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Experimental Investigation of Short Square Normal and Hybrid Fiber Reactive Powder Concrete Columns Subjected to Chloride Solution Attack

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ABSTRACT

In this research, the structural behavior of reinforced concrete columns made of normal and hybrid reactive powder concrete (hybrid by steel and polypropylene fibers) subjected to chloride salts with concentration was 8341.6 mg/l. The study consists of two parts, the first one is experimental study and the second one is theoretical analysis. Three main variables were adopted in the experimental program; concrete type, curing type and loading arrangement. Twenty (120x120x1200) mm columns were cast and tested depending on these variables. The samples were reinforced using two different bars; Ø8 for ties and Ø12 with minimum longitudinal reinforcement (0.01Ag). The specimens were divided into two main groups based on curing type: The first group consists of casting and testing of ten columns that cured in tap water for 28 days with two types of concrete (normal and hybrid), five columns for each type. While the second group consists of ten columns that direct cured and fully immersed in chloride water (8341.6 mg/l) 6 months with two types of concrete (normal and hybrid), five columns for each type. The specimens were tested under three types of loading, the first one is axial load, the second one is eccentric load with three different eccentricities (50,100 and 150) mm and where (e/h) are (0.42, 0.83 and 1.25) respectively from the center of column while the third type of loading is tested the specimens as beam. The experimental results showed an increase in ultimate load capacity and higher chlorides resisting for hybrid reactive powder concrete in comparison with normal concrete in both types of curing (tap and chloride water) through studying strain profile. Interaction diagram charts were obtained from different types of loading for each specimen. These charts showed high values for hybrid reactive powder concrete in comparison with normal concrete.

Keywords: normal strength, hybrid fiber reactive powder concrete.

التصرف العملي للأعمدة الخرسانية القصيرة مربعة المقطع ذات الخرسانة العادية والمساحيق الفعالة المسلحة باللياف هجينة والمعرضة لهجوم محلول الكلورايد

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الخلاصة

في هذا البحث تم دراسة التصرف الانشائي للاعمدة الخرسانية والمعرضة للاملاح الكلوريدية و (بتركيز 8341.6 ملغم/لتر) في نوعين من الخرسانة العادية وذات المساحيق الفعالة والمهجنة بالالياف (steel and polypropylene fibers). تم اجراء (جانبيين في البحث الاول الجانب العملي والثاني الجانب النظري. يتضمن الجانب العملي ثلاث متغيرات هي نوع الخرسانة ونوع المعالجة ونوع التحميل، حيث تم صب وفحص 20 عمود خرساني بابعاد (120×120) ملم وبارتفاع 1200 ملم واستخدام نوعين من الاقطار لحديد التسليح $8\emptyset$ للاطواق المقاومة للقص و $12\emptyset$ التسليح الطولي وبنسبة 1%، تم تجزئة الجانب العملي الى جزئين: الجزء الاول وهو صب 10 اعمدة ومعالجتها في المياه العادية لمدة 28 يوم بنوعين من الخرسانة العادية والمهجنة 5 اعمدة لكل نوع خرسانة اما الجزء الثاني هو صب 10 اعمدة ومعالجتها بالمياه الكلوريدية و (بتركيز 8341.6 ملغم/لتر) وغمرها كلياً لمدة 6 اشهر وايضا بنوعين من الخرسانة ولكل نوع 5 اعمدة. في الفحص تم تسليط ثلاث انواع من الحمل وهي الحمل المحوري واللامحوري وهي (50، 100، 150) ملم ونسبة (e/h) 0.42 ، 0.83 ، 1.25) من سنتر العمود والحمل الاخير هو فحص النموذج كعتبة. اظهرت النتائج العملية زيادة في الحمل والمقاومة في كلا المعالجة العادية والكلوريدية للخرسانة المهجنة مقارنة بالخرسانة العادية من خلال الحصول على *interaction diagram chart, strain profile* من خلال اختلاف نوع الحمل لكل نموذج حيث اظهرت النتائج الارقام العالية لرسم ال *chart* للخرسانة المهجنة مقارنة بالعادية.

1.INTRODUCTION

The durability of concrete depends upon its resistance to deterioration caused by external as well as internal agents. The external agents are like weathering, natural or industrial liquids and gases, aggressive environmental etc. **The ACI-committee 201, 2001**, describes durability of hydraulic cement concrete as its capability to resist weathering conditions, chemical attack abrasion or any other condition of deterioration, that is durable concrete will keep its original stage, quality, and serviceability when exposed to its environment. According to **British Standard Code BSI, 1992**, of practice CP3 durability is defined as the quality of maintaining a satisfactory appearance and satisfactory performance of required functions. The behavior of the deterioration of a material depends upon the properties of the material and the environment. So, using reactive powder concrete (RPC) is considered as the best solution for durability problem because it is a type of concrete which exhibits superior mechanical and durability properties, **Abdulla, 2007**. The columns are a compression member, usually vertical or predominantly vertical, used primarily to support the axial compressive load, but can also resist moment, shear or torsion, **ACI Committee 318, 2014**. The columns are used in buildings to support the floor systems, hence, to transfer the vertical loads from the floors into the foundations. A major part of civil engineering reinforced concrete (RC) in infrastructure all over the world including: Bridges, municipal buildings, transportation system, and parking facilities are facing problem of deficient design and/or construction practices, space, functionality or loading alteration, overuse, seismic upgrading and of course inadequate maintenance, **Al- Mosawi, 2012**.

Three types of reinforced concrete compression members are in use:

1. Members reinforced with longitudinal bars and lateral ties.
 2. Members reinforced with longitudinal bars and closely spaced spirals.
 3. Composite compression members reinforced longitudinally with structural steel shapes, pipes, or tubing, with or without additional longitudinal bars.
- Types 1 and 2 are more usual than type 3.

Many researcher study effect of aggressive environment on the durability of reactive powder concrete such as, **Al-Kadhi, 2007**, studied the strength of RPC samples that were partially immersed in aggressive water containing a high percentage of sulfate and chloride ions after 28 days of moist curing. **Mahdi, 2009**, studied the durability of self-compacted reactive powder concrete (SC-RPC) exposed to the harsh environment. There were no decreases in the properties of the SC-RPC due to exposing its samples to partial immersion in a saline



solution containing high percentages of chloride and sulfate ions. The salts components used were ($\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$, NaCl , and $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$) up to 360 days, after 28 days of initial curing. **Hawi, 2014**, studied the effect of sulfate attack with external effect on normal strength concrete (NSC) with mix ratio equal to 1: 1.5:3 and cement content 380 kg/m^3 , all samples initial curing is in tap water for 28 days after it has been exposed to a solution of sulfate, three different sulfate solutions used in this study including sodium, magnesium, and calcium at four levels (0%, 2%, 4% and 6%) each for three exposure periods of (60, 90 and 120) days. **Islam, et al.**, studied experimentally and theoretically using finite element procedure, the behavior of short square columns that cast using steel fiber reinforced concrete (SFRC) in order to construct the P-M interaction diagram. Their work supplied real experimental data also FE analysis on P-M Interaction Diagram of square RC columns for expecting the axial load as well as bending capacity. According to the experimental program, P-M Interaction Diagram was successfully developed for PC and SFRC square columns and the combined effect of axial load and bending moment capacity due to eccentricity is effectively investigated. **AL-Hassani and Hannawayya, 2014**, derived equation for the ultimate analysis of short rectangular RPC columns under a combination of axial load and uniaxial bending. The derived equations are used to construct the required interaction diagrams which denote actual failure envelopes of eccentrically loaded RPC columns. To allow a close comparison with the corresponding interaction diagrams of ordinary reinforced concrete (ORC) columns, a $300 \times 500 \text{ mm}$ RPC column having concrete compressive strength, $f_c' = 110 \text{ MPa}$ and steel yield stress $f_y = 400 \text{ MPa}$ is analyzed twice (for steel ratio ρ equal to 0.01. and 0.03). The obtained interaction diagrams are compared with the corresponding interaction diagrams of ORC column having the same cross-section, same steel properties but different concrete compressive strength. The comparison presented that failure envelopes of RPC columns, being affected by the compression and tension capabilities of concrete and yield stress of steel bars, are significantly larger than the corresponding failure envelopes of ORC columns which is influenced by the compression strength of concrete only and the yield stress of steel bars. Notwithstanding this, interaction diagram of Hybrid Fiber Reactive Powder Concrete (HFRPC) under exterior attack of sulfate and chloride salts were not sufficiently addressed in the prior research studies. In a current research paper, an interaction diagram chart on HFRPC was conducted with variants of curing period under salt effect.

