Effect the Steel Ring Beam on Behavior of Reinforced Concrete Domes

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Abstract: *Experimental tests on five reinforced concrete domes are carried out to investigate its structural behavior. The main aim of this study is to examine the dome behavior braced with steel channel ring beam at the dome extremities. The impact of several parameters including thickness of steel channel section and thickness of steel horizontal crossed rib were investigated. The domes dimensions are kept constant as 600mm, 300mm and 20 mm of diameter, height and thickness respectively. The point load was applied statically at the top of domes. From the experimental results, it can be conclude that the ultimate loads of domes were improved by 72%, 80%, 81.3%, and 126.67 for domes braced with 2mm steel ring, 4mm steel ring, 2mm steel ring and horizontal rib, and 4mm steel ring and horizontal rib respectively. Accordingly, the first crack loads were increased by 50%, 100%, 100%, and 150% respectively. The improvement in the performance of domes appeared positively on the reduction in deformations of the domes in addition to increasing the stiffness and ductility of tested domes. The first meridional cracks were appeared at dome bottom in non braced specimens, while the first meridional cracks were appeared at mid-height of the specimens.*

Keywords: *dome, steel ring, steel rib, meridional crack and bracing.*

I. Introduction

Thin shells as structural elements occupy a leadership position in engineering and, in particular, in civil, mechanical, architectural, aeronautical, and marine engineering. Examples of shell structures in civil and architectural engineering are large-span roofs, liquid-retaining structures and water tanks, containment shells of nuclear power plants, and concrete arch domes [1]. The wide application of shell structures in engineering is conditioned by their following advantages:

1. Efficiency of load-carrying behavior.
2. High degree of reserved strength and structural integrity.
3. High strength: weight ratio, this criterion is commonly used to estimate structural component efficiency: the larger this ratio, the more optimal is a structure. According to this criterion, shell structures are much superior to other structural systems having the same span and overall dimensions.
4. Very high stiffness.
5. Containment of space.

In addition to these mechanical advantages, shell structures enjoy the unique position of having extremely high aesthetic value in various architectural designs [2].

In recent years with the development of engineering materials and techniques, the researchers work to improve the structural behavior of domes using different materials and strengthening techniques.

The most important studies deals with improving the behavior of domes are the study of Meleka N.N. et.al.(2007)[3], this study discussed the behavior of reinforced concrete domes under the effect of bracing the dome bottom by Carbon fiber strips and glass fiber. The failure load of strengthened specimens was increased by 250% and 25% if compared with reference specimen. Farther more, the cracking load was increased by 100% and 60% with respect control specimen. Hani (2011) [4)] performed a study to investigate the behavior and strength of modern thin spherical shell domes made of concrete with and without ribs, using finite element method via ANSYS software. This study concluded that ultimate load was increased by 33.15% and 46.2% for domes supported with one rib and two ribs respectively if compared with unsupported dome. The potential impacts of thickness and skeletal reinforcement on the strength and performance of thin domes constructing from ferro cement and subjected to uniformly distributed loading condition was investigated by Wail and Azad (2013) [5]. the ultimate strength of tested domes was increased by 100% higher than reference specimen with one layer of skeletal reinforcement.

II. Experimental Program

Five specimens were poured and tested under static load. The domes dimensions were kept constant; 600mm of diameter, 300 mm of height and 20mm of thickness, the dome reinforcement was kept constant (welded wire mesh Φ1@15mm, see Table (1). the steel rig was used at the dome bottom with two thicknesses; 2mm and 4mm in specimens DRS2 and DRS4 respectively, the steel strips are crossed at the dome bottom take the shape of positive sign (+) in specimens DRRS2 and DRRS4, see Figure (1).

Table (1) Specimens Details

Specimens Configuration	Diameter of Dome (mm)	Thickness of Dome (mm)	Concrete Type	Bracing Type
NR	600	20	NSC	w/o bracing
DRS2	600	20	NSC	Steel ring with (40mm height, 2mm thickness)
DRS4	600	20	NSC	Steel ring with (40mm height, 4mm thickness)
DRRS2	600	20	NSC	Steel ring with rib(40mm height, 2mm thickness)
DRRS4	600	20	NSC	Steel ring with rib(40mm height, 4mm thickness)

Figure (1) Dome Braced with Steel Rib

III. Materials

1. **Cement**

The cement type adopted in manufacturing the concrete of this study was ordinary Portland cement (Type I). The cement physical and chemical specifications are illustrated in Tables (2) and (3) respectively. The tests results confirm the Iraqi standards specification No.5/1984 [6].

