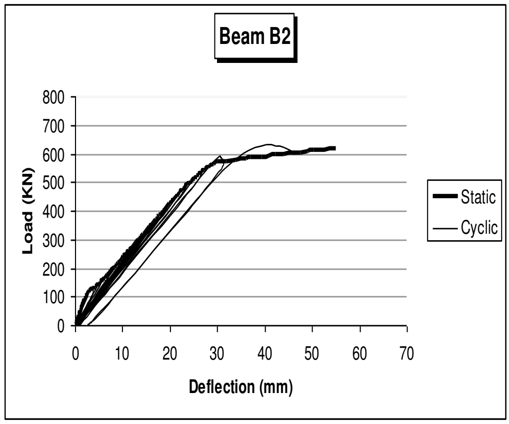

Fig (6-b)

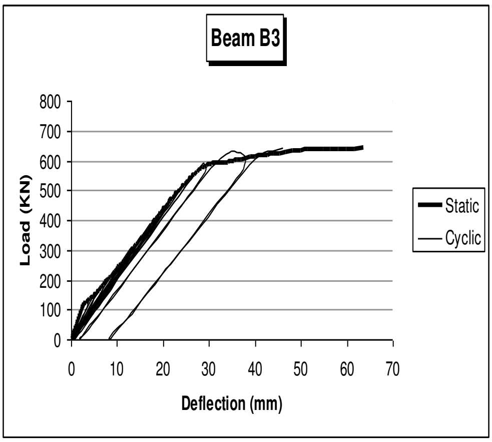

Fig (6-c)

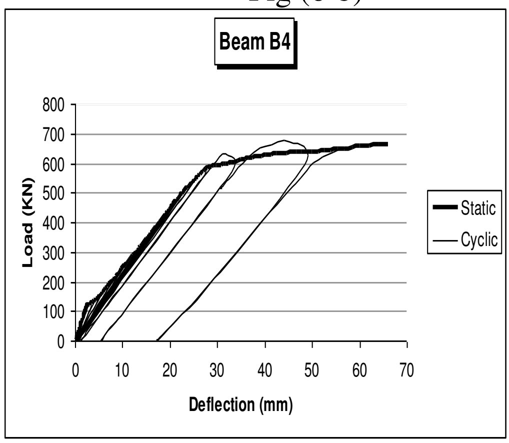

Fig (6-d)

Fig 6 load deflection curve for beams group {B}

Figure (7) shows the load deflection curves for beams with compression strength of concrete fcu =60 MPa. It is obvious from the figures that the ultimate load values required to failure increases with the increasing of compression steel ratio for the same deflection values for static loading case, the ultimate load values required to failure increases with increasing of compression steel ratio for the same deflection values and number of cycles for cyclic loading cases. In general in all cases, the failure is ductile. For beam C1, the numbers of cycles are 21 cycles with residual deflection equals to 32% of maximum deflection. In C2, the number of cycles increased and become 22 cycles which means that the increasing compression steel ratio 25% increases no of cycles, with residual deflection equals to 40% of maximum deflection.

For beam C3, the same style of beam C2 with increasing the compression steel ratio about 40 %, the numbers of cycles still 22 cycles, with residual deflection equals to 50% of maximum deflection.

For C4, for the same style of C2 and C3, the number of cycles generated about 22 cycles by increasing the compression steel ratio 60%, with residual deflection equals to 32% of maximum deflection.

From above it is saying that the ultimate load and deflection are really connected by increasing the compression steel ratio in static loading case and also the ultimate load, deflection and numbers of cycles are connected by increasing the compression steel percentage in cyclic loading case

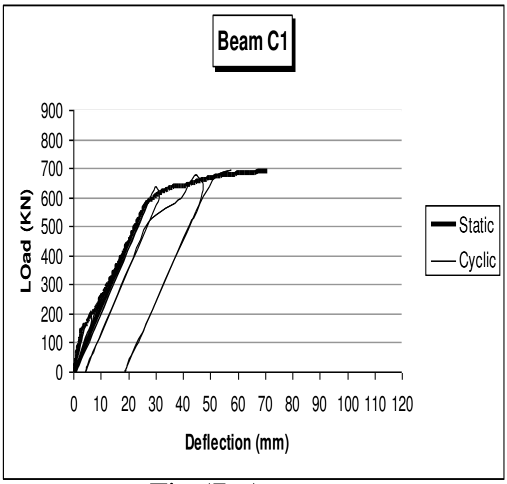

Fig (7-a)

