Shear Behavior of RC Deep Box Beams Strengthened Internally by Transverse Ribs

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Abstract

This research presents an experimental study of shear behavior of RC deep box beam strengthened internally by reinforced concrete transverse ribs. Eight beam specimens were tested, six box-deep beams and two solid-deep beams. The effect of type of concrete (NSC and SCC) and the number of internal cells on the behavior of deep box beam were tested. All beams were (2000mm) long and have been tested over a clear span of (1900mm) with a width of (450 and 200 mm) for top and bottom flanges respectively and (500mm) depth, the shear span-depth ratio (a/d) was (2) and longitudinal reinforcement ratio (ρ) was (0.00835). All beam specimens were simply supported under the effect of single point loading at mid span. The beam length, shear span-depth ratio (a/d), longitudinal and transverse reinforcement were kept constant for all tested beams. Test results indicated that all tested beams failed by shear and the failure took place by diagonal splitting mode for all tested beams except one beam, where its shear failure took place by diagonal compression mode. The results reveal that as (f'_c) increased from (30.7 MPa) to (58 MPa), increase in the first diagonal cracking load of (solid, one cell, two cells, and four cells) beams were about (17%, 27%, 23%, and 24%) respectively. Also, It was found that as (f'_c) increased from (30.7 MPa) to (58 MPa) increase in the ultimate load of (solid, one cell, two cells, and four cells) beams were about (63%, 56%, 45% and 59%) respectively. Test results indicated, also, that the box-deep beams which have two cells and four cells have the highest first diagonal cracking and ultimate loads as compared with box-deep beam which has one cell.

Keywords: **Shear, Deep beam, box beam, strengthening, NSC, SCC, Rib.**

سلوك القص للعتبات الخرسانية المسلحة الصندوقية العميقة المقواة داخليا بالأضلاع المستعرضة

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الخلاصة:

يتناول البحث الحالي دراسة عملية لسلوك القص للعتبات الخرسانية المسلحة العميقة الصندوقية المقواة داخليا بالاتجاه العرضي بواسطة أضلاع خرسانيه مسلحه . تم فحص (8) عتبات، قسمت إلى ستة عتبات خرسانية صندوقيه وعتبتين خرسانيتين صلدة ، لدراسة تأثير كل من نوع الخرسانة ،حيث تم استخدام الخرسانة العادية بمقاومه انضغاط (30.7 MPa) و الخرسانة الذاتية الرص بمقاومه انضغاط (58 MPa)، وعدد الخلايا (cells) المجوفة داخل العتبات الصندوقية على سلوك العتبات العميقة الصندوقية . جميع العتبات كانت بطول (2000mm) وقد تم اختبارها تحت فضاء (1900mm) وعرض (200 and 450) لكل من الشفة (Flange) العليا والسفلى على التوالي وب عمق كلي (500mm)،وكانت نسبه فضاء القص إلى العمق الفعال (a/d) تساوي (2) ونسبة حديد التسلح الطولي (0.00835) .جميع العتبات المفحوصة كانت ذات إسناد بسيط وتحت تأثير حمل مفرد (في المنتصف) حتى الفشل. تم الإبقاء على طول العتبة ، نسبة فضاء القص إلى العمق الفعال (a/d)، ونسبة حديد التسلح الطولي وتسليح القص دون تغيير لكافة العتبات المفحوصة . اشارت نتائج الفحص الى ان جميع العتبات المفحوصه فشلت بالقص وحصل الفشل نتيجة التشرقق القطري لجميع العتبات المفحوصه ما عدا عتبه واحده حصل فيها فشل بالقص نتيجة الانضغاط القطري . اظهرت النتائج انه بزيادة مقاومة انضغاط الخرسانه من (30.7 ميكاباسكال) الى (58 ميكاباسكال) كانت الزياده في حمل الشق القطري الاول بحدود (17%،27%،23% و 24%) للعتبلت الصلده و ذات التجويف الواحد وذات التجويفين وذات الاربعة تجويفات على التوالي. كذلك، اظهرت النتائج، انه بزيادة مقاومة انضغاط الخرسانه من (30.7 ميكاباسكال) الى (58 ميكاباسكال) كانت الزياده في الحمل الاقصى بحدود (63%،56%،45% و 59%) للعتبات الصلده و ذات التجويف الواحد وذات التجويفين وذات الاربعة تجويفات على التوالي . ان العتبات الصندوقيه العميقه الحاويه على تجويفين او اربعة تجويفات تكون فيها احمال الشق القطري الاول و الاحمال القصوى اكبر عند مقارنتها مع العتبه الصندوقيه العميقه ذات التجويف الواحد.

1-Introduction

A deep beam is a beam having a depth relatively high comparable to the span length. A reinforced concrete member in which the total span or shear span is exceptionally small in relation to its depth is called a deep beam [1]. Reinforced concrete deep beams appear as common structural elements in many structures ranging from tall buildings to offshore gravity structures. They are used as panel beams, foundation beams, and as deep grid walls in offshore gravity-type concrete structures [2].

Box or Hollow cross section beam, mean closed thin walled section beam. A thin walled beam is characterized by relative magnitude of its dimensions; the wall thickness is small compared to the other linear dimensions of the cross section[3].The applications of structural hollow sections nearly cover all fields. Sometimes hollow sections are used because of the beauty of their shape, to express lightness or in other cases their geometrical properties determine their use. These sections are used for the various fields such that in buildings, hall, bridges, offshore structure and towers [4]. A box girder structure consists of top and bottom flanges connected by vertical or inclined webs to form a cellular section. It is one of the most popular forms of highway bridges; primarily because of the high flexural and torsion rigidities .The use of box beams in highway-bridge construction has proven to be a very efficient structural solution [5].

Self-compacting concrete (SCC), is a new kind of high performance concrete (HPC) with excellent deformability and segregation resistance. It is a flowing concrete without segregation and bleeding, capable of filling spaces in dense reinforcement or inaccessible voids without hindrance or blockage [6]. SCC has been defined by EFNARC as a Concrete that is able to flow under its own weight and completely fill the formwork, even in the presence of dense reinforcement, without the need of any vibration, whilst maintaining homogeneity [7]. SCC can be used in situations where it is difficult or impossible to use mechanical compaction for fresh concrete, such as underwater concreting, cast in site pile foundations, machine bases and columns or walls with congested reinforcement [8].

In the present research, shear behavior of reinforced concrete deep box beam strengthened internally by reinforced concrete transverse ribs will be studied as well as the effect of type of concrete (NSC and SCC) and the number of internal cells which were separated from each other by reinforced concrete ribs.

2-Research objective

The objective of this research is to evaluate the shear behavior of reinforced concrete deep box beam strengthened internally by reinforced concrete transverse ribs. Discussions are presented regarding the ultimate shear strength and, mode of failures, deflection.

3-Experimental Program

Tests were carried out on eight simply supported beam specimens with minimum shear reinforcement have been tested under a monotonically concentrated load. The tested beams have been designed to ensure shear failure.