Table (2) Physical Properties of Cement

Physical Properties	**Test Result**	**Limit of IOS No.5: 1984**
Fineness of cement (by air permeability apparatus (cm^2/kg)	4420	>2300
Soundness (by autoclave method)	0.21%	<0.8%
Setting time (by vicats instrument) Initial Final	 190 min 5 hr	 >45 min <10 hr
Compressive strength for mortar cube (70.7 mm) at 3 days (MPa) 7 days (MPa)	 23 30	 >15 >23

Table (3) Chemical Properties of Cement

Compound composition	**Chemical composition**	**Percentage by weight**	**Limit of IOS No.5: 1984**
Lime	CaO	62.11	-
Silica	SiO_2	21.37	-
Alumina	AL_2O_3	5.2	-
Iron oxide	Fe_2O_3	4.42	1.5
Magnesia	MgO	1.73	Less than 5
Sulfate	SO_3	2.62	Less than 2.8
Loss on ignition	L.O.I	2.76	Less than 12
Insoluble residue	I.R	0.71	Less than 1.5
Lime saturation factor	L.S.F	0.94	0.66 - 1.02
Main Compounds (Bougue's equations)			
(C3A)	6.31		
(C3S)	41.64		
(C2S)	30.1		
(C4AF)	13.43		

2. Fine Aggregates

The maximum size and fineness modulus of Natural sand were (4.75mm) and (2.35) respectively. The test results are in match with Iraqi standard (No.45 /1984) [7]. Both Tables (4) and (5) show the sand gradients and chemical specifications.

Table (4) Sand Sieving Analysis

No.	Sieve Size (mm)	Passing%	Iraqi Specifications Limits No.45/1984 for zone 3
1	4.75	93.6	90-100
2	2.36	86	85-100
3	1.18	80	75-100
4	0.6	71	60-79
5	0.3	30	12-40
6	0.15	9	0-10

Table (5) Chemical Properties of Sand Analysis

Property	Test Result	Limit of Iraqi Specification No.45/1984
Specific gravity	2.5	-
Amount of sulfate	0.11%	≤0.5%
Absorption ratio	0.78%	-

3. Coarse Aggregates (Gravel)

The maximum size and bulk specific gravity of Crushed gravel were (5 mm) and 2.7 respectively. The tests results conformed to the national formal specifications IQS No.45/1984 [7] as revealed in Table (6).

Table (6) Grading of Coarse Aggregate

No.	Sieve Size (mm)	Passing%	Limit of Iraqi Specification No.45/1984 [4]
1	14	100	90-100
2	10	95	85-100
3	5	6	1-10
4	2.36	4	0-5
5	1.18	0	---

4. Welded Wire Mesh

Square welded wire meshes were used to reinforcing domes; the specifications of welded wire mesh are illustrated in Table (7). The specifications of welded wire mesh were evaluated according to ASTM 185A/A185M-07 [8].

Table (7) Specifications of the Welded Wire Mesh

Property	Specifications
Yield strength (fy)	380 MPa
Ultimate strength (Fu)	485 MPa
Elastic modulus (Ec)	168000 MPa
Average diameter	1 mm
Opening size of mesh	(15*15) mm

5. Steel Strips

Two thicknesses of steel plate (2mm and 4mm) was manufactured as a channel, and used as a ring at the bottom of the domes. Also, steel plate was used as a rib. The plate was cut to dimensions 30mm width by 500 mm length for purpose of testing. The specifications of steel plate are mentioned in Table (8) for two thicknesses.

Table (8) Specifications of Steel Plate

Plate Thickness (mm)	Yield stress (f_y) (MPa)	Ultimate Strength (F_u) (MPa)	Elongation (%)
2	316.28	395.7	10.26
4	526.14	666	0.98

IV. Load- deflection relationships

1. Effect of Steel Ring

The load-deflection history of specimens NR, DRS2 and DRS4 are shown in Figures (2) to (4) respectively. From these Figures, it is observed that specimen (NR) have deflection higher than specimens DRS2 and DRS4, it is also concluded that three stages can be recognized; linear stage, starts at beginning of loading until first crack appearance, second linear stage starts at first crack until yielding of reinforcing steel, and nonlinear stage starts at the end of yielding stage and extended to the failure of specimens. Notice that the deflection of reference dome results due to tensile membrane force. These forces result high stress in concrete dome. In braced dome (DRS2 and DRS4), these deflections are minimized by ring stiffness at the dome bottom.

