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COMPARISON BETWEEN THE BEHAVIOR OF REINFORCED CONCRETE BEAMS AND RPC BEAMS UNDER BENDING AND TORSION MOMENTS

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Abstract

Typically, the beams were subjected to bending and torsion moments especially at building edge. However, most of the studies focus on the flexural or torsional behavior of the beams independently, and few studies investigated these two combined effects. The research intends to explore the structural behavior of eight 1500mm x 200 mm x 150 mm rectangular beams that were tested under the combined effects of bending and torsional moments, with four main values of (T/M) ratio: pure bending, pure torsion, and two combined cases. The research investigates the effect of using reactive powder concrete (RPC) on beam behavior compared to normal concrete (NC). The outcome demonstrates that using RPC in beams instead of NC beams will significantly increases the cracking capacity by 136.4% in the case of pure bending and significantly increases the ultimate capacity by 118% in the case of combined moments with (T/M = 1). Also, using RPC leads to significant reduction in deflection and rotation values especially after beam cracking. RPC reduces compressive concrete strain and values of strains in longitudinal and transverse reinforcement especially in advanced loading stages.

Keywords:

Bending moment;
Torsional moment;
Combined moments;
Reactive powder concrete;
Reinforced concrete beam.

1 Introduction

Reactive powder concrete (RPC), developed by Pierre Richard and Marcel Cheyrezy for the French construction company Bouygues in 1993, is an innovative mechanical material with ultra-high strength and great ductility. It is a type of concrete made from cement, silica fume, sand, quartz powder, superplasticizer, and steel fiber. Its microstructure and performance are influenced by its low water binder ratio and lack of coarse aggregate [1-3]. with fine sand (600 µm maximum) [4]. Adding steel fibers to nonfibrous RPC transformed the nonfibrous matrix into a composite mass with plastic behavior after the first crack, providing a longer plastic range of load-deflection behavior with higher crack load and larger post- crack toughness. The inclusion of steel fibers on the failure mode of RPC cylinders, has been shown to have a more beneficial impact on splitting tensile strength than compressive strength [5]. Steel fibers enhance the ductility and control crack extension in RPC beams. beams without reinforcement, only one main crack occurs during failure, while with reinforcement, numerous subordinate cracks are created near the main cracks. Increased reinforcement increases subordinate cracks [6].

Most of the previous research on the flexural behavior of RPC I-beam or RPC T-beam studied the impact of the increasing longitudinal steel reinforcement, fibers ratio, and silica fume ratio. In these investigations, it was found that these modifications caused an increase in the ultimate load and that the inclusion of steel fiber by 2% increased the cracking load, the ultimate load, and the maximum deflection. The fibers have a substantial impact on RPC beams' flexural behavior as compared to nonfibers RPC beam. Also they have concluded that fiber type and amount can change the manner of failure from brittle failure to more ductile behavior [7-10].

Previous studies have investigated the torsional behavior of RPC I-beams or RPC T-beams and have examined the impact of increasing fibers ratio, longitudinal or transverse reinforcement ratio and doubling the flange's width and thickness. The findings of these investigations have revealed that these modifications result in an enhancement in both cracking and ultimate torques and the addition of 2%

steel fiber substantially affects the cracking pattern of RPC beams, increasing the number of fractures while decreasing their width. It was determined that the type of RPC beams (solid or hollow) had no significant influence on the angle of inclination of the cracks, cracking and ultimate torque, and beam elongation, the number of cracks was greater in hollow sections than in solid sections. The presence of web cut-outs reduces the section's ultimate torque capacity, increasing the size of the web cut-outs also decreases the section's torque capacity, as the opening widened the density of the fractures increased [11-14].

Most studies focus on flexural or torsional behavior independently and few studies investigate the combined effect of torsion and bending moments, making it essential to investigate both. The focus of this research is to investigate experimentally the effect of using reactive powder concrete (RPC) instead of normal concrete (NC) in rectangular beams under combined loading of bending and torsion moments.

2 Experimental work

The experimental work program involved casting 8 specimens and testing them, as well as performing several tests on control specimens (cylinders, and prisms) to evaluate the mechanical properties of RPC and NC. The adopted variables include the type of concrete (NC and RPC), and torsion to bending moment ratio (T/M).

2.1 Beams details and reinforcement

In this research, 4 NC beams group(A) and 4 RPC beams group(B) rectangular beams were used to study the effect of the adopted variables on the behavior of the beams. Table 1 shows reinforcement details for beams and parameters of the study.

The first beams in each group were subjected to a pure bending moment in the case of (T/M) = 0, the second beam in each group was subjected to a combination of bending and torsion moments in the case of (T/M) = 0.5, the third beam in each group was subjected to a combination of bending and torsion moments in the case of (T/M) = 1, and the fourth beam in each group was subjected to a pure torsion moment in the case of (T/M) $= \infty = ((P\ /\ 2) * (150\ mm)/0)$.

The beams are designed according to ACI specifications. Beams in Groups A and B are reinforced by 2Ø12 mm bottom longitudinal steel bars, 3Ø6 mm top longitudinal steel bars with a top-to-bottom reinforcement ratio of 0.375, and a transverse reinforcement of Ø6 mm@90 mm of ties within the middle zone and Ø6mm@50mm within the shear zone was designed to prevent shear failure and to ensure the occurrence of flexural, torsional, or both failures.

Table 1: Details of tested beams and research parameters.

Group name	Concrete type	Beam name	Bottom longitudinal reinforcement	Top longitudinal reinforcement	Transverse reinforcement for shear zone	Transverse reinforcement for middle zone	T/M
Group A	NC	A0	2Φ12	3Φ6	6@50mm	6@90mm	0
	NC	A0.5	2Φ12	3Φ6	6@50mm	6@90mm	0.5
	NC	A1	2Φ12	3Φ6	6@50mm	6@90mm	1
	NC	A∞	2Φ12	3Φ6	6@50mm	6@90mm	∞
Group B	RPC	B0	2Φ12	3Φ6	6@50mm	6@90mm	0
	RPC	B0.5	2Φ12	3Φ6	6@50mm	6@90mm	0.5
	RPC	B1	2Φ12	3Φ6	6@50mm	6@90mm	1
	RPC	B∞	2Φ12	3Φ6	6@50mm	6@90mm	∞

2.2 Materials and concrete mixing ratios

Iraqi ordinary Portland cement was used for RPC and NC mixes and it conforms to Iraqi specifications requirements No. 5/1984 [15]. For NC mixes, a grade of fine aggregate with a maximum size of 4.75 mm was used and it conforms to Iraqi Specifications Requirements No. 45/1984 [16], Natural gravel with a maximum size of 14 mm was used and it conforms with Iraqi Specifications Requirements No. 45/1984. while for RPC mixes a different grade with a maximum size of 600 µm was used, and it conforms to Iraqi Specifications Requirements No. 45/1984 [16], Silica fume has a fineness of 8820 $\boldsymbol{cm^2}$/gm was used which conforms with ASTM C1240/2005 requirements[17]. Also were used low-carbon, copper-coated microsteel fibers with lengths of 12 - 14, diameters of 0.2 - 0.25 mm, and tensile strengths greater than 2850 MPa. A liquid high-performance polycarboxylic ether-based superplasticizer was used for RPC to reduce workability loss, this plasticizer is types A and F according to the classification given in ASTM C494[18].

