Engineering Research Journal

journal homepage: https://erj.journals.ekb.eg/

Studying the effect of using seawater on the deep beams behavior reinforced with GFRP bars

Alaa Ismael[1,*], Magdy M. M.[1], Waleed Abdallah[1], Aml Hassanin[1]

[1] Helwan University - Faculty of Engineering Mataria - Department of Structural Engineering - Egypt

[*]Corresponding author E-mail: alaaismael2@gmail.com

Abstract.

Using seawater as an alternative of fresh water, due to fresh water scarcity, becomes common. In addition, using fiber reinforced polymers (F-R-P) as a replacement for conventional steel in marine environment is considered a promising solution to overcome steel corrosion. Thus, this investigation aims to understand the behavior of deep beams reinforced with glass fiber reinforced polymers (G-F-R-P) bars and cast using seawater as an alternative of fresh water. Experimental program is carried out using eight specimens of deep beams. Four reinforced concrete (RC) specimens with a target compressive strength of 25 MPa and the other four beams with a target compressive strength of 45 MPa. The test parameters were the longitudinal and transverse (traditional steel and G-F-R-P bars) bars, compressive strength (25 MPA or 45 MPa), mixing and curing used water (fresh water and seawater), and cement type (ordinary Portland cement (O-P-C) and sulphated- resistant cement (S-R-C)). Typical failure mode was crushing of the concrete diagonal strut as predicted from manual calculations using strut and tie model (S-T-M). All tested beam specimens were failed after the propagation of cracks upwards to loading area or downwards to supporting area. The location of failure crack was almost at the diagonal strut zone of tested beams. The analysis findings showed that the capacity of reinforced deep beams with higher compressive strength was slightly higher than lower compressive strength deep beams. In addition, the overall sulphated- resistant cement performed better than (O-P-C) in sewer environment.

Keywords: Seawater, G-F-R-P bars, deep beam, capacity of shear , crack patterns, failure mode. S-

1 Introduction`

As a replacement to traditional steel reinforced bars for reinforcing concrete (RC) elements, fiber-reinforced - polymer (F-R-P) bars are highly increase being recognized in various design standards [1–3]. Because of its better performance, Glass-F-R-P (G-F-R-P) bars are mainly the most often utilized type of F-R-P bars for longitudinal reinforcement in North America. G-F-R-P reinforcement offers a high strength-to-weight ratio, outstanding fatigue capabilities, good resistance to chemical attack, and good electromagnetic resistance as well as to its exceptional corrosion resistance. G-F-R-P bars have remarkable resistance to chemical aggression and can be utilized in concrete structural components such foundations, breakwaters, and other constructions exposed to harsh environmental influences.

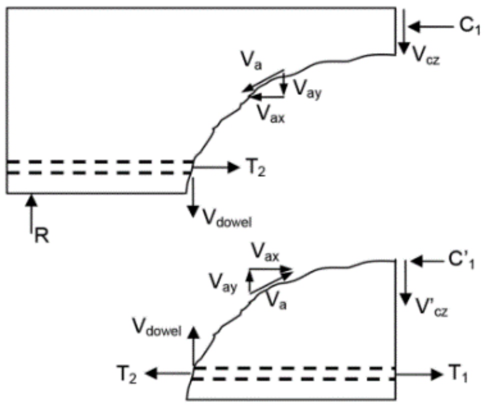
In recent decades, a lot of investigation has been done to understand the main behavior of F-R-P RC elements and to enhance design recommendations, particularly the shear design equations. According to ACI-ASCE [4], the amount of shear strength in concrete can be thought of as a grouping of five main

DOI: 10.21608/erj.2025.349654.1174

Received 01 January 2025; Received in revised form 12 March 2025; Accepted 18 March 2025

Available online 01 June 2025

mechanisms that are activated after diagonal cracks form: (1) uncracked concrete, (2) aggregate interlock, (3) dowel action of the longitudinal reinforcement, (4) arch action (which is connected to deep beams element) , and (5) residual tensile stresses across the inclined crack (see Fig. 1). The contribution of the uncracked concrete in RC members depends mainly on the concrete compressive strength and on the depth of the uncracked zone, which is function of the main longitudinal reinforcement.



where:
R = reaction
C_1, C'_1 = compression forces
T_1, T_2 = tension forces
V_{cz} = shear transferred in the uncracked concrete (flexural compression zone)
V_a = interface shear transfer (aggregate interlock)
V_{dowel} = dowel shear

Fig. 1. Forces in beam with no stirrups (cracked) [5].