2. EXPERIMENTAL PROGRAM

2.1 Materials Used

A total of 20 columns were investigated by using experimental work. All columns have a square cross-section with 120 mm. the materials used for the specimens are normal strength concrete (NSC) designed for 25 MPa as by **ACI 318M-14** and rebars as specified in ASTM A615. The other materials are used HFRPC (reactive powder concrete with steel and polypropylene fibers). All detailing specification for columns as per reconditions of ACI 318M-14. The shape and size of the specimens loading arrangement and strain measurement of the test specimens are given in this section. The columns were studied the following variables:

- 1) Type of concrete
- 2) Curing condition
- 3) Loading arrangement

Fig. 1 and Plate 1 show the geometry and reinforcement details of specimens.



2.1.1 Steel reinforcement

In all the specimens ($\varnothing 12$ mm) diameter for steel bars with a nominal yield strength 636 MPa conforming to, **ASTM A615, 2005**, were used as main steel with 1% steel reinforcement ratio to confirm minimum reinforcement requirement of ACI 318M-14. The ties were fabricated using ($\varnothing 8$ mm) diameter for steel. The minimal conditions to be satisfied in terms of hoops spacing (S) proposed in ACI318 for buildings design should satisfy the following condition: $S = \min. (16 \times \varnothing_{\text{longitudinal}} \text{ or } 48 \times \varnothing_{\text{tie}} \text{ or smaller dimension of the section})$. The tensile test was performed achieved by the testing machine SANS (1000 kN), as shown in **Plate 2** and **Table 1**, available at the Materials Laboratory, Faculty of Engineering AL-Mustansiriayah University. The bars were tested to evaluate the yield stress and ultimate stress. Steel reinforcement used in this study is of Ukrainian origin.

2.1.2 Mix proportion

The ordinary Portland cement was used in the concrete mix of a proposition by weight (1:1.5:3) for normal strength concrete (cement: sand: gravel). Reactive powder concrete was used in concrete mix (1:1:0.15) for (cement: sand: silica fume). The steel fibers used in the specimens (straight, density 7800 kg/m^3 , length 13mm, diameter 0.175mm, aspect ratio 74, tensile strength 2600 MPa). The polypropylene filers used in the specimens (straight, density 910 kg/m^3 , length 12mm, diameter 0.12mm, aspect ratio 100, tensile strength 450 MPa). **Table 2** gives more details about the material used in the mix for this study. Control specimens consisting of (150×300) mm and (100×200) mm cylinders and (100×100×500) mm prisms were also cast with each specimen to determine the compressive and splitting tensile strength, modulus of rupture and modulus of elasticity. The workability was 12cm in this study. The mix proportion used in this study depending on the several trail mixes and the same previous researches **ISS NO.5, 1984., ISS NO.45, 1984.**

2.1.3 Mixing water

Ordinary tap water is prepared and used for mixing and curing of all the concrete specimens as well as the control specimens.

2.2 Structural Behavior

2.2.1 Tests of columns

The details of each parameter are reviewed in the following articles:

1-Type of Concrete: The two types of concrete were used, type one: hybrid fiber reactive powder concrete (HFRPC) this concrete contains (high content of cement+ fine aggregate, silica fume, superplasticizer (Glenium 51) with water and steel fiber with polypropylene fiber), type two: Normal strength concrete (NSC) "conventional concrete" this concrete contains (cement, fine aggregate, coarse aggregate, and water).

2-Type of Curing: In order to study the influence of the two types of the curing in structural behavior for HFRPC and NSC columns. Two types of curing in this study tap water curing (28 days) and chloride water curing (6 months) are used tap and chloride water.

2.3 Concrete Mixing, Placing and Curing

2.3.1 Concrete mixer, vibrating and mixing



The specimens were cast on level ground in the casting yard established within the heavy test hall of the lab using wood formwork. Prior the casting, the forms were coated with shuttering oil in the inside surface and 10 mm thick cover blocks were used to give the derived cover to the steel. Mixing procedure by **Wille, et al., 2011**.

The concrete mixer 0.19 m³ and due car. was taken during preparation of the mix to avoid fiber balling. Using table vibrator ensured good compaction of concrete. The columns were cast casing in a horizontal position and stripped after 24hr of cured for 28 days by using water tanks. Curing was carried out for 28 days for NSC and HFRPC in tap water for group A. In chloride, curing was carried out for 6 months for NSC and HFRPC for group B in order to get high disintegration with the exposure time. **Table 3** shows that.

2.4 Preparation of the Saline Solution

One of the principal problems of concrete durability is the external attack of sulfate and chloride salts, especially those present in soil and underground water in the southern parts of Iraq and other parts of the world. In this study the salt used in preparing the solution is pure sodium chloride (NaCl) added up equal to 3.5% from weight water used in chloride curing (3.5% from weight water used in tank chloride water), this percentage is the hardest environment in which concrete is exposed. Plate 3 shows sample from chloride used in this study also Plate 4 and 5 show type of curing. for tap water, the chloride concentration was 14.99 mg/l (Plate 4) while in chloride water the concentration of chloride was 8341.6 mg/l after application ratio 3.5% from weight of water (Plate 5).

2.5 Testing of Concrete Column

2.5.1 Loading arrangement

The columns were tested under concentric and eccentric axial loads using the hydraulic universal testing machine (MFL). The position of the load was variable with five values of eccentricity. The first position was with no eccentricity, so the column was subjected to axial load only, the other values of eccentricity were (50,100 and 150 mm) from the center of the column while the last column was tested as a beam to obtain ($e=\infty$).

2.5.2 Loading caps

The loading cap was a rectangular section (140×260mm) and thickness 40mm, consisted of four eccentrics. The eccentric load was applied to the loading cap via a wedge plate that was located into the 0 mm, 50mm, 100mm, 150mm channels, respectively. The loading caps were prepared of high strength steel and each end of the columns was covered with loading cap. Plate 6 shows cap loading.

2.5.3 Strain measurement

Strains are measured to determine the degree and behavior of structural member against the applied stresses. The use of devices with high accuracy is required to calculate the amount of strain in the steel and concrete. Two types of strain gauges were used, the first type of steel reinforcement (-) produced by TML company and the second for concrete (PL-60) produced by TML company. Data logger type (TML/ TC-32K) was used to measure the strains in steel reinforcements and concrete. It is an automatic, multichannel, scanning data logger for reading strain gauges and transducers. The strain gages were fixed in two different locations, the first one was fixed in main reinforcement in mid of column length at tension zone, while the second one was settled on compression face of concrete in mid-length of concrete.



2.5.4 Test procedure

One type of test was conducted on columns specimens, the type of test the load was increased steadily up to failure. Before testing, columns were checked dimensionally, and detailed visual inspection was made with all recorded information carefully. A hydraulic actuator was prepared and used for applying the axial load to the column specimens as shown. The lower ends of the specimens were attached to the actuator, while the upper ends were supported on the steel reaction cap, both end supports were designed as hinged connections with predefined eccentricity by using loading caps. A total three linear variable displacements (dial gauge) in mid-distance of the column for the measurements of lateral displacement, bottom and axial deflection and two strain gage in compression zone face in concrete and tension zone in steel reinforcement. The load was increased gradually and in every 10 kN step for HFRPC and 5 kN for NSC, the order of the sample is shown in **Plate 7**. The midspan deflection is recorded at each 10 kN for HFRPC and 5 kN for NSC load increment. The load is applied via a hydraulic jack. The schematic diagrams for the column and beam are shown in **Fig. 2 and 3**.