There were two types of concrete mixes for normal concrete and reactive powder concrete, Table 2 provides the material quantities for two types of mixes.

Table 2: Quantities of material.

Concrete type	W/C Ratio	Cement [Kg/ m^3]	Sand [Kg/ m^3]	Gravel [Kg/ m^3]	Silica Fume %	Microsteel fibers %	Water [L/ m^3]	Super-plasticizer %
NC*	0.47	400	600	1200	_	_	188	_
RPC **	0.2	1000	1000	_	25	2	200	7

*NC mix quantities are obtained from reference [19].

**RPC mix quantities are obtained from reference [20].

2.3 Instrumentation and measurements

The 6 mm Japanese steel strain gauge type (FLAB-6-113LJC-F) was used for all beams, placed on transverse and longitudinal reinforcements as shown in Fig. 4. A 60 mm concrete strain gauge type (PL-60-11-3LJC-F) was installed as shown in Fig. 1. On the upper side of the beam's middle span in order to get the maximum value of strain. After cleaning the surface, gauges were attached using glue.

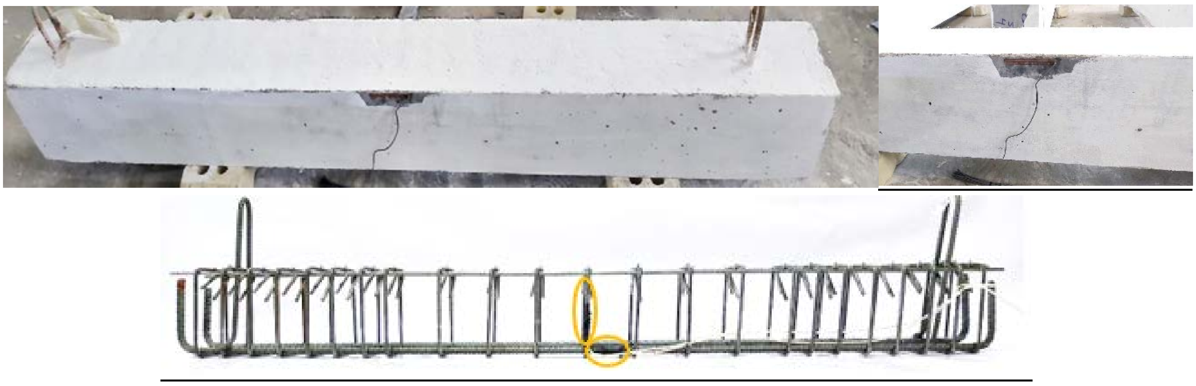


Fig. 1: Placement of strain gauges.

Two steel inspection arms were intended to be installed on the beam and used to apply the combined bending, torsion moments, and for pure torsion moment. The arms were made with sufficient section using the Staad pro. program to resist the expected stresses from the applied loads. Fig. 2 shows the section with all dimensions in mm.

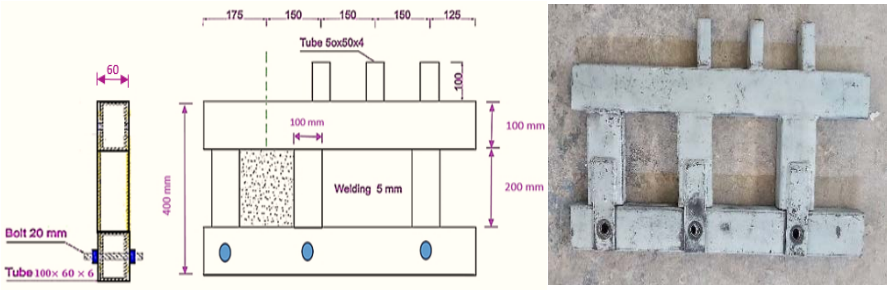


Fig. 2: The frame section with dimensions.

LVDT was used to measure the vertical deflections at the mid-beam and another LVDT was installed on both sides at the beam end to measure the beam deflections as demonstrated in Fig. 3. The rotation is determined using the formula shown below:

$$\theta = \frac{\Delta}{L} * \frac{180}{\pi} \tag{1}$$

where:
Δ – average of deflection value, for both sides of beam,
L – distance between the LVDT’s tip and the canter of the beam,
Θ – angle of twist in degree.

Fig. 3: Deflection and rotation measurement.

Fig. 4 displays the test setup with a data logger arm microcontroller Lab VIEW language was used to record the readings of the test, it received electrical signals from the load cell that was installed in contact with the base from the top of the hydraulic device. Data logger also received electrical signals from strain gauges and from LVDT that measured the deflection. Giving 80 readings per second and the data were logged throughout time with each reading and recorded the reading through the LabVIEW program.

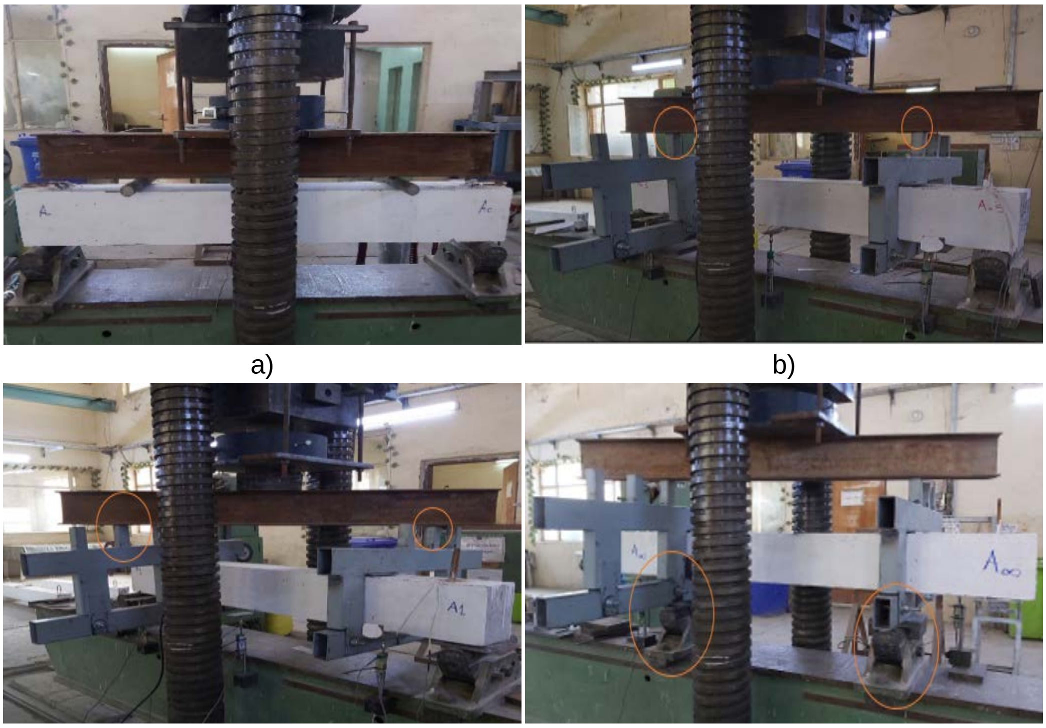
Fig. 4: beam test setup.