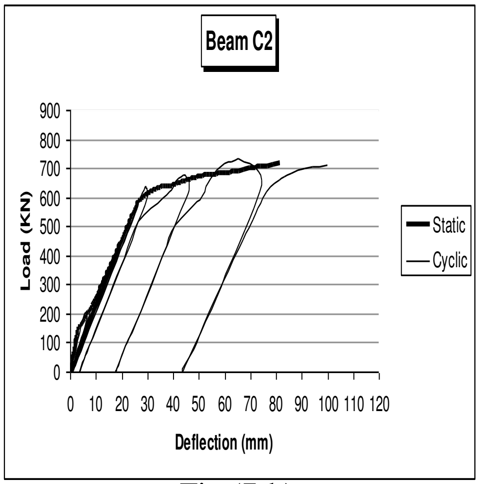

Fig (7-b)

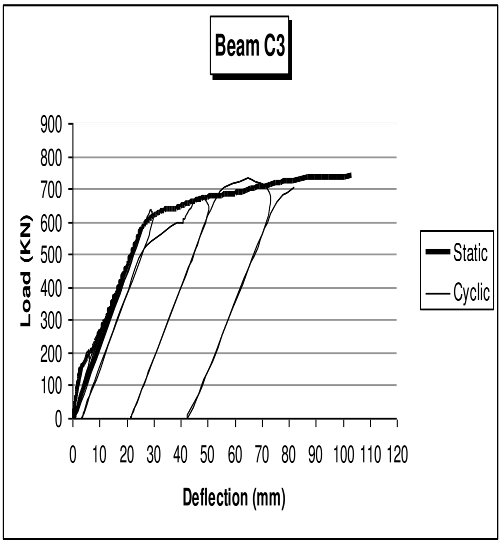

Fig (7-c)

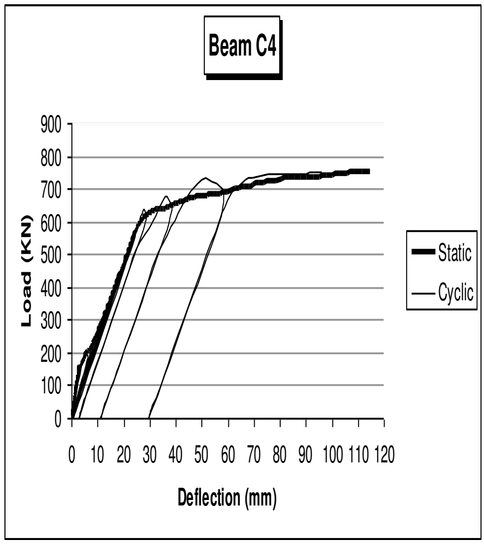

Fig (7-d)

Fig 7 load deflection curve for beams group {C}

Figure (8) shows the load deflection curves for beams with compression strength of concrete fcu =80 MPa. It is obvious from the figure that the ultimate load values required to failure increases with the increasing of compression steel ratio for the same deflection values for static loading case , the ultimate load values required to failure increases with increasing of compression steel ratio for the same deflection values and number of cycles for cyclic loading cases. In general in all cases, the failure is ductile. For beam D1, the numbers of cycles are 22 cycles with residual deflection equals to 37% of maximum deflection. In D2 the number of cycles still 22 cycles which means that increasing compression steel ratio 25% does not affect any more on numbers of cycles, with residual deflection equals to 37% of maximum deflection.

For beam D3, the same style of beam D2 with increasing the compression steel ratio about 40 %, the numbers of cycles still 22 cycles, with residual deflection equals to 37% of maximum deflection.

For D4, the same style of D2 and D3 the number of cycles generated about 22 cycles by increasing the compression steel ratio 60%, with residual deflection equals to 37% of maximum deflection.

