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Reinforced Concrete Circular T-Shaped Deep Beams – Finite Element Investigation

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ABSTRACT

The current work investigates the behavior and strength of T-shaped cross section ring deep beams through a Finite element parametric study. Currently, ring diameter, loading type, concrete compressive strength and number of supports are taken into consideration. It is found that increasing ring diameter of beam by 12.5-25% leads to increase the maximum positive moment, maximum negative moment, maximum torsional moment and midspan deflection by 1.1-2.2%, 2.2-4.3%, 3-6% and 16-33%, respectively, while the load ultimate capacity increases by 11-17%. The positive and torsional moments at midspan and midspan deflection decrease by 23-36%, 3-11% and 6-14%, respectively when the loading type varies from concentered to full uniformly load over a span length of 33, 50, 67 and 100%, respectively. In a related context, this change in load type leads the negative moment at support and the load ultimate capacity to increase by 2-21% and 6-85%, respectively. The midspan positive moment, negative moment, torsional moment and load ultimate capacity increase by 20.4-71.3%, 20-69.7%, 15.6-43.8% and 21-73%, respectively, whereas deflection decreases by 1.4-11%, when increasing the compressive concrete strength by 45-190%. Finally, it is found that the load ultimate capacity increases by 82-348%, when number of supports increases by 25-100%, while torsional moment, maximum positive moments, maximum negative moments and midspan deflection decrease by 11-50%, 38-76.4%, 38.6-76.8% and 14-39%, respectively due to this increase in the number of supports.

1. Introduction

Reinforced concrete deep beams, which are circular in plane, are used in many fields in engineering structures such as highway bridges and crossroads in large urban areas to achieve a smooth traffic flow, circular water tanks, circular foundation and other structures [1]. T-Shaped RC circular deep beams that are loaded and supported loads normally to their planes, are under torsion, in addition, bending and shear. Thus, taking the combined effect is an essential feature when analyzing and designing.

The ACI 318M-14 Code describes deep beams as [2]: "the beams that are supported on a face and loaded on the opposite face as shear stresses can form between the loads and supports. That through (1) or (2): (1) concentrated loads occurred in a displacement 2h from face of support; and (2) Clear span is not more than four times the beam depth h". Therefore, the authors note that, in previous research work, the greatest focus was on deep beams that have single span [3-6] and/or continues deep beams [7-11], but not on circular deep beams with T-shaped section. From another hand, finite element is so permitted tool

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to analyze reinforced concrete structures [12-20]. Circular deep beams are widely used in structural engineering, whereas lack of such investigations on circular deep beams is understandable. Upon it, this paper showed analytical investigation for twenty reinforced concrete T-shaped circular deep beams in order to achieve the effects of beam diameter, load type, concrete compressive strength and number of supports on positive bending moments, negative bending moments, torsional moments, midspan deflection, load capacity, and failure location

2. Finite element model

The methodology comprises using the ETABS software to investigation the parametric effect on T-shaped circular deep beam. The whole investigation is broken down into the steps below.

2.1 Modeling

The use of three-dimensional (3D) finite element (FE) analysis to predict the behavior of structural elements has become increasingly popular. The models are created utilizing ETABS 2018 software. The beam design to ACI 318-14 utilizing the maximum capacity of load. The vertical slice mesh has about 96-100 elements along the T-shaped circular beams. Number of elements was chosen based on convergence studies to find the best mesh for relatively accurate solution with minimal computational time. In the current study, an elastic perfectly plastic behavior is assumed for the reinforcing steel bars in both tension and compression as shown in Figure 1, and concrete is consider as a quasi-brittle material that has different behavior in tension and compression, Figure 2.

2.2 Reinforced concrete T-Shaped circular deep beam – parametric investigation

Twenty reinforced concrete T-shaped circular deep beams are divided into four groups; A, B, C and D. Each group includes five specimens as shown in Table 1. All T-cross section reference beams have a diameter of 4000 mm c/c, a web thickness of 250 mm, a flange depth of 250 mm, a flange width of 1000 mm and a beam height of 1000 mm. Group A includes five specimens that have various values of c/c diameter, more specifically, 3000 mm, 3500 mm, 4000 mm, 4500 mm, and 5000 mm.

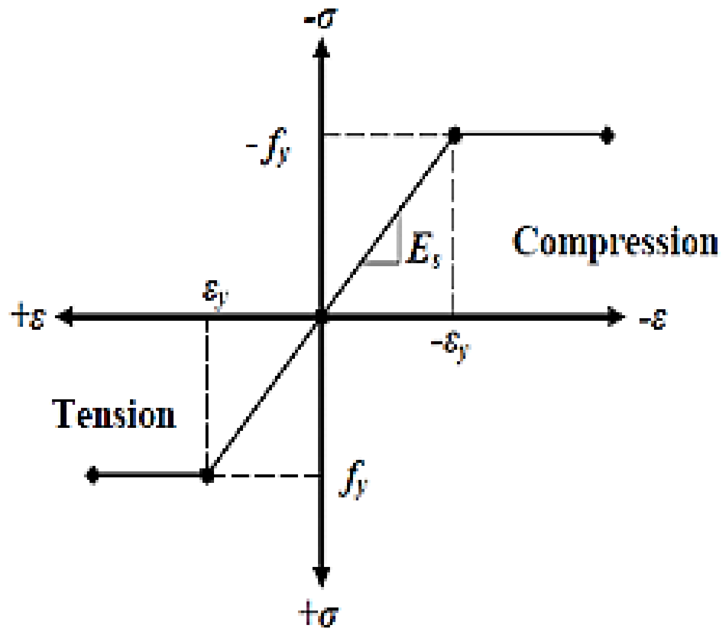

Figure 1. Assumed elastic perfectly plastic stress-strain relationship in the used reinforcing steel bars

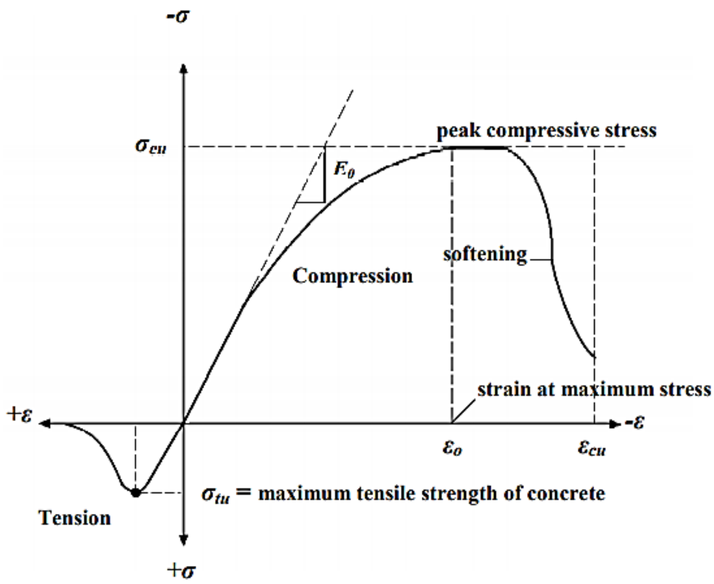

Figure 2. Assumed stress-strain relation in the used concrete

Group B includes five specimens that have various load type; concentrated load, 33% of the span length partial uniform load, 50% of the span length partial uniform load, 67% of the span length partial uniform load and Full uniform load, i.e. 100% of the span length. Group C includes five specimens that have various values of concrete compressive strength; 20 MPa, 27.58 MPa, 40 MPa, 60 MPa and 80MPa. Finally, group D includes five specimens with different numbers of supports; 4, 5, 6, 7 and 8 supports. Figure 3 shows the T-shaped circular deep beam in 3D modeling.