2.4 Testing procedure

A distance of 1400 mm between the supports in case of pure bending moment and combined cases, the load is applied through an I-section steel beam that is 300 mm away from the support and is positioned away from the center of the beam so that the distance between two-point loads is 800 mm, and two-point loads are applied at the beam's two sides in order to provide a constant torque moment as well as a constant bending in the middle zone (torsion-bending zone).

The torque to bending moment T/M ratio can be changed by adjusting the torsion arm while maintaining the bending arm fixed, I-section steel beam rests on the arms and 150 mm away from the beam center to achieve (T / M) = 0.5, and to achieve (T / M) = 1 an I-section steel beam rests on the arms and 300 mm away from the beam center. For case of pure torsion, the support will be under the steel frame arms at a position away from the center of the beam so that the spacing between the supports and between two-point loads is 800mm.

Due to a constant angle of twist in the distance between the support and the steel arm frame, the angle of twist was measured at a distance of 15 cm from the support. Fig. 5 illustrates the application of load in four cases, and Fig. 6 shows application diagram of combined loads.



a) b)

c) d)

Fig. 5: Application of load: a) T/M=0, b) T/M=0.5, c) T/M=1, d) T/M=∞.

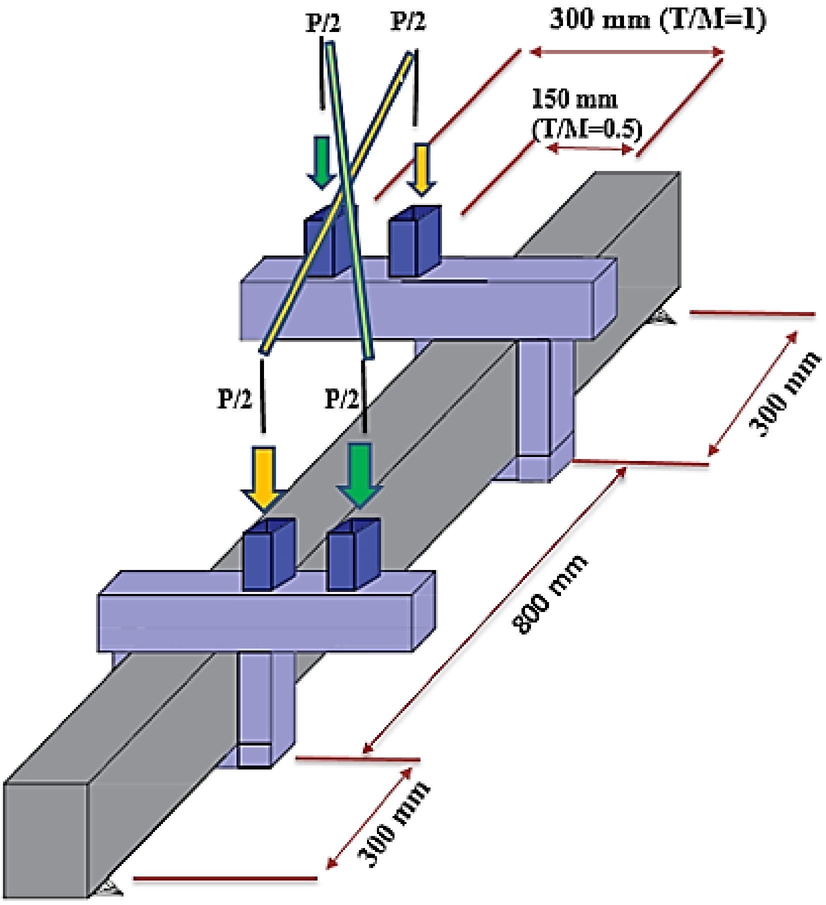


Fig. :6 Application diagram of combined loads when (T/M=0.5), and (T/M=1).

3 Result and discussion

3.1 Mechanical properties of concrete and result of tested beams

Stander cylinder specimens, and standard prism were cast and tested for determination of compressive strength, tensile strength, and modulus of rupture and elasticity at 28 days. Table 3 summarizes the previous tests performed on RPC and NC control samples. The outcomes represent the average results of three samples.

Table 3: Summary of test results.

Concrete type	Compressive Strength $f_{c'}$ [MPa]	Splitting Tensile Strength f_{sp} [MPa]	Modulus of Rupture f_r [MPa]	Modulus of Elasticity *Ec* [GPa]
RPC	110.42	13.7	13.82	46.1
NC	33.08	3.09	3.29	26.31

Table 4 demonstrates the results of tests on 8 beams, including the first cracking moments, ultimate moments, and ratio between ultimate and cracking moments, as well as key elements distinguishing between groups and beams.

Table 4: Experimental results of tested beams.

Beam name.	T/M	Type of concrete	P_{cr} [KN]	P_u [KN]	M_{cr} [KN.m]	T_{cr} [KN.m]	M_u [KN.m]	T_u [KN.m]	M_{cr}/M_u	T_{cr}/T_u
A0	0	NC	33	168.96	4.95	-	25.34	-	0.19	-
A0.5	0.5	NC	29	98.00	4.35	2.18	14.70	7.35	0.29	0.29
A1	1	NC	22	57.55	3.30	3.30	8.63	8.63	0.38	0.38
A∞	∞	NC	82	116.80	-	6.15	-	8.76	-	0.70
B0	0	RPC	78	230.15	11.70	-	34.52	0.00	0.33	-
B0.5	0.5	RPC	65	169.93	9.75	4.88	25.49	12.74	0.38	0.38
B1	1	RPC	49	125.47	7.35	7.35	18.82	18.82	0.39	0.39
B∞	∞	RPC	106	218.11	-	7.95	-	16.36	-	0.48

The results of $P_{cr}$and $P_u$in pure torsion are based on beam test at the first arm distance (150mm or 0.5* distance between support and load position).