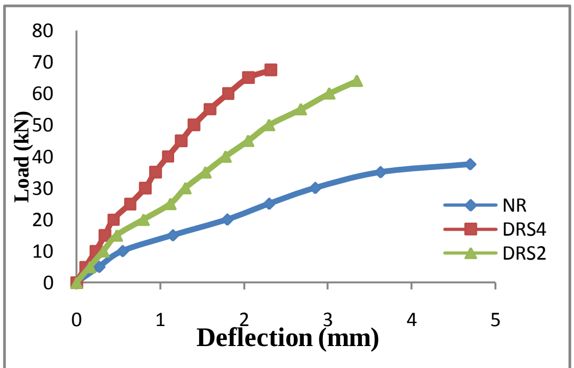


Figure (2) Load-deflection Curves at 20mm

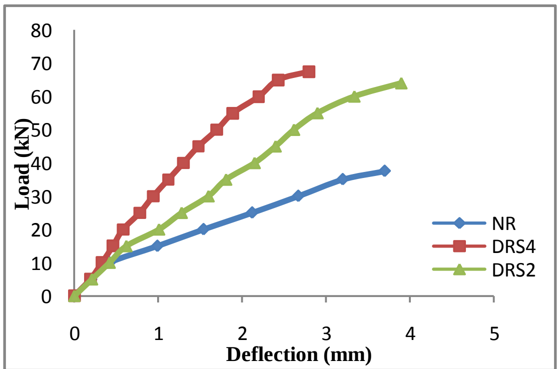


Figure (3) Load-deflection Curves at 50mm

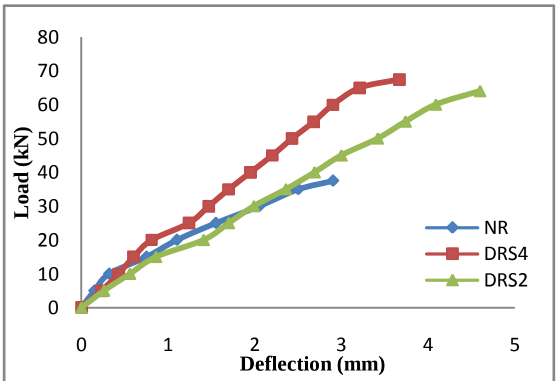
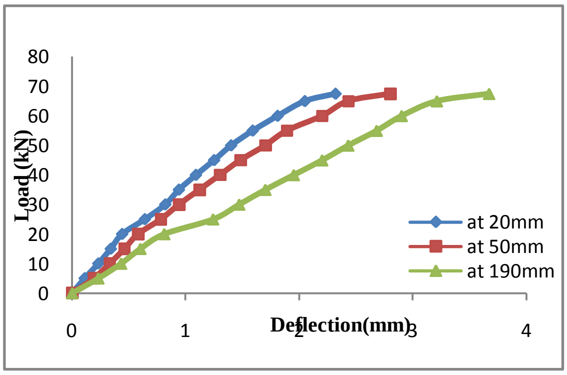
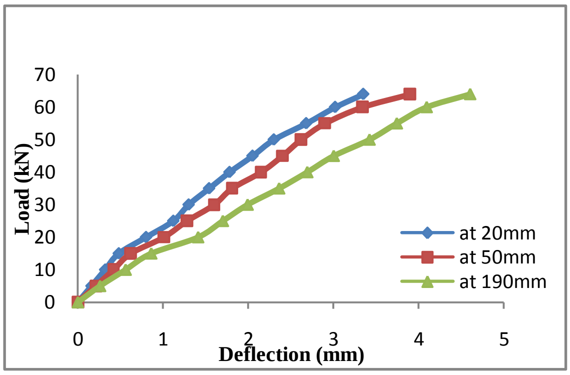


