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Structural Implications of Steel Mesh and Fiber Reinforcement in Underground Beams/ Case Study: Iraq

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Abstract

In the distinct geotechnical landscape of Al-Karkh, Baghdad, ensuring the structural robustness of underground reinforced concrete beams is imperative. This work delves into the potential advantages of integrating steel fibers and steel meshes into these beams using three types of concrete: Normal Strength Concrete, Sulphate Resistance Concrete, and Reactive Powder Concrete. Instead, it employs Type V Portland cement, known for its sulfate resistance. This study analyzes their load-carrying capacity and deflection behavior. Initial outcomes suggest that beams reinforced with Steel Fiber and Steel Mesh exhibit enhanced load-bearing capacity, reduced deflection, and improved resilience to environmental stressors. The integration of both Steel Fiber and Steel Mesh will increase the ultimate load of Normal Strength Concrete, Sulphate Resistance Concrete, and Reactive Powder Concrete by 55%, 69%, and 119% respectively. Significantly, the presence of steel meshes was linked to augmented beam strength. This work underscores the potential structural benefits of Steel Fiber and Steel Mesh. In addition, using Portland cement Type V in Reactive Powder Concrete is possible, emphasizing the applicability in urban underground frameworks, especially in contexts mirroring Al-Karkh's conditions.

Keywords: Reactive Powder Concrete; Steel Fibers; Steel Mesh; Sulphate Resistance Concrete; Underground Reinforced Concrete Beams.

1. Introduction

In recent times, a notable transformation has unfolded within the construction industry, marked by a departure from conventional construction methods and a shift in the choice of building materials, particularly within the confines of the city [1]. A comprehensive analysis of gathered statistics shows a discernible contrast in construction practices has emerged within Baghdad, specifically between the Karkh and Rusafa districts, as shown in Fig.1 [2].

Rewinding to the 1970s, the Karkh side comprised lush orchards adorned with trees and palm trees [3]. As urbanization swept through Baghdad, the Rusafa side experienced a surge in population and construction, notably hosting various state ministries [4]. Iraq is a country in Asia at latitude 33°19′15.60″ North. The ensuing years witnessed a substantial spike in real estate prices in Rusafa, reaching multifold the values seen in Karkh, especially post-2003 [5].

Yet, the distinctive features in construction style, architectural design methodology, and the selection of infrastructure materials requirements in Karkh prompt probing questions. Amidst these factors, this work concentrates specifically on the impact of soil nature on concrete structures. The interplay of these variables adds complexity to the evolving landscape of construction practices in Baghdad, emphasizing the need for a nuanced understanding of the intricate relationship between nature, technology, and societal dynamics. As consultant engineers, we were requested by the building construction company to study the feasibility of incorporating steel fibers and steel mesh into underground reinforced concrete structures in Al-Karkh locations, and the required treatment methods.

While the integration of steel fibers and meshes in concrete beams is not new, their application in underground settings is less explored. This work produces the superior properties of reinforced concrete beams incorporated with steel fibers and steel meshes of underground concrete beams made with three types of concrete: Normal Strength Concrete (NSC), Sulphate Resistance Concrete (SRC), and Reactive Powder Concrete (RPC). Their ability to withstand harsh underground environments, enhanced load-carrying capacities, and reduced deflection make them invaluable for urban construction [6].

1.1. Steel Fiber and Steel Mesh

The incorporation of Steel Fibers (SF) and Steel Meshes (SM) into concrete beams enhances structural properties [7] and increases resistance against crack propagation, especially in flexural members [8]. Incorporation of both steel fibers (SF) and steel meshes (SM) in concrete structures enhances ductility, toughness, and crack resistance[9]. The presence of steel meshes in concrete significantly offers a unique advantage by acting as crack arresters [10]. It's widely used in construction, rehabilitation, and reinforcing structures with ferrocement and shotcrete [11]. The use of fiber reinforcement in concrete can significantly increase energy absorption at early ages [12]. It also reduces shrinkage cracking [13], enhances the durability of concrete, and makes it more resistant to salinity and groundwater exposure [14]. The inclusion of steel fibers could impact the workability of the concrete mixture [15]. It may affect the surface finish of the concrete [16]. While steel fibers enhance toughness, there may be limitations in terms of the level of toughness achieved, especially in highly demanding structural applications [17].

1.2. Underground Reinforced Concrete Constructions

Structures situated underground encounter distinctive challenges associated with exposure to dynamic loads, ground movement, moisture, and corrosive agents. As outlined by Agency [18], these circumstances have the potential to undermine the structural stability of reinforced concrete beams. The presence of groundwater and aggressive soil conditions can lead to accelerated corrosion of reinforcing elements, causing premature structural failure [19]. In addition, the presence of sulphate salts at high rates negatively affects the hardened cement paste and internal stresses causing cracks in the concrete mass and affecting the resistance [20]. Therefore, when SF and SM are incorporated into reinforced concrete beams, they can resist underground environmental factors, especially moisture-related effects (Fig. 1, Iraq, Baghdad). Karkh and Rusafa sides.

2. Types of Concrete and Materials

The mix design proposed for this work used a 0.45 water-to-cement ratio, and the mix proportion ratio of the cement: sand: gravel was (1:2:4) by volume. All the chemical and physical properties of the material used in this work are mentioned in Tables 1, 2, 3, and 4 and are free and supported by the materials supplier.