3.2 Effect of concrete type on behavior and capacity of beams

This section discusses the effect of concrete type on the behavior and capacity of tested beams, focusing on cracking moments, ultimate moments, moment-deflection response, torque-rotation response, and strains in concrete and reinforcement. The NC beams of group (A) will represent the reference for the RPC beams of group (B).

3.2.1 Effect of concrete type on cracking behavior

Using RPC instead of NC improved the cracking behavior where the cracking capacity significantly improved by 136.4%, 124.1%, and 122.7% for cases of (T/M) =0, 0.5, and 1 respectively, while the improvement on the crack capacity for case (T/M) = ∞ is slight by 29.3%.

Fig. 7 shows an interaction diagram for the relation between cracking bending capacity and cracking torsional capacity for both types of beams. It can be noted that the chart for RPC beams shows a significant difference from NC beams for all cases of combination and they significantly have stronger capacity than NC beams.

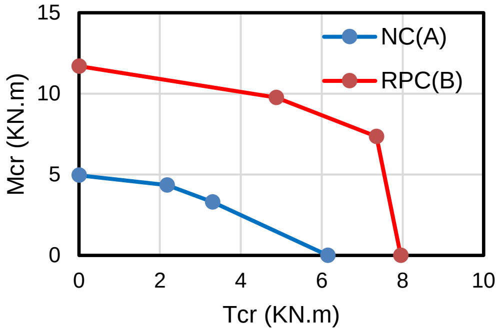


Fig. 7: $\mathbf{M_{cr}} - \mathbf{T_{cr}}$ Relation for RPC and NC beams.

3.2.2 Effect of (T/M) ratio on cracking capacities ($\mathbf{M_{cr}}$) and ($\mathbf{T_{cr}}$)

It can be noticed when (T/M) ratio increased from 0 to 1, the cracking bending moment decreased for both NC and RPC. For NC beams, increasing (T/M) ratio reduced the cracking bending moment (M_{cr}) by 12.12% when (T/M) increased from 0 to 0.5 and by 33.3% when (T/M) increased from 0 to 1. For RPC beams, increasing (T/M) ratio reduced the cracking bending moment (M_{cr}) by 16.67% when (T/M) increased from 0 to 0.5 and by 37.3% when (T/M) increased from 0 to 1.

When (M/T) ratio increased from 0 to 2, the cracking torsional moment (T_{cr}) decreased for both NC and RPC. For NC beams, increasing (M/T) ratio reduced the cracking torsional moment (T_{cr}) by 46.34% when (M/T) increased from 0 to 1 and by 64.6% when (M/T) increased from 0 to 2. For RPC beams, increasing (M/T) ratio reduced the cracking torsional moment (T_{cr}) by 7.55% when (M/T) increased from 0 to 1 and by 38.7% when (M/T) increased from 0 to 2.

3.2.3 Effect of concrete type on ultimate capacity

Using RPC instead of NC improved beam behavior at ultimate case where the ultimate capacity well improved by 36.2%, 73.4%, and 86.7% for cases of (T/M) =0, 0.5, and ∞ respectively, while the improvement on the ultimate capacity for (T/M = 1) is significant by 118%. Fig. 8 shows an interaction diagram for the relation between ultimate moment capacity and ultimate torsion capacity for both types of beams. It can be noted that the chart for RPC beams shows a significant difference in capacity under combined moments and they significantly have stronger capacity than NC beams.

Fig. 9 shows non-dimensional interaction diagram for the relation between the ultimate bending capacity to ultimate pure bending capacity ratio and the ultimate torsion capacity to ultimate pure torsion capacity ratio for both types of beams. The chart for RPC beams shows a significant difference and have stronger capacity than NC beams under combined loading of bending and torsional moments. The maximum difference between the capacities of two types of beams is at (T/M=1).

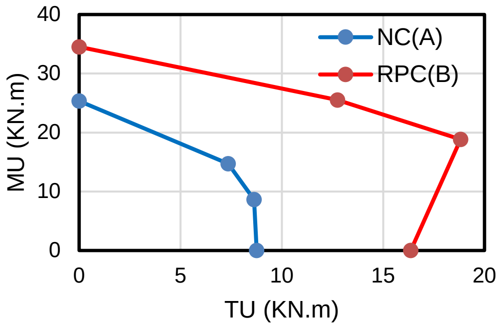


Fig. 8: $\mathbf{M_u} - \mathbf{T_u}$ Relation for RPC and NC beams.

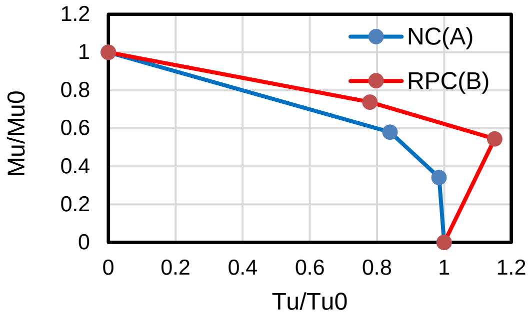


Fig. 9: Non-dimensional interaction diagram for ($\mathbf{M_u} - \mathbf{T_u}$) ratio.

3.2.4 Effect of (T/M) ratio on ultimate capacities ($\mathbf{M_u}$) and ($\mathbf{T_u}$)

It can be noticed when (T/M) ratio increased from 0 to 1, the ultimate bending moment (M_u) decreased for both NC and RPC. For NC beams, increasing (T/M) ratio reduced the ultimate bending moment (M_u) by 42% when (T/M) increased from 0 to 0.5 and by 65.9% when (T/M) increased from 0 to 1. For RPC beams, increasing (T/M) ratio reduced the ultimate bending moment (M_u) by 26.17% when (T/M) increased from 0 to 0.5 and by 45.5% when (T/M) increased from 0 to 1. The (T/M) ratio affects the ultimate bending moment (M_u) more in NC beams than RPC beams due to the higher strength and presence of steel fibres in RPC beams. Using RPC reduces the effect of (T/M) ratio on weakening beam capacity and delaying crack propagation in the compression zone.

When (M/T) ratio increased from 0 to 2, the ultimate torsional moment decreased for NC beams and increased for RPC beams at a small value of (M/T=1) and decreased at a high value of (T/M=2) for both types of concrete. For NC beams, increasing (M/T) ratio reduced the ultimate torsional moment (T_u) slightly by 1.48% when (M/T) increased from 0 to 1 and by 16.1% when (T/M) increased from 0 to 2. For RPC beams, the ultimate torsional moment (T_u) increased by 15.06% when (M/T) increased from 0 to 1 and decreased by 22.1% when (M/T) increased from 0 to 2. Applying a small bending moment to the torsional moment in RPC beam improved torsional capacity due to preventing the propagation of torsional cracks and improving resistance to torsional effects, this fact is mentioned in reference [21]. This effect in RPC is due to presence of steel fibres which delays and prevents the propagation of bending cracks, thereby increasing the efficiency of beam to resist torsional moments.