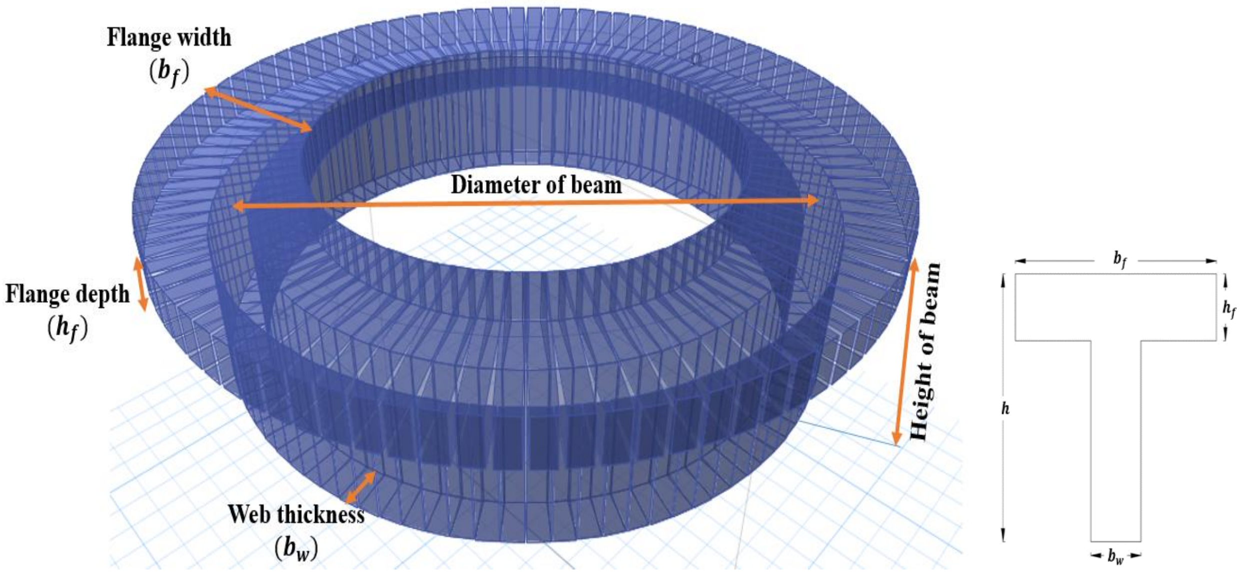

Figure 3. Modeling of T-shaped circular deep beam

Table 1: The studied parameters in detail

No.	Group		Parameter	Diameter c/c (mm)	Concrete Compressive Strength (MPa)	No. of Supports
1	A		Diameter of ring	3000	27.58	4
2				3500		
3				4000		
4				4500		
5				5000		
6	B	Load type	Concentrated load	4000	27.58	4
7			Partial uniform load (33%)			
8			Partial uniform load (50%)			
9			Partial uniform load (67%)			
10			Full uniform load (100%)			
11	C	Material	Concrete Compressive Strength	4000	20	4
12					27.58	
13					40	
14					60	
15					80	
16	D	Configuration	No. of Supports	4000	27.58	4
17						5
18						6
19						7
20						8

2.3 Material properties

T-shaped circular deep beams are constructed using two materials: concrete and reinforcement steel. Each element type in this modeling had been utilized to represent a specified beam's materials.

The geometrical properties of the used elements, such as cross- sectional area, is required for the real constants. The needed material properties based on mechanical tests such as yield stress of main reinforcement (f_y), concrete compressive strength ($f'c$), Poisson`s ratio (ν), yield stress of web reinforcement (f_{ys}), modulus of elasticity of steel reinforcement (Es) and modulus of elasticity of concrete (Ec) are shown in Table 2.

Table 2: Material properties

E_c (MPa)	E_s (MPa)	f'_c (MPa)	Poisson`s ratio for concrete (ν)	Poisson`s ratio for steel (ν)	f_y (MPa)	f_{ys} (MPa)
21019	199948	20	0.2	0.3	450	450
24682.8		27.58				
29725.4		40				
36406		60				
42038.1		80				

3. Parametric study

Using ETABS software, the results of maximum torsional moments, maximum negative moments, maximum positive moments, load capacity, maximum midspan deflection, and failure location of all beams are illustrated in the following paragraphs. The details of the twenty T-shaped circular deep beams to conduct the parametric study are presented in Table 3.

Table 3: Results of all specimens

No.	Group	Parameter		Diameter (mm)	Compressive Strength of Concrete (MPa)	No. of supports	Midspan M+ve (kN.m)	Support M-ve (kN.m)	Max. Torsional Moment (kN.m)	Max. Shear (kN)	Load capacity (kN)	Change In Load Capacity	Deflection (mm)	Change In Deflection	Type of failure
1	A	Diameter of ring		3000	27.58	4	171	174	34	284	2176	+27%	0.206	-27%	T.SF*
2				3500			177	181	35	241	1920	+12%	0.243	-14%	
3				4000			181	185	36	230	1708	-	0.283	-	
4				4500			183	189	37	209	1528	-11	0.327	+16%	
5				5000			185	193	38	194	1380	-19%	0.377	+33%	
6	B	Load type	Concentrated load	4000	27.58	4	181	185	36	230	1708	-	0.283	-	T.SF
7			Partial uniform load (33%)				139	188	35	237	1813	+6%	0.265	-6%	
8			Partial uniform load (50%)				124	191	34	249	1947	+14%	0.256	-10%	
9			Partial uniform load (67%)				115	196	33	277	2161	+27%	0.249	-12%	
10			Full uniform load (100%)				116	224	32	401	3166	+85%	0.243	-14%	
11	C	Material	Concrete Compressive Strength	4000	20	4	154	158	31	197	1444	-15%	0.285	+0.7%	T.SF
12					27.58		181	185	36	230	1708	-	0.283	-	
13					40		218	222	43	275	2068	+21%	0.279	-1.4%	
14					60		268	272	53	235	2548	+49%	0.264	-7%	
15					80		310	314	62	385	2952	+73%	0.252	-11%	
16	D	Configuration	No. of Supports	4000	27.58	4	181	185	36	230	1708	-	0.283	-	T.SF
17						5	204	206	32	323	3100	+82%	0.244	-14%	
18						6	209	211	27	399	4656	+173 %	0.218	-23%	
19						7	202	204	23	453	٦١٦٧	+261 %	0.294	-31.4%	
20						8	191	192	18	487	٧٦٥٦	+348 %	0/174	-39%	

* T. SF = Torsion and shear failure

3.1 Effect of beam diameter

This parameter is extremely important. Five beams that had various diameter values; 3000 mm, 3500 mm, 4000 mm, 4500 mm and 5000 mm that subjected to single concentrated load of each span were investigated. The effect of diameter has been studied and found to be significant where increasing circular diameter by 12.5-25% leads to:

- The load capacity decreases by about 11-17%, Figure 4.
- Positive moments at midspan increase by about 1.1-2.2%, Figure 5.
- Negative moments at supports increase by about 2.2-4.3%, Figure 6.
- Maximum torsional moments increase by about 3-6%, Figure 7.
- The deflection increases by about 16-33%, Figure 8.
- The mode of failure in all beams occurred between loading and support points, indicting torsional and shear failure. As an example, Figure 9 shows the failure when diameter is 4000 mm.