Generally, there is a paucity of the experimental investigation regarding RC members reinforced with F-R-P bars using seawater as a mix water and as a curing [6-9]. Many researches have been conducted to investigate the deep beam behavior as: [1] examine how sewer environmental affects the shear capacity of deep beams with G-F-R-P reinforcement bars. [2] Study the impact of G-F-R-P vertical and transverse stirrups on the concrete deep beams strength in sewer environment using sulphate- resistant cement. [3] Study the influence of concrete compressive strength on the concrete shear strength of deep beams.

2 Research Significance

G-F-R-P bars are being more and more widely used in different types of RC structures due to its durability performance. No research, however, seems to have investigated G-F-R-P in RC deep beam with seawater and sulphate- resistant cement. In addition, guidelines as ACI 440.1R-15and CSA S806-12 do not provide guidance for seawater and sulphate- resistant cement in beams reinforced with GFRP bars. Therefore, this paper tries to fill this gap. The test results and outcomes of this study can be used to assess and explore the feasibility of using GFRP as longitudinal reinforcement RC deep beams with seawater and sulphate- resistant cement. Moreover, the results reported in this thesis represent a significant contribution to the relevant literature and provide designers, engineers, and members of code committees with much-needed data and recommendations to advance the use of basalt FRP reinforcement in concrete structures.

3 Objectives

This investigation is a part of a huge research program conducted at housing and building national research center (H-B-N-R-C) on the deep beams under varied loading scenarios. This investigation aimed to study the behavior, failure mode, and load transmission processes of deep beams reinforced with G-F-R-P bars. In addition, investigate the effect of seawater, concrete compressive strength, mixing, and curing water on the capacity of deep beam specimens.

4 Experimental Program

4.1 Materials

Normal-weight concrete N-W-C with a target compressive strength of 25 MPa and 45 MPa after 28 days was used to construct the beams. The mixing proportions of the N-W-C employed in this investigation are shown in Table 1. Six concrete cylinders measuring 100 x 200 mm were used to calculate the actual compressive strengths of concrete (f'c) in compliance with ASTM C39/C39M [11]. Each cylinder was treated as way as the beams.

Table 1. Concrete mix design

Concrete compressive strength MPa	25	45
Water (Kg/m^3)	18.9	29.7
Cement type	(OPC and SRC)	(OPC and SRC)
Cement amount (Kg/m^3)	42	66
Fine aggregate denisty (Kg/m^3)	72	63.6
Coarse aggregate density(Kg/m^3)	158.6	127.2

The G-F-R-P bars used in this investigation were produced in Egypt. The bars had a fiber content of 73% and were composed of continuous longitudinal fibers impregnated in a thermosetting vinyl-ester resin. As the bottom reinforcement (R-F-T), No. 3 G-F-R-P (9.50 mm diameter) and No. 4 G-F-R-P (d = 12.7 mm) have been used. The stress-strain relationship of the G-F-R-P bars is shown in Fig. 2. The surface texture of the G-F-R-P bars is shown in Fig. 3. The nominal values chosen for this inquiry were used in all studies and in the design of the beam specimens. In accordance with ASTM D7205, the strain at rupture, ultimate tensile strength, and modulus of elasticity were calculated [13] (see Table 2) .

To secure the stirrups behind the supports, two bars with an (10) mm diameter were employed as top reinforcement. Additionally, steel stirrups of (10) mm in diameter were made to be used underneath the supports for every beam (see Fig. 4).

The experimental program consisted of a total of eight reinforced concrete deep beams. All of the test beams were constructed using normal strength concrete (N-S-C). G-F-R-P bars with ribbed surface were used as a reinforcement of the concrete beams. The beam specimens were 1600 mm long, 150 mm wide, and 500 mm deep, as shown in Fig. 5. All beams had a 200 mm overhang length beyond the supports on each side as anchorage length to prevent premature bond failures. 10 mm diameter steel stirrups (two stirrups at each side) were placed at the overhangs behind the supports. This was done to improve bond behavior and secure the longitudinal bars in place.