3.2.5 The effect of type concrete on cracking to ultimate capacity ratio (M_{cr}/M_u) and (T_{cr}/T_u)

Using RPC instead of NC in beams increased cracking to ultimate capacity ratio by 73.5%, 29.3% for cases of (T/M) = 0, 0.5 respectively, and slightly increased it by 2.2% for (T/M) = 1 and decreased it by 30% for (T/M) = ∞. As the (M/T) ratio increased from 0 to ∞, the cracking to the ultimate capacity ratio increased for RPC and NC, which indicated a reduction in post-cracking capacity. The presence of steel fibres and structural homogeneity in RPC beam improved its resistance to first cracks and thereby enhancing the cracking to ultimate capacity ratio.

3.2.6 Effect of type of concrete on moment-deflection responses and torsion-rotation responses

The effect of concrete type NC and RPC on moment-deflection response and torsion-rotation response with different (T/M) ratio values are shown in Fig. 10 and Fig. 11 respectively. It is concluded that the use of RPC in beam construction leads to stiffer responses at all loading stages, and significantly reduced beam deflection values and rotation values especially in advanced load stages.

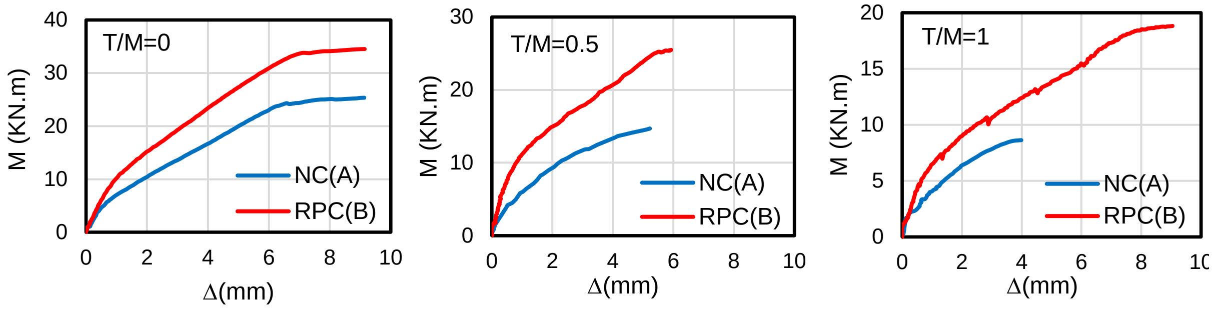


Fig. 10: Moment-deflection response.

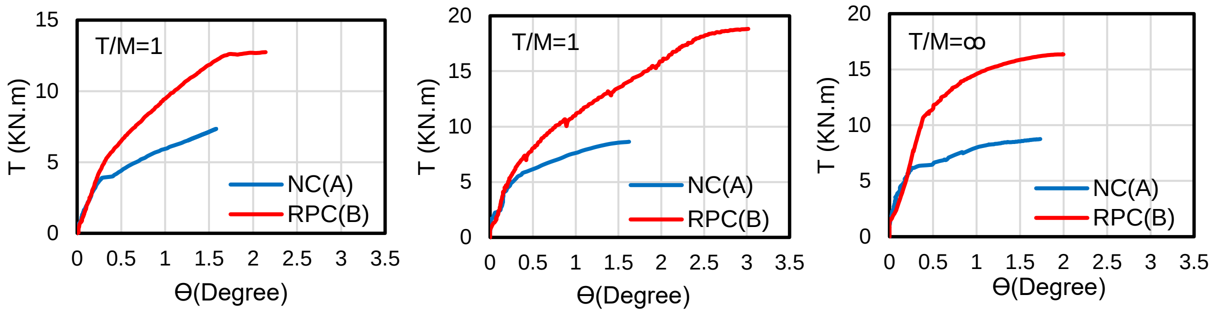
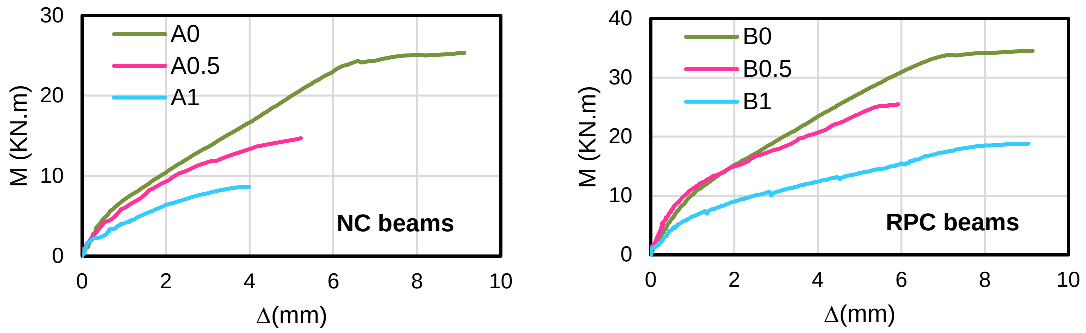


Fig. 11: Torsion-rotation response.

Fig. 12 shows the effect of (T/M) ratio on moment- deflection response for both types of beams. With increasing this ratio, the response became softer especially in advanced loading stages. For RPC beams, increasing (T/M) ratios from 0 to 0.5 slightly affect the response, but increasing (T/M) ratios from

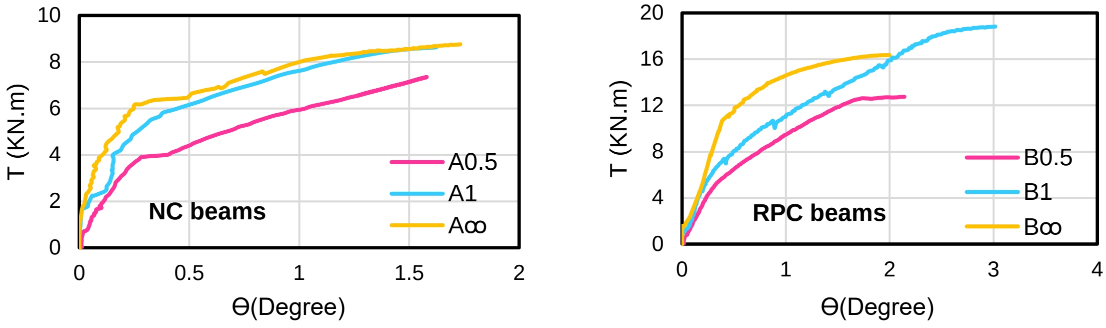
0 to 1 leads to significant differences in deflection values especially in advanced loading stages. For NC beams, increasing (T/M) ratios from 0 to 0.5 slightly affect responses in earlier load stages and significantly affect it in advanced loading stages, while increasing (T/M) ratios from 0 to 1 leads to significant differences in deflection values for all loading stages. The effect of the (T/M) ratio on softening the response is larger in NC beams than in RPC beams.



a) b)

Fig. 12: Moment–deflection response: a) group A, b) group B.