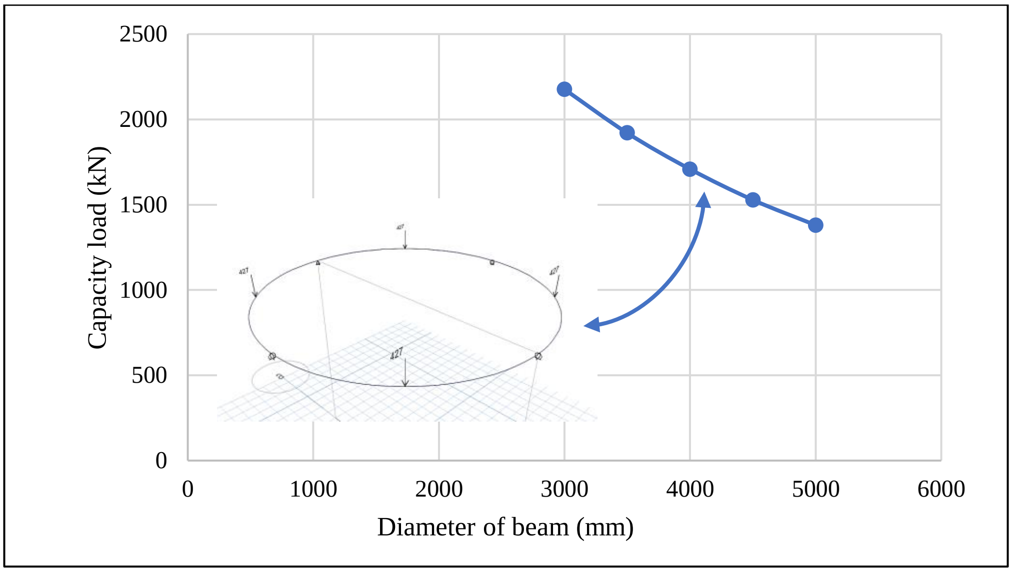

Figure 4. Diameter effect on load ultimate capacity

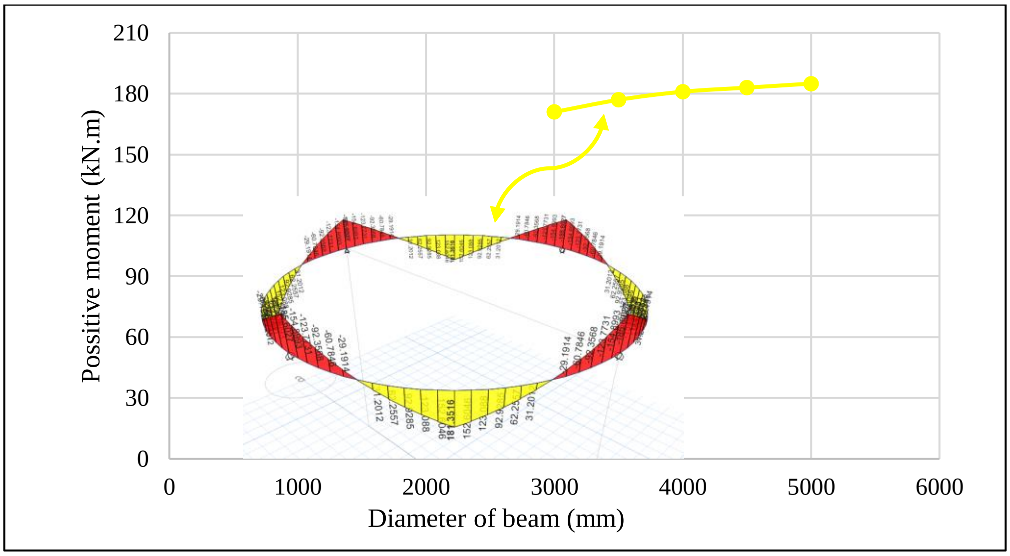

Figure 5. Diameter effect on positive moment

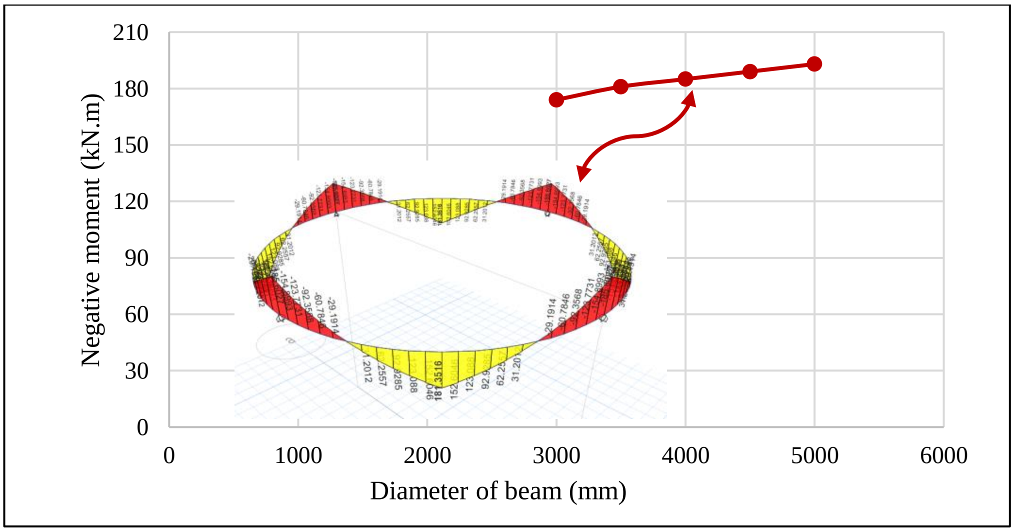

Figure 6. Diameter effect on negative moment

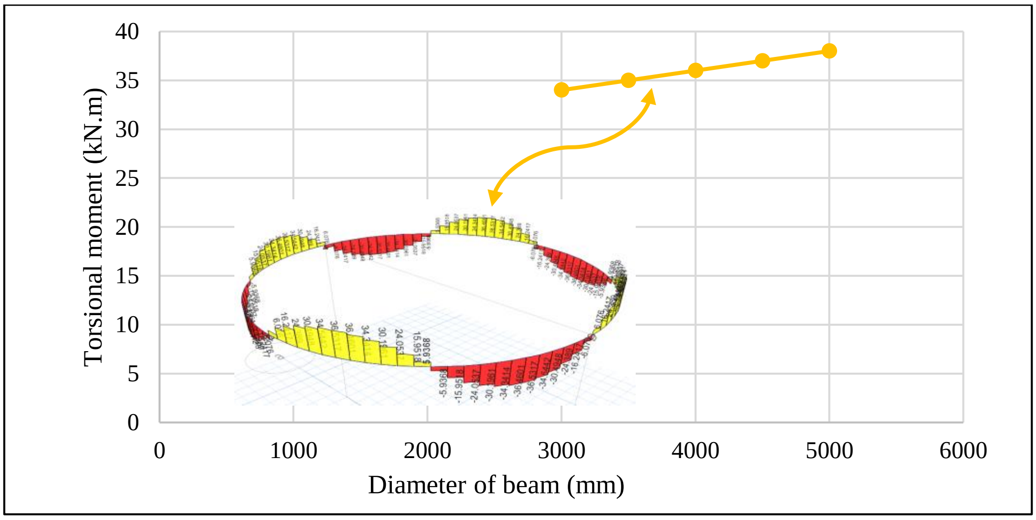

Figure 7. Diameter effect on torsional moments

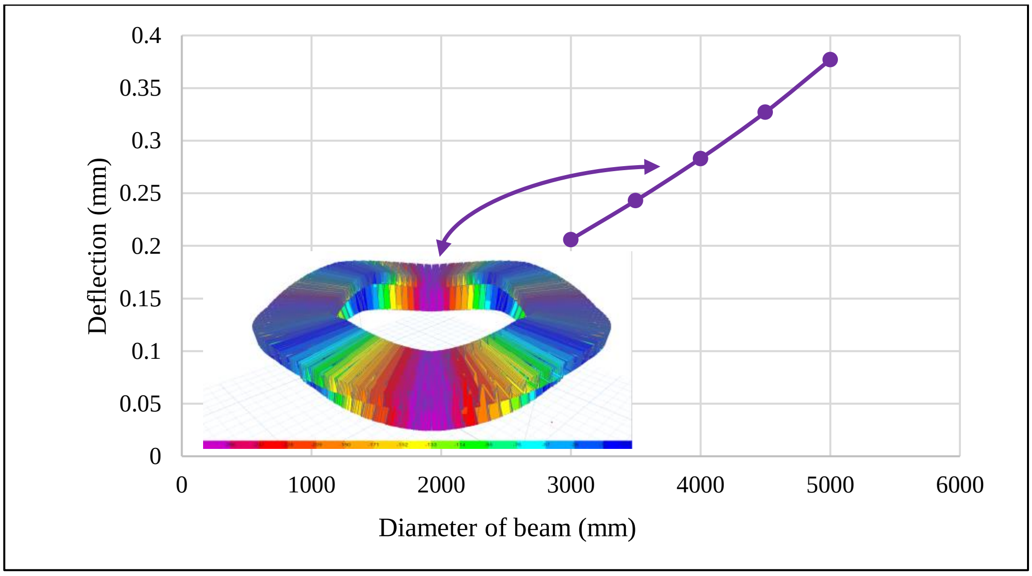

Figure 8. Diameter effect on deflection

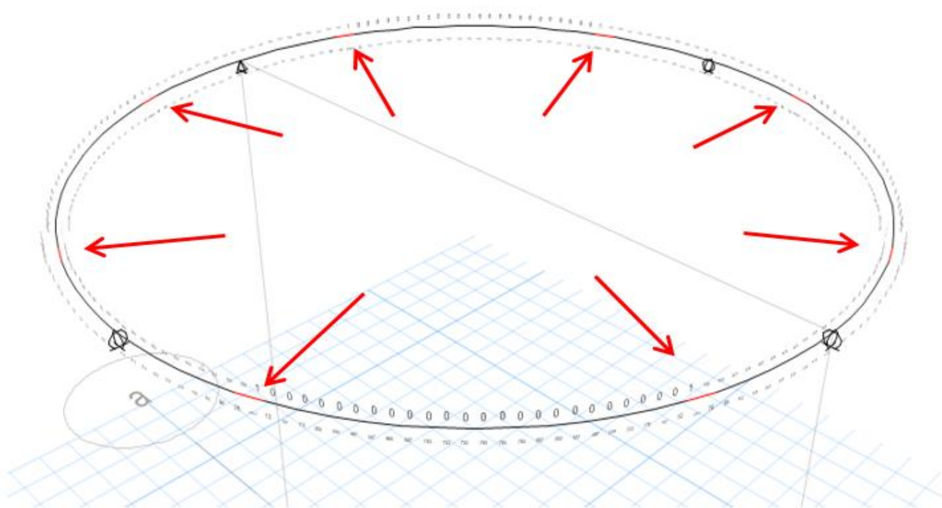

Figure 9. Location of failure in beam with 4000 mm diameter

3.2 Effect of loading type

Common loading types on beams are concentrated loading and uniformly distributed loading of varying degrees; 33%, 50%, 67% and 100% of the span's overall length, Table 1. The higher the negative moments and load capacity of the beam, the lower the positive moments, torsional moments and deflection, because the load concentration generates a concentration of stresses, resulting in early failure. In more detail:

- Applying a partial or full uniformly distributed load over a span length of 33, 50, 67, and 100% decreases the positive moments by 23, 31, 36.5, and 36%, respectively, when compared to a concentration load as shown in Figure 10.
- When a partial or full uniformly distributed load was applied over a span length of 33, 50, 67, and 100 %, the negative moments increased by 2, 3, 6, and 21%, respectively, compared to load concentration case, Figure 11.
- Applying a partial or full uniformly distributed load over a span length of 33, 50, 67, and 100% decreases the torsional moments by 3, 6, 8, and 11%, respectively, when compared to the concentration load case as shown in Figure 12.
- Applying a partial or full uniformly distributed load over a span length of 33, 50, 67, and 100% increases the load capacity by 6, 14, 27, and 85%, respectively, when compared to the concentration load case as shown in Figure 13. The effect of stress concentration can be linked to those differences attributed to results.
- Applying a partial or full uniformly distributed load over a span length of 33, 50, 67, and 100% led to decrease the deflection by 6, 10, 12, and 14%, respectively, in comparison to the concentration load case, Figure 14.
- In all cases, the location of beam failure lies at zones between loading and supporting points.