Figure (4) Load-deflection Curves at 190mm

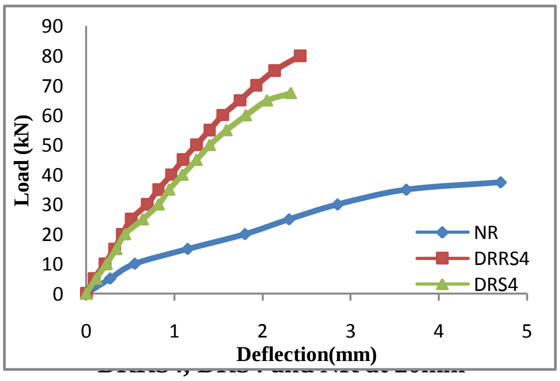
The load-deflection curves at different level of specimens are shown in Figures (5) and (6). The specimen with (4mm) steel ring achieved minimum deflection at 20mm in comparison with deflection at 50mm and 190mm. Similarly the specimen (DRS2) achieved minimum deflection at 20mm from the base; while the normal specimen (NR) achieved maximum deflection at 20mm from the base.

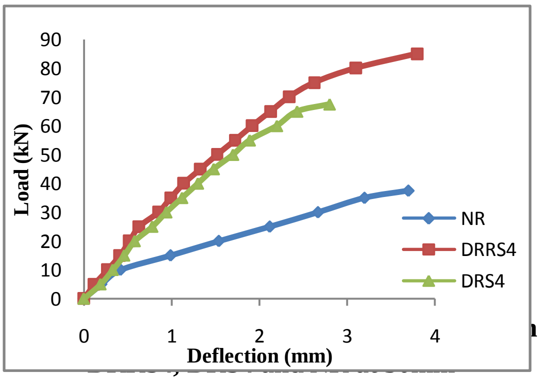




2. Effect of Steel Rib

It seems that steel rib decreased the deflection at 20mm, 50mm and 190mm. The specimens with large rib thickness have deflection smaller than the specimens with small thickness, because the specimen with large rib thickness can connect both sides of the dome bottom and blocking the deterioration of specimen more than the specimen with small rib thickness, see Figures from (7) to (12).