3. RESULTS AND DISCUSSION

3.1 Interaction Diagram

The experimental axial load-bending moment interaction diagrams for NSC and HFRPC specimens were drawn using axial load ($e = 0$ mm), uniaxial load ($e = 50$ mm, $e = 100$ mm and $e = 150$ mm) and bending ($e = \infty$ as beam) to investigate the axial load bending moment capacity of the tested specimens. The bending moment capacity M_n of the specimens tested as columns were calculated using Eq. (1):

$$M_n = P \times e \quad (1)$$

where P is the applied axial load.

M_n is the bending moment capacity

The typical interaction diagram of NSC and HRPC column can be divided into many parts depending on the type of failure of the column: -

- 1) Balanced failure: This failure takes place at the onset of tensile steel yielding and concrete crushing, both of which occurring simultaneously.
- 2) Tension failure: When the column fails by yielding of tension reinforcement.
- 3) Compression Failure
When the column fails by crushing of concrete.
- 4) Pure Bending: When the axial force $P \rightarrow 0$ and $e \rightarrow \infty$ then the column will be under a pure bending moment.
- 5) Pure Axial Compression

If e approaches zero, then P is maximum and the whole cross section is in compression.

3.1.1 Effect of type of curing on interaction diagram columns

Fig. 4 and 5 show the effect of type of curing on interaction diagram. From these figures, it is noted the interaction diagram for NSC (1st crack and ultimate stages) in chloride water is lower than interaction diagram in tap water, while in HFRPC column when cured in chloride water approach and lower than interaction diagram in tap water. Because the HFRPC contains mineral fiber and non-metal (steel + polypropylene), which resists microcracks and tension forces resulting from the saline medium in which it was placed, so it was noted the little difference in the draw interaction diagram for this type of concrete by the compressive between tap water and chlorine water.



3.1.2 Effect of type of concrete on interaction diagram columns

Fig. 6 and Fig. 7 shows that interaction diagram for HFRPC larger than NSC during two stages (1st crack and ultimate) because of HFRPC more homogeneous and high compressive strength from NSC.

3.1.3 Effect of eccentricity on interaction diagram columns

From **Fig. (4, 5, 6 and 7)** it can be seen that increasing the eccentricity transport from compression stage to tension stage. The effect of eccentricity on peak axial loads specimens tested as columns is an increase in eccentricity resulted in a larger reduction in peak axial loads in HFRPC specimens than NSC specimens.

3.2 Strain-Profile

The variation of concrete strain along the depth of tested columns during different stages of loading at the constant moment region is shown in **Fig. 8 and 9**. The strains at mid-height section of the columns in compression zone for concrete and tension zone for steel reinforcement are measured using the data logger. At early stages of the testing process, when the column is free from cracks, the concrete resists the tensile stresses. However, by increasing the applied load, cracks appear and the concrete layer at the mid-height of the columns becomes out of concrete tensile stresses resistance and the reinforcing steel begins to resist these stresses alone. At the last stage of the test when the crack height rises up, the yield in the reinforcing steel becomes more eventual in the tension zone at the mid or rear of the column, as well as, the compression zone of the columns suffers from decreasing in its depth and high compressive stresses. That means, at the last stage of the test, the behavior of columns is inelastic and high strain values exceed the yield strain value in the reinforcing steel and concrete at the mid of the columns crushes. All the tested columns in the present study exhibit similar behavior in the property of the concrete strains, but with variations in the value of strains from one column to the other during the different stages of the applied load and a failure. Also, it can be noted that the compressive and tensile strains are affected by three parameters including:

3.2.1 Effect of type of curing on the strain

From **Fig. 8 and 9** noted from strain profile for NSC columns when the column is exposed to aggressive environment such as chloride attack, compressive and tensile strain of concrete is larger than columns exposed to normal curing (tap water) in comparison at the same load, this behavior may be attributed to the chloride attack which causes degradation in tensile stress for concrete and leads to tension cracks increase in width and amount, where the maximum strain in the compression zone is in specimen N2E50, NC2E50 is $0.00194\mu\text{m}$ in tap water while the strain of increased to $0.007074\mu\text{m}$ when cured with chloride water, also the maximum strain in the tension zone in specimens N5EB, NC5EB is $0.01812\mu\text{m}$ in tap water, while these strain became $0.03579\mu\text{m}$ when cured with chloride water. but for HFRPC columns compressive and tensile strain was noticed for columns cured in tap water approximately equal column cured in chloride water when comparing at the same load, The maximum strain in the compression zone was in specimens H1E0, HC1E0 was $0.0011\mu\text{m}$ in the tap water while the very few reactions were very low to $0.0021\mu\text{m}$ when cured with chloride water, also the maximum strain in the tension zone is in the same specimens H3E100, H3CE100 was $0.0279\mu\text{m}$ in tap water, while these strain became $0.0303\mu\text{m}$ when cured with chloride water and these values are Converged because of the quality of hybrid concrete.



3.2.2 Effect of type of concrete on the strain

In comparison between strain profile for NSC columns with HFRPC columns, high strain is noted at small load for all HFRPC columns, increase when the load is increased and a crack appears. In other words, with an increase in compressive strength, the strain of concrete increase, the reason for the increase is attributed to the increase in tensile strain for concrete which has high compressive strength.

3.2.3 Effect of eccentricity on the strain

From **Fig. 8 and 9** noted that the compression zone in N1E0 and H1E0 specimens increase by increase load because of axial loading on the column and noted in other specimens that the tension zone increase by increase eccentricity load for normal strength concrete and Hybrid reactive powder concrete for both tap water and chloride water curing.

4. CONCLUSIONS

4.1 Conclusions of Interaction Diagram for Experimental Results

4.1.1 Effect of type of curing on interaction diagram:

The experimental results show that the interaction diagram for NSC (1st crack and ultimate stages) in chloride water is lower than interaction diagram in tap water, where percentage decrease in the force applied to the column for axial and uniaxial loading at the 1st crack stage when curing the specimens in chloride water is (35.4, 27.3, 24.1 and 20)% but percentage decrease in ultimate loading is (18.1, 26.9, 23.5, 16)% while in HFRPC column when cured in chloride water approach and lower than interaction diagram in tap water, where percentage decrease in the force applied on the column for axial and uniaxial loading at the 1st crack stage when curing the specimens in chloride water is (20, 7.3 and 7.6)% but percentage decrease in ultimate loading is (1.5, 2.2, 8.1, 5.4)%.

4.1.2 Effect of type of concrete on interaction diagram:

The experimental results show that interaction diagram for HFRPC larger than NSC during two stages (1st crack and ultimate) because HFRPC more homogeneous and high compressive strength from NSC, where percentage increase in the force applied to the column compared to the NSC and HFRPC in the stage (1st crack, ultimate loading) are (23, 96.9), (233, 96), (182,194) and (290, 192)% on respectively at curing in tap water while at curing in chloride where percentage of increase is (109.5, 136.6), (266, 269), (245, 253) and (350, 228)% on respectively.

4.1.3 Effect of eccentricity on interaction diagram:

The experimental results show that, by increase eccentricity transport from compression stage to tension stage. The effect of eccentricity on peak axial loads specimens experimental as columns is increased in eccentricity resulted in larger lowering in peak axial loads in HFRPC specimens than NSC specimens.

4.2 Conclusions of Strain-Profile

The experimental results show that:

1. The strain in the concrete increased in exposure to the aggressive environment (chloride water) compared with specimens cured in tap water. Where the rate of increase of strain when cured with chloride water for the region (compression, tensile) for a maximum strain is (264, 97.5) % at NSC and (90.1, 8.6) % at HFRPC.
2. An increase in compressive strength, the strain of concrete increase, the reason for the increase is attributed to the increase in tensile strain for concrete which has high compressive strength.