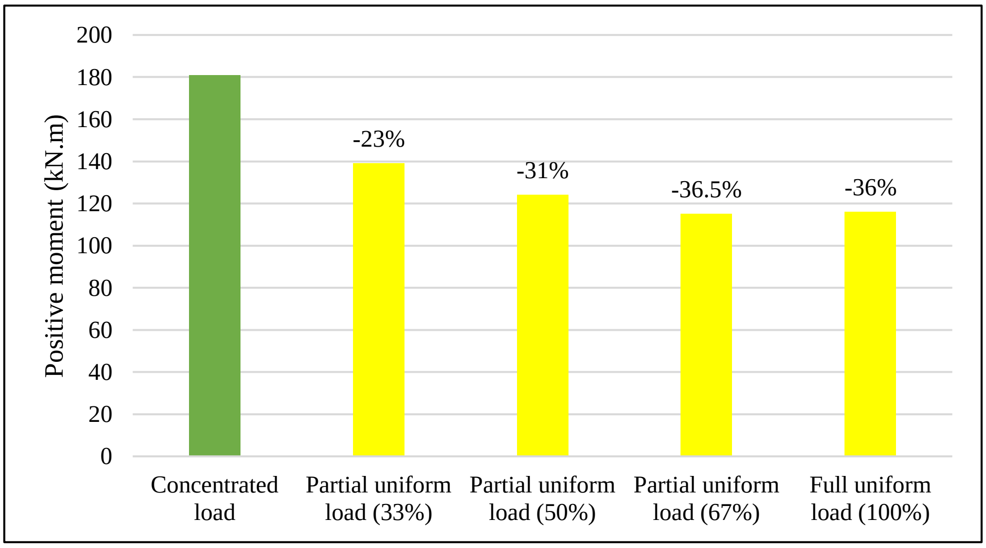

Figure 10. Loading type effect on positive moments

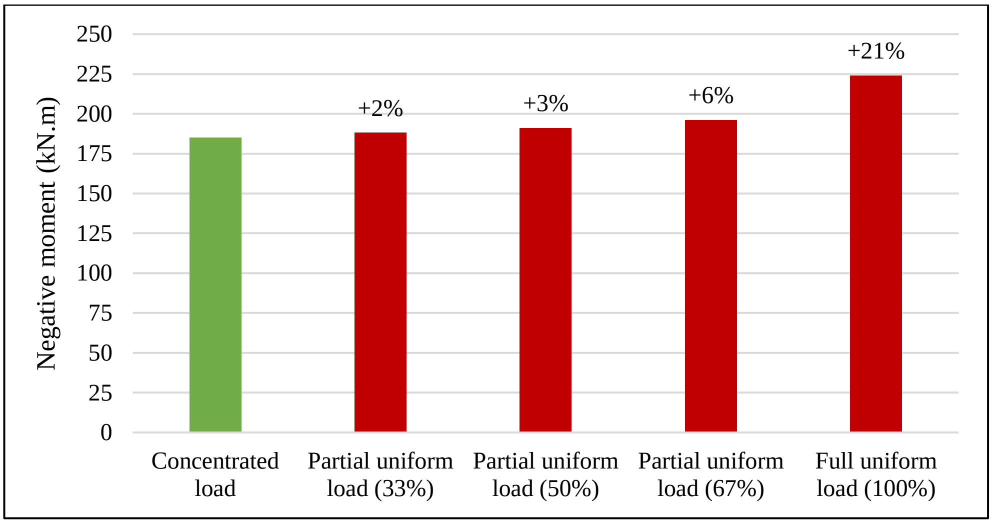

Figure 11. Loading type effect on negative moments

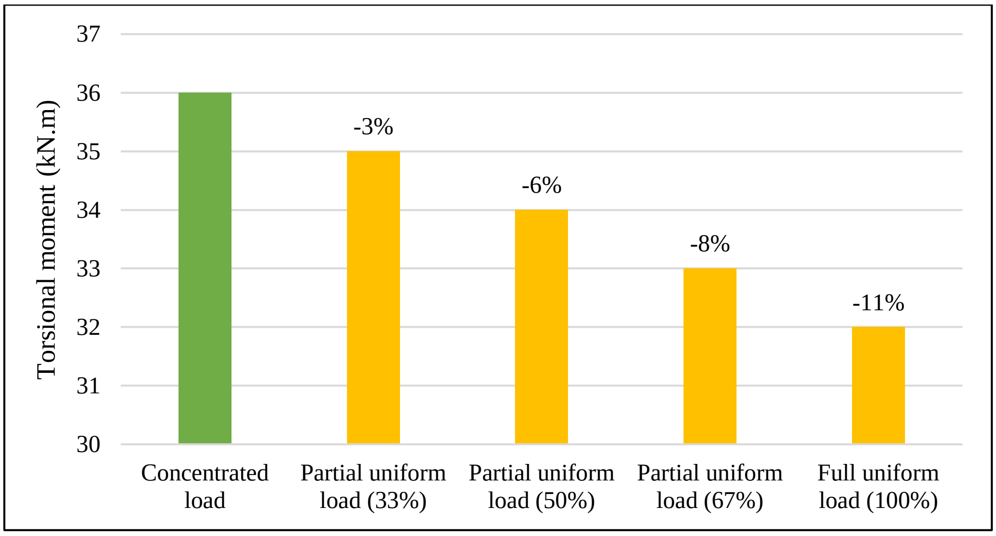

Figure 12. Loading type effect on torsional moments

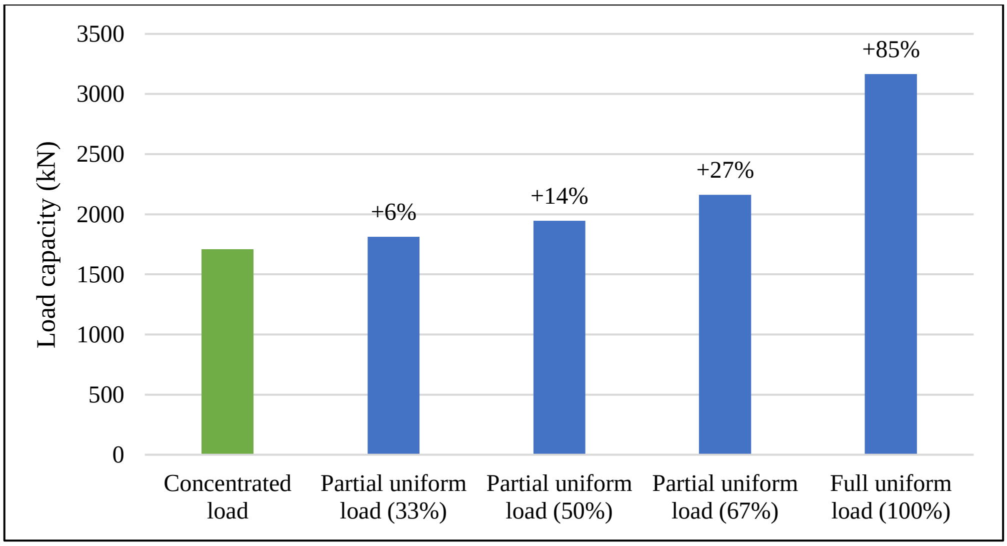

Figure 13. Loading type effect on load capacity

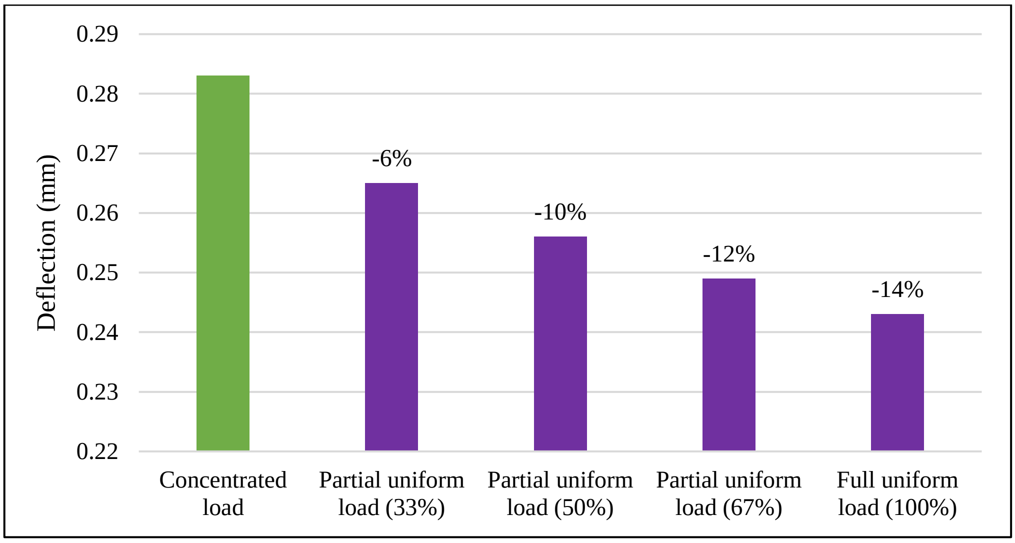

Figure 14. Loading type effect on deflection

3.3 Effect of concrete compressive strength

Under one concentrated load at mid span, five beams with different compressive strength values of 20 MPa, 27.58 MPa, 40 MPa, 60 MPa, and 80 MPa were investigated. The increase of 45-190% in concrete compressive strength, increases the ability for both shear and compressive stresses of the beam section. The following conclusions are reached:

- Increasing the positive moments at mid span by 20.4-71.3%, Figure 15.
- Increasing the negative moments at supports by 20-69.7%, Figure 16.
- Maximum torsional moments increase by about 15.6-43.8%, Figure 17.
- Increasing the load capacity by about 21-73%, Figure 18.
- Decreasing the deflection at midspan by about 1.4-11%, Figure 19.

In all T-shaped ring deep beams, the failure mode occurred between loading and support points indicating the shear and torsion failure.