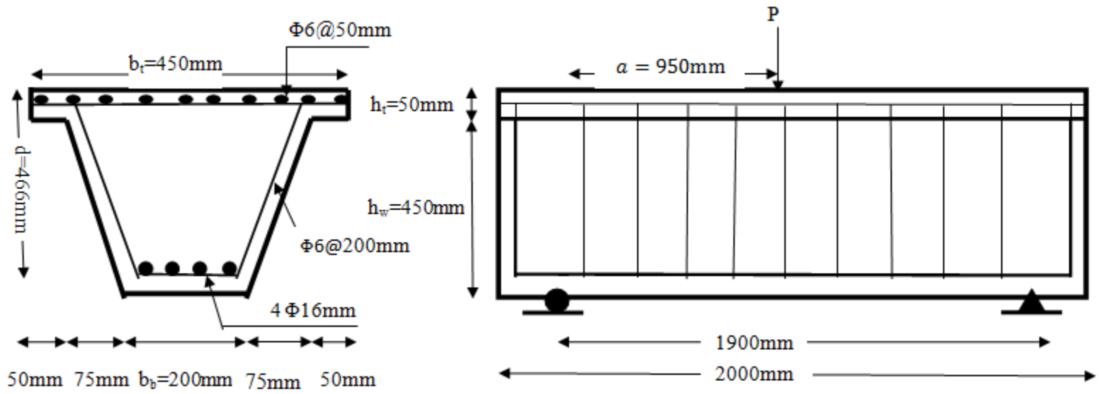
The variables were the type of concrete (NSC and SCC) and the number of internal cells which were separated from each other by reinforced concrete ribs. The beam length, shear span-depth ratio (a/d), longitudinal and transverse reinforcement were kept constant for all tested beams.

3-1-Beam Specimens Details

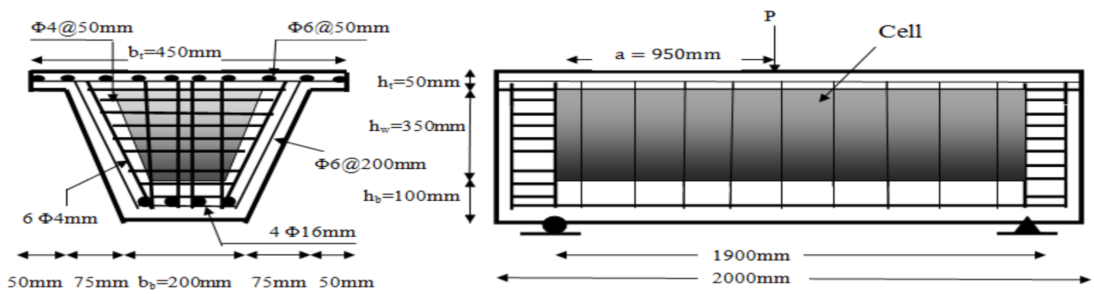
All beam specimens were (2000mm) long and overall depth of (500mm). They have been tested over a clear span of (1900mm) with shear–span ratio of (2). These beams reinforced longitudinally with ($\rho_=$0.00835) and transversally with ($\rho_{w=}$0.00136). Description and details of the test specimens are shown in Table (1) and Figure (1). It may be noted that, each beam is designated to referred to type of concrete and number of cells which are separated from each other by reinforced concrete ribs, for example, the beam NSC2, is a beam specimen made of NSC with two cells (containing three ribs).

Table (1): Beam Specimens Details

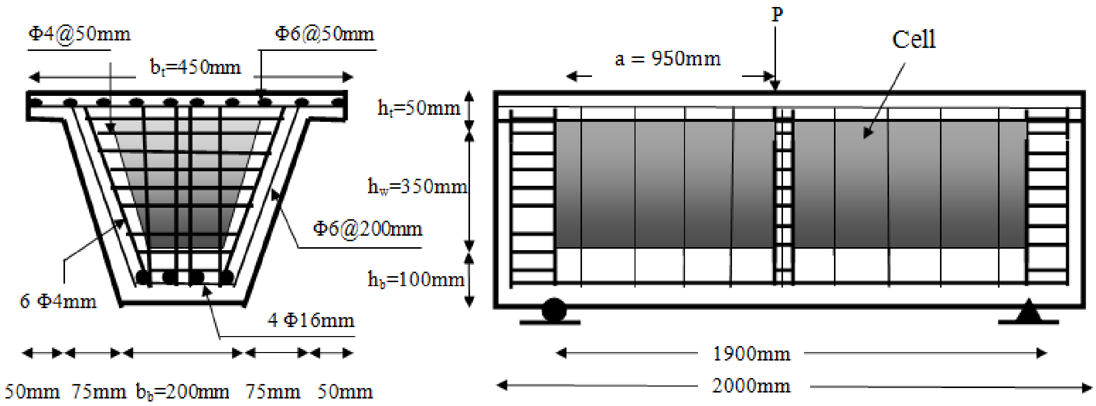
Group No.	Beams	b_t mm	b_b mm	h_t mm	h_b mm	h_w mm	No. of cells	f'_c MPa
G-1	NSC0	450	200	50	-	450	0	30
	NSC1	450	200	50	100	350	1	
	NSC2						2	
	NSC4						4	
G-2	SCC0	450	200	50	-	450	0	60
	SCC1	450	200	50	100	350	1	
	SCC2						2	
	SCC4						4	



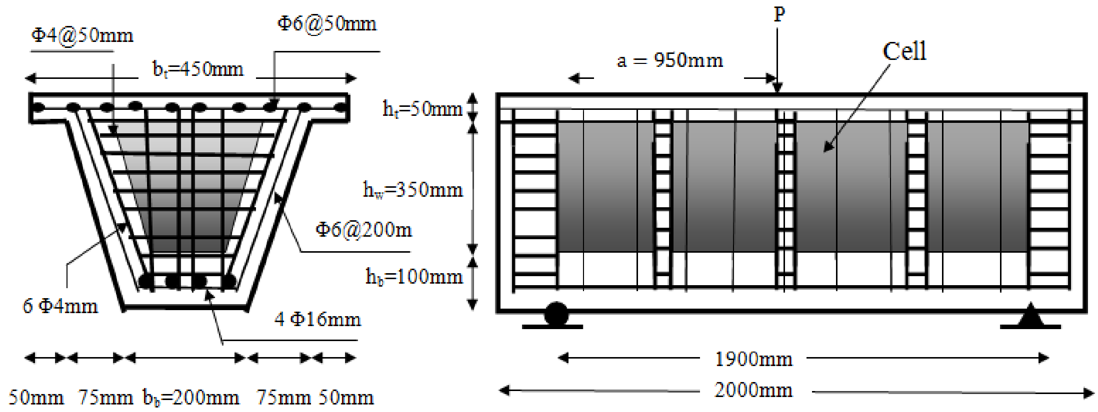
a-Without Cells



b-One Cell



c-2-Cells



d-4-Cells

Figure (1): Details of Deep Box Beam.

3-2-Materials

In manufacturing the test specimens, the properties and description of used materials are reported and presented in Table (2); and the concrete mix proportions are reported and presented in Table (3).