3. An increase in concrete strain with an increase in eccentricity, these results occur when columns are cured in tap and chloride water.

6- REFERENCES

- Abdulla, N.A., 2007, *Effect of Saline Environment on the Strength of Reinforced Concrete Beams*, AL-Rafdain Engineering Journal, Vol.16, No.2, pp.1-23.
- ACI Committee 201, 2001, *Guide to Durable Concrete*, American Concrete Institute, pp.41.
- ACI Committee 318, 2014, *Building Code Requirement for Structural Concrete and Commentary*, American Concrete Institute, pp.35.
- Al-Hassani, H., and Hannawayya, S., 2014, *Interaction Diagrams of Short Rectangular RPC Columns Under Combined Axial Load Plus Uniaxial Bending*, Journal of Engineering and Development, Vol. 18, No.4, ISSN 1813- 7822.
- Al-Kadhi, A., 2007, *Durability and Dynamic Properties of Reactive Powder Concrete Exposed to Aggressive Ions*, Ph.D. thesis, University of Technology, Iraq.
- Al-Mosawi, A.H., 2012, *Experimental Study of RC Columns Square section Strengthened with CFRP Composites under Eccentric Loading*, M.Sc. Thesis, University of AI –Mustansiriya, Iraq, pp.2-5.
- ASTM A615, 2005, *Standard Specification for Deformed and Plain Carbon Structural Steel Bars for Concrete Reinforcement*, Annual Book of ASTM Standards, Vol.01, No.02.
- British Standard Institution, 1992, *Guide to the durability of Building and Building Elements, Products and Components*, BSI, BS 7543, London.
- Hawi, K.H. 2014, *Effect of External Sulfate Attack on Concrete*" Journal of The University of Babylon, Vol.3, No.22,pp.581-593. (Arabic Translator).
- Hmeed, Y.M., 2014, *Behavior of Reinforced Concrete I-Beams Containing Reactive Powder Concrete*", Ph.D. thesis, University of Mustansiriayah, Iraq.
- Islam, M.M., Dhar,A., and Patowary, F., Asif, J.H., S. Rahman, S., Das, S.S., Das, S., Chowdhury, M.A., *Experimental Investigation and Finite Element Analysis on P-M Interaction Diagram of RC Square Columns made of Steel Fiber Reinforced Concrete (SFRC)*, Ahsanullah University of Science and Technology, pp.1-9, Dhaka 1208, Bangladesh.
- Iraqi Specification, No.5, 1984, *Portland cement*. (Arabic Translator).
- Iraqi Specification, No.45, 1984, *Aggregate from Natural Sources for Concrete and Construction*. (Arabic Translator).
- Mahdi, B.S., 2009, *Properties of Self-Compacted Reactive Powder Concrete Exposed to Saline Solution*, Ph.D. thesis, University of Technology, Iraq.
- Wille, K., Naaman, A.E.and Montesinos, G.J., 2011, *Ultra-High Performance Concrete with Compressive Strength Exceeding 150 mpa :a Simple way*, ACI Materials Journal, Vol.108, No.1, pp.46-54.

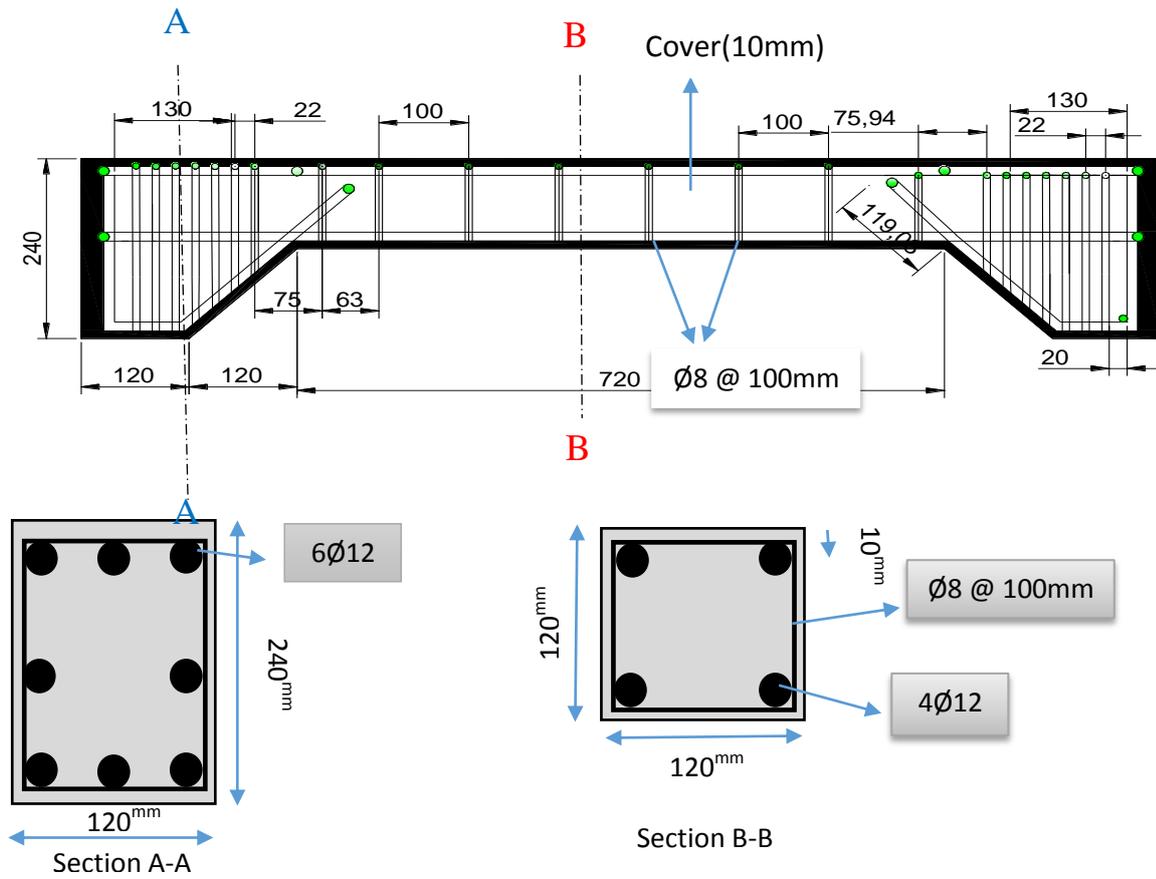


Figure 1. Dimensions and Reinforcement Details of Tested Columns.



Plate 1. Reinforcement Details

Table 1. Properties of steel bars*

Nominal diameter mm	Actual diameter(mm) after test	Yield stress (Fy) MPa	Ultimate strength (Fu) MPa	Percentage of reduction area = $\frac{\text{nominal area} - \text{actual area}}{\text{nominal area}}$ %
8.66	5.26	696	961	62.68
12.15	6.92	636	818	66.88

* Each value is an average of three specimens.



Plate 2. Tensile Machine for Steel Bars Testing

Table 2. Mix Proportions of NSC and HFRPC.

Concrete Type	NSC	HFRPC
Cement (C) (kg/m ³)	400	1000
Sand (S) (kg/m ³)	600	1000
Gravel (G) (kg/m ³)	1200	-
Silica Fume (SF%)* (kg/m ³)	-	150 (15)
Super-plasticizer(SP)** Glenium51%	-	6
Water (W) (kg/m ³)	180	200
Water/ cement ratio W/C	0.45	0.2
Steel fiber*** (STF%)	-	0.75
Polypropylene fiber*** (PPF%)	-	0.15
Total fiber volume*** %	-	1.15
Mix proportion by weight	1:1.5:3 Cement : Sand : Gravel	1:1: 0.15 Cement : Sand : Silica fume

* Percent of cement weight.

** Percent of binder (cement and silica fume) weight.

*** Percent of mix volume.

Table 3. Columns Details.