Table 2. Mechanical-properties of the G-F-R-P bars

Bar type	G-F-R-P bars	
Bar size	No. 3	No. 4
Diameter (mm)	9.50	12.7
A_f [a] (mm^2)	71	129
A_{im} [b] (mm^2)	91 ± 2	129 ± 3
E_f (GPa)	41.3 ± 1	39.0 ± 1.25
f_{fu} (MPa)	719 ± 23	751 ± 31
ε_{fu} (%)	1.05	1.1

[a] Nominal cross-sectional area.
[b] Immersed cross-sectional area (measured).

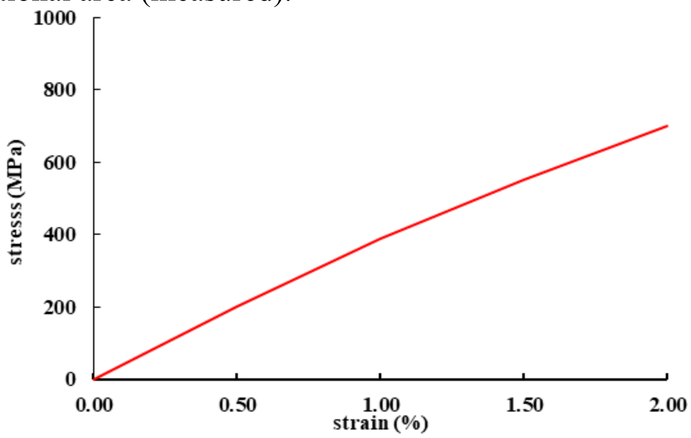


Fig. 2. Tensile test of G-F-R-P bars.

Fig. 3. Surface characteristics G-F-R-P bars.

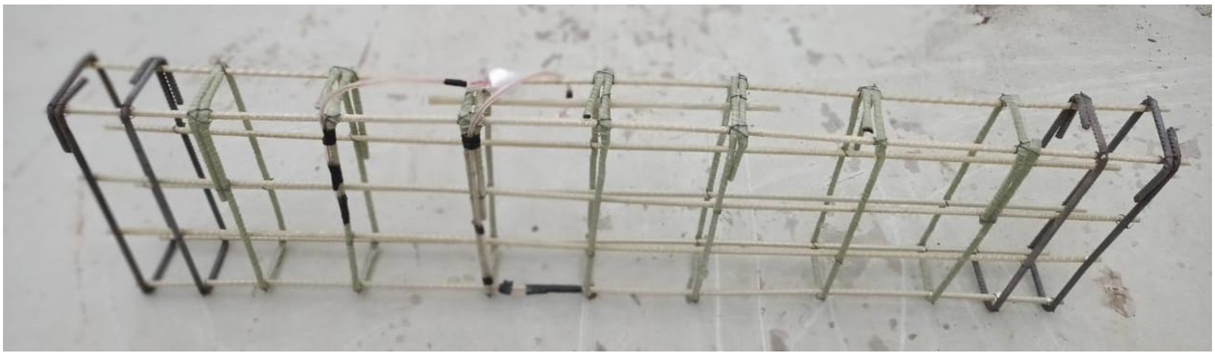


Fig. 4. Reinforcement details of specimen.