2.1. Normal Strength Concrete (NSC)

Traditional concrete was employed, with the objective of a compressive strength of 25 MPa, according to ACI 318-19 [21]. The concrete included Bazian ordinary Portland cement sourced from Iraq, by Iraqi Standard Specifications No. 1984-5 and ASTM C150/C150M − 16′1 [22].

2.2. Sulphate-Resistant Concrete (SRC)

A Portland cement resistant to sulphates Type V, CEM I 42.5SR, was used in this work. High-resistance Portland cement resistant to sulfate salts is one of the common types according to Iraqi Standard Specifications No. 1984-5 and European Standards No. 1:2011-197. This cement is produced with a low content of tricalcium aluminate (C3A) so that it does not exceed 3.5%. This type of cement is distinguished from other types by the low content of tricalcium aluminate, which is responsible for interacting with sulphate ions in the soil or groundwater, which causes the concrete to expand and crack.

2.3. Reactive Powder Concrete (RPC):

Reactive Powder Concrete (RPC), originating in France during the early 1990s, represents an ultra-high strength and high ductility cementitious composite characterized by advanced mechanical and physical attributes [23]. Its distinctive microstructure is meticulously optimized through precise particle gradation within the mix to achieve maximum density [24]. Leveraging the pozzolanic properties of highly refined silica fume and optimizing the chemistry of Portland cement result in the formation of the highest strength hydrates [25]. The composition encompasses finely powdered materials such as cement, sand, and silica fume, according to ASTM C1240-20 [26]; their content rates are shown in Table 1, along with optional steel fibers, according to ASTM C 1609/C 1609M–12 [27], shown in Table 2. The superplasticizer meets the requirements for superplasticizer specified by ASTM C494, 2013 [28], as shown in Table 3. The judicious use of the superplasticizer, at its optimal dosage, concurrently reduces the water-to-cement ratio (w/c) and enhances concrete workability. The attainment of a remarkably dense matrix through optimal granular packing of the dry fine powders imparts ultra-high strength and durability to RPC [29]. While Ordinary Portland Cement is commonly used in Reactive Powder Concrete (RPC), this work opts for Portland cement Type V, which is known for its resistance to sulphates. However, it is crucial to emphasize that the choice of materials in RPC requires careful consideration, and the use of a particular type of Portland cement may influence the overall performance of the mixture. Therefore, when contemplating the incorporation of Portland cement Type V in RPC, many trials of mix design were done to assess its compatibility with other mix components and its alignment with the desired properties of the final concrete, especially the workability.

Table 1. Chemical analysis of the silica fume.

Chemical Composition	Content (%)
CaO	0.5
Fe_2O_3	1.4
Al_2O_3	0.5
SiO_2	92.1
MgO	0.3
K_2O	0.7
Na_2O	0.3
SO_3	0. 1
L.O. I	2.8

Table 2. Properties of the steel fibers.

Property	Specifications
Density	7850 kg /m3
Yielding strength	1125 MPa
Modulus of elasticity	200 x 103 MPa
Strain	5625 x 10-6
Poisson's ratio (γ)	0.303
Average length	45 mm
Nominal diameter	0.45 mm
Aspect ratio	100

Table 3. Typical properties of Glenium 51.

Main action	Concrete superplasticizer
Color	Light brown
pH. Value	6.6
Form	Viscous liquid
Chlorides	Free of chlorides
Relative density	1.08 – 1.15 gm/cm3 @ 25°C
Viscosity	128 ± 30 cps @ 20°C
Transport	Not classified as dangerous
Labeling	No hazard label required

2.4. Steel Mesh (SM)

Steel mesh (SM) or welded wire reinforcement consists of high-strength wires arranged in grids and welded at intersections [30], as shown in Fig. 2. These wires can be plain, deformed, or mixed. They bond to concrete through the mechanical anchorage at welded intersections, with deformed wire also using its deformations for added bond [31]. Steel meshes are incorporated into concrete to enhance its strength, toughness, and durability; the properties of the steel mesh used in this work are shown in Table 4.

Figure 2. Steel meshes used in the work.

Table 4. Properties of the steel meshes**.**

Property	Specifications
Density	7850 kg /m3
Yielding strength	425 MPa
Average diameter	1.78 mm
Opening size of mesh	25 x 25 mm

2.5. Fine Aggregate

AL–Ukhaidher natural sand was used in this work. It has fineness modulus (F.M.) of (2.60), bulk specific gravity (S.G.) of (2.58), and sulphate content (SO3%) of (0.09%) by sand weight, which is compatible to the Iraqi standard specification No. 45 / 1984. For RPC mixes, only the passing sand from sieve No. 4 (600 μm) was used to achieve the mixing requirements and properties.

2.6. Coarse Aggregate

For NSC, Crushed gravel with a maximum size of 14 mm is used. The bulk specific gravity (S.G.) of the aggregate is (2.64), and its grading complies with the Iraqi standard specification No. 45 / 1984.

3. Material and Method

3.1. Program

The experimental program intended to study the effect of steel fibers (SF) content and steel mesh (SM) content on the structural behavior of beams. Twelve reinforced concrete beams with dimensions of (200×250×1100mm), shown in Fig. 3, were tested. The NSC has of a nominal compressive strength of 25 MPa, Sulphate Resistance Concrete (SRC) has a nominal compressive strength of 35 MPa, and Reactive Powder Concrete (RPC) has a nominal compressive strength of 80 MPa, as shown in Table 5.