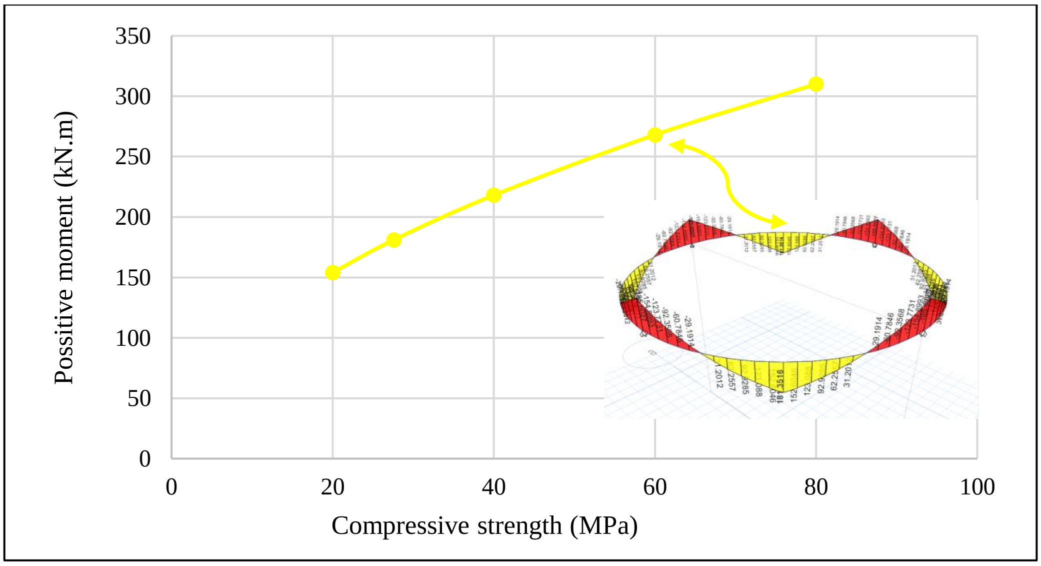

Figure 15. Effect of concrete compressive strength variation on positive moments capacity

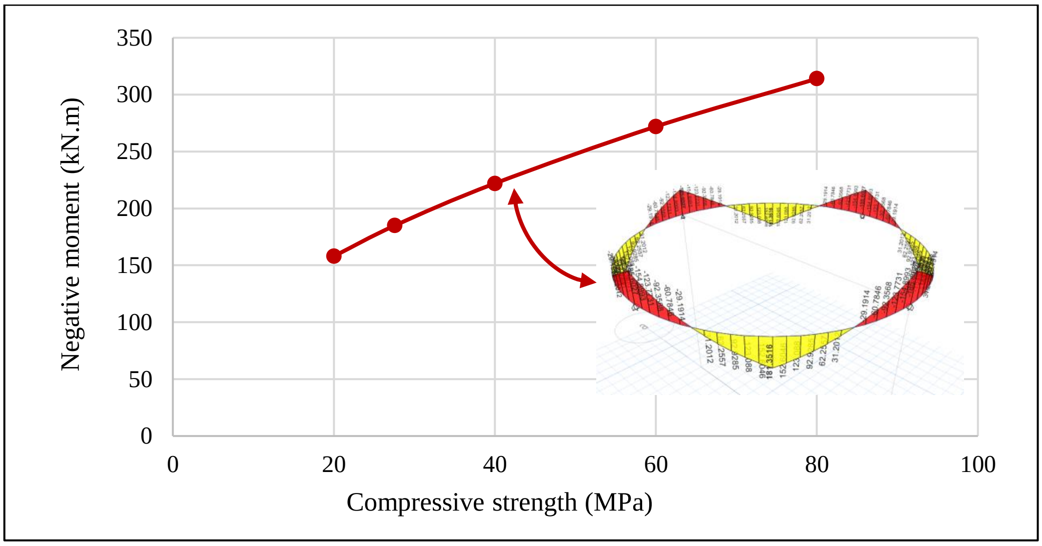

Figure 16. Effect of concrete compressive strength variation on negative moments capacity

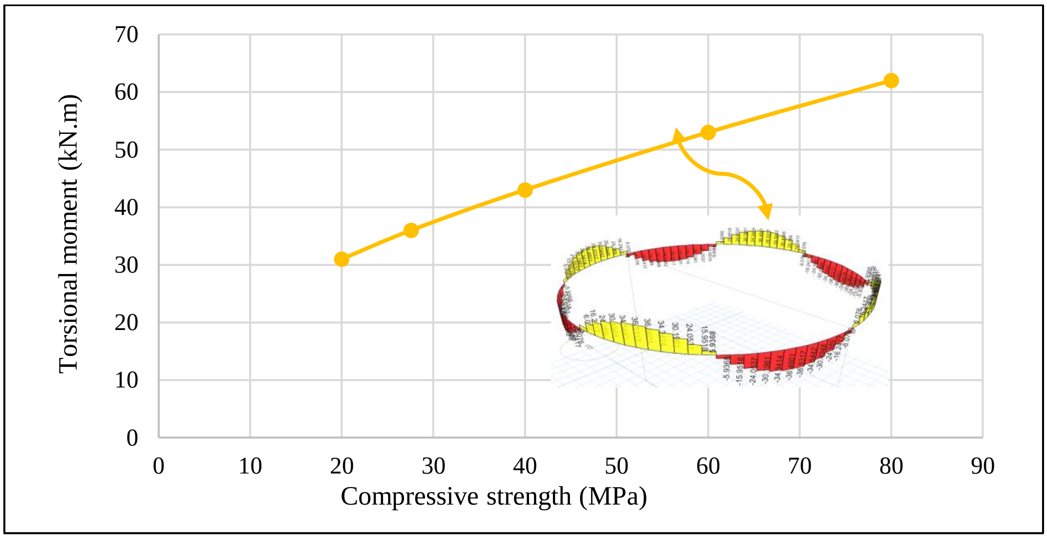

Figure 17. Effect of concrete compressive strength variation on torsional moments capacity

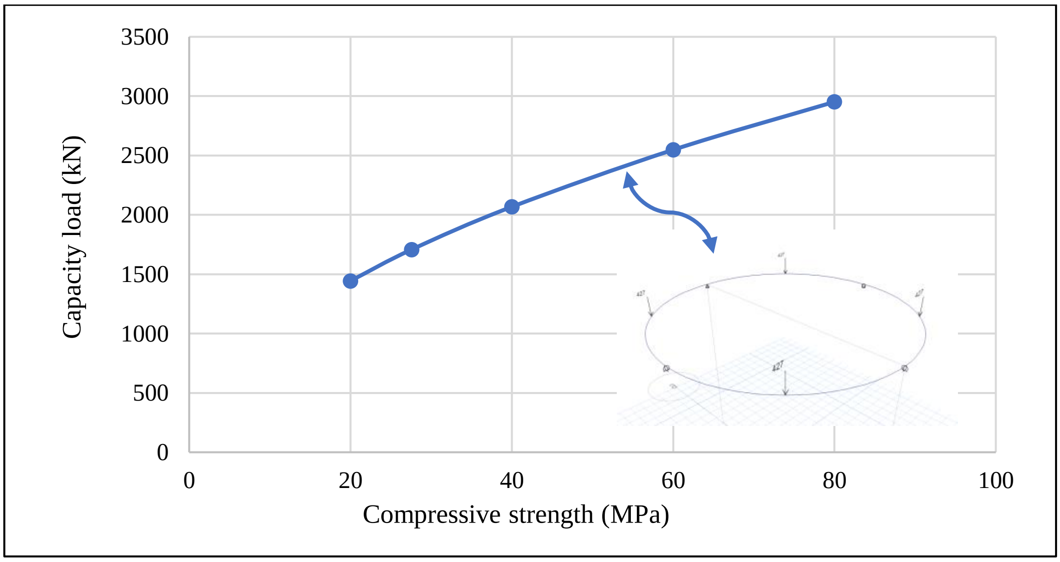

Figure 18. Effect of concrete compressive strength variation on load ultimate capacity