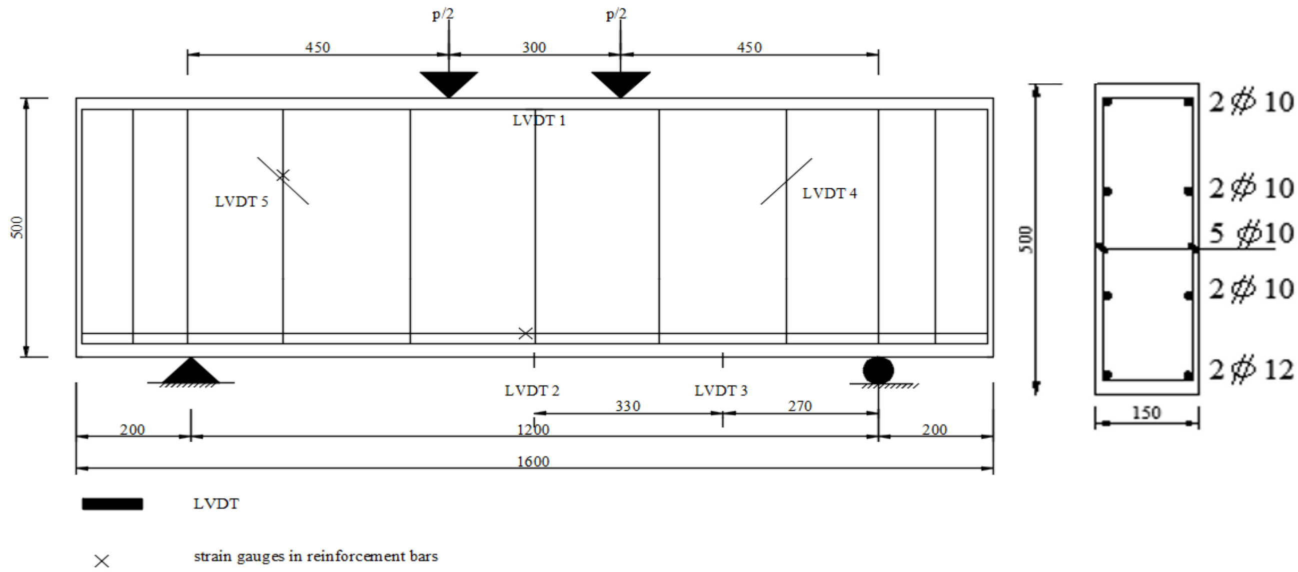


Fig. 5. Beam details of the test specimens.

Table3. Specimen properties

Group	Beam ID	Reinforcing Material	*f'c* (MPa)	R-F-T	
				Bars	ρ_f (%)
I	S -F-O	Steel	25	2#12	0.51
	G -F-O	GFRP	25	2#12	0.51
	G -S-O	GFRP	25	2#12	0.51
	G -S-S	GFRP	25	2#12	0.51
II	S -F-O	Steel	42	2#12	0.51
	G -F-O	GFRP	42	2#12	0.51
	G -S-O	GFRP	42	2#12	0.51
	G -S-S	GFRP	42	2#12	0.51

The effect of seawater, reinforcement type, and cement type on the deep beam behavior were investigated by testing the specimens under four point loading up to failure. Each beam was identified with a tripartite numbering code. The first part—S or G—refers to the type of R-F-T used. The second part—F or S—identifies the mixing and curing water type. The third part refers to the type of cement ("O" for ordinary Portland cement (O-P-C) or "S" short for sulphate- resistant cement(S-R-C)). The test variables were the concrete compressive strength, the cement type, and the mixing and curing water type. Table 3 presents the matrix of the tested beam specimens.

4.2 Instrumentation and Test set up

Instrumentation of all the beam specimens contained five linear variable differential transducers (L-V-D-T) at different positions for Deflection and strain measurement. An L-V-D-T stablished at the compression surface of each specimen to measure the compressive concrete strains. The strain gauges were protected by a waterproof layers to prevent any damage from water and during the process of casting the concrete and handling. Each beam specimen was equipped with two electrical resistance strain gauges at mid-span to measure tensile strains and at a vertical stirrup. Epoxy was used to attach the strain gauges to the beam surface after it was cleaned carefully. Fig. 6 illustrates the instrumentation details of the test beams. During loading process, the creation of cracks on the both sides of the beams were also marked on the beam specimen surfaces and recorded on a sheet note also.

Four-point loading was applied to the beam specimens on a clear span length of 1200 mm (refer to Fig. 6). Two steel plates were positioned on the supports to support the beams. A 550 kN hydraulic jack was used to apply the weight in two stages. Up to the first crack, the load was applied in load-controlled mode during the first phase at a rate of 2 kN/min. The beam was then loaded in load -controlled mode until it failed, at a rate of 4 kN/min. Two equal loads were applied to the specimen using the stiff steel beam. As soon as the test beams reached the failure load, the load was withdrawn.

Fig. 6. Test set up

5 Experimental Results and Discussions

5.1 Failure Mode and Cracking

Prior to attaining their flexural capabilities, the specimens evidently failed in typical failure of deep beam which is crushing in the diagonal strut. In the flexural span zone, thin vertical cracks perpendicular to the direction of the highest primary stress caused by pure bending moment were found in every specimen. Like flexural cracking, cracking outside the flexural span zone began as the stress rose. The shear stress produced a curved pattern in both shear spans toward the loading locations as the load increased. The typical failure mode of the tested beam specimens is depicted in Fig. 7. It was observed that specimens with lower concrete compressive strength have wider and deeper cracks than those with higher concrete compressive strength. In addition, the first crack was created in specimens with lower concrete compressive strength before specimens with higher concrete compressive strength. Moreover, cracks was deeper in specimens reinforced with G-F-R-P than steel specimens. Using seawater and sulphate- resistant cement has no remarkable effect on crack size or creation.