Portland cement resistant to sulphates Type V was used instead of Ordinary Portland cement in the reactive powder concrete (RPC), which was cast and cured for 28 days. Steel fiber (SF) ratio Vsf = 1% and Steel Mesh (SM) ratio Vsm = 2% were used, and the beams were tested under two-point loading conditions.

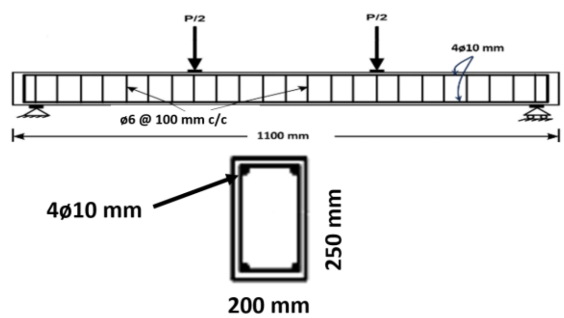


Figure 3. Details of the tested beams.

Table 5. Percentages of steel fiber and steel mesh used in this work.

Beam No.	Type of concrete	Steel fiber Vsf %	Steel mesh Vsm %
B1	NSC	-	-
B2	NSC	1	-
B3	NSC	-	2
B4	NSC	1	2
B5	SRC	-	-
B6	SRC	1	-
B7	SRC	-	2
B8	SRC	1	2
B9	RPC	-	-
B10	RPC	1	-
B11	RPC	-	2
B12	RPC	2	2

3.2. Soil Properties in Al-Karkh /Baghdad (Case Study)

The National Center for Construction Laboratories conducted soil investigation work for this paper, including extensive work on the general engineering properties of the soil layers in Baghdad. The findings revealed that Baghdad possesses unique properties, distinct from other cities, owing to millennia of early human activities primarily centered around agriculture. The historical use of various irrigation and drainage methods has induced significant soil variations from one region to another. Furthermore, alterations in the river's course have led to the deposition of sandy soil during floods near the river's edge. At the same time, the alluvial and soft materials are carried by water to deposit in areas farther from the river. Consequently, the layer sequence in Baghdad is asymmetrical and unpredictable. The groundwater level of Baghdad ranges between (0.2) and (6.0) m below the surface of the natural ground level, and it is lower the farther away we are from the Tigris River because the area near the river is paved [4].

Although the presence of a high percentage of sulphate concentrations in the soil of Baghdad [32],[33], Gypsum was found in the upper cohesive soil of Baghdad in many areas such as Sheikh Omar, Al-Sadr, Al-Wahda, Al-Riyadh, Al-Waziriya, and Al-Mustansiriyah [18]. Table 6 presents the properties of the location case study. All tests and values were conducted in the National Center for Construction Laboratories and Research.

Table 6. Soil properties of location case study*.

Description	Details
Minimum Groundwater level	0.2 meter
Natural moisture content of soil	(17 – 30)%
Soil water limit	(25 – 55)%
plasticity index	(9 – 37)%
Undrained Shear Strength	25-250 kN/m2
Angle of internal friction for granular soil	32-41 degrees
Soil bearing capacity	50-150 kN/m2, 5-15 Ton/m2
Soil connectivity	Low to very low
Soil permeability	Low to very low
Underground water type	Chloride
Underground water Salinity	Moderately brackish water
Type of soil	alkaline, or basic

*All tests were made in the National Center for Construction Laboratories and Research.

Al-Karkh stands out as the area most susceptible to shallow groundwater, as depicted in Fig. 4, with the presence of sulphate materials and salts [18] evident in Fig. 5.

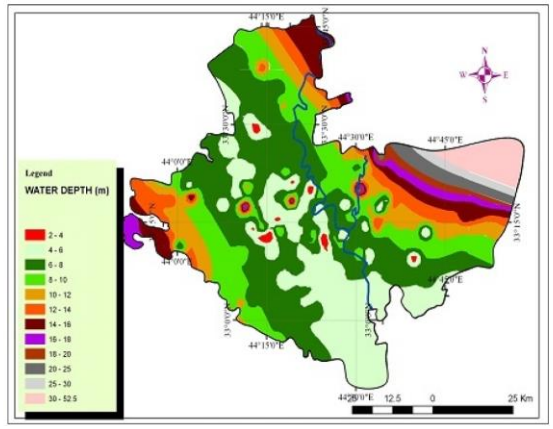


Figure 4. Groundwater depth of Baghdad Governorate [19].