From the above, one can say that the ultimate load and deflection are really connected by increasing the compression steel ratio in static loading case and also the ultimate load, deflection and numbers of cycles are connected by increasing the compression steel percentage in cyclic loading case

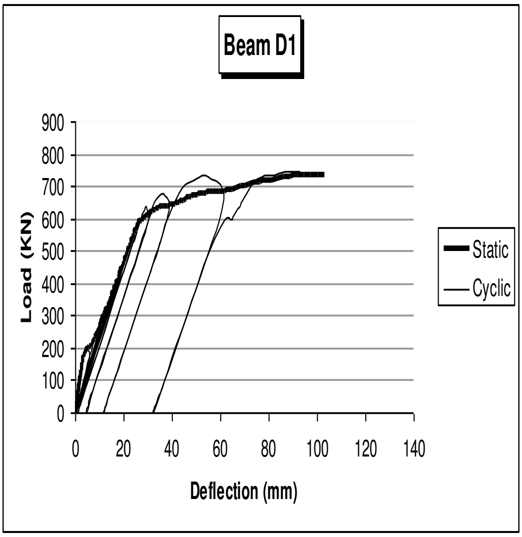

Fig (8-a)

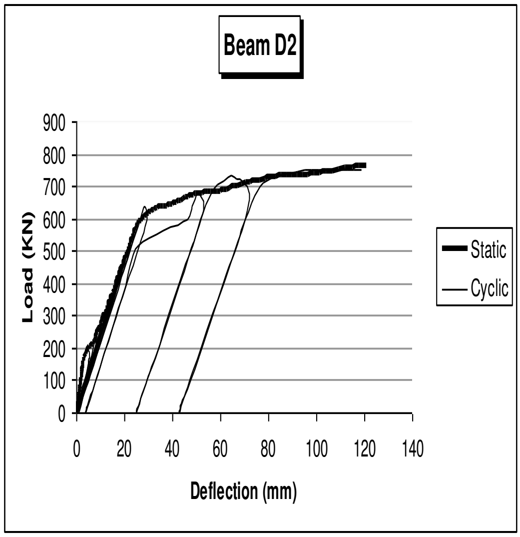

Fig (8-b)

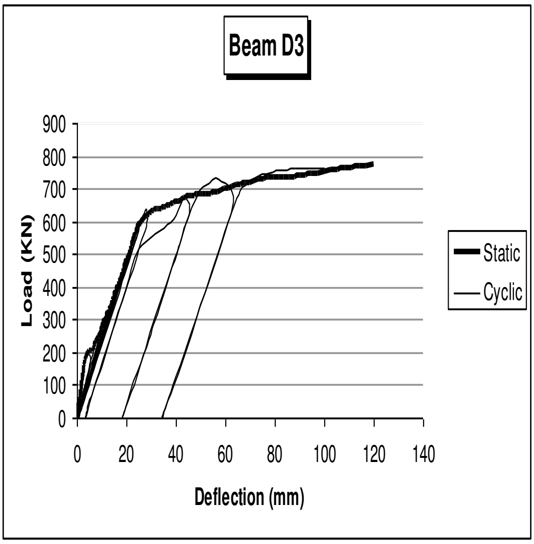

Fig (8-c)

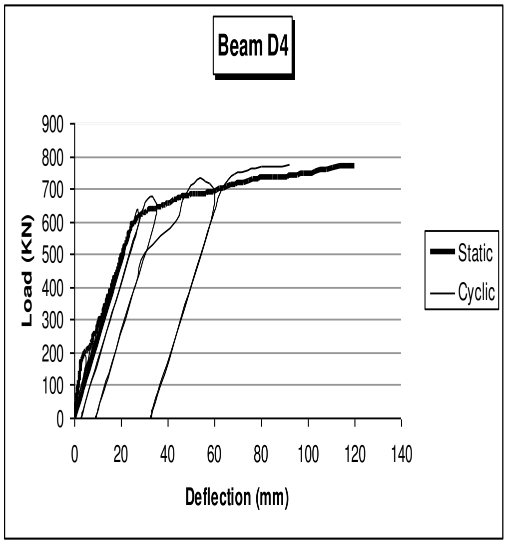

Fig (8-d)

Fig 8 load deflection curve for beams group {D}

3.2.2 Values of ultimate and yielding loads and mode of failure

The definition of ductility in this paper is the ultimate deflection divided by the value of deflection at the yielding point. Where the ultimate deflection is the value of the max deflection of beam, this deflection occurs at ultimate load which causes failure of the beam. To investigate the values of yielding deflection, the relations of the applied load are plotted against steel stresses in tension zone. These relations are plotted to determine the yielding load which causes the yielding deflection as shown in the two following figures 9 and 10.