Fig. 13 shows the effect of (T/M) ratio on moment-rotation response for both types of beams. With increasing this ratio, the response became softer in advanced loading stages.



a) b)

Fig. 13: Torsion- rotation response: a) group A, b) group B.

For RPC beams, decreasing the (T/M) ratio from ∞ to 1 significantly affects the response especially in advanced loading stages. For NC beams, decreasing (T/M) ratio from ∞ to 1 slightly affects responses in all loading stages and significantly in advanced loading, while decreasing (T/M) ratio from ∞ to 0.5 leads to significant differences in rotation values especially in advanced loading stages.

3.2.7 Effect of type of concrete on compressive strain value in concrete

Fig. 14 illustrates the relationship between moment- compressive concrete strain within loading stages for both types of beams. Using RPC instead of NC leads to a significant reduction in concrete strain value for all loading stages and the difference becomes larger as the load increases. The high strength of RPC and the presence of steel fibres delay the first cracking and propagation of cracks, and this leads to reduction in concrete strain values. The tension zone is more effective in RPC, where steel fibres absorb part of the stresses causing the reductions in concrete strain in the compression zone.

The strain values in the pure torsion case are small and irregular, and using RPC significantly reduced them and made them converge to zero within a large part of loading. Any point on the concrete surface is subjected to combined tensile and compression strains with perpendicular and inclined lines (about 45°) from the beam axis, therefore, the concrete strain resultant are small and may be compression or tension.

Using RPC instead of NC in beams leads to reductions in strain readings under the same load at the service stage (at a value of 70% of NC ultimate capacity) by 36.06%, 50.55%, 12.04%, and 93.7% for (T/M) =0, 0.5, 1 and ∞ respectively.

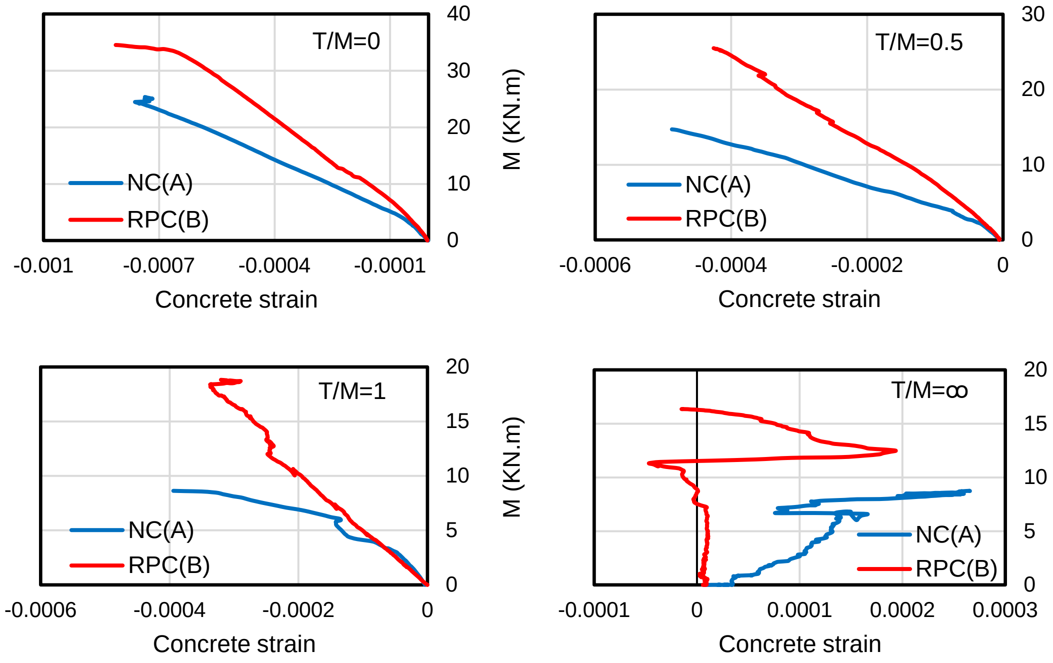
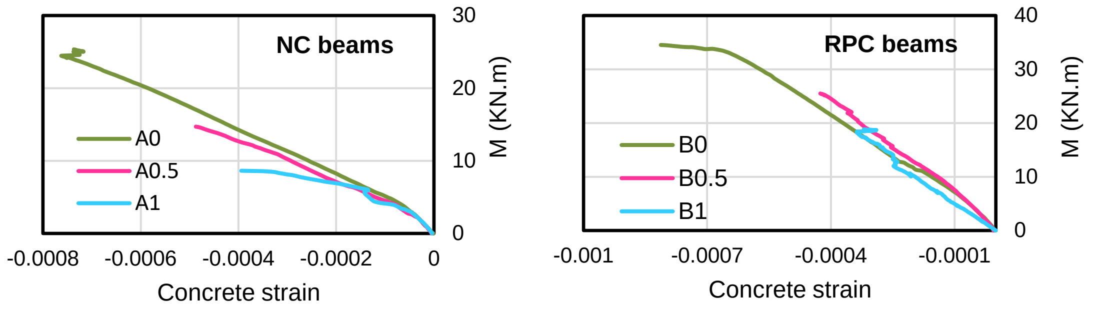


Fig. 14: Moment-concrete strain.

Fig. 15 demonstrates the impact of the (T/M) ratio on the moment-concrete strain relationship for RPC and NC beams. An increase in the (T/M) ratio makes the response softer with a larger effect in advanced loading stages. The (T/M) ratio has a greater impact on softening the response in NC beams than in RPC beams.



a) b)

Fig. 15: Moment-concrete strain: a) group A, b) group B.

3.2.8 Effect of concrete type on strains in longitudinal and transverse reinforcement

The impact of concrete type on the relationship between moment-longitudinal reinforcement strain and moment-transverse reinforcement strain are shown in Fig. 16 and Fig. 17 respectively. Using RPC beams instead of NC beams reduced longitudinal reinforcement strain values and transverse reinforcement strain values and the difference becomes larger as the load increased. The high strength of RPC and presence of steel fibres contributes in resisting tensile stresses and that reduces the tensile stresses resisted by longitudinal reinforcement and transverse reinforcement, therefore the stain values will be decreased in both reinforcement. In the case of pure torsion, the responses become softer after the first crack and both strain values significantly increase in NC beams if compared with those in RPC beams.