Table (2) Properties of Construction Materials

Material	Descriptions
Cement	Ordinary Portland Cement (Type I)
Sand	Natural sand from Al-Ukhaider region with maximum size of (4.75mm)
Gravel	Crushed gravel of maximum size (10 mm)
Limestone powder	fine limestone powder (locally named as Al-Gubra) of Jordanian origin
Superplasticizer	Glenium 51 manufactured by BASF Construction Chemicals, Jordan.
Reinforcing Bars	(ϕ16mm) deformed steel bar, having (491 MPa) yield strength (f_y) (ϕ6mm) plain steel bar, having (383 MPa) yield strength (f_y) (ϕ4mm) plain steel bar, having (461 MPa) yield strength (f_y)
Water	Clean tap water

Table (3) Proportions of Concrete Mix

Parameter	Concrete Type	
	NSC)	(SCC)
Cement (kg/m^3)	400	550
Fine Aggregate (kg/m^3)	600	825
Course Aggregate (kg/m^3)	1200	850
Limestone powder (kg/m^3)	-	50
Water (kg/m^3)	180	150
Water/cement ratio	0.45	0.27
Superplasticizer (L/m^3)	-	12

3-3-Test Measurements and Instrumentation

All beams were tested by using the Hydraulic Universal Testing Machine (MFL system) with a maximum range capacity of (3000kN). Vertical deflection was measured at mid-span and quarter of beam specimen length by using a dial gauge of (0.01mm/div.) accuracy at every load stage. The gage is placed under the bottom face of the tested beam.

3-4-Test Procedure

The beam specimens have been placed directly on the machine supports with a clear span (1900mm), as shown in Figure (2). The marked loading point has been covered by (450x50x30) mm steel plate to avoid stress concentrations on the upper face of the beams during loading. All beam specimens have been tested under monotonic loading with single concentrated load applied at the mid-span of the specimens. The dial gauge was mounted in their marked position to touch the bottom of center and quarter of the beam was fixed in their correct location. All beam specimens were loaded to failure. Each beam was initially "exercised" by applying a small load to ensure that the test setup and the instrument worked properly. The beam specimens were loaded in increments of (5kN), the rate of load increment was about (1kN/Sec).The positions and extents of the first and the other consequent cracks were marked on the surface of the beam. As failure occurred, when the beam failed abruptly at simultaneity with the load indicator stopped in recording or return back and the deflection increased very fast.

Figure (2): Beam Specimen Setup.

4-Results and Discussion

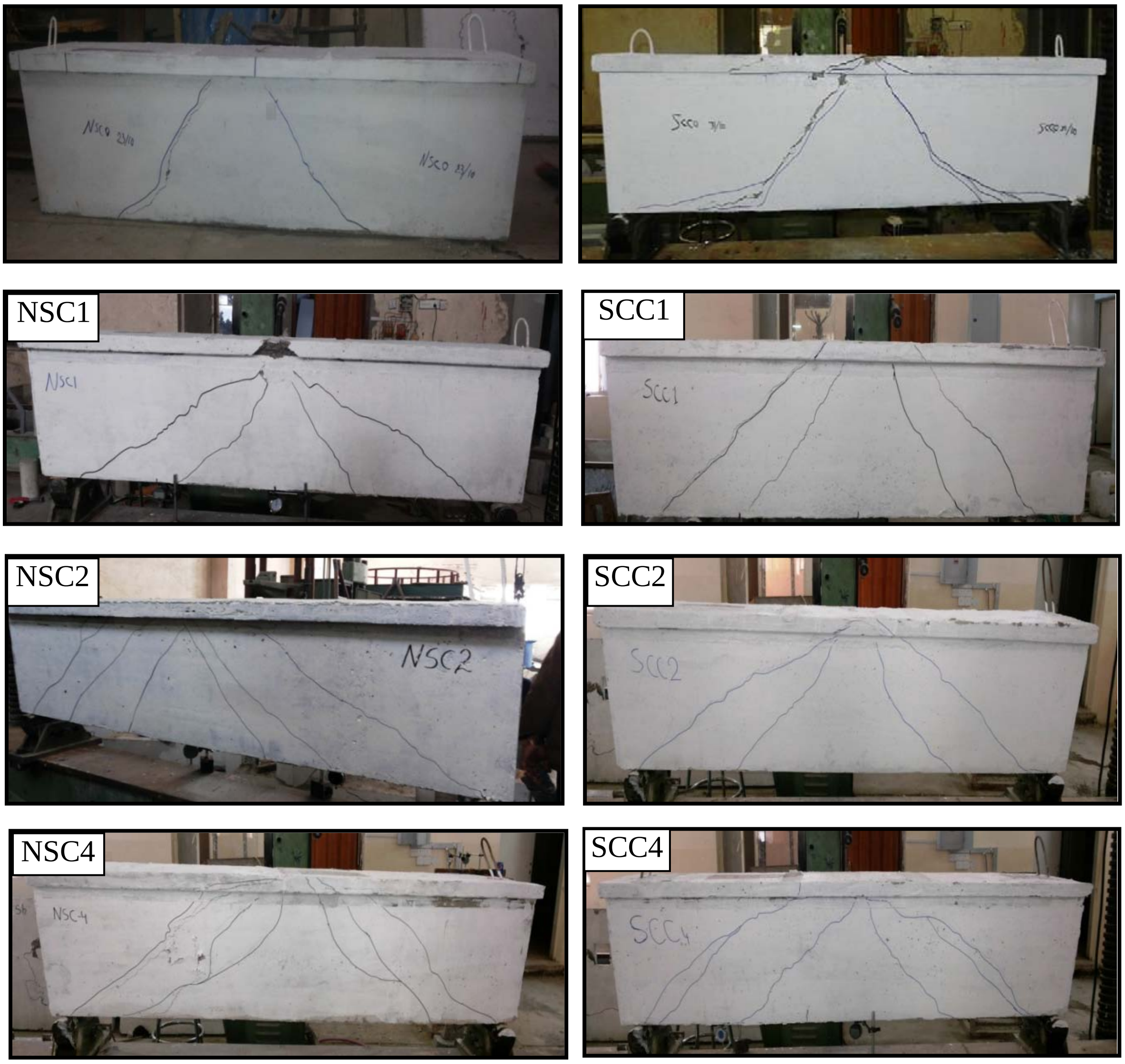
As mentioned before, the main objectives of this study are to examine or assess the shear behavior of reinforced concrete deep box beam strengthened internally by reinforced concrete transverse ribs**.**

During the experimental work, ultimate loads, load versus deflection at mid and quarter span for each beam were recorded. Photographs for the tested beams are taken to show the crack pattern and some other details. The recorded data, general behavior and test observations are reported as well as recognizing the effects of various parameters on the shear behavior.

4-1-General Behavior

The test results are given in Table (4) and Figure (3). All beam specimens have been designed to fail in shear, which is recognized by the formation of diagonal inclined cracks at a position of approximately mid-depth of tested beams. The general behavior of the tested beams can be described as follow:-

At low load levels, all the tested beams behaved in an elastic manner. At this stage of loading, beams were free of cracks, deflections were small and proportional to the applied loads, consequently the stresses were small and the full cross section was effective in carrying the loads. As the load increased, the first diagonal crack (web shear crack) appears at the mid height of the diagonal region bounded by load and support positions. As the load is further increased, the inclined crack expand and extend toward the support(s) and load position, also new cracks form parallel to the first crack and approximately near the middle of shear span. The latter cracks are progress toward load position as load increased. At load levels close to failure, existing cracks began to widen and propagate into the compression zone at the loading position until failure took place by opening up of first diagonal crack over the entire depth of the beam.



Group No.1 **Group No.2**

Figure (3): Crack Patterns for Tested Beams.