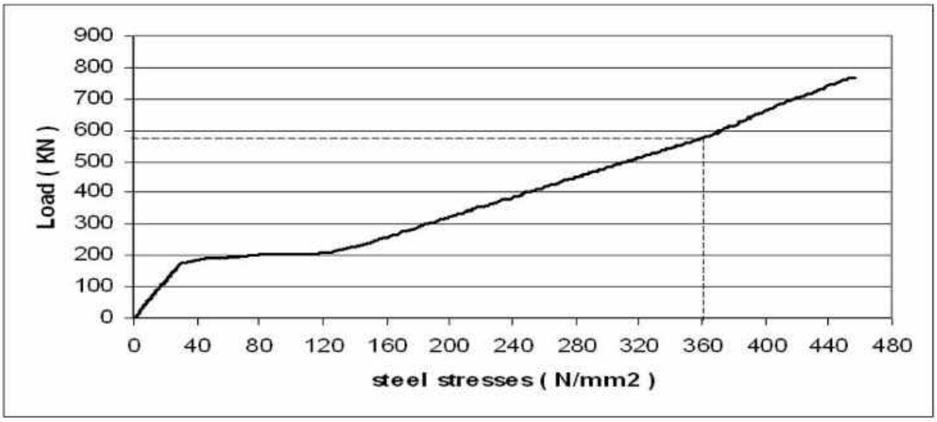

Fig 9 shows the relation between the load and steel stresses in case of static loading

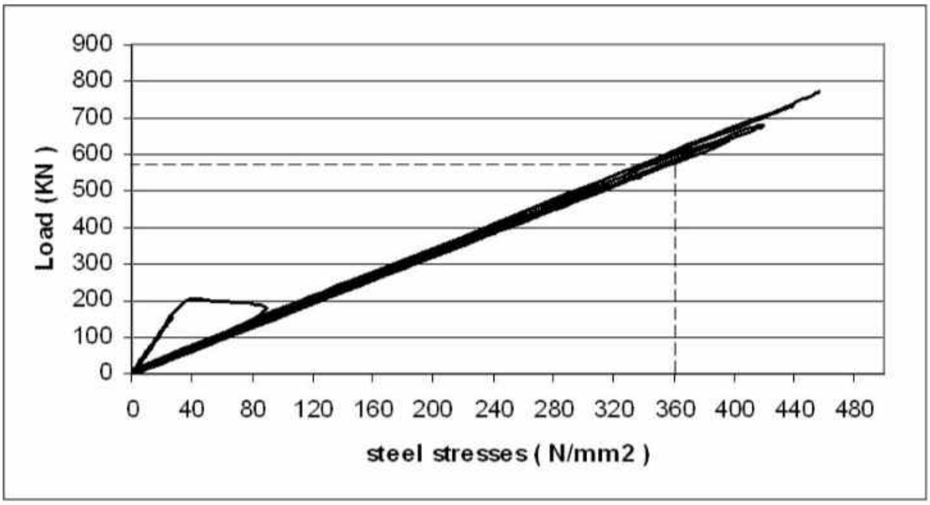

Fig 10 shows the relation between the load and steel stresses in case of cyclic loading

Tables 3 and 4 show the ultimate loads, yielding loads, ultimate deflections, yielding deflections, and mode of failures for all the analyzed beams.

3.2.3 Effect of compression steel ratio on the ductility of RC beams with different concrete strength

Based on the failure mode of all the examined cases (Tables 3 and 4), the beams with concrete strength of 25 MPa is excluded from the following discussions.
Under the effect of static loading, the compression steel ratio has a significant effect on the ductility of beams having concrete strength of 35 and 60 MPa, see Figure 11. For instance, the ductility of beams with concrete strength of 35 MPa and 60 MPa,

the increase is 27 % and 40 %, respectively. However, the increase in compression steel ratio over 25 % could not show any effect on the ductility of beams having concrete strength of 80 MPa.