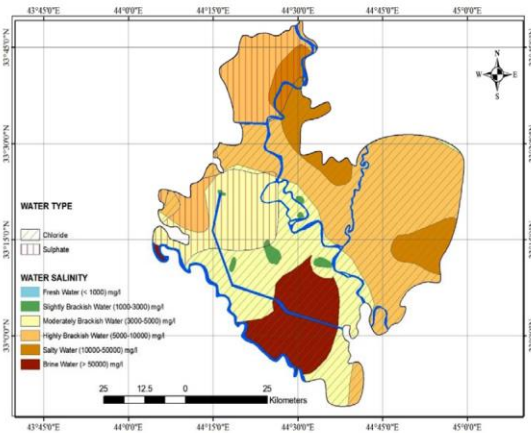
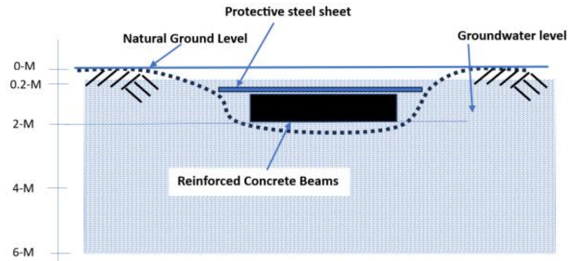


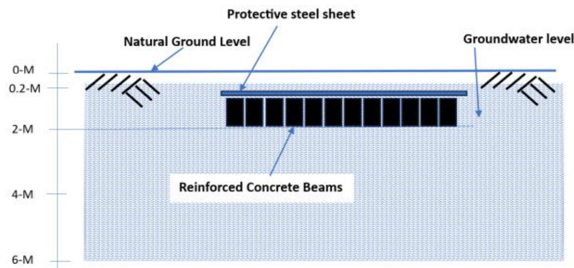
Figure 5. Distribution of the salinity and water types zones in Baghdad Governorate [19].

The specific site, shown in Fig. 6, was chosen for burying the twelve reinforced concrete beams in an excavated hole 2 meters below ground level for 355 days, as shown in Fig. 7.

Figure 6. Preparing the location of the beams at a 2-meter underground level.



Side View



Front View

Figure 7. Position level of reinforced concrete beams.

The preparation of the excavation site, transportation, and burial proved exceptionally challenging, particularly during the lifting of concrete beams from the pit. Some models were adversely affected during the removal process, resulting in unexpected and substantial damage. Consequently, these damaged models were excluded from the results.

4. Results and Discussions

Preliminary results showed that beams with SF and SM exhibited improved structural performance in underground settings, demonstrating increased load-bearing capacity, reduced deflection, and enhanced resistance to environmental-induced deterioration. Particularly, steel meshes appeared to significantly influence beam strength and reduce potential crack development. Fig. 8 shows the crack pattern of the tested beam specimens, which seem to be shear cracks.

4.1. Deflection

Differences in ultimate deformation are observed between the SRC and NSC beams.

The theoretical maximum deflection calculated using the double integration method for a supported beam with two point loads, as shown in Fig. 9, using (1):

$$(\Delta max) = \frac{P*a}{24EI} * (3L^2 - 4a^2) \quad (1)$$

Modulus of Elasticity for conventional types of concrete, calculated using (2), ACI 318-2005 [34]:

$$E = 4730\sqrt{fc} \quad (2)$$

Figure 8. Crack pattern of the tested beam Specimens.

The relationship between the elastic modulus of RPC and the compressive strength of the cylinder was obtained by (3) [35]:

$$E = 3840\sqrt{fc} \quad (3)$$

Table 7 shows the theoretical and experimental values of maximum deflection for each beam.

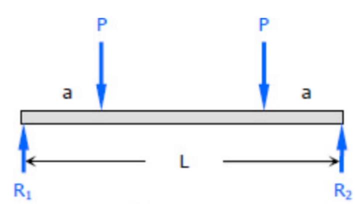


Figure 9. Simply supported beam, two-point loads.

Steel reinforcement and concrete body of RPC beams integrated with SM and SF were unaffected by corrosion and the effect of salt in the case study. This represents a favorable aspect worth taking into account. Table 8 and Fig. 10 show the deflection values for the three types of concrete used in this work. Figs. 11, 12, and 13 show the load deflection curves for each type of concrete used in this work.

Table 7. Experimental and estimated theoretical deflection (mm).

Beam #	Type of concrete	*fc* Mpa	E Mpa	Failure. load KN	Theoretical Deflection mm	Experimental Deflection mm
B1	NSC	25	23,6	290	1.22	3.75
B2	NSC	25	23,6	360	1.51	2.35
B3	NSC	25	23,6	415	1.74	1.66
B4	NSC	25	23,6	450	1.89	1.2
B5	SRC	35	27,9	325	1.15	3.65
B6	SRC	35	27,9	390	1.38	3.1
B7	SRC	35	27,9	450	1.60	2.66
B8	SRC	35	27,9	490	1.74	1.43
B9	RPC	80	34,3	373	1.08	1.87
B10	RPC	80	34,3	465	1.35	0.69
B11	RPC	80	34,3	520	1.50	0.79
B12	RPC	80	34,3	635	1.84	0.66

Table 8. Deflection values of the NSC, SRC and RPC beams.