For cubes with seawater suffer from deeper cracks and slightly lower strength than those without seawater. In addition, cylinders with sulphate- resistant cement achieved slightly lower early strength, but this does not significantly affect capacity. With sulfate-resistant cement, the rate of expansion in concrete cubes exposed to sulfate solutions is significantly lower than with normal Portland cement. This expansion can lead to cracking, spalling, and structural damage. Concrete cubes made with sulfate-resistant cement exhibit minimal expansion, even in aggressive sulfate environments.

Fig. 7. Typical crack pattern of beams

5.2 Load –Deflection Behavior

The load-deflection curves of the study specimens in both groups are presented in this part to illustrate how test factors affect the behavior and the capacity of the specimens, as seen in Figures 8,9,10, and 11. It is evident that the load-deflection relationship was bilinear. All beams showed a linear response in the first stage of the load-deflection curve until they reached flexural cracking. In the other stage, following cracking, all specimens exhibited a notable rise in their point load deflections together with a significant loss of stiffness. Because of the varying reinforcement types and the concrete compressive strength, the stiffness varied. It is evident that at all loading levels, steel reinforcement bars increased the material's stiffness and reduced its deflection. Specimens with higher concrete compressive strength have maximum deflection and capacity than specimens with lower concrete compressive strength (B5 has capacity and maximum deflection higher than B1).

Table 4 . Capacity prediction of the tested deep beams

Group	**Beam ID**	**Reinforcing Material**	**EXPER.** *Pu(KN)*	**STM** *Pu(KN)*
I	S -F-O	Steel	526	515
	G -F-O	GFRP	414	425
	G -S-O	GFRP	358	373
	G -S-S	GFRP	381	401
II	S -F-O	Steel	596	575
	G -F-O	GFRP	529	542
	G -S-O	GFRP	393	408
	G -S-S	GFRP	408	414

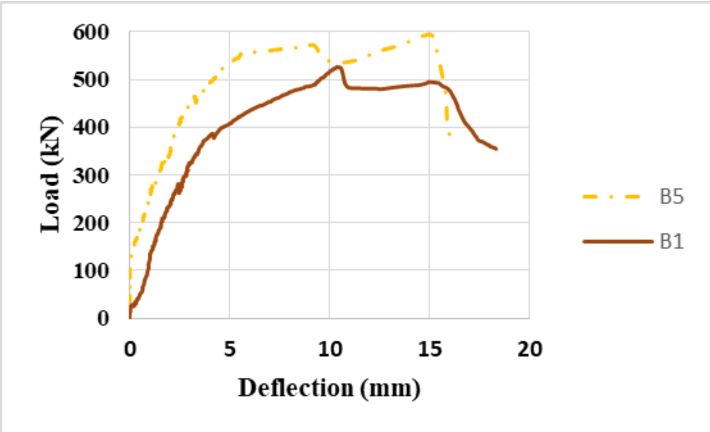


Fig. 8. Load–deflection curves for B1 and B5.

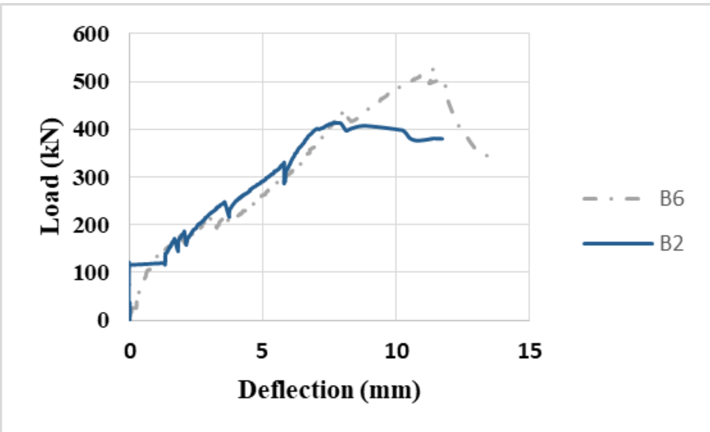


Fig. 9. Load–deflection curves for B2 and B6.