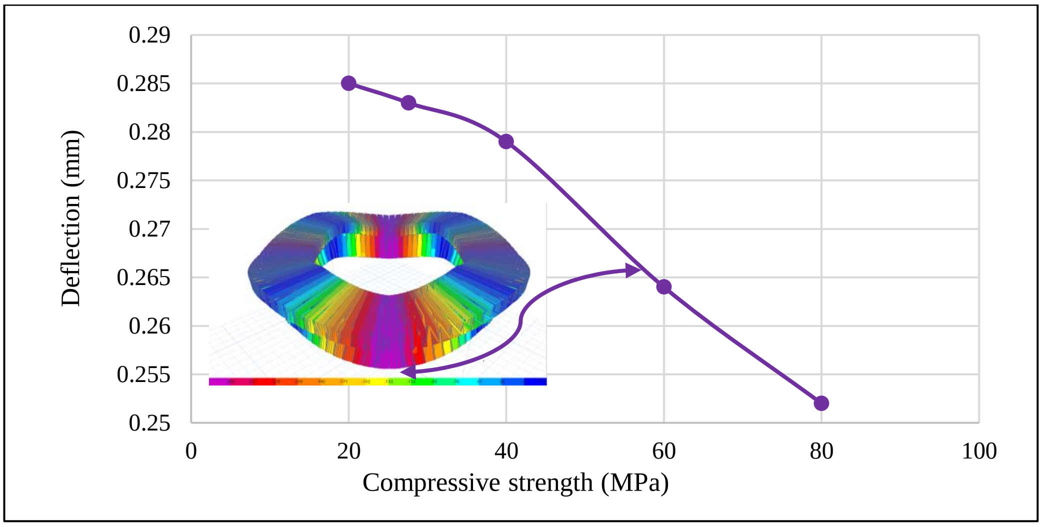

Figure 19. Effect of compressive strength variation on deflection

3.4 Effect of the number of supports

The strength and behavior of five T-shaped circular deep beams were carried out according to various number of supports; 4, 5, 6, 7 and 8. More number of supports, increasing by 25-100%, leads to a shortening of the span length:

1. When increased number of supports from 4 to 8 increased slightly on the positive moments at midspan, but this increased due to increase in capacity of beams. Therefore, when divided the ultimate capacity over positive moment that clearly decreased in moment strength by 38-76.4% when incresed number of supports, Figure 20.
2. Increasing slightly on the negative moments,but this increased due to increase in capacity of beams. Therefore, when divided the ultimate capacity over negative moment that clearly decreased in moment strength by 38.6-76.8% when incresed number of supports, Figure 21.
3. Decreasing the maximum torsional moments by 11-50%, Figure 22.
4. Increasing the load of capacity by about 82-348%, Figure 23.
5. Decreasing the deflection at midspan by 14-39%, Figure 24.

In all T-shaped ring deep beams, the failure occurred between loading and supporting points indicating the shear and torsion failure.