Table (4): Test Results of Specimen Beams.

Group No.	Beam Designation	No. of Cell	No. of Ribs	Load (kN)		Maximum Deflection (mm)		P_{cr} / P_u %	Mode of Failure
				P_{cr}^{*}	P_u^{**}	Mid	Quarter		
1	NSC0	0	0	115	295	6.64	4.75	39	Diagonal Splitting
	NSC1	1	2	45	160	4.22	3.52	28	Diagonal compression
	NSC2	2	3	65	220	5.5	3.8	30	Diagonal Splitting
	NSC4	4	5	89	267.5	6.83	5.25	33	=
2	SCC0	0	0	135	480	10.34	9.44	28	=
	SCC1	1	2	57	250	5.74	2.94	23	=
	SCC2	2	3	80	318	7.85	4.41	25	=
	SCC4	4	5	110	425	9.75	7.33	26	=

P_{cr}^{*} : First diagonal cracking load. P_u^{**} : Ultimate load.

4-2-First Cracking Load (Pcr)

The first cracking loads are presented in Table (4), Figure (4), and the crack patterns for all tested beams are shown in photographs of Figure (3). The visible first diagonal cracking loads of the beams varied from (23%) to (39%) of the experimental ultimate loads, and all first diagonal cracks were initiated at a position approximately mid-depth of the diagonal region bounded by load and support positions.

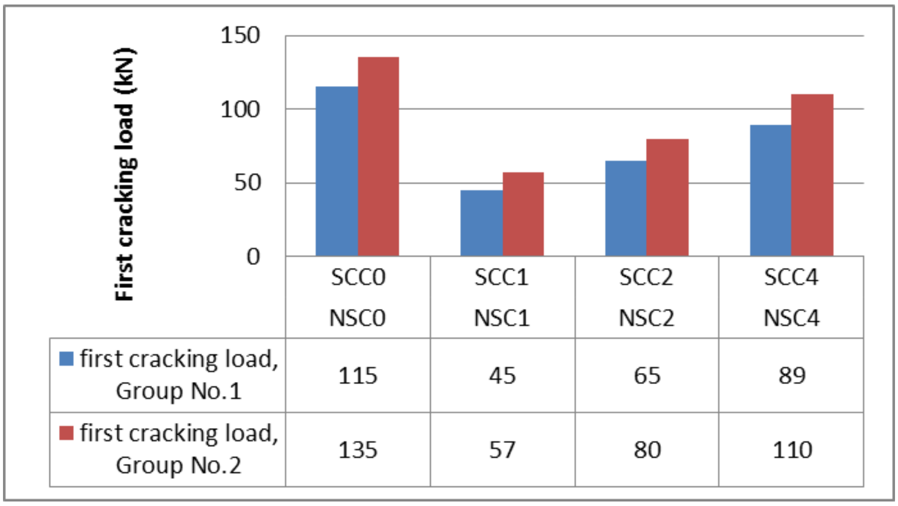


Figure (4): First Diagonal Cracking Load of Specimens.

For box-deep beams (NSC1, NSC2and NSC4)**,** test results in Table (4) and Figure (4) show that the first diagonal cracking loads decrease about (61%, 43% and 23%), respectively compared with that of solid-deep beam NSC0. Also, the test results for box-deep beams

(SCC1, SCC2, and SCC4) show that the first diagonal cracking loads decrease about (58%, 41% and 19%), respectively compared with that of solid-deep beam SCC0. This decreasing was may be due to the presence of cells in box-deep beams, which was lead to occupy a considerable portion of concrete in web and caused decreasing in effectiveness of concrete to resistance the tensile cracking. Therefore, the stiffness of box-deep beams was decreased, and this lead to accelerate the first diagonal cracks formation and decreasing the first diagonal cracking loads.

The test results in Table (4) and Figure (4) show that the first diagonal cracking loads for (NSC2,and NSC4) increased about (44%, and 98%), respectively compared with that of NSC1, and the first diagonal cracking loads for NSC4 increased about (37%) compared with that of NSC2.Also, the test results in Table (4) and Figure (4) show that the first diagonal cracking loads for (SCC2,and SCC4) increased about (40%, and 93%), respectively compared with that of SCC1, and the first diagonal cracking loads for SCC4 increased about (38%) compared with that of SCC2. From the results shown above, it can be concluded that there is a significant increase in first diagonal cracking load as the number of intermediate ribs increase. As a result, the intermediate ribs appeared to be effective in delaying the formation of first diagonal cracks (i.e. intermediate ribs allowed the box-deep beams to carry additional shear load as the test continued without causing a shear failure of the beam, which is able to sustain larger compressive forces). So, it was concluded that the RC rib participates in load transfer process and this leads to increase the stiffness of testing box-beams.

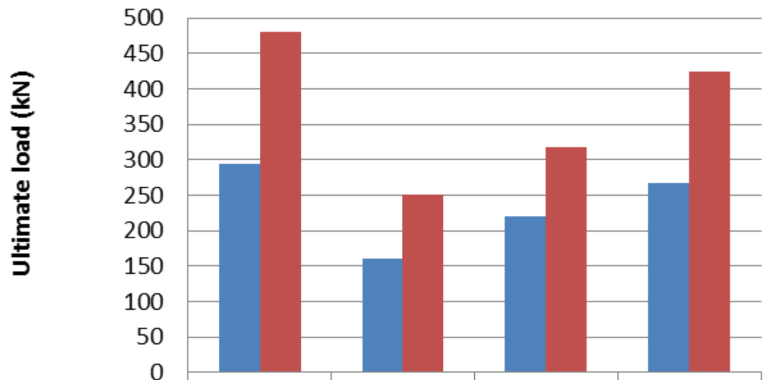
The test results in Table (4) and Figure (4) show that the beams (SCC0, SCC1,SCC2,and SCC4) in Group No.2 had increasing in first diagonal cracking load about (17%, 27%, 23% ,and 24%) compared with first diagonal cracking load for Group No.1 (NSC0, NSC1, NSC2,and NSC4), respectively. This increasing is due to the beams in Group No.2 had a compressive strength approximately twice the strength of beams in Group No.1. Thus, this causes an increase in beam stiffness and delaying the formation of first diagonal cracks.

4-3-Ultimate Load (Pu)

All beam specimens have been tested up to failure. The recorded ultimate loads of the tested beams are presented in Tables (4) and Figure (5).

Test results in Table (4) and Figure (5) show that the box-deep beams (NSC1,NSC2,and NSC4) had decreasing in ultimate loads (P_u) about (46%, 25%, and 9%), respectively compared with the ultimate load for solid-deep beam NSC0.Also, test results show that the box-deep beams (SCC1,SCC2,and SCC4) had decreasing in ultimate loads (P_u) about (48%, 34%, and 11%), respectively compared with the ultimate load for solid deep beam SCC0.

This decreasing is may be due to the reduction in effectiveness of the concrete in resisting shearing stress of box beam because of existence of cells led to occupied a considerable portion of concrete in web (the decrease of the effective compressive area of the concrete) and subsequently causes reduction in stiffness and the ultimate loading capacity of box-deep beams. Thus, the cells can be considered as a weak region in box-deep beams. But from the results shown above, it can be concluded that this decreasing ratio in ultimate loads less when increased the number of internal ribs. It can be noted that the box-deep beams which had highest number of rib (4) (NSC4 and SCC4), failure at load closer to ultimate load of solid beam with small decreasing ratio about (9% and 11%), respectively.