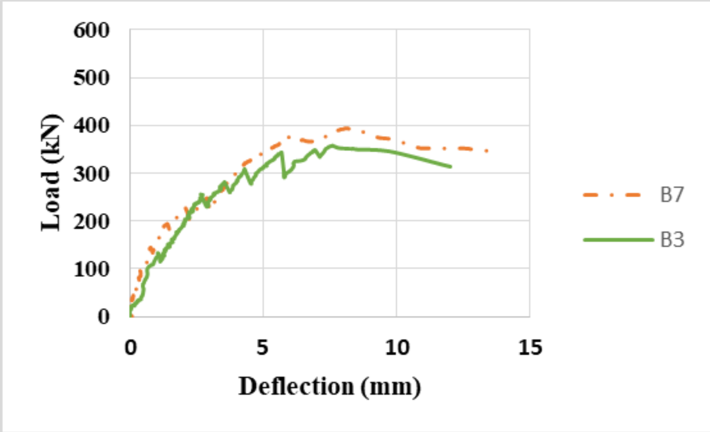


Fig. 10. Load–deflection curves for B3 and B7.

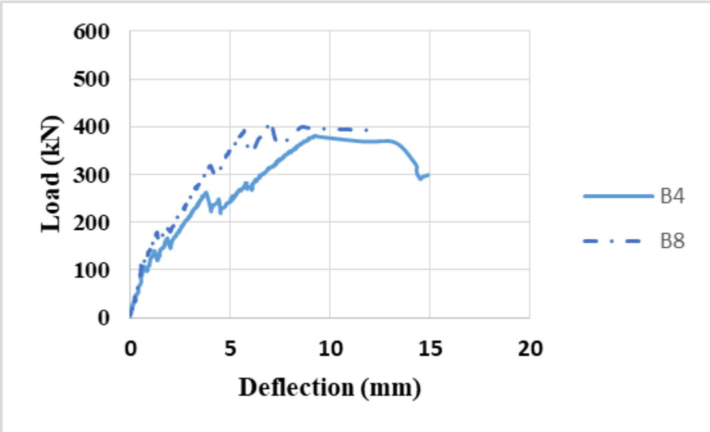


Fig. 11. Load–deflection curves for B4 and B8.

Table 4 represent the experimental capacity and the predicted capacity for all tested beams. The capacity prediction using the STM [14] for FRP reinforced beams was overestimated with a mean experimental to predicted value of 0.95.On the other hand, the capacity of tested beams with steel reinforcement have higher value than predicted capacity about 2%. The same observation has been reported in previous studies (Abbood et al. 2023).
Fig. 12 and Fig.13 show that the stiffness of the RC deep beams decreased when the beams have the lower concrete compressive strength. In other words, B 5 was stiffer than B 1 at the same cement type and water. The same behavior has been reported in past studies (Ye Li et al. 2021). In addition, specimens with steel bars have higher stiffness than G-F-R-P specimens. Using sulphate- resistant cement lead to increase the stiffness. B 8 was stiffer than B 7 at the same reinforcement and water.