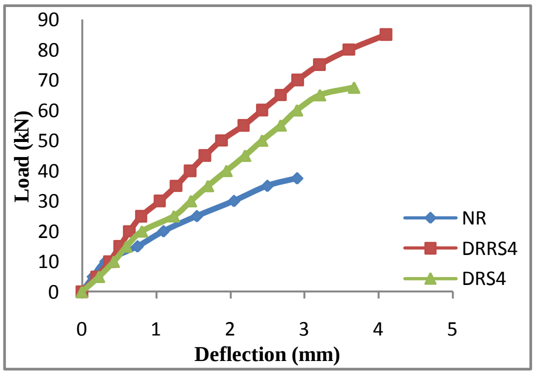


Figure (9) Load-deflection Curves of Specimen DRRS4, DRS4 and NR at 190mm

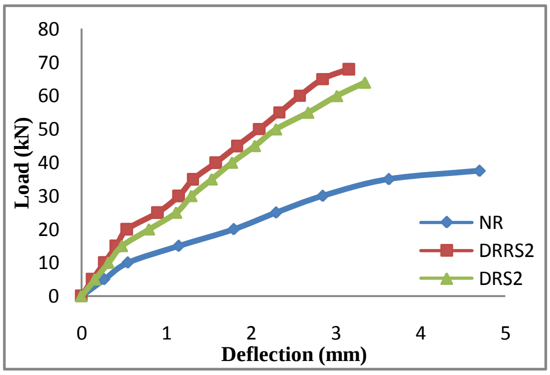


Figure (10) Load-deflection Curves of Specimen DRRS2, DRS2 and NR at 20mm

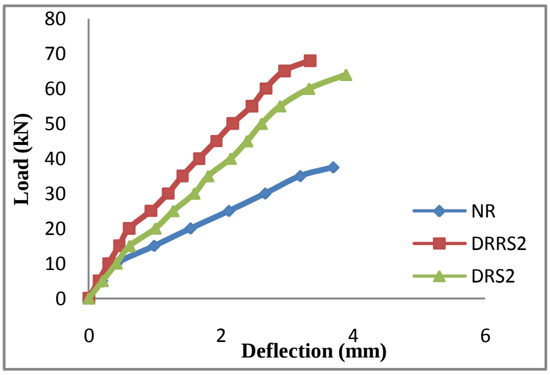


Figure (11) Load-deflection Curves of Specimen DRRS2, DRS2 and NR at 50mm

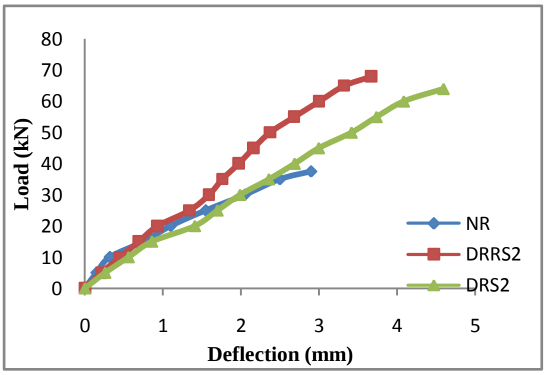


Figure (12) Load-deflection Curves of Specimen DRRS2, DRS2 and NR at 190mm

V. Failure Pattern

The first crack of reference specimen was opened at dome bottom, see Figure (13). While, the first crack was appeared at the mid-height of strengthened specimen; it increased in width and extended vertically toward the top and bottom of the specimen. The dome with (2mm) ring thickness achieved crack width wider than specimen of (4mm) ring thickness, in additional to punching of the dome at the top due to concentration of stresses under point load and restriction of the dome at bottom, the steel ring and rib delayed the extension of cracks to the dome bottom, so hairline cracks appeared in the (DRS2 and DRRS2) wider than the (DRS4 and DRRS4) specimens. The crack width of specimen (DRS4) was thinner than crack width of (DRS2), see Figures (14) to (17). The reverse action of steel ring and rib against the dome deformations at the bottom contributes to decrease the crack width; this indicates that the hoop stresses were reduced to lower value. At the dome mid-height, the maximum crack width was found, this may be gives an indication about the position of maximum hoop stresses.