	SCC0 NSC0	SCC1 NSC1	SCC2 NSC2	SCC4 NSC4
ultimate load, Group No.1	295	160	220	267.5
ultimate load, Group No.2	480	250	318	425

Figure (5): Ultimate Load of Specimens.

In Table (4) and Figure (5) for box-deep beams in Group No.1, the increasing in ultimate loads (P_u) for (NSC2 and NSC4) were (38% and 67%), respectively compared with ultimate load for (NSC1), and the increasing in ultimate load (P_u) for (NSC4) was(22%) compared with ultimate load for (NSC2). Also, In Table (4) and Figure (5) for box-deep beams in Group No.2, the increasing in ultimate loads (P_u) for (SCC2 and SCC4) were (27% and 70%), respectively compared with ultimate load for (SCC1), and the increasing in ultimate load (P_u) for (SCC4) was (34%) compared with ultimate load for (SCC2). From the results shown above, it can be concluded that there is a significant increase in ultimate load (P_u) as the number of intermediate ribs increased and this appears when compared box-deep beams had end and intermediate ribs with box-deep beams which had only end ribs. Also, when compared box-deep beam had three intermediate ribs with deep box beam had one intermediate rib (both of them had end ribs). This increasing was may be due to that as mentioned before, the stiffness of box-deep beams was increased as the number of intermediate ribs increased and this leads to an increase in carrying capacity.

Test results in Table (4) and Figure (5) show that the beams (SCC0, SCC1,SCC2,and SCC4) in Group No.2 had increasing in ultimate loads (P_u) about (63%, 56%, 45% ,and 59%) compared with ultimate loads for Group No.1 (NSC0, NSC1, NSC2,and NSC4), respectively.

This increasing was may be due to the beams (SCC0, SCC1, SCC2, and SCC4) in Group No.2 had a compressive strength approximately twice the strength of beams in Group No.1 (NSC0, NSC1, NSC2, and NSC4). So, this led to an increase in beam stiffness and improved the resistance to tensile cracking in the beam and as a result, the overall strength of the beam was increased.

4-4-Crack Patterns

Two crack patterns were monitored during the test, as shown in Figure (3). The first one was appeared in solid-deep beams, and the second one was appeared in box-deep beams with reinforced concrete ribs. Cracking of each specimen is generally as follows:-

4-4-1- Crack Patterns of Solid-deep beams

The crack pattern which was appeared in (NSC0, and SCC0) presented by one conspicuous diagonal crack formed between load and support position in shear span. The primary difference between the observed crack patterns in (NSC0, and SCC0) was the angle at which the primary shear crack was formed. The crack inclination observed in beam SCC0 was steeper than that observed in beam NSC0. Another observed difference was the splitting of SCC0 beam was more pronounced than the splitting of NSC0 beam, also presence of several short inclined cracks in flange and a little crushing of the concrete near the positions of the applied loads were occurred due to propagated of diagonal cracks into the compression zone in flange. This is attributed to high concrete compressive strength used in SCC0 beam and this led to brittle behavior which makes the failure to arise suddenly, accompanied by higher noise and gives wider splitting line by comparison with NSC0 beam.

4-4-2- Crack Patterns of Box-deep beams with RC ribs

The crack pattern which was appeared in all box-deep beams presented by two or three conspicuous web shear cracks formed in the shear span**.** As previously mentioned, the cracks pattern resulted in these tests were different but there are similarities between the two situations (solid and box beam). It can be noted that the failure took place by opening up of diagonal crack which is connects between load and support position (diagonal splitting lines).

4-5-Failure Mode

The failure modes of all tested beams are reported in Table (4). All beams have similar failure mode by diagonal splitting failure (by opening up of diagonal crack which is connects between load and support position), except NSC1 which failed in diagonal compression. In this beam NSC1 the failure occurred due to the destruction of portion of concrete in compression zone under the point load, where the compression stresses in concrete reach their maximum capacity before the cracks penetrate the compression zone, and this attributed to low compressive strength of concrete. This type of failure (diagonal compression mode) makes the behavior sudden and more brittle.

4-6-Load-Deflection Relationship

The load versus mid span deflection curves of the tested beams at all stages of loading up to failure have been constructed and shown in Figure (6) to Figure (11). Each one of these curves initiated in a linear form (elastic behavior) with a constant slope, and the initial change of slope of the load-deflection curves is between (23%) to (39%) of the experimental ultimate loads. This change in slope indicates the first diagonal crack was appearing. Beyond the first diagonal crack stage, each beam behaves in a certain manner. As expected, after the first diagonal cracks occur the deflections at mid span show greater values than the deflections at quarter span for each beam until failure.

Table (5) and Figures (6) and (7) show the effect of presence of ribs on load- mid span deflection response. From these Table and Figure, it can be seen that at a certain load level, the solid-deep beam has lower deflection values than box-deep beams because of its moment of inertia greater than box-deep beam. Also, it can be seen that the deflection values decreased as a number of intermediate ribs were increased. This may be due to the influence of moment of inertia (stiffness) where it increased as the number of intermediate ribs was increased. As well as the stiffness, where it increased as the number of intermediate ribs was increased.

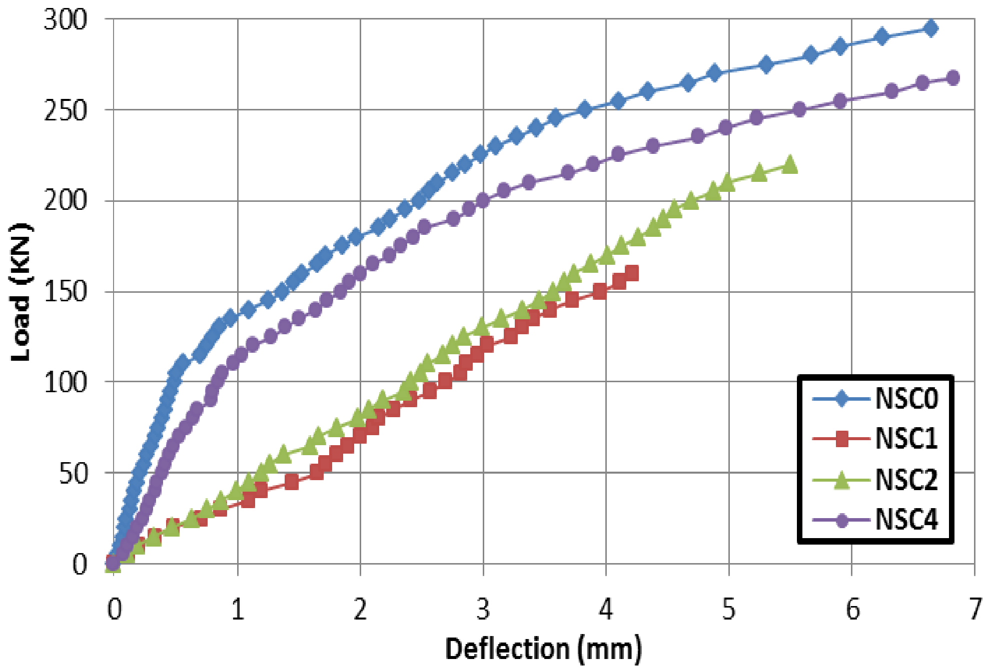


Figure (6): Load-Mid Span Deflection Relationship for Group No.1.