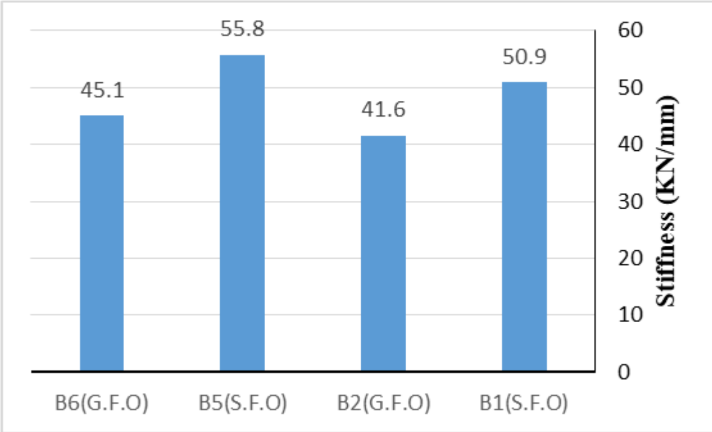


Fig. 12. Reinforcemennt type influence on post crack stiffness for specimens

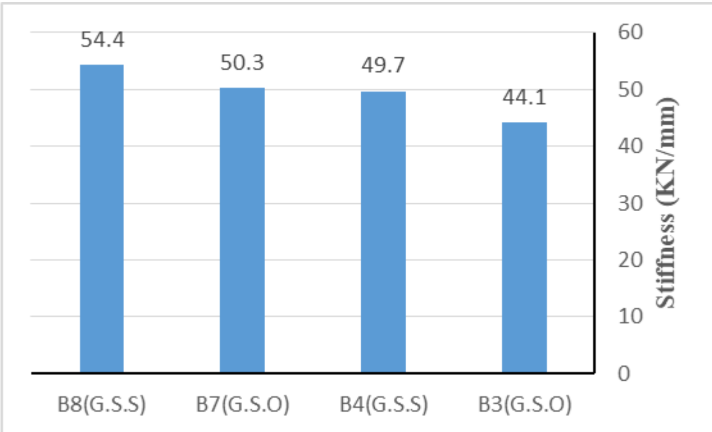


Fig. 13. Cement type influence on post crack stiffness for specimen

6 Conclusions

This paper presents the results of a research program to investigate the effect of seawater on the behavior of traditional steel and G-F-R-P RC deep beams . The main remarks from the study can be drawn as follow:

1. The deep beam specimens reinforced with traditional steel have higher first crack and shear strength capacity than specimens reinforced with G-F-R-P bars as the G-F-R-P stirrups lose about 40% from its strength. Thereby the G-F-R-P specimens have lower capacity than steel reinforced specimens.
2. The deep beam specimens reinforced with traditional steel bars have higher stiffness than reinforced deep beams with G-F-R-P bars, so that they have low deflection at the same load level.
3. Using higher concrete compressive strength lead to decrease the total number of initial cracks. In addition, specimens with higher concrete compressive strength have higher capacity than specimens with lower concrete compressive strength.
4. Specimens with sulphate- resistant cement have higher stiffness than ordinary Portland cement.

References

[1] Tracy, C. D. (2005). “Fire endurance of multicellular panels in an FRP building system.” Ph.D. thesis, École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland.
[2] ACI Committee 440. (2015). “Guide for the Design and Construction of Structural Concrete Reinforced with FRP Bars.” ACI 440.1R-15, *American Concrete Institute*, Detroit, MI, 83 p.
[3] Mufti, A.; Onofrei, M.; Benmokrane, B.; Banthia, N.; Boulfiza, M.; Newhook,J. P.; Bakht, B.; Tadros, G.; and Brett, P(2007). "Field Study of Glass-Fibre- Reinforced Polymer Durability in Concrete," Canadian Journal of Civil Engineering, V. 34, No. 3, pp. 355-366. doi: 10.1139/106-138.
[4] Mufti, A. A.; Newhook, J.; Benmokrane, B.; Tadros, G.; and Vogel, H. M.(2011) "Durability of GFRP Rods in Field Demonstration Projects across Canada," Proceedings of the 4th International Conference on Durability and Sustain ability of Fibre Reinforced Polymer (FRP) Composites for Construction and Rehabilitation, CDCC2011, Quebec City, Canada, July 20-22, 9 pp.
[5] El-Salakawy, E. F., and Benmokrane, B. (2003) "Design and Testing of a Highway Concrete Bridge Deck Reinforced with Glass and Carbon FRP Bars," ACI Special Publication, Field Applications of FRP Reinforcement: Case Studies, SP-215-2, Aug., pp. 37-54.
[6] Canadian Standards Association (CSA). (2019). “Canadian highway bridge design code.” CSA S6-19, Rexdale, Ontario, Canada.
[7] C. Ballinger, "Structural FRP Composites", ASCE Civil Engineering, vol. 60, pp. 63-66, July (1990).
[8] Zobel H.: Mosty kompozytowe,50. Jubileuszowa Konferencja Naukowa Kiliw pan i KN PZITB, Krynica, (2004)
[9] Tuakta Use of Fiber Reinforced Polymer Composite in Bridge Structures Massachusetts Institute of Technology, (2005)
[10] Kolding, Fiberline Design Manual, Fiberline Composites A/S, (2003)
[11] Dong-Woo Seo, Ki-Tae Park, Young-Jun You and Sang-YoonLee, Experimental Investigation for Tensile Performance of GFRP-Steel Hybridized Rebar, Structural Engineering Research Institute (SERI), Korea Institute of Civil Engineering and Building Technology (KICT), Goyang, 411712, South Korea; 2016.
[12] CSA (Canadian Standards Association). (2012). “Design and construction of building structures with fiber reinforced polymers.” CSA S806-12, Toronto.
[13] AASHTO, “AASHTO LRFD Bridge Design Specifications,” 1st Edition, American Association of State Highway and Transportation Officials (AASHTO), Washington, 2007.
[14] ACI Committee 318 (2008). “Building Code Requirements for Structural Concrete and Commentary (ACI 318-08).” ACI, Farmington Hills, MI, 473 pp.
[15] Oh J.-K., Shin, S.-W. (2001). “Shear Strength of Reinforced High-Strength Concrete Deep Beams,” ACI Structural Journal, 98(2), pp. 164-173.
[16] Collins, M. p, Bentz , E. G., Sherwood ,E. G (2008) (WHERE IS SHEAR REINFORCEMENT REQUIRED?) REVIEW OF RESEARCH RESULTS AND DESIGN PRODUCER.
[17] Brown, M. D., Bayrak, O. (2007). “Investigation of Deep Beams with Various Load Configurations,” ACI Structural Journal, V. 104, No. 5, pp. 611-620.
[18] Razaqpur, G., Isgor, O. B. (2006). “Proposed Shear Design Method for FRP-Reinforced Concrete Members without Stirrups,” ACI Structure Journal, 103(1), pp. 93-102.
[19] Breña, S. F., Roy, N. C. (2009). “Evaluation of Load Transfer and Strut Strength of Deep Beams with Short Longitudinal Bar Anchorages.” ACI Structural Journal, 106(5), pp. 679-689.
[20] Wight, J. K. and MacGregor, J. G. (2009). “Reinforced Concrete: Mechanics and Design.” (5th edition), Pearson Prentice Hall, Upper Saddle River, New Jersey.
[21] ACI Committee 318 (2011). “Building Code Requirements for Structural Concrete and Commentary (ACI 318-11).” ACI, Farmington Hills, MI, 503 pp.
[22] ACI Committee 318 (2014). “Building Code Requirements for Structural Concrete and Commentary (ACI 318-14).” ACI, Farmington Hills, MI, 520 pp.
[23] Tan, K.H., Cheng, G. H., Zhang, N. (2007). “Experiment to mitigate size effect on deep beams,” Magazine of Concrete Research, Online, 15 pp.