Group No.	Column Designations	Eccentricity (mm)	Type of concrete	Type of curing
A	N1E0	0	Normal Strength Concrete	Tap Water
	N2E50	50		
	N3E100	100		
	N4E150	150		
	N5EB	beam		
	H1E0	0	Hybrid Reactive Powder Concrete	
	H2E50	50		
	H3E100	100		
	H4E150	150		
	H5EB	beam		
B	NC1E0	0	Normal Strength Concrete	Chloride Water (8341.6 mg/l)
	NC2E50	50		
	NC3E100	100		
	NC4E150	150		
	NC5EB	Beam	Hybrid Reactive Powder Concrete	
	HC1E0	0		
	HC2E50	50		
	HC3E100	100		



	HC4E150	150		
	HC5EB	Beam		



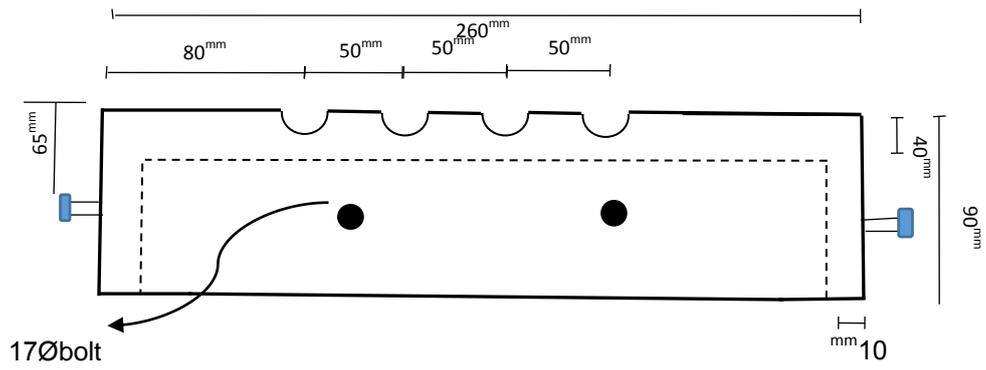
Plate 3. Chloride Used in Test.



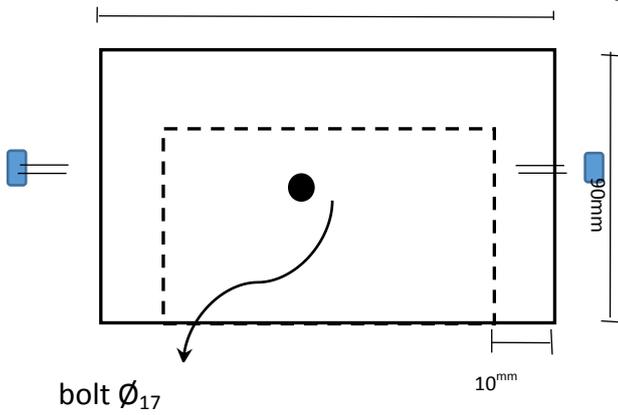
Plate 4. Curing of Specimens in Tap Water.



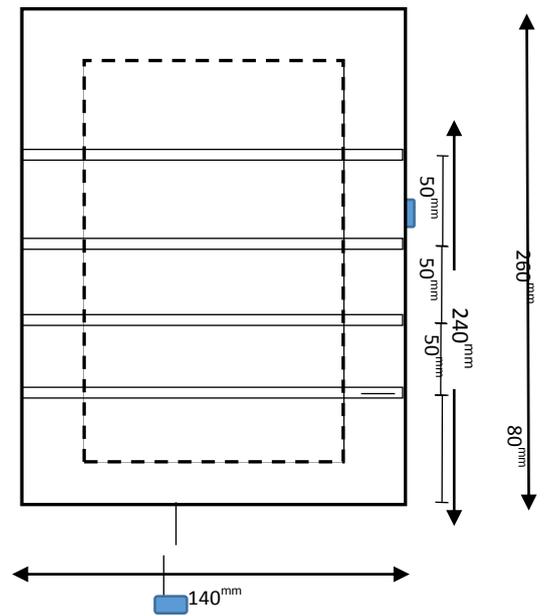
Plate 5. Curing of Specimens in Chloride Water.



a-side view



b-front view



c-top view



Plate 6. Cap Loading Details.

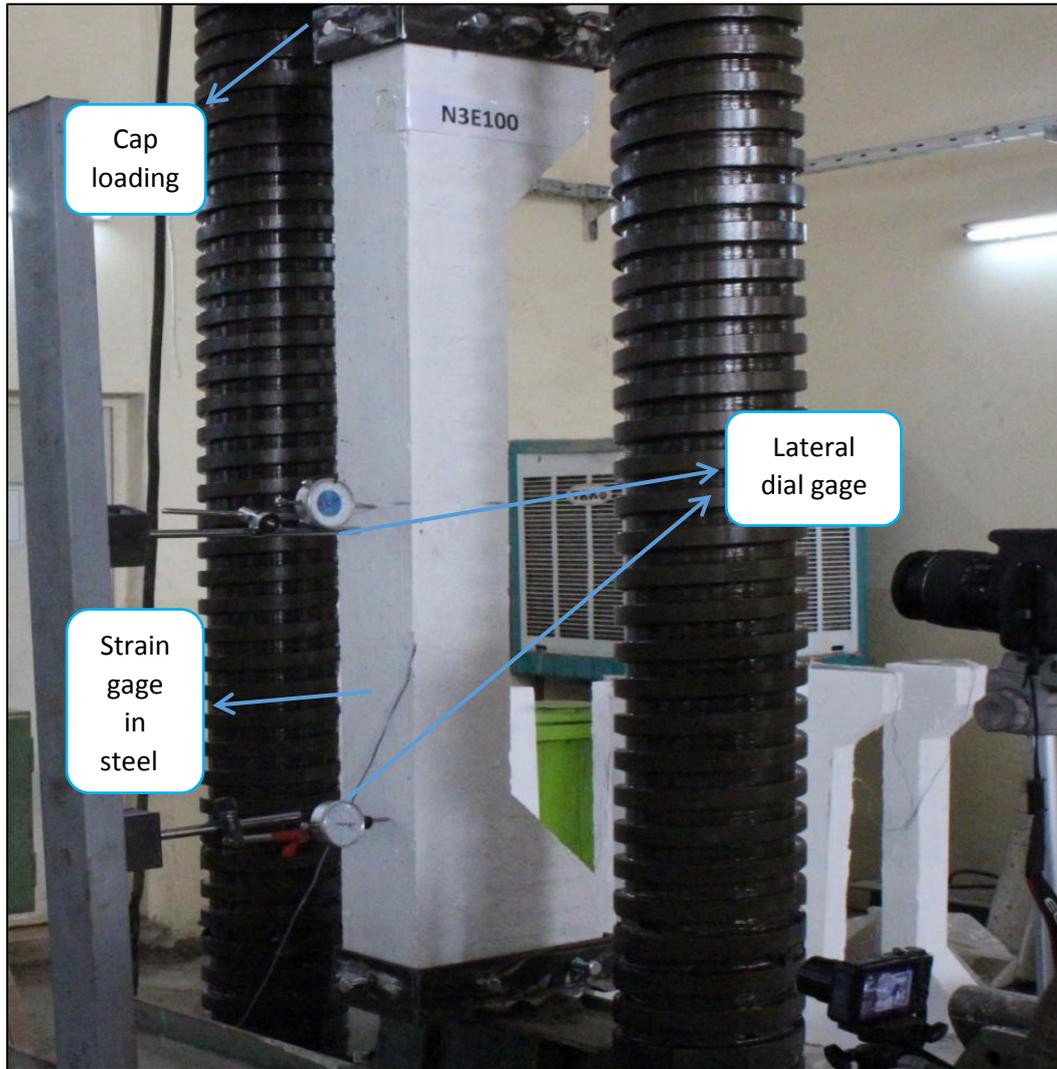


Plate 7. Test setup.