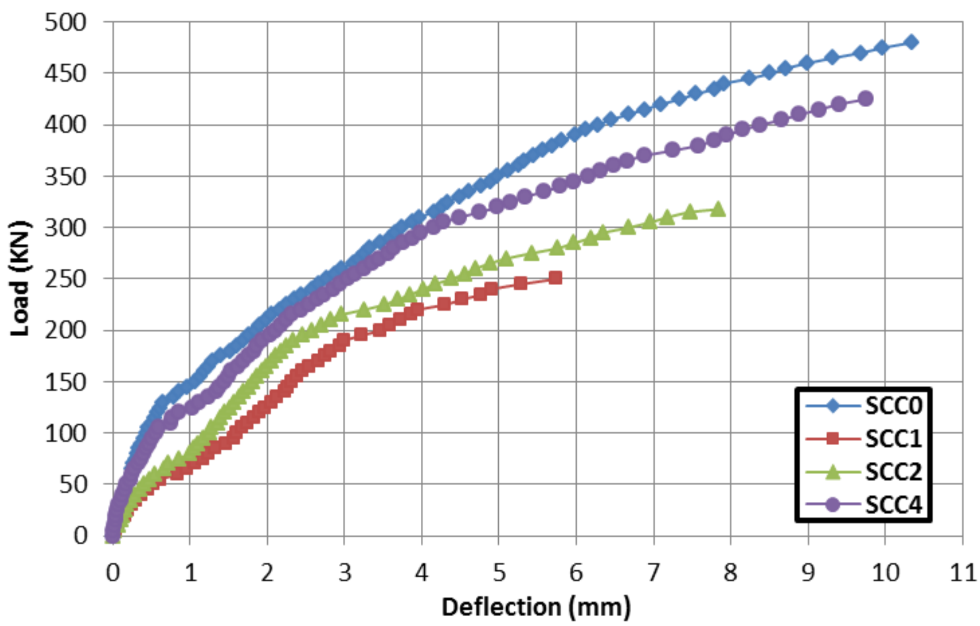


Figure (7): Load-Mid Span Deflection Relationship for Group No.2.

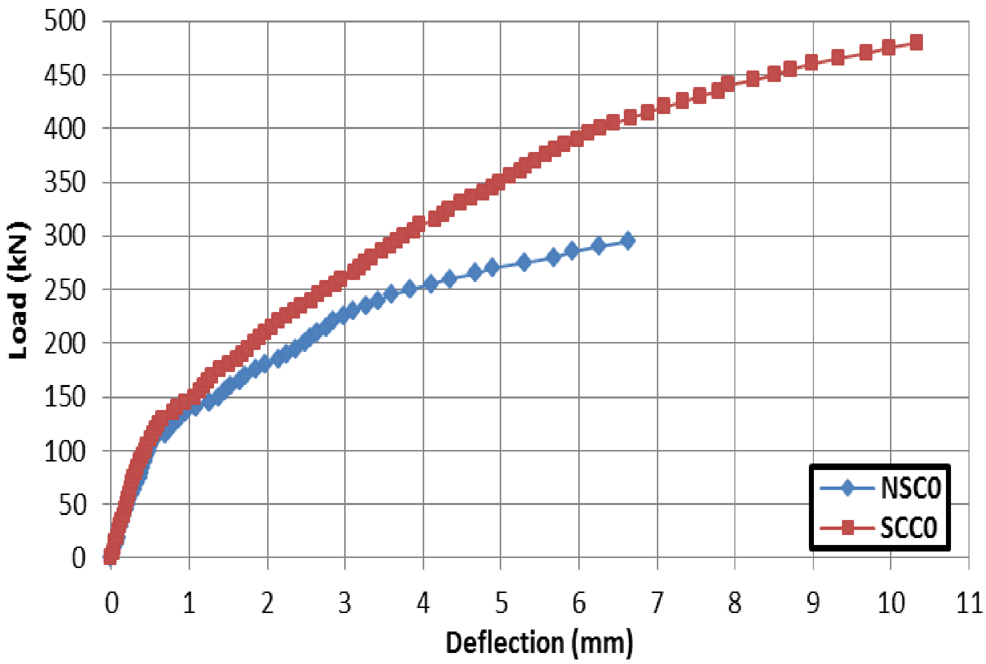


Figure (8): Load-Mid Span Deflection Relationship for solid-deep beams.

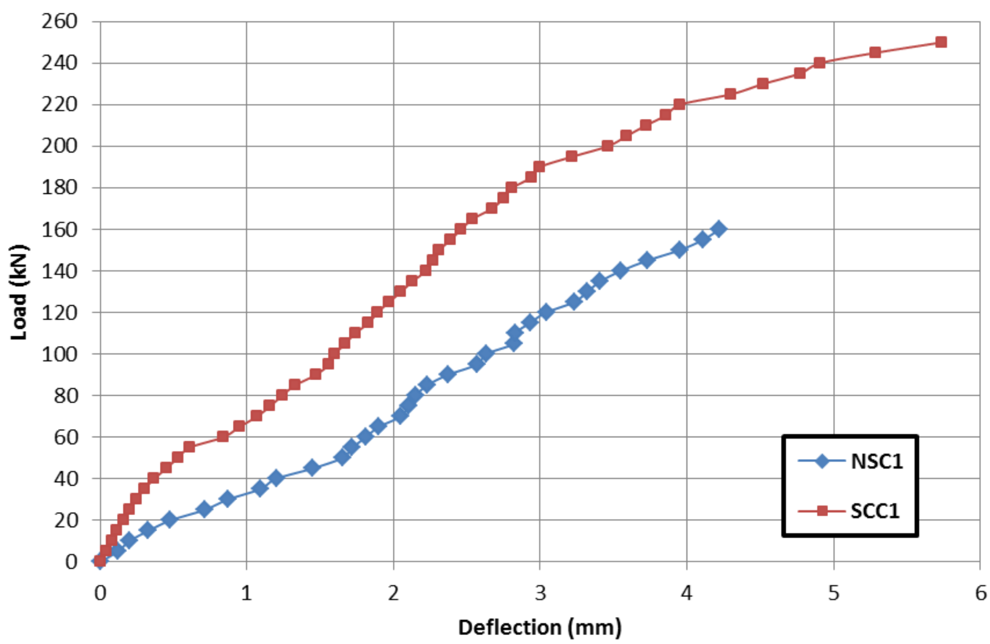


Figure (9): Load-Mid Span Deflection Relationship for box-deep Beams with One Cell.

As shown in Table (5) and Figure (6), for group No.1, an increasing in ultimate deflection of (NSC0) was observed when comparing with (NSC1, and NSC2), But (NSC4) exhibits scantiness increase in ultimate deflection when comparing with (NSC0), this may be due to the fact that the rate of increase in deflection was so fast beyond the ultimate load during the test. Also, as shown in Table (5) and Figure (7), for group No.2, an increasing in ultimate deflection of (SCC0) was observed when comparing with (SCC1, SCC2, and SCC4).