Concrete Types	Beams #	Deflection (Δ) (mm)	Decrease with respect to reference beam (%)	Decrease with respect to B1 (%)
NSC	B1*	3.75	-	-
	B2	2.35	63	63
	B3	1.66	44	44
	B4	1.2	32	32
SRC	B5*	3.65	-	97
	B6	3.1	85	83
	B7	2.66	73	71
	B8	1.43	39	38
RPC	B9*	1.87	-	50
	B10	0.69	37	18
	B11	0.79	42	21
	B12	0.66	35	18

* This symbol refers to the reference beam in each group

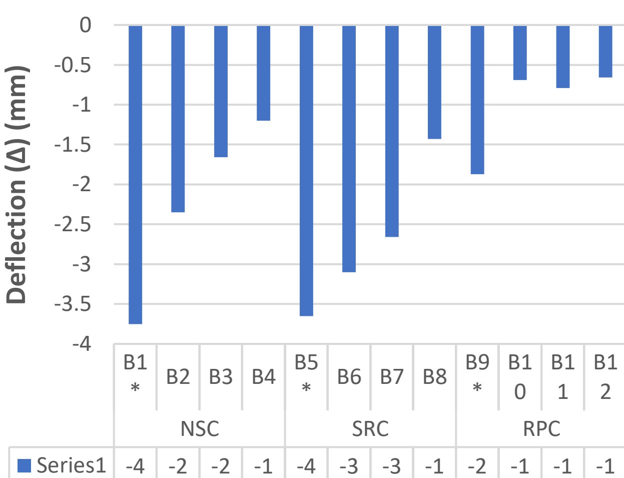


Figure 10. Comparison of deflections for three types of concrete.

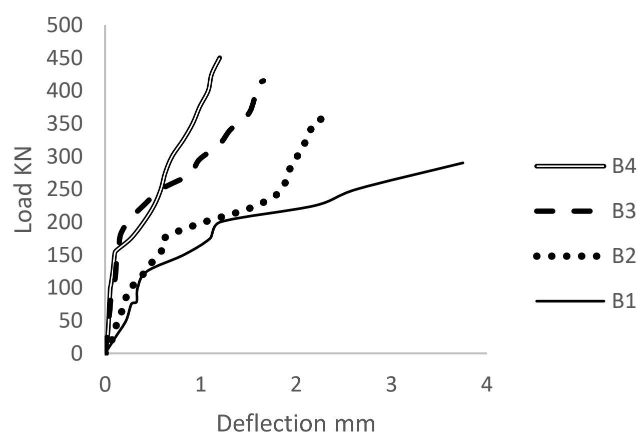


Figure 11. Load-Deflection curve/NSC.

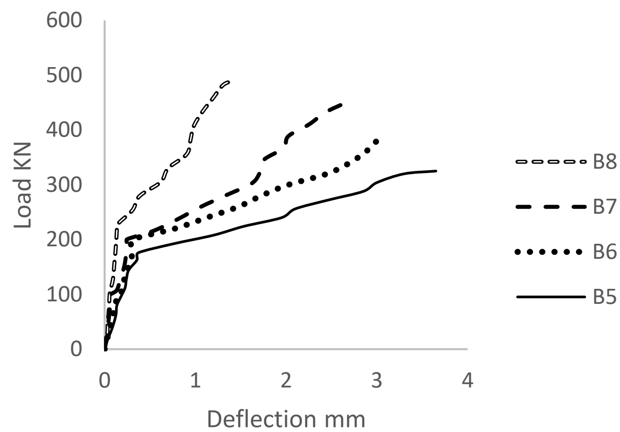


Figure 12. Load-Deflection curve/SRC.

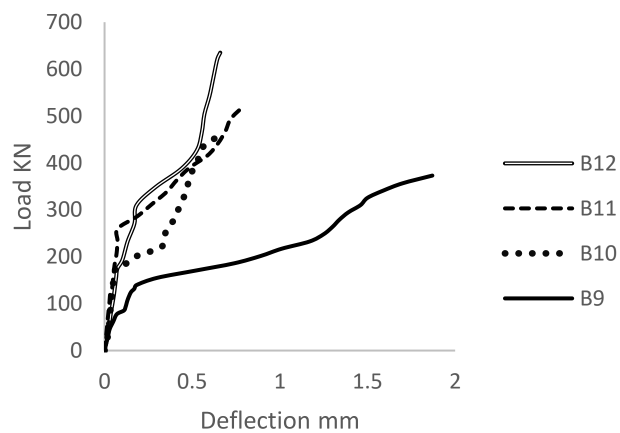


Figure 13. Load-Deflection curve/RPC.

4.2. Ultimate load capacity for SF and SM

The load-carrying capacity reflects the ultimate applied load that the tested beam can withstand. Table 9 and Figs. 14 and 15 show the values and present the improvements in load-carrying capacity for the tested beams due to differences in the steel fibers and steel mesh content. While the steel mesh enhances the structural strength and ultimate load capacity of reinforced concrete beams, the integration of both steel fibers and steel mesh content in the section increases the ultimate carrying capacity of the beam.

Theoretical load is calculated using (4)-(9), which are the standard equations used for the analysis and design of reinforced concrete beams by Nilson and Darwin.

$$\rho_b = 0.85 * \beta * \frac{f'c}{fy} * \frac{600}{600+fy} \tag{4}$$

$$\rho = \frac{A_s}{b*d} \tag{5}$$

$$As * fs = 0.85 * f'c * a * b \tag{6}$$

$$Ø * Vc = Ø * \frac{1}{6} * \sqrt{f'c} * b * d * 10^{-3} \tag{7}$$

$$Ø * Vs = Vu - Ø * Vc \tag{8}$$

$$s = \frac{Ø*Av*fy*d}{Ø*Vs} * 10^{-3} \tag{9}$$

4.3. Surface structure of the concrete

The surface of reinforced concrete beams is affected by several factors, including the concrete mix composition, environmental conditions, and exposure duration.

The original smooth finish of the NSC beams B1-B4 with ordinary Portland cement mix is compromised, and the texture of the surface concrete becomes uneven with areas of increased roughness or spalling. This effect does not appear in other beams, especially the beams with RPC.