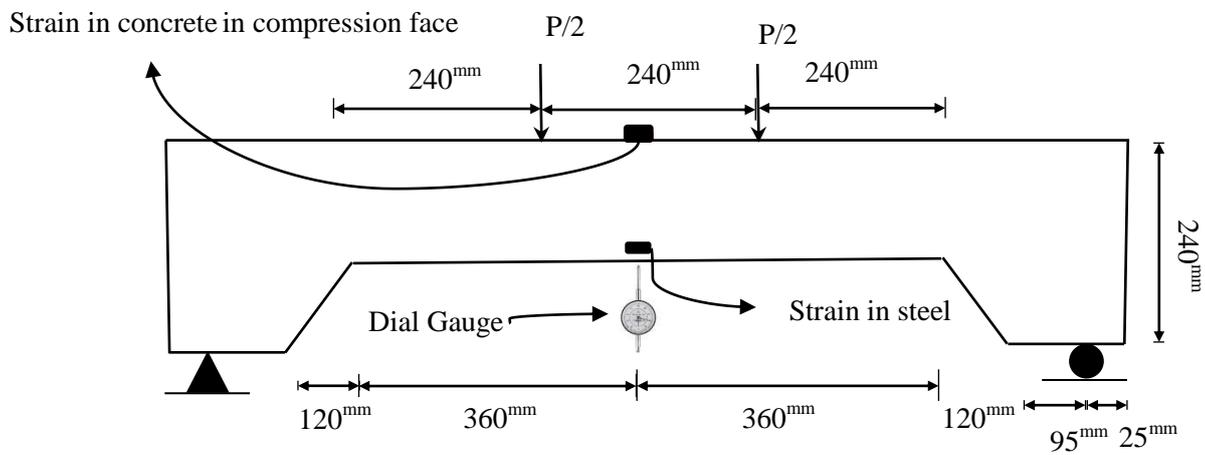


Figure 2. Testing beam diagram.

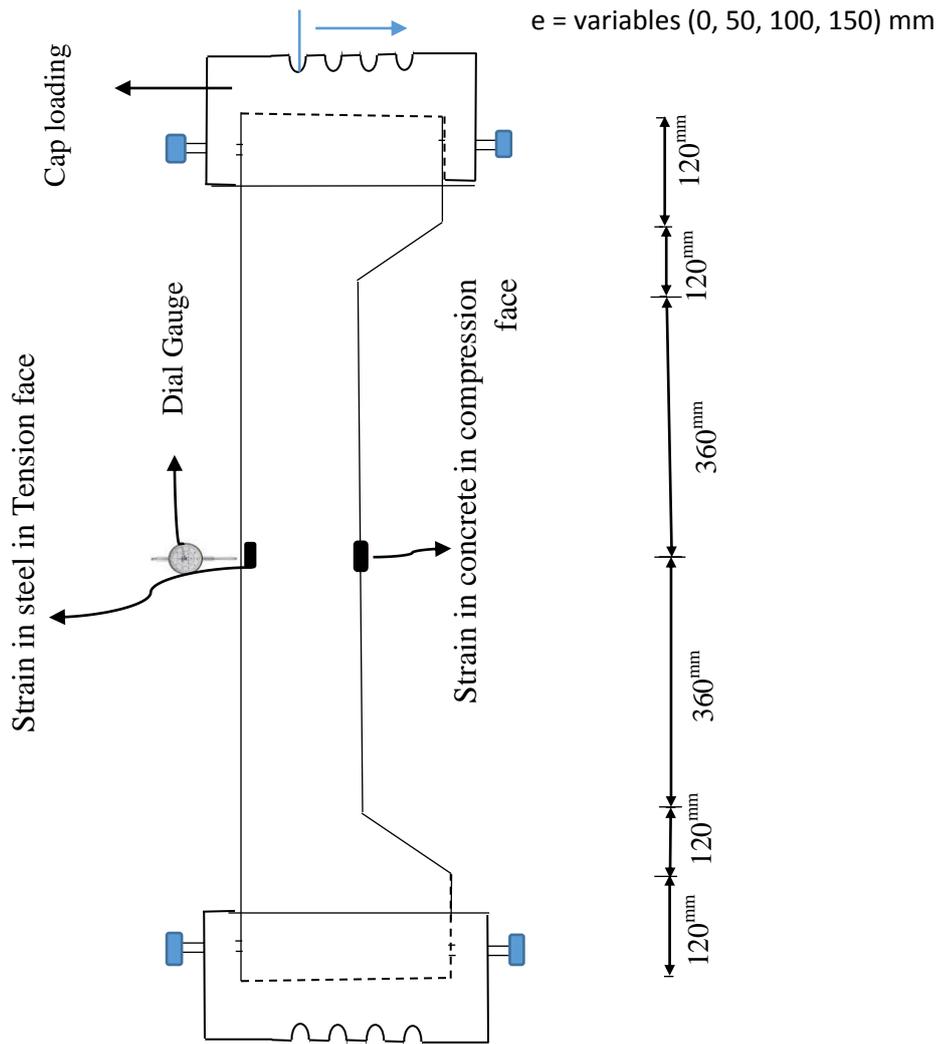


Figure 3. Testing column diagram.

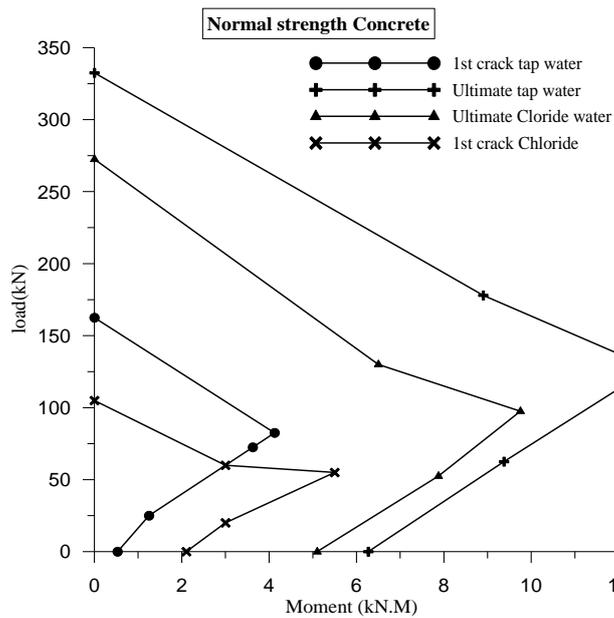


Figure 4. Effect of type of curing on Interaction diagram in NSC columns.

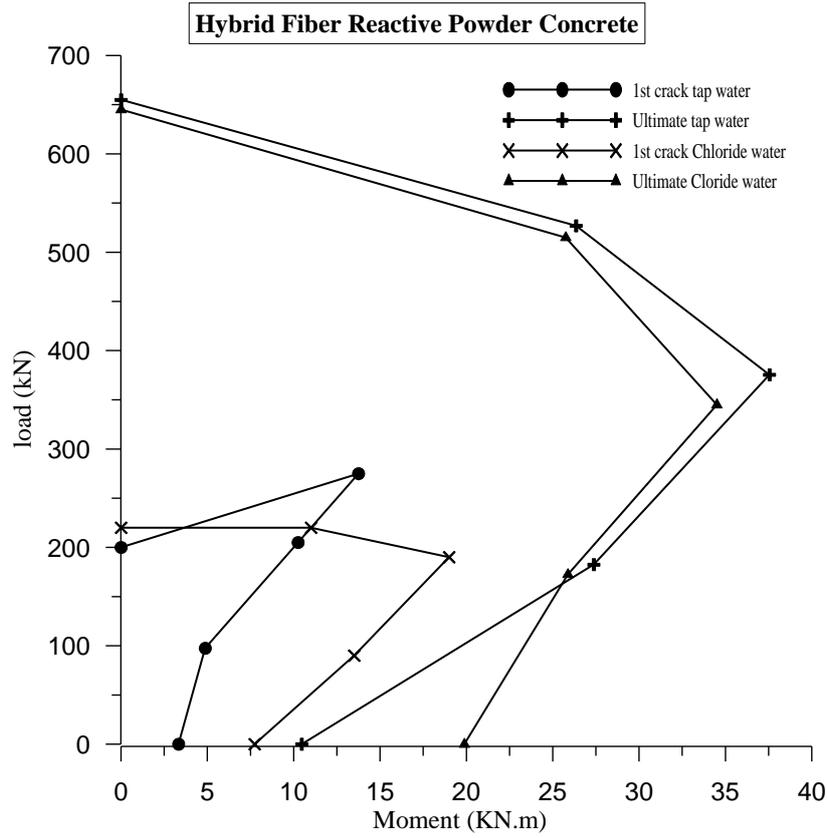


Figure 5. Effect of Type of Curing on Interaction diagram in HFRPC Columns.