This increasing is due to higher stiffness of solid deep beams which lead to an increase in the load carrying capacity beyond the first cracking load and this is reflected in the corresponding deflections.

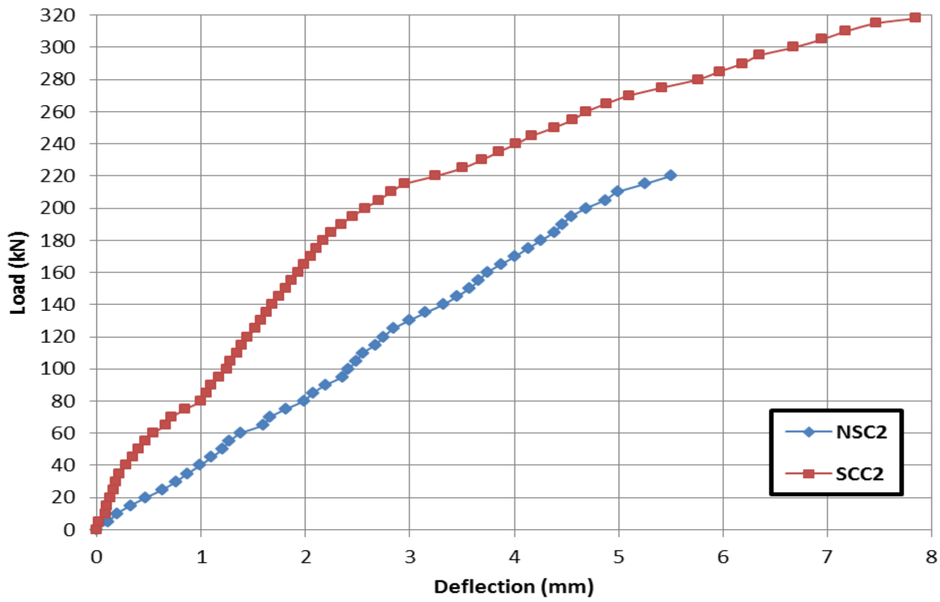


Figure (10): Load-Mid Span Deflection Relationship for box-deep Beams with Two Cells.

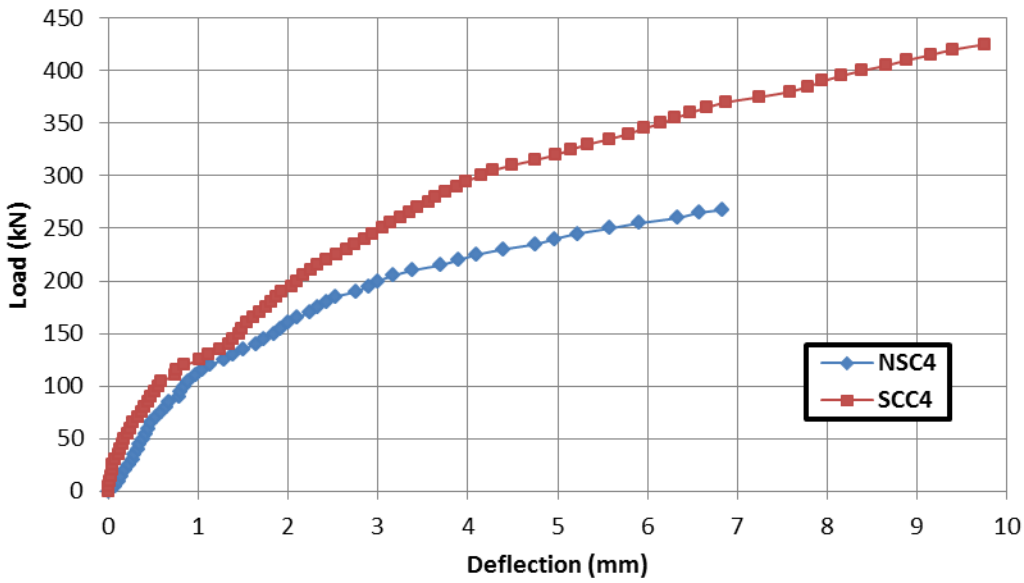


Figure (11): Load-Mid Span Deflection Relationship for box-deep Beams with Four Cells.

Table (5): Effect of Cells and Ribs on Load-Deflection Relationship.

Group No.	Beam Designation	P_u (kN)	ultimate Mid span Deflection (mm)	Load (kN)	Mid span Deflection
1	NSC0	295	6.64	160	1.53
	NSC1	160	4.22	160	4.22
	NSC2	220	5.5	160	3.74
	NSC4	267.5	6.83	160	2
2	SCC0	480	10.34	250	2.76
	SCC1	250	5.74	250	5.74
	SCC2	318	7.85	250	4.38
	SCC4	425	9.75	250	3.05

Table (6): Effect of (f 'c) on Load-Deflection Relationship.

No. of Cell	Beam Designation	P_u (kN)	ultimate Mid span Deflection (mm)	Load (kN)	Mid span Deflection
Solid	NSC0	295	6.64	260	4.34
	SCC0	480	10.34	260	2.95
1	NSC1	160	4.22	125	3.23
	SCC1	250	5.74	125	1.97
2	NSC2	220	5.5	190	4.46
	SCC2	318	7.85	190	2.34
4	NSC4	267.5	6.83	230	4.39
	SCC4	425	9.75	230	2.65

As shown in Table (5) and Figure (6), for group No.1, a decreasing in ultimate deflection of (NSC1) was observed when comparing with (NSC2, and NSC4), and (NSC4) shows increase in ultimate deflection when comparing with (NSC2). Also, as shown in Table (5) and Figure (7), for group No.2, an decreasing in ultimate deflection of (SCC1) was observed when comparing with (SCC2, and SCC4), and (SCC4) exhibits increase in ultimate deflection when comparing with (SCC2).

As discussed before, the stiffness of box-deep beams was increased as the number of intermediate ribs was increased. This is led to an increase in the load carrying capacity beyond the first cracking load and this was reflected in the corresponding deflections.

Table (6) and Figures (8) to (11) show the effect of concrete compressive strength (f'_c) on load- mid span deflection response. From these Table and Figures, it can be seen that at a certain load level, the increase in (f'_c) value of beams in group No.2 leads to reduce the deflection values compared with beams in group No.1 . The increase in (f'_c) results in a significant increase in the modulus of elasticity. This leads to larger flexural rigidity (EI) which reduces the deflection by a significant amount. Also, these Table and Figures show that the ultimate deflection values of beams in group No.2 were increased when comparing with beams in group No.1. This may be due to increase in the stiffness and ultimate load carried by beams of group No.2 which caused the increase in ultimate deflection; where (as discussed before) the beams in Group No.2 had a compressive strength approximately twice the strength of beams in Group No.1.

4-7-Effect of Cells and Ribs on Beam's Weight

The effect of presence of cells and ribs on beam's weight is shown in Table (7) and Figure (12).These Table and Figure, reveal that the presence of cells in beams led to decrease the weight of box-deep beams with different number of ribs (two, three, and five) about (38%, 37%,and 35%), respectively compared with solid-deep beams. As discussed before, this led to decrease the ultimate strength (P_u) of the beams.

Table (7): Effect of Cells and Ribs on Beam's Weight.