The effects of salinity, moisture, and potential chemical reactions on the concrete beams, combined with exposure to groundwater with dissolved salts, cause the concrete to develop cracks and scaling on the surface. Salt crystals can form within the concrete pores, leading to internal pressure and surface damage, as shown in Fig. 16.

Table 9. Theoretical and ultimate load capacity.

Concrete type	Beam #	Theoretical calculated Load (KN)	Ultimate Load Capacity (Pu) (kN)	Increase with respect to the reference beam (%)	Increase with respect to B1 (%)
NSC	B1*	124	290	-	-
NSC	B2	124	360	24	24
NSC	B3	124	415	43	43
NSC	B4	124	450	55	55
SRC	B5*	126	325	-	12
SRC	B6	126	390	20	34
SRC	B7	126	450	38	55
SRC	B8	126	490	50	69
RPC	B9*	128	373	-	29
RPC	B10	128	465	25	60
RPC	B11	128	520	39	79
RPC	B12	128	635	70	119

* This symbol refers to the reference beam in each group

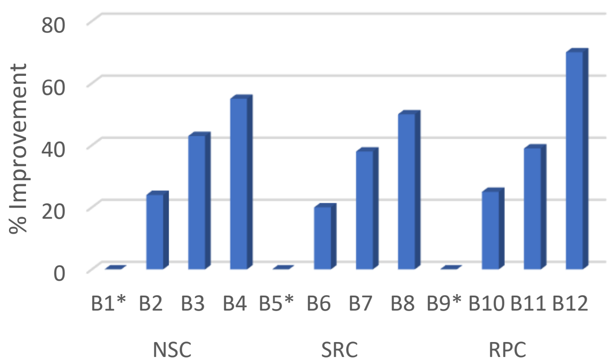


Figure 14. Increase in ultimate load capacity with respect to reference beam (%).

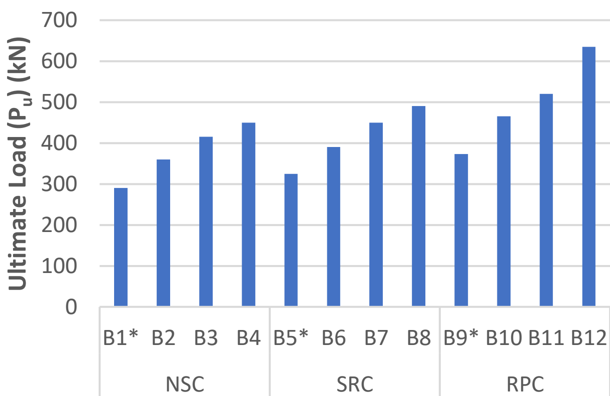


Figure 15. The ultimate load for all beams.

Figure 16. The effect of groundwater salinity on the concrete surface.

4.4. Deterioration Due to Corrosion of Steel Fiber

Observations indicate that steel fibers located near the concrete surface exposed to groundwater, particularly in environments containing salts or organic materials, exhibit evident corrosion and rust. Conversely, the farther the steel fiber is positioned from the outer surface of the concrete, the less pronounced the corrosion and rust become. Fig. 17 and Fig. 18 show the effect of rust on SF on the concrete far and closer to the surface of the concrete.

5. Conclusions

Based on the results of this work, the significant advantages and disadvantages of integrating steel fibers and meshes are underscored. When the NSC beams are exposed to corrosion, which will increase the susceptibility of the steel fibers to rust, the steel fibers will be considered a weak point to initiate failure. Therefore, using steel fiber in reinforced NSC is not preferable. In addition, the steel mesh is not immune to the risk of corrosion inherent in saline environments.

Figure 17. The effect of concrete corrosion on steel fiber located far from the surface of the concrete beam.

Figure 18. The effect of concrete corrosion on steel fiber located near the surface of the concrete beam.

While the inclusion of steel fibers enhances the flexural strength of the concrete, contributing to improved load-carrying capacity and overall structural performance, the potential for corrosion in saltwater environments remains a significant concern. Proper concrete cover and quality installation can help protect it in saltwater and sewage conditions.

The use of Portland cement Type V in reactive powder concrete is possible, but careful consideration, evaluation, and potential adjustments to the mix design are essential to achieve the desired performance and durability in Sulphate-rich environments.

In areas where the percentage of groundwater levels resulting from water leakage from sewer or sewage pipes increases, it is preferred to increase the compressive strength of concrete and use sulfate-resistant concrete instead of increasing the amounts of steel reinforcement, steel fiber, and steel mesh. Also, using ordinary cement in concrete is prohibited.

Finally, it is not recommended to add steel fiber to underground NSC exposed to salt or organic groundwater.

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Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Author Contribution Statement

Haider Amer Mushatat: Formulated the problem statement and collected data.

Wael Shahadha AbdulKareem: Developed the theory and discussed the results analysis.

Lubna Mohammed Abd: Verified the analytical methods.

Reem Wael Shahadha: Performed the computations.