On the other hand, under the effect of cyclic loading, the use of compression reinforcement with maximum 25% could guarantee the enhancement in the ductility for concrete strengths 60 and 80 MPa, as shown in Figure 12; where compression steel is 25% for the cases C2 and D2 (Tables 3, 4), the ductility increased by 53 % and 21 % in comparison with C1, and D1 with 10 % compression reinforcement ratio. For all the studied cases of concrete strength 35 MPa, the increase in compression steel ration is accompanied by insignificant increase in the ductility.

Table 3 the values of ultimate & yielding loads and mode of failure for static analyzed beams

Beam	Yielding load (KN)	Ultimate load (KN)	Yielding deflection (mm)	Ultimate deflection (mm)	Failure mode
A1	-	415	-	24.3	Brittle failure
A2	-	462	-	29.6	Brittle failure
A3	519	573	29	42.8	Ductile failure
A4	550	560	34	35	Ductile failure
B1	517	573	28	46.7	Ductile failure
B2	544	620	27.4	55	Ductile failure
B3	553	642	26.5	63.6	Ductile failure
B4	564	664	26.5	66.16	Ductile failure
C1	567	690	26.13	70.9	Ductile failure
C2	565	715	25.5	81.5	Ductile failure
C3	567	737	25	103.4	Ductile failure
C4	583	753	25.4	114.7	Ductile failure
D1	566	735.6	25	103.32	Ductile failure
D2	574.7	764.4	24.8	120.8	Ductile failure
D3	573	773.2	24.2	119.95	Ductile failure
D4	574	768.1	23.9	119.8	Ductile failure

Table 4 the values of ultimate & yielding loads and mode of failure for cyclic analyzed beams

Beam	Yielding load (KN)	Ultimate load (KN)	Yielding deflection (mm)	Ultimate deflection (mm)	Failure mode
A1	-	392	-	28.2	Brittle failure
A2	-	457.9	-	28.1	Brittle failure
A3	-	495.1	-	29.1	Brittle failure
A4	538	595	32	49.6	Ductile failure
B1	519	546	28	43	Ductile failure
B2	539	596	27.6	46.16	Ductile failure
B3	580	643	26.9	46	Ductile failure
B4	575	653.8	26	56.9	Ductile failure
C1	580	697.7	26	57.4	Ductile failure
C2	581	709.3	25.5	99.8	Ductile failure
C3	565	705.7	24	81.9	Ductile failure
C4	588	751.2	25.4	95.81	Ductile failure
D1	589	745.4	25	92.7	Ductile failure
D2	590	751.8	25.2	118.7	Ductile failure
D3	591	765.1	25	100	Ductile failure
D4	592	772.2	24.4	91.9	Ductile failure