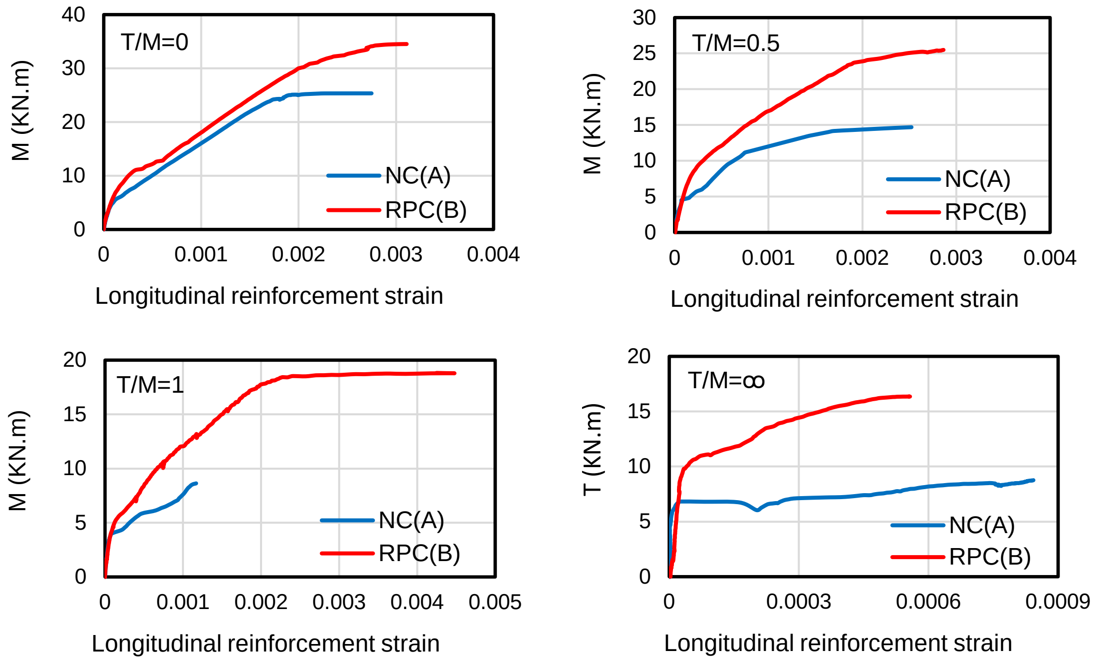


Fig. 16: Moment-longitudinal reinforcement strain.

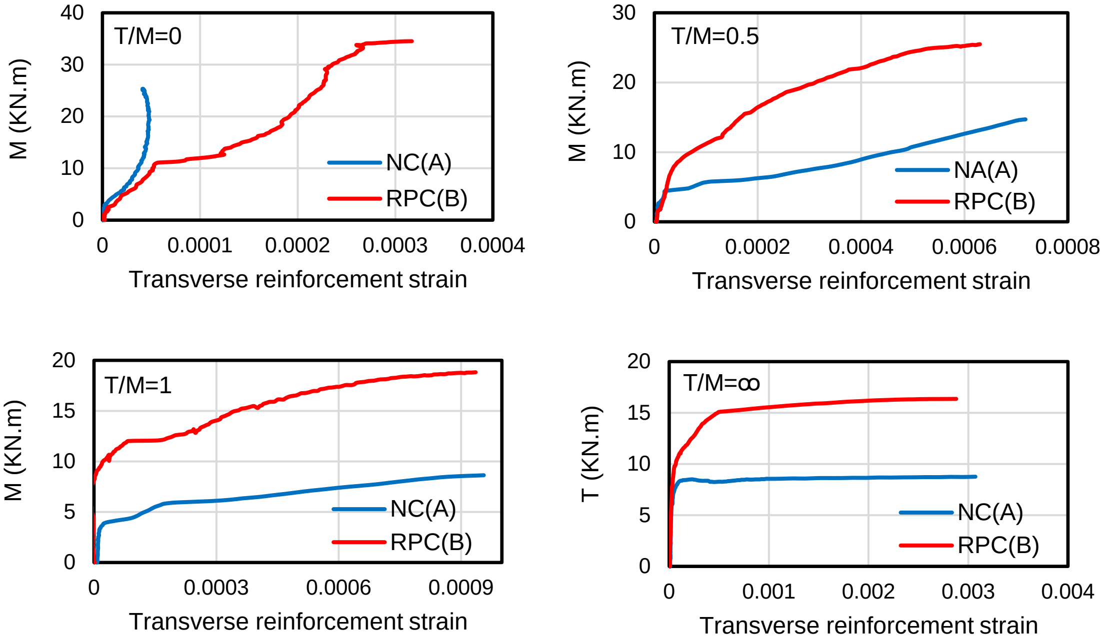
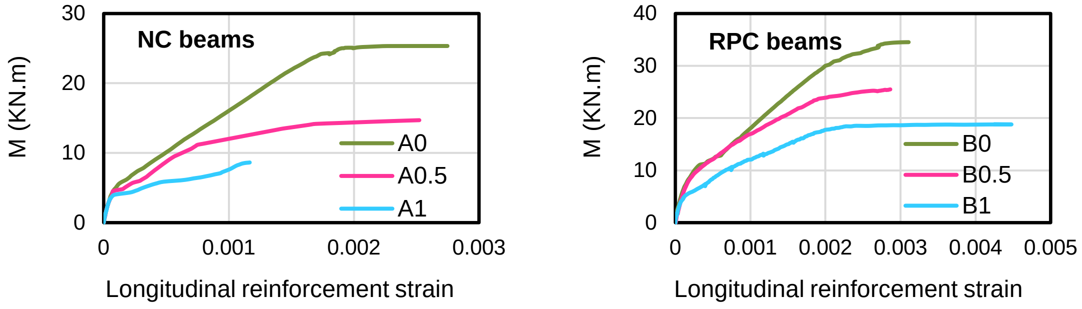


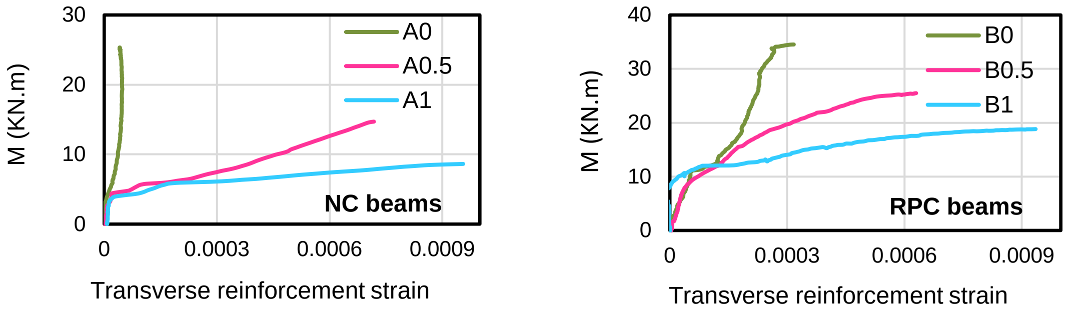
Fig. 17: Moment-transverse reinforcement strain.