References

[1] A. Chandaliya, G. Surecha, N. Sharma, M. Tank, K. Dangi, and M. Meena, “Contrasting conventional and modern building construction methods,” *International Advanced Research Journal in Science, Engineering and Technology (IARJSET),* vol. 11, no. 4, pp. 9- 11, 2024, doi: https://doi.org/10.17148/IARJSET.2024.111002

[2] Z. R. Abaas, “Impact of development on Baghdad’s urban microclimate and human thermal comfort,” *Alexandria Eng. J.*, vol. 59, no. 1, pp. 275–290, Feb. 2020, doi: https://doi.org/10.1016/j.aej.2019.12.040.

[3] T. A. J. Abdullah, “The Mandaean Community and Ottoman-British Rivalry in Late 19th-Century Iraq: The Curious Case of Shaykh Ṣaḥan,” *J. Econ. Soc. Hist. Orient*, vol. 61, no. 3, pp. 396–425, Apr. 2018, [Online]. Available:https://www.jstor.org/stable/26572309

[4] H. H. Karim, S. J. Wadaa, “Geotechnical Study of Baghdad Soil,” *Glob. J. Eng. Sci. Res. Manag.*, vol. 4, no. 9, pp. 92–106, 2017, [Online]. Available:https://www.gjesrm.com/index.php/gjesrm/article/view/481 .

[5] A. A. A. Sajit and S. M. Eyal, “Population of Iraq: Demography and diversity,” in The Geography of Iraq, S. M. Awadh and M. Al-Dabbas, Eds. Cham, Switzerland: Springer, 2024, pp. 375–390, doi: https://doi.org/10.1007/978-3-031-71356-9_17

[6] S. M. Hama and D. N. Hamdullah, “Reactive powder concrete beam’s behavior in flexural: Review,” *Diyala Journal of Engineering Sciences*, vol. 14, no. 4, pp. 113–131, Dec. 2021, doi: https://doi.org/10.24237/djes.2021.14410

[7] V. V Sawant, C. P. Pise, and P. G. D. Lakade, “Experimental Study on High Performance Steel Fibre Reinforced Concrete using Metakaolin,” *International Journal of Engineering Research & Technology*. vol. 10, no. 02, pp. 67–71, 2021. [Online]. Available:https://www.ijert.org/experimental-study-on-high-performance-steel-fibre-reinforced-concrete-using-metakaolin

[8] S. H. Majeed, E. K. Sayhood, and N. S. Mohammed, “Residual strength capacity of reinforced reactive powder concrete two-way slabs subjected to drop weight,” *Al-Qadisiyah J. Eng. Sci.*, vol. 16, no. 1, pp. 70–75, Mar. 2023, doi: https://doi.org/10.30772/qjes.v16i1.920.

[9] T. K. Mohammedali, “Experimental and Analytical Study on Pull-out Force of Steel Fiber-Reinforced Concrete Blocks,” *Diyala J. Eng. Sci.*, vol. 15, no. 1, pp. 30–39, Mar. 2022, doi: https://doi.org/10.24237/djes.2022.15103.

[10] S. Fayed, M. Ghalla, A. Hamoda, M. Alkharisi, E.-S. Bayoumi, M. H. Sobuz, S. Abubakar, and B. Ramadan, “Using steel mesh as internal reinforcement in the concrete supports subjected to partially compressive load,” *Scientific Reports*, vol. 15, 2025, doi: https://doi.org/10.1038/s41598-025-26266-9.

[11] M. N. Abbas, F. H. E. Al-rubyei, W. Shahadha, and A. Kareem, “Effect of Adding the Rice Husks Residues Remaining from Water Treatment to the Strength of Concrete Mixture Reaching to Zero Residues Level (ZRL),” *International Journal of Innovative Science and Research Technology*. vol. 4, no. 6, pp. 543–548, 2019. [Online]. Available:https://ijisrt.com/wp-content/uploads/2019/07/IJISRT19JU451.pdf .

[12] H. Wang, X. He, M. Zhou, C. Wu, and J. He, “Study on bending failure and crack characteristics in ductile fiber-reinforced concrete beams,” *Structural Concrete,* vol. 25, no. 2, pp. 916–934, 2024, doi: https://doi.org/10.1002/suco.202300530

[13] B. Zhang, H. Zhu, T. Xiong, et al., “Flexural behavior of FRP bars reinforced seawater coral aggregate concrete beams incorporating alkali-activated materials,” *Materials and Structures,* vol. 57, p. 26, 2024, doi: https://doi.org/10.1617/s11527-024-02298-x

[14] J. Ahmad, Z. Zhou. “Mechanical properties of natural as well as synthetic fiber reinforced concrete: A review,” *Construction and Building Materials*, vol. 333, p. 127353, 2022, doi: https://doi.org/10.1016/j.conbuildmat.2022.127353.

[15] T.-F. Yuan, D. Y. Yoo, J.-M. Yang, et al., “Shear capacity contribution of steel fiber reinforced high-strength concrete compared with and without stirrup,” *International Journal of Concrete Structures and Materials*, vol. 14, p. 21, 2020, doi: https://doi.org/10.1186/s40069-020-0396-2.

[16] Y. Guo, D. Gao, W. Ma, and J. Liu, “Multiscale analysis of hybrid sisal/steel fiber reinforcement mechanisms in fully recycled geopolymer concrete under uniaxial compression,” *Construction and Building Materials,* vol. 525, p. 146378, 2026, doi: https://doi.org/10.1016/j.conbuildmat.2026.146378.