Figure (13) Crack Pattern of Specimen NR

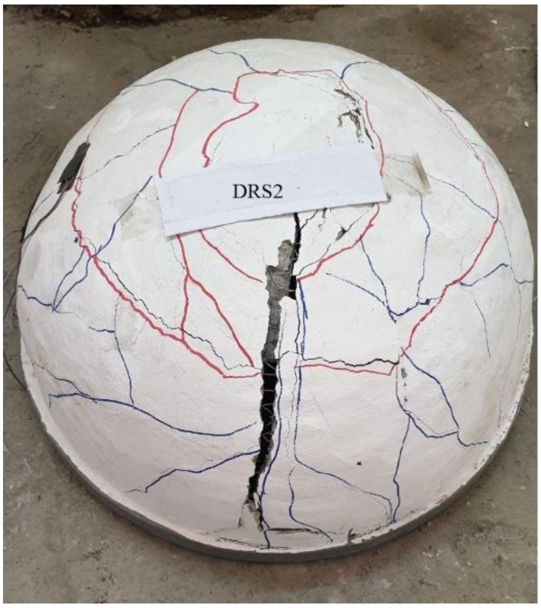


Plate (14) Crack Pattern of

Specimen DRS2

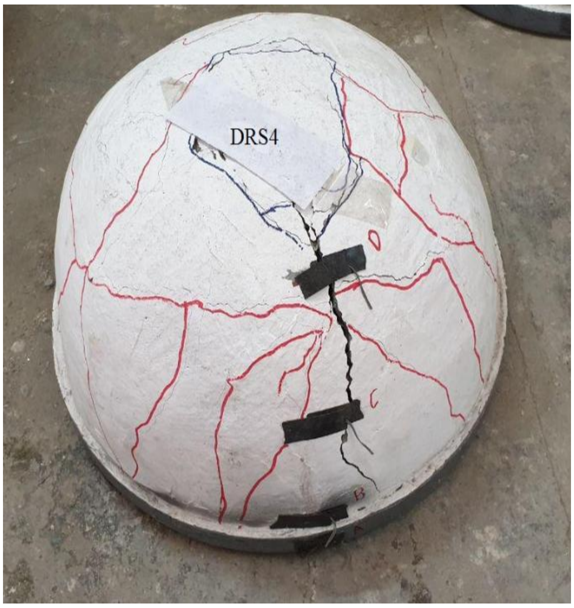


Plate (15) Crack Pattern of

Specimen DRS4

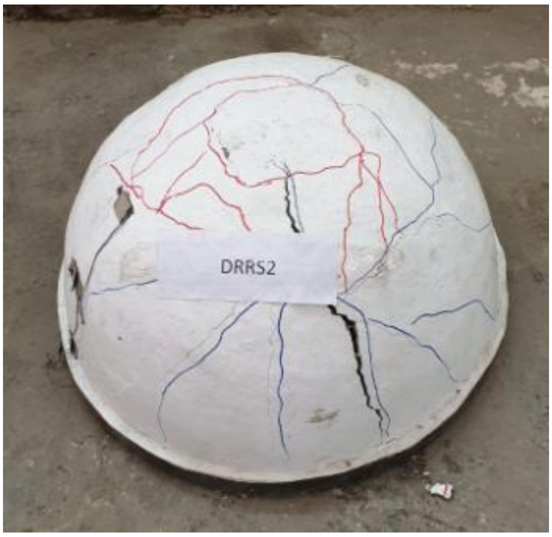


Plate (16) Crack Pattern of

Specimen DRRS2

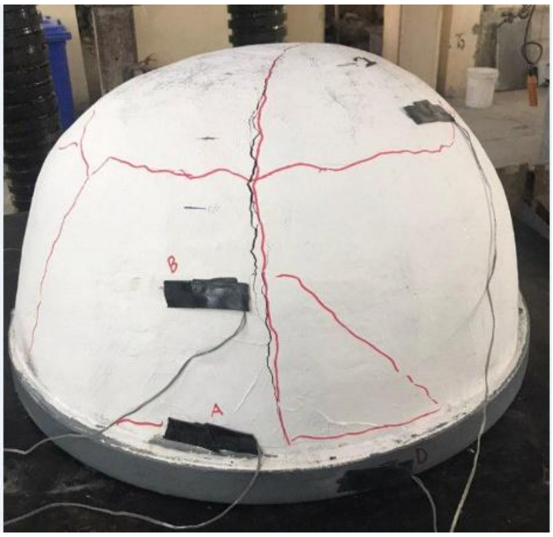


Plate (17) Crack Pattern of

Specimen DRRS4

VI. Ultimate Load Carrying Capacity

1. Effect of Steel Ring

For specimen with ring thickness 2mm (DRS2), the ultimate load of dome increased (72%) with respect to reference specimen (NR).Consequently, for specimen with ring thickness 4mm (DRS4), The ultimate load of dome increased (80%) in comparison with reference specimen (NR).The increased in ultimate load indicates that, the confinement of dome specimen was increased, result a decrease in specimen deterioration, see Table (9).

Table (9) Ultimate Load for Group Three

Specimen Configuration	Ultimate Load (kN)	Improvement in Ultimate Load (%)
NR	37.5	Reference
DRS2	64.5	72
DRS4	67.5	80

2. Effect of Steel Rib

The specimen (DRRS2) recorded (81.3%) increase in ultimate load over the reference specimen (NR), while specimen without rib (DRS2) achieved (72%) increasing in ultimate load over the reference specimen (NR). On the other hand the specimen (DRRS4) with 4mm rib thickness achieved increased in ultimate load about (126.67%). For comparison, the specimen (DRS4) (without rib) recorded increased in ultimate load about (80%), see Table (10). The steel rib limited the buckling of steel ring, so additional reverses force was formed at ring bottom, the overall stiffness of ring was increased, and the dome stiffness was developed accordingly.

Table (10) Ultimate Load for Group Four

Specimen Configuration	Ultimate Load (kN)	Improvement in Ultimate Load %
NR	37.5	Reference
DRS2	64.5	72
DRRS2	68	81.3
DRS4	67.5	80
DRRS4	85	126.67

Stiffness of Tested Specimens

Stiffness defined as the resistance of the body to the deformations, it represent the slop of the line that connect the initial load to a specific load in load-deflection curve that required to calculate stiffness[9], i.e. stiffness can be calculated from equation below:

$$k = \frac{Pi - Po}{\Delta i - \Delta o} = \frac{Pi}{\Delta i}$$

Where:-

$k =$ Stiffness $(\frac{\text{kN}}{\text{mm}})$

Pi = Load the required to calculate stiffness

$\Delta i =$ Deflection at (Pi)

Po = Initial load (kN)

$\Delta\text{o} =$ Initial deflection (mm)

Increasing the steel ring thickness significantly effect on the rate of degradation in stiffness of tested domes. The specimen DRS2(steel ring with 2mm thickness) lost about 22.06% from its stiffness at 25%.While the specimen DRS4(steel ring with 4mm thickness) achieved a decrease in its stiffness at 50% about 18.4% with respect to its stiffness at 25%. At failure, the specimen DRS2 lost about 16.67% with respect to its stiffness at 50%, and the specimen DRS4 lost about 21.53% from its stiffness at 50%. A comparison was made between specimens have different thicknesses of steel ribs. The specimen DRRS4 (with 4mm steel rib thickness) lost 18.4% and 21.35% from its stiffness at 25% and 50% respectively. On the other hand specimenDRRS2 achieved reduction in its stiffness at 25% and 50% about 28.45% and 18.61% respectively. Also, the reduction in stiffness was lower than that reference specimen NR, as shown in Table (11).