The impact of (T/M) ratio on moment-longitudinal reinforcement strain and moment-transverse reinforcement strain for RPC and NC beams were shown in Fig. 18 and Fig. 19 respectively. An increase in the (T/M) ratio made the response softer especially in advanced loading stages. The effect (T/M) ratio in softening this response is larger in NC beams than in RPC beams.



a) b)

Fig. 18: Moment-longitudinal reinforcement strain: b) group A, b) group B.



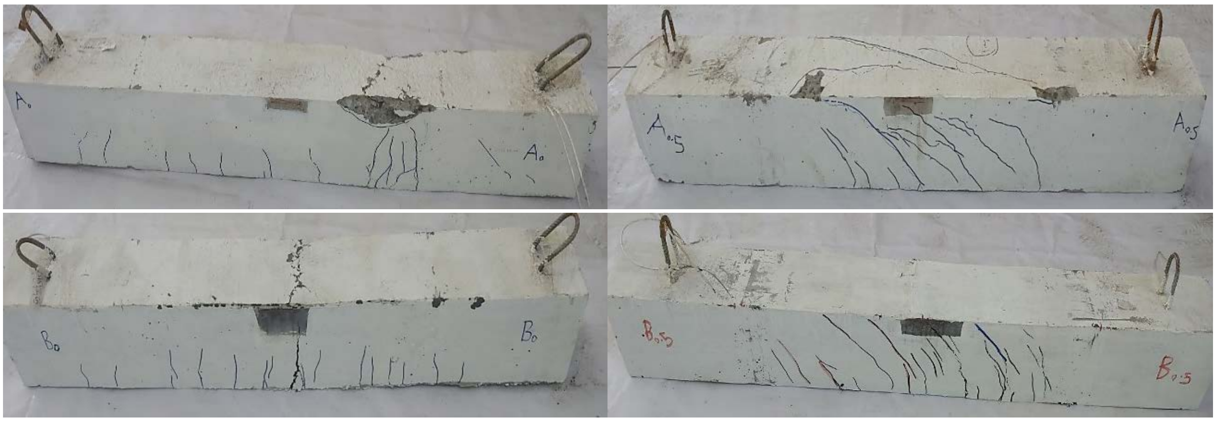
a) b)

Fig. 19: Moment-transverse reinforcement strain: a) group A b) group B

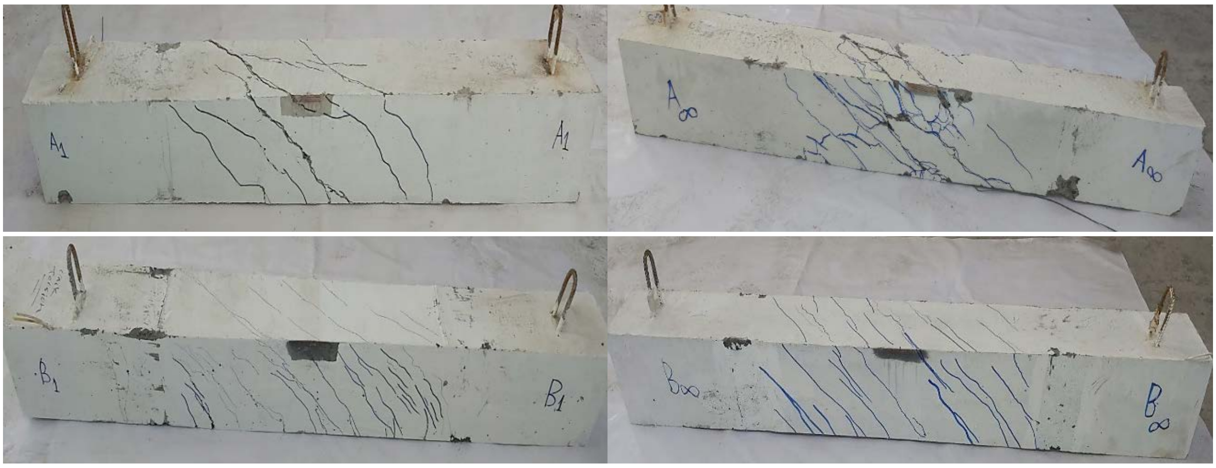
3.2.9 Failure mode

The crack pattern for tested beams is displayed in Fig. 20. The cracks in beams that failed by flexural mode when T/M=0 (pure bending case) were perpendicular to the direction of bending (vertical cracks). While for the beams failed by torsional mode at T/M=∞ (pure torsion case), the main cracks were inclined at an approximate 45° angle. The flexural-torsional failure mode for beams subjected to combined loadings is characterized by some vertical cracks resulting from flexural effects as well as inclined cracks with degree smaller than 45° resulting from torsional effects. As the T/M ratio increased the cracks' inclination increased.

A smaller number of cracks, wider and more propagated are found in NC beams than in RPC beams, this is because of the efficiency of steel fibers in RPC.



a) b)



c) d)

Fig. 20: Crack pattern for the tested beams: a) T/M=0, b) T/M=0.5, c) T/M=1, d) T/M=ꝏ.

4 Conclusion

1) using RPC instead of NC improved the cracking behaviour where the cracking load capacity was significantly increased by (29.3% to 136.4%) and significantly increased the ultimate capacity by (36.2% to 118%) with maximum effect in case of combined moments with (T/M) = 1.

2) Applying a small bending moment to the torsional moment in RPC beams improves the torsional capacity due to the presence of steel fibres in RPC which delays and prevents the propagation of bending cracks, thereby increasing the efficiency of beam to resist torsional moments.

3) Using RPC in R.C. beams makes the M-T capacity interaction is stiffer that reflects the effect of rule of RPC in improving beam capacity for all cases of combination of bending and torsional moments.

4) Effect of (T/M) ratio in decreasing beam capacity is smaller in RPC beams than in NC beams due to larger ability of RPC to resist the shear stresses resulted from torsional moment to prevent expanding and propagation of torsional cracks.

5) It is concluded that the impact of RPC on moment-deflection response and torsion-rotation response is significant for different (T/M) ratios where using it leads to stiffer responses at all loading stages and for all combination cases. It results in significant reductions in beam deflection and rotation values especially in advanced loading stages.

6) Using RPC instead of NC in R.C. beams contributes in reducing the maximum concrete compressive strain especially in advanced loading stages.

7) Using RPC in R.C. beams leads to smaller values of strain in longitudinal and transverse reinforcement. This effect is clearer with progressing loading stages and it is larger with increasing (T/M) ratio.

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