No. of Cell	No. of Ribs	Beam Designation	P_u (kN)	Weight (Kg)
Solid	-	NSC0	295	702
		SCC0	480	
1	2	NSC1	160	437
		SCC1	250	
2	3	NSC2	220	445
		SCC2	318	
4	5	NSC4	267.5	459
		SCC4	425	

Test results in Table (7) show that the box-deep beams with(three, and five) ribs had a significant increasing in ultimate loads (P_u) about (38% and 67%) for (NSC2,andNSC4), respectively and(27% and 70%) for (SCC2,and SCC4), respectively with a small increasing in weight about (2%, and 5%), respectively compared with box-deep beams with (one cell and two end ribs)(NSC1,and SCC1). Test results in Table (7) for box-deep beams (NSC4, and SCC4) show that the decreasing in ultimate loads (P_u) were (9%, and 11%), respectively compared with the ultimate loads for solid-deep beams (NSC0, and SCC0) while the decreasing in weight about (35%).

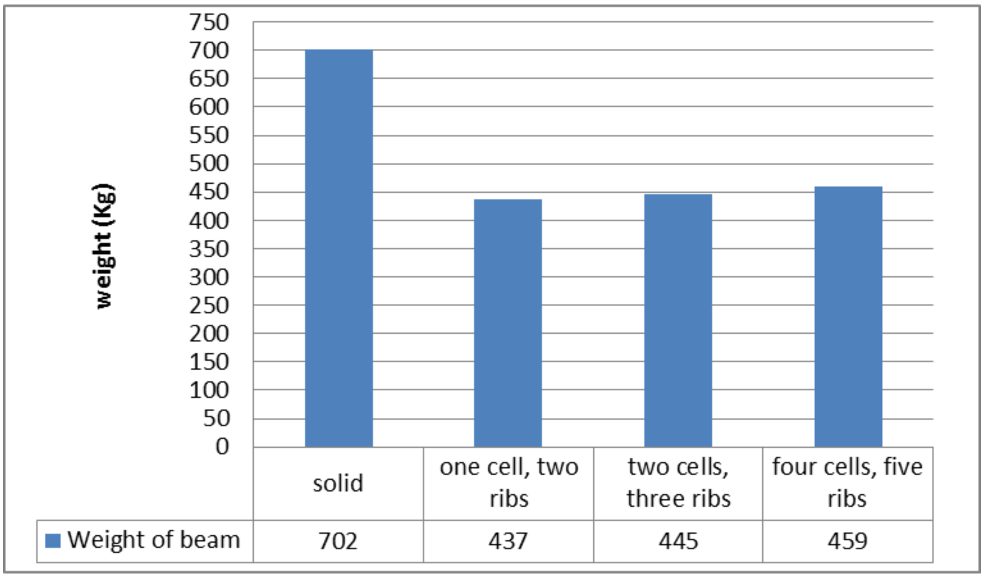


Figure (12): Weights of Beams

From above results, it can be concluded that presence of ribs in box-deep beams led to a considerable increasing in ultimate loads (P_u) while the increasing in weight was slight. Also, the box-deep beams with highest number of ribs had the ultimate loads (P_u) close to solid-deep beams with significant decrease in weight. Thus, the presence of ribs provides advantages from a construction and an economic standpoint by increasing strength while decreasing the dead load.

5-Conclusions

Based on the obtained results and observations, the following conclusions can be drawn:

1-All tested deep beams failed by shear. The shear failure took place by diagonal splitting mode for all tested beams except beam (NSC1) where its shear failure took place by diagonal compression mode.

2-Two cracking patterns are monitored during the tests. The first one appeared in solid-deep beam which presenting by one conspicuous diagonal crack formed between load and support position in shear span and; the second one appeared in box-deep beam with RC ribs which presenting by two or three conspicuous web shear cracks formed in the shear span.

3-The first diagonal cracking load increased as the compressive strength of concrete increased. The results reveal that as (f'_c) increasing from (30.7 MPa) to (58 MPa), the percentages of increase in the first diagonal cracking load of (solid, one cell, two cells, and four cells) beams are about (17%, 27%, 23%, and 24%) respectively. This means that the diagonal cracking load depends on tensile strength of concrete which depends originally on compressive strength.

4- The ultimate load increased as the compressive strength of concrete value was increased. It was found that as (f'_c) increasing from (30.7 MPa) to (58 MPa) (approximately twice the original value) the percentages of increase in the ultimate load of (solid, one cell, two cells, and four cells) beams are about (63%, 56%, 45% and 59%) respectively. This means that the compressive strength of concrete represent a major parameter of shear strength of RC members as well as dimensions.

5-The results reveal that the first diagonal cracking and ultimate loads for box-deep beams having different number of cells (one cell, two cells, and four cells) less than the first diagonal cracking and ultimate load for solid-deep beam as follow:

a) For normal box-deep beams NSC, the first diagonal cracking loads decrease by about (61%, 43% and 23%) respectively, and the ultimate loads by about (46%, 25%, and 9%) respectively.

b) For SCC box-deep beams, the first diagonal cracking loads decrease by about (58%, 41% and 19%) respectively, and the ultimate loads about (48%, 34%, and 11%) respectively.

6-It was found that the percentage of decrease in the first diagonal cracking loads and ultimate loads for the box-deep beams with different number of cells reduced as the number of ribs increases. This may be due to a certain contribution of each rib in both, first diagonal cracking load and load carrying capacity.

7-The box-deep beams which have two cells separated from each other by one intermediate rib and four cells separated from each other by three intermediate ribs (and both of them have end ribs in each end) have the highest first diagonal cracking and ultimate loads as compared with box-deep beam which has one cell with end ribs in each end. It was found that the percentages of increase in first diagonal cracking and ultimate loads as follow:

a) For normal box-deep beams NSC, the first diagonal cracking loads increase by about (44%, and 98%) respectively, and the ultimate loads by about (38% and 67%) respectively.

b) For SCC box-deep beams, the first diagonal cracking loads increase by about (40%, and 93%) respectively, and the ultimate loads by about (27% and 70%) respectively.

8-It can be seen that at a certain load level, the solid deep beams had lower deflection values than box-deep beams with different number of cells. Also, it can be seen that the deflection values decrease as a number of intermediate ribs increase.

9- The presence of cells led to significant decrease in weight of deep beams. Also, it can be seen that the presence of ribs in box-deep beams led to a considerable increasing in ultimate load (P_u) while the increasing in weight was slight. Also, the box-deep beams with highest number of ribs had the ultimate load (P_u) close to solid-deep beams with significant decrease in weight. Thus, the presence of ribs provides advantages from a construction and an economic standpoint by signification increasing of strength while slightly increase in the dead load of box-deep beam.

6-References

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7-Notation

a= Shear Span;

a/d = Shear span to depth ratio;

b_b= Bottom flange width (mm);

b_t= Top flange width (mm);

d= Effective depth (mm);

f_c' = Cylinder compressive strength of concrete (MPa);

h= Total depth of beam (mm);

h_b= Thickness of bottom flange (mm);

h_t= Thickness of top flange (mm);

L= Beam length (mm);

P= Applied load (kN);

P_{cr}= First diagonal cracking load (kN);

P_u= Ultimate load (kN);

ρ= Ratio of longitudinal tensile reinforcement;

ρ_w= transverse reinforcement ratio;