[24] Mihaylov, B. I., Bentz, E. C., Collins, M. P. (2010). “Behavior of Large Deep Beams Subjected to Monotonic and Reversed Cyclic Shear.” ACI Structural Journal, 107(6), 726734.

[25] Birrcher, D. B., Tuchscherer, R. G., Huizinga, M., Bayrak, O. (2013). “Minimum Web Reinforcement in Deep Beams.” ACI Structural Journal, 110 (2), 297-306..

[26] Oh J.-K., Shin, S.-W. (2001). “Shear Strength of Reinforced High-Strength Concrete Deep Beams,” ACI Structural Journal, 98(2), pp. 164-173.

[27] Yang, K.-H., Chung, H.-S., Lee, E.-T., Eun, H.-C., (2003). “Shear characteristics of highstrength concrete deep beams without shear reinforcements,” Journal of Engineering Structures, 25(10), pp. 1343-1352.

[28] Brown, M. D., Bayrak, O. (2006). “Minimum Transverse Reinforcement for BottleShaped Struts,” ACI Structural Journal, V. 103, No. 6, November 2006, pp. 813-822.

[29] Birrcher, D., Tuchscherer, R., Huizinga, M., Bayrak, O., Wood, S., and Jirsa, J., (2009).

[30] Tuchscherer, R., Birrcher, D., Huizinga, M., Bayrak, O. (2011). “Distribution of Stirrups across Web of Deep Beams,” ACI Structure Journal, 108(1), pp. 108.

[31] Breña, S. F., Roy, N. C. (2009). “Evaluation of Load Transfer and Strut Strength of Deep Beams with Short Longitudinal Bar Anchorages.” ACI Structural Journal, 106(5), pp. 679-689.

[32] Luangtriratana, P., Kandola, B. K., and Myler, P. (2015). “Ceramic particulate thermal barrier surface coatings for glass fibre-reinforced epoxy composites.” Mater. Des., 68, 232–244.

[33] ECP, 208-05. (2005) Egyptian Code for the Use of Fiber Reinforced Polymers in the Construction Field. Housing & Building National Research Center, Cairo, Egypt.

[34] Abbood, Imad Shakir. "Strut-and-tie model and its applications in reinforced concrete deep beams: A comprehensive review." *Case Studies in Construction Materials* (2023): e02643.

[35] Li, Ye, et al. "Effect of member depth and concrete strength on shear strength of RC deep beams without transverse reinforcement." *Engineering Structures* 241 (2021): 112427.