Table (11) Stiffness of Tested Domes

CODE	Stiffness at 25% (1)	Stiffness at 50% (2)	% Decrease between (1) and (2)	Stiffness at 100% (3)	% Decrease between (2) and(3)
NR	18.203	11.43	37.2%	7.8	31.75%
DRS4	45.45	37.088	18.4%	29.1	21.53%
DRRS4	49.02	41.16	16.03%	30.575	25.72%
DRS2	29.412	22.92	22.06%	19.104	16.67%
DRRS2	36.95	26.43	28.45%	21.518	18.61%

First Crack Load

The test results of first crack load of tested domes are shown in Table (12). The first crack load means that the applied stresses exceed the concrete tensile strength [10].

The first crack load was increased about (50%) for specimen DRS2 and (100%) for specimens DRS4 in comparison with first crack of specimen (NR). The steel ring delayed first crack load through preventing the concrete dome to deform under load. The 4mm steel ring contributes to some extent in reducing the deflection in post crack stage larger than the specimen with 2mm steel ring. When using steel rib at dome bottom**,** there is clear increasing of the first crack load in comparison with reference specimen; the specimens DRRS4 (with 4mm rib) achieved first crack load at 25 kN, while specimen DRS4 (with steel ring only) achieved first crack load at 20 kN. On the other hand, the specimen DRRS2 (with 2mm rib) achieved first crack load at 20kN, while specimen DRS2 (with steel ring only) achieved first crack load at 15 kN. The steel rib added some additional bracing against dome deterioration.

Table (12) first Crack Load and Deflections of Tested Specimens

CODE	First crack (kN)	Improve of First Crack (%)	Deflection (mm) at First Crack		
			at 20mm	at 50mm	at 190mm
NR	10	R	0.55	0.42	0.32
DRS4	20	100	0.44	0.58	0.81
DRRS4	25	150	0.51	0.63	0.8
DRS2	15	50	0.48	0.62	0.86
DRRS2	20	100	0.54	0.61	0.93

Energy Absorption

Energy absorption can be defined as amount of energy that the specimen can be absorbed before failure. The energy absorption gives an indication on the ductility of the specimen [11], it can be determined from the area under the load-deflection curve.

1. Effect of Steel Ring

The increase in the thickness of steel ring gives a beneficial effect in increasing the absorbed energy of tested domes; the specimen DRS2 of 2mm ring thickness gives energy absorption higher than reference specimen by about 13.74%. The energy absorption of the dome was increased with increasing the thickness of steel ring to 4mm by about 20.1%, as shown in Table (13). Large thickness of steel ring gives high ultimate load accompanied with small deflection made the area under load-deflection curve increased accordingly.

2. Effect of Steel Rib

The energy absorption of specimen with large rib thickness 4mm higher than that of specimens with 2mm rib thickness, the increase in energy absorption of specimen DRRS4 higher than reference specimen (NR) by about 32.09%, while specimen DRRS2 achieved an increase in energy absorption about 14.68% in comparison with same reference specimen (NR), as shown in Table (13).

Table (13) Energy Absorption of Tested Domes

Labeling	Energy Absorption (kN.mm)	Percentage (%) Improvement of Energy Absorption
NR	107.1625	Reference
DRS4	128.7125	20.1
DRRS4	141.55	32.09
DRS2	121.89	13.74
DRRS2	122.9	14.68

Conclusion

The following conclusions can be draw from the above experimental investigation:

1. The test results confirm that the bracing of domes with steel ring contribute in increase the ultimate load, first crack load, stiffness of specimens and energy absorption of specimens.
2. The deflection and strain of domes specimens were decrease when bracing the specimen with steel ring.
3. It is found that steel rib increase the ultimate load, first crack load, stiffness of specimen and absorbed energy of specimens.
4. It is observed that using steel rib at the bottom of dome decrease the deflection and strains of the dome specimens.

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