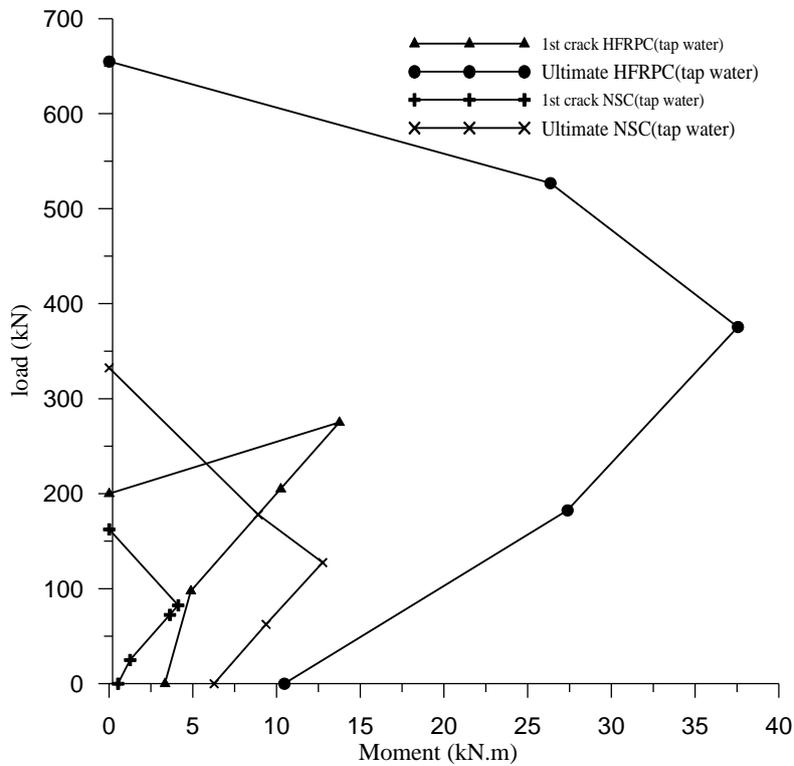


Figure 6. Effect of Type of Concrete on Interaction Diagram Columns in tap water.

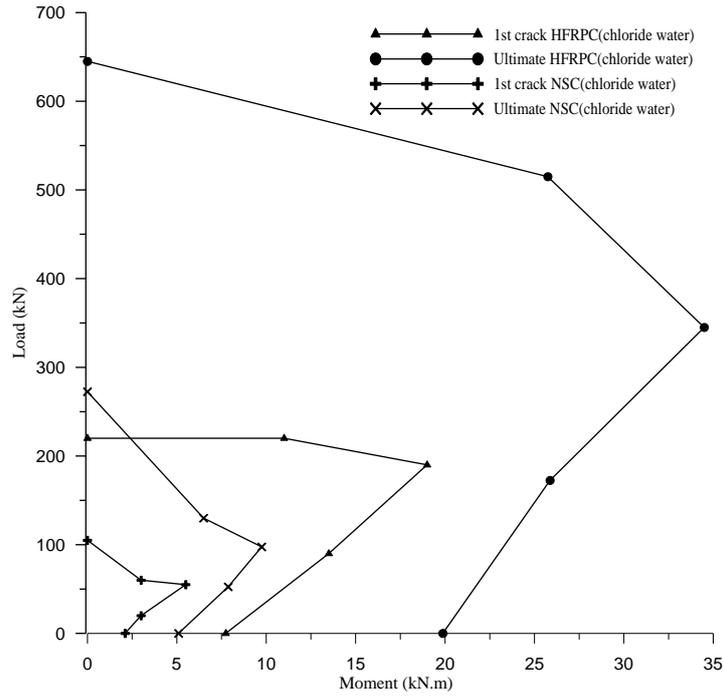
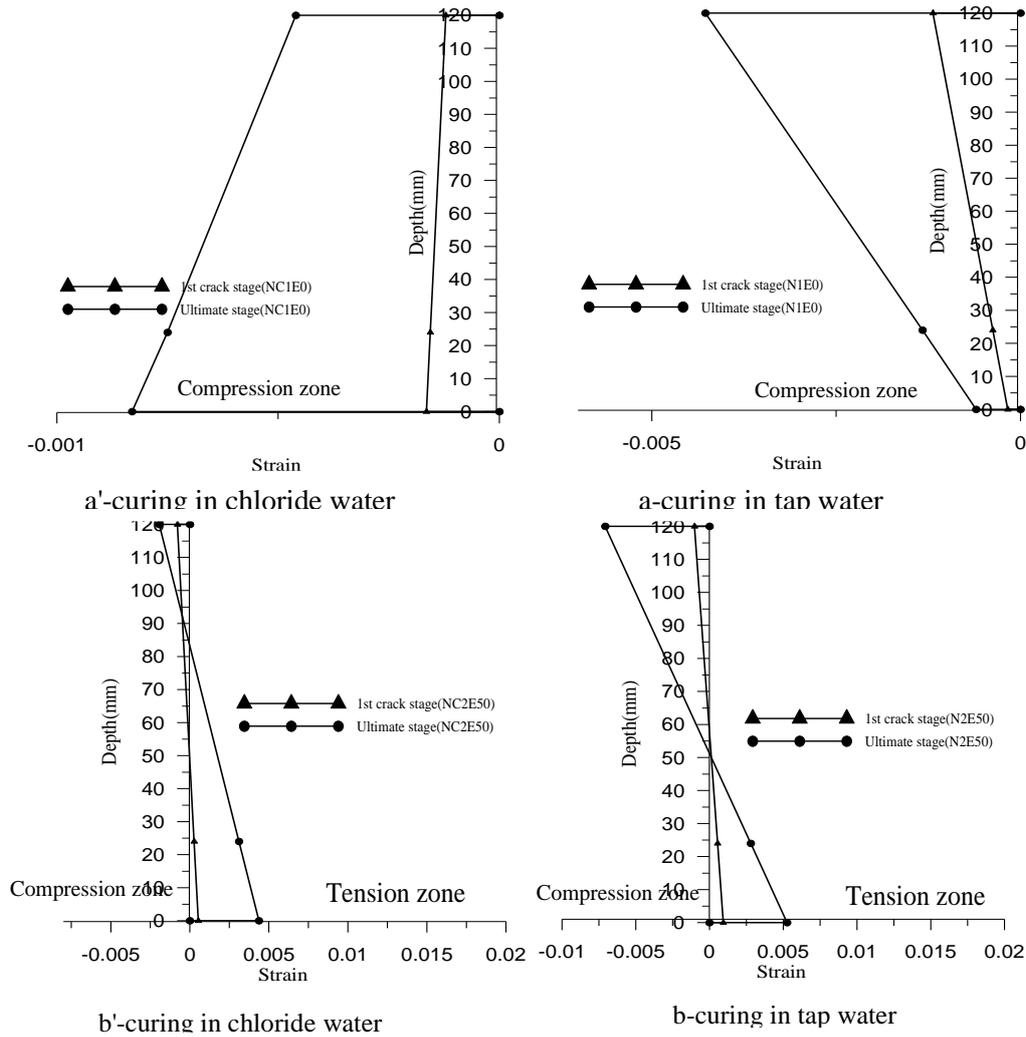


Figure 7. Effect of Type of Concrete on Interaction Diagram Columns in chloride water.