[17] E. Garcia-Taengua, M. Bakhshi, and L. Ferrara, "Meta-Analysis of Steel Fiber-Reinforced Concrete Mixtures Leads to Practical Mix Design Methodology," *Materials*, vol. 14, no. 14, p. 3900, Jul. 2021, doi: https://doi.org/10.3390/ma14143900

[18] Japan International Cooperation Agency (JICA), “The Feasibility Study On Baghdad Water Supply System Improvement Project Final Report Volume II,” 2006. Japan International Cooperation Agency (JICA) Global Environment Department [Online]. Available:https://openjicareport.jica.go.jp/618/618/618_305_11836491.html

[19] N. H. Al-Basrawi, J. H. Awad, and T. A. Hussain, “Evaluation of the Ground Water in Baghdad Governorate / Iraq,” *Iraqi J. Sci.*, vol. 56, no. 2C, pp. 1708–1718, 2015. [Online]. Available:https://ijs.uobaghdad.edu.iq/index.php/eijs/article/view/10022

[20] S. Mousavinezhad, W. K. Toledo, C. M. Newtson, and F. Aguayo, “Rapid assessment of sulfate resistance in mortar and concrete,” Materials, vol. 17, no. 19, p. 4678, 2024, doi: https://doi.org/10.3390/ma17194678.

[21] ACI Committee 318, *318-19 Building Code Requirements for Structural Concrete and Commentary*. USA, 2019. American Concrete Institute, doi: https://doi.org/10.14359/51716937

[22] ASTM International, Standard Specification for Portland Cement, ASTM C150/C150M-16, 2016, doi: https://doi.org/10.1520/C0150_C0150M-16.

[23] R. J. Shi, Z. Xiang, S. G. Liu, D. H. Wang, and Y. Z. Ju, “Mechanical Properties of Reactive Powder Concrete: A Review,” *IOP Conference Series: Materials Science and Engineering,* vol. 629, no. 1, p. 012009, Sep. 2019, doi: https://doi.org/10.1088/1757-899X/629/1/012009.

[24] A. H. Wenas, W. S. AbdulKareem, and H. A. Mushatat, “Structural behavior of MRPC beams exposure to riverine simulated circumstances using GFRP and CFRP bars,” *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 1076, no. 1, p. 012103, 2021, doi: https://doi.org/10.1088/1757-899x/1076/1/012103.

[25] M. Sanjuán and C. Andrade, “Reactive powder concrete: Durability and applications,” *Applied Sciences,* vol. 11, no. 12, p. 5629, 2021, doi: https://doi.org/10.3390/app11125629.

[26] ASTM International, Standard Specification for Silica Fume Used in Cementitious Mixtures, ASTM C1240-20, 2020, doi: 10.1520/C1240-20.

[27] ASTM International, Standard Test Method for Flexural Performance of Fiber-Reinforced Concrete (Using Beam With Third-Point Loading), ASTM C1609/C1609M-12, pp. 1–4, May 31, 2019.

[28] ASTM International, Standard Specification for Chemical Admixtures for Concrete, ASTM C494/C494M-13, p. 10, 2013, doi:

10.1520/C0494_C0494M-13.
[29][Y.-M. Chun, P. Claisse, T. R. Naik, and E. Ganjian, S*ustainable Construction Materials and Technologies. Proceedings of the Conference on Sustainable Construction Materials and Technologies, 11-13 June 2007, Coventry, United Kingdom*, 1st ed. London: CRC Press, 2007. doi: https://doi.org/10.1201/9781003061021.
[30]O. Cengiz and L. Turanli, “Comparative evaluation of steel mesh, steel fibre and high-performance polypropylene fibre reinforced shotcrete in panel test,” Cement and Concrete Research, vol. 34, no. 8, pp. 1357–1364, 2004, doi: https://doi.org/10.1016/j.cemconres.2003.12.024.
[31]A. Muttar, S. T. Abdulhussain, O. Al-Kerttani, and O. Khalid, “The Behavior Of Concrete Containing Polypropylene Fibers And Steel Mesh On The Impact Resistance,” *J. Eng. Sustain. Dev.*, vol. 28, no. 3, pp. 333–341, May 2024, doi: https://doi.org/10.31272/jeasd.28.3.3.
[32]S. A. Ati, “The effect of soil on the subsidence of the earth’s surface in some areas of Karkh,” *Coll. Educ. Girls Mag.*, vol. 2007, no. 18, p. 9, 2007, [Online]. Available: https://jcoeduw.uobaghdad.edu.iq/index.php/journal/article/view/462/420
[33]O. H. Saif Altameemi, A. Abdullah, and A. A. Abdulsamad, “Engineering performance of sulfate-bearing soils in Iraq and their impact on concrete foundations: Mechanisms, evaluation methods, and mitigation approaches—A critical review,” *Rafidain Journal of Engineering Sciences*, vol. 4, no. 1, pp. 531–539, Mar. 2026, doi: https://doi.org/10.61268/fd5qvn51
[34]ACI Committee.318-05"Building code requirements for structural concrete and commentary (ACI 318R-05)." American Concrete Institute, 2005.
[35]H. A. Sabit and A. N. Abbas, “Structural Behavior Of Hybrid Reinforced Concrete Coupled Beams Containing Reactive Powder Concrete And High Strength Concrete,” *J. Eng. Sustain. Dev.*, vol. 25, no. 2, pp. 68–77, Feb. 2022, doi: https://doi.org/10.31272/jeasd.25.2.8.