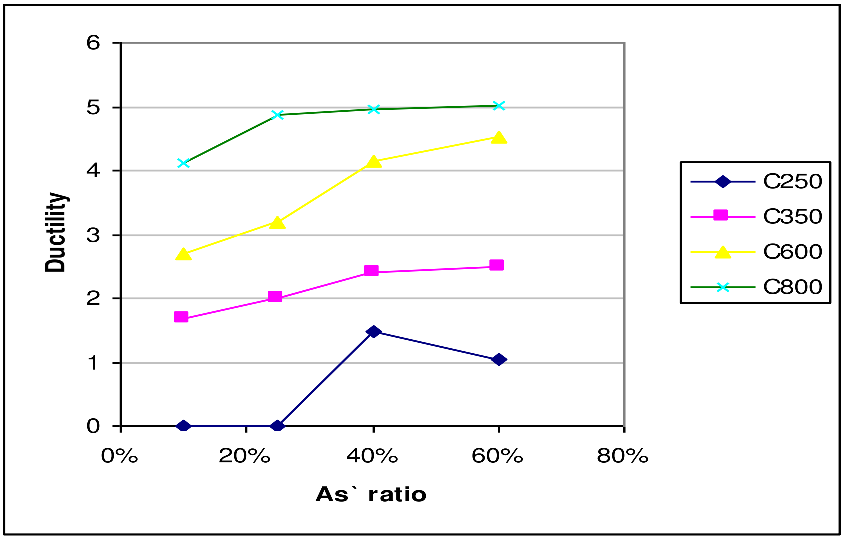

Fig 11 ductility with compression steel ratio for static loading beams

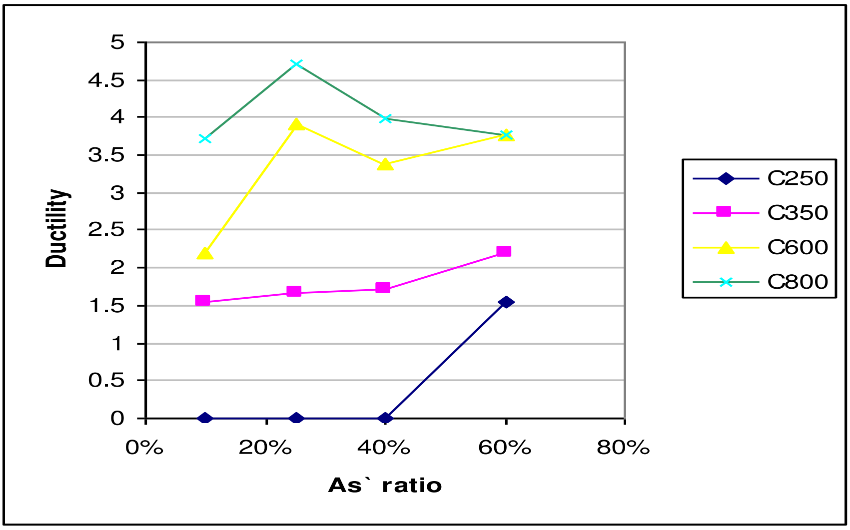

Fig 12 ductility with compression steel ratio for cyclic loading beams

4. Conclusions

Compression of steel ratio for the analyzed beams has a significant effect on the beams with normal strength concrete such as grade C250 and C 350 where the ratio changed the failure mode from crushing in concrete to tensile steel failure because the compression steel acts as stiffener to compression zone which gives the opportunity for steel to reach yielding and then to ultimate stress and failure.

Under the effect of static loading, the compression of steel ratio has a significant effect on the ductility of beams having concrete strength of 35 and 60 MPa, on the other hand, under the effect of cyclic loading, the use of compression reinforcement with maximum 25% could guarantee the enhancement in the ductility for concrete strengths 60 and 80 MPa

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دراسة عدديه لكمرات الكباري الخرسانيه تحت تأثير الأحمال الاستاتيكية والترددية

هذه الدراسة تهتم بفحص الكمرات بسيطة الارتكاز تحت تأثير الحمل الإستاتيكى والحمل المتردد . وفى هذه الدراسة تم فحص هذه الكمرات مع تغير رتبه الخرسانة وكذلك نسب حديد التسليح فى منطقه الضغط وشملت الدراسة الخرسانة ذات مقاومه 250 كجم/سم2 وهى الخرسانة المتداولة فى معظم المنشات العادية وكذلك الخرسانة 350 كجم/سم2 و 600 كجم/سم2 و 800 كجم/سم2 اما نسب حديد التسليح فى منطقه الضغط للكمرات البسيطة فتم اخذها كنسبه من حديد التسليح فى منطقه الشد وبنسب 10% و 25% و 40% و 60% .

كمرات هذه الدراسة أجريت على اثنى عشر كمره ذات بحر 9 متر وقطاع 25سم x 90 سم وتم اعتبار الحمل مركز فى نقطتين تبعد كل واحده عن الركيزة بمقدار 3.6 متر مما يحق نسبه القص الى العمق الفعال بمقدار 4.00 .

ومن اهم نتائج فى هذا البحث هى ان نسبه حديد التسليح فى منطقه الضغط ذات تأثير قوى فى حاله الخرسانة ذات الرتب العادية اما الخرسانة ذات المقاومه العالية فان زيادة نسبه حديد الضغط لها تأثير ضعيف على قدرة الكمرة و ممطوليتها مع زيادة مقاومه الخرسانة . وكذلك ان ممطوليه الكمرة تقل عند تغير نوع الحمل من استاتيكى الى متردد .