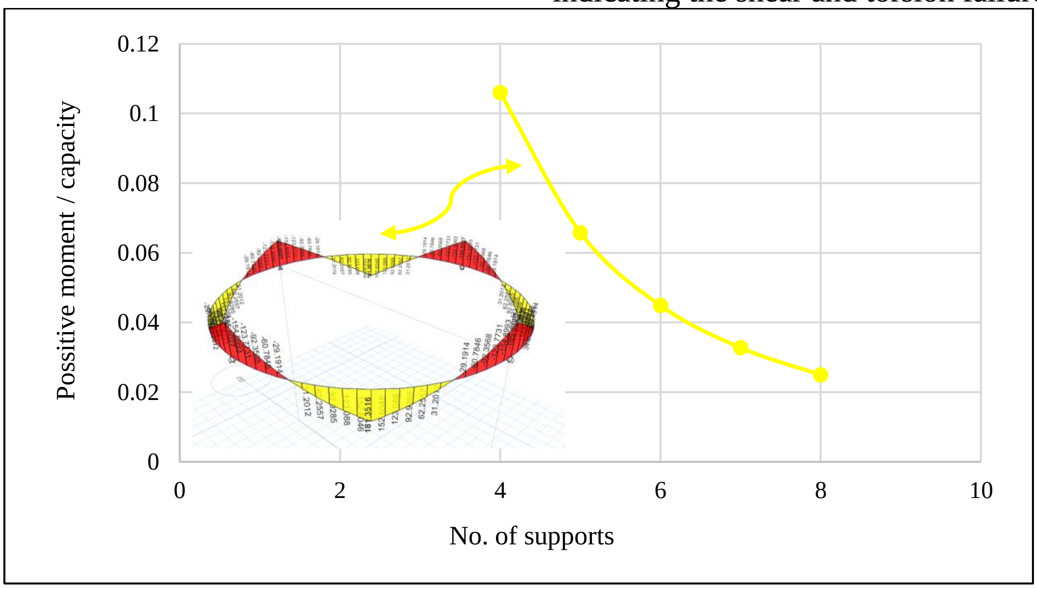

Figure 20. Effect of number of supports variation on positive moments

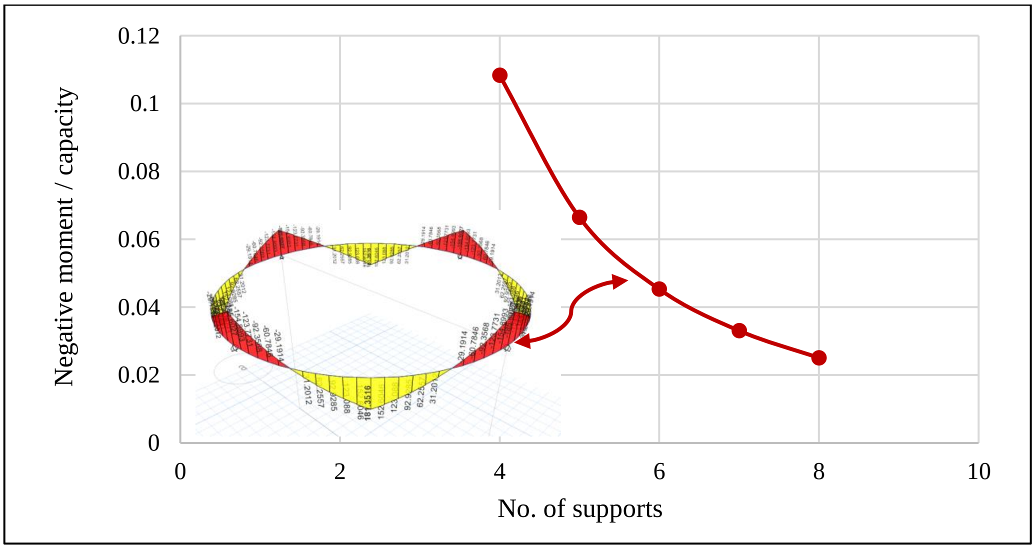

Figure 21. Effect of number of supports variation on negative moments

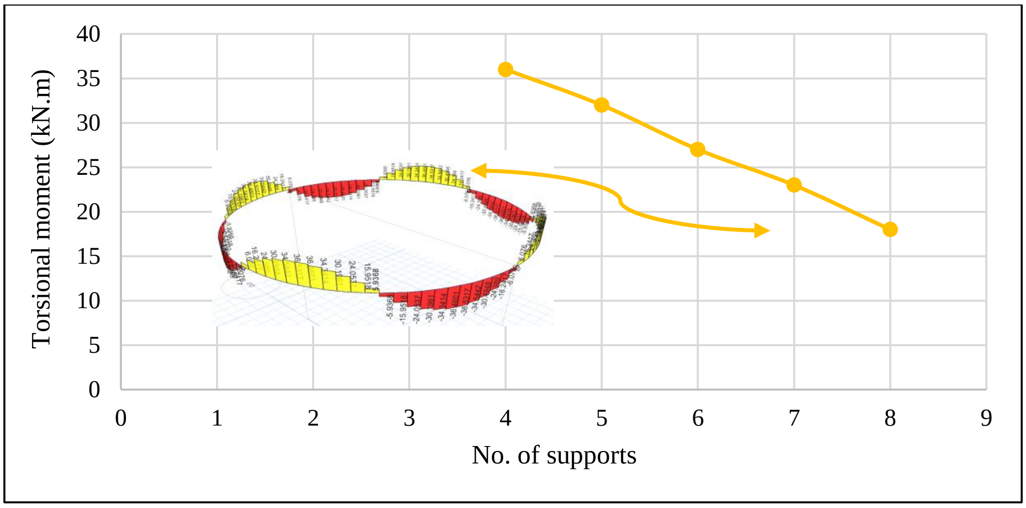

Figure 22. Effect of number of supports variation on torsional moments

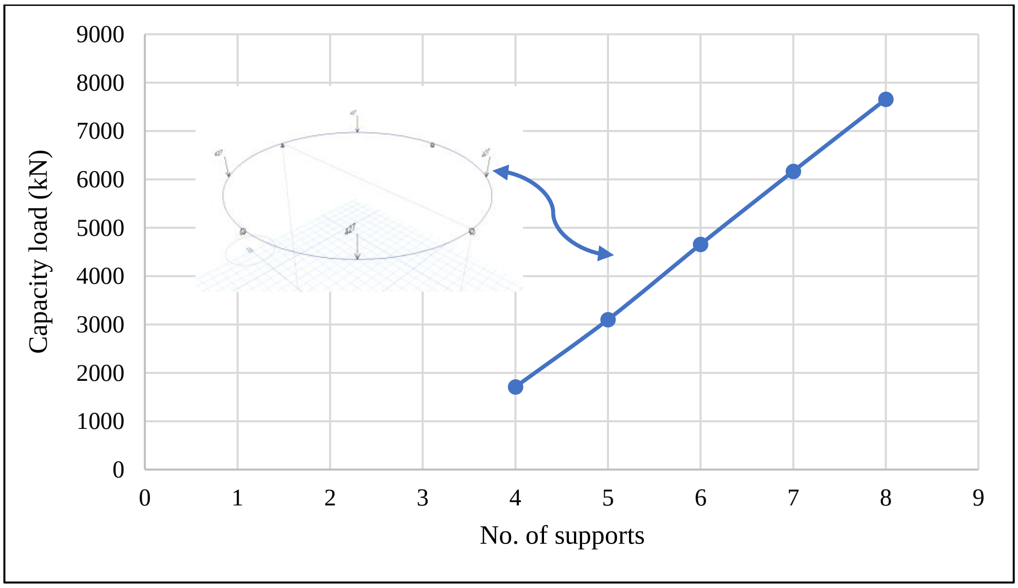

Figure 23. Effect of number of supports variation on load capacity

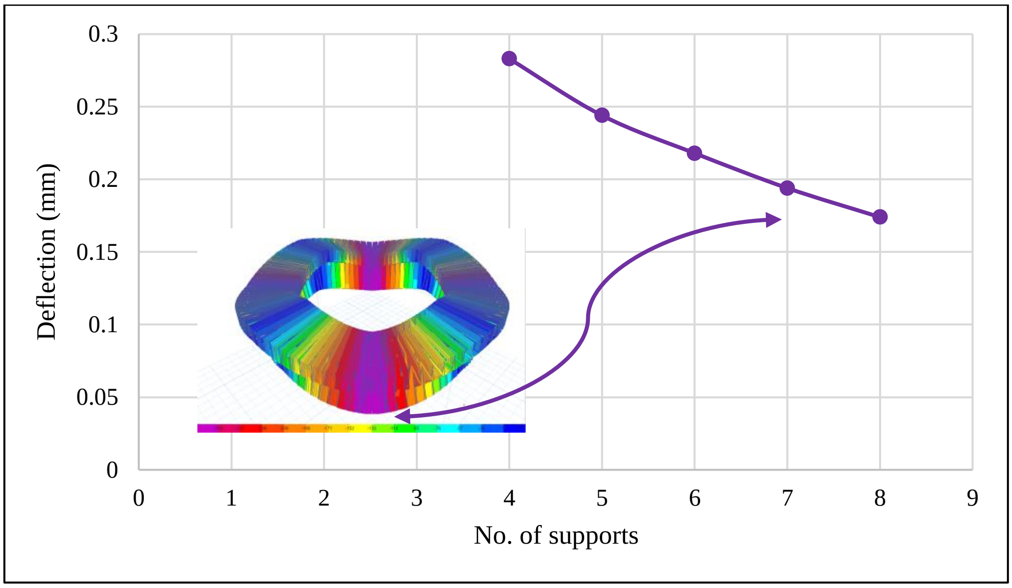

Figure 24. Effect of number of supports variation on deflection

4. Conclusions

In the current research work, finite element method is used to investigate most influential parameters that affect the behavior of the reinforced concrete deep ring beams that having T-shaped section. The main parameters were ring diameter, loading type, concrete compressive strength and number of supports. The following findings were reached:

1- The torsional, positive and negative moments in addition to mid-span deflection increase by about 3-6%, 1.1-2.2%, 2.2-4.3% and 16-33%, respectively, when beam diameter increases by 12.5-25%. Whereas this diameter increase leads to decrease the load capacity by about 16-33. That can be attributed to span elongation that caused by diameter increase.

2- The torsional, positive and negative moments in addition to mid-span deflection decrease by about 3-11%, 23-36% and 6-14%, respectively, when replacing the applied load type from concentrated to uniformly distributed one over a portion of span length of 33, 50, 67 and 100%, respectively. While the maximum negative moment and the load ultimate capacity increase by 2-21% and 6-85%, respectively, when replacing the applied load type from concentrated to uniformly distributed one over the same aforementioned span length values. The difference in results occurred because expanding the load application area decreases the concentration of stresses.

3- The negative, positive and torsional moments in addition to load capacity increase by about 20-70, 20.4-71.3, 15.6-44 and 21-73%, respectively, when concrete compressive strength increases by 45-190%, while this concrete compressive strength increase leads to deflection decrease by about 1.4-11%. This difference took place due to the fact that increasing concrete compressive strength increases shear resistance capacity.

4- When increasing number of supports by 25-100%, the positive bending moment decreases by about 38-76.4%. From other side, maximum negative bending moment decreases by about 38.6-76.8%. While torsional moment and midspan deflection decrease by about 11-50% and 14-39%, respectively when number of supports increases by 25-100%. In addition, the load ultimate capacity increases by about 82-348%. In other words, the length of span decreases when increasing number of supports, resulting in higher strength capacity.

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