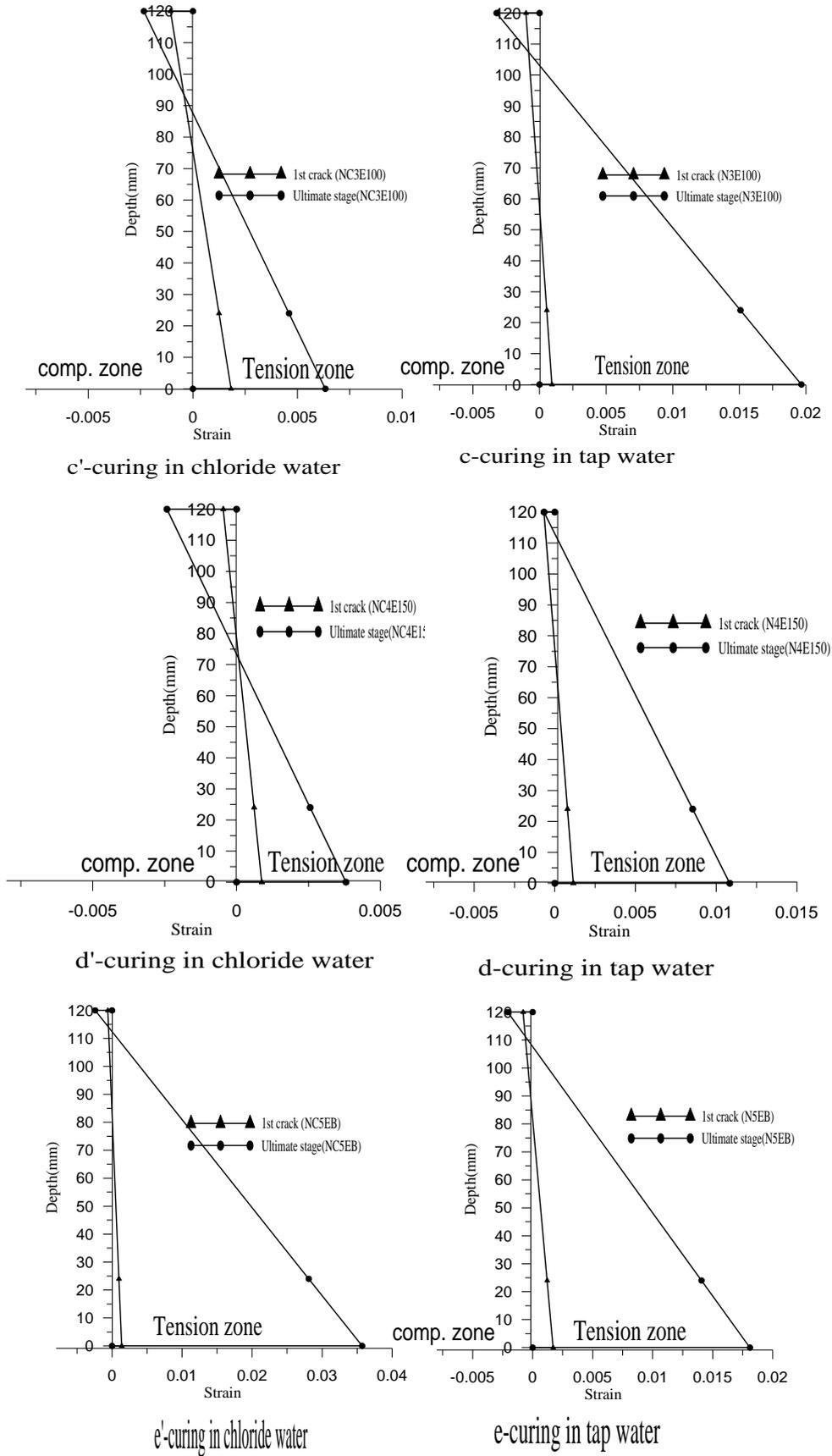
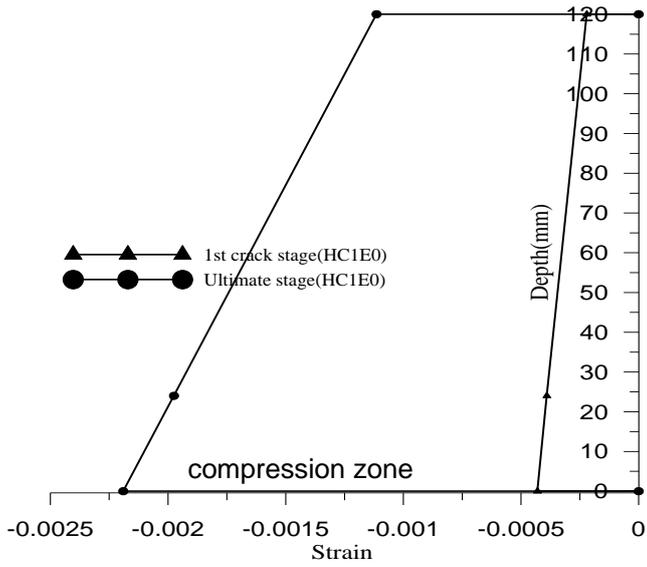
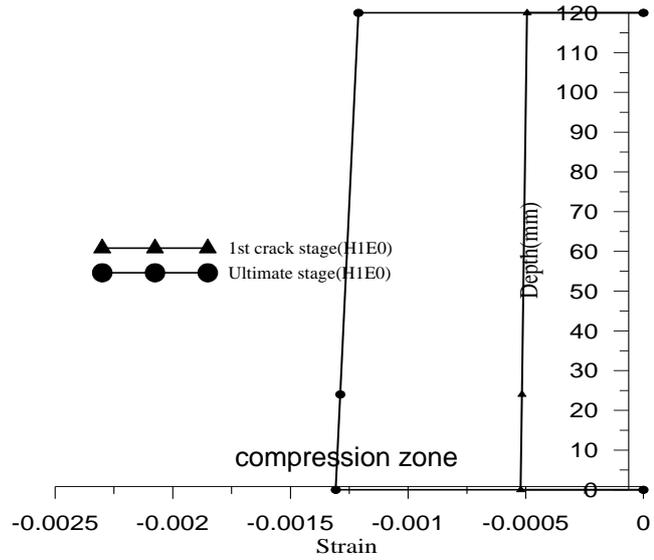


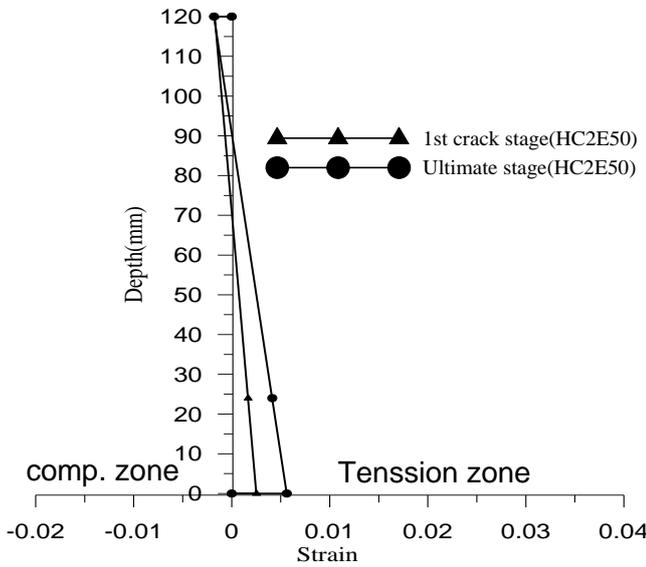
Figure 8. Strain Profile Along Depth of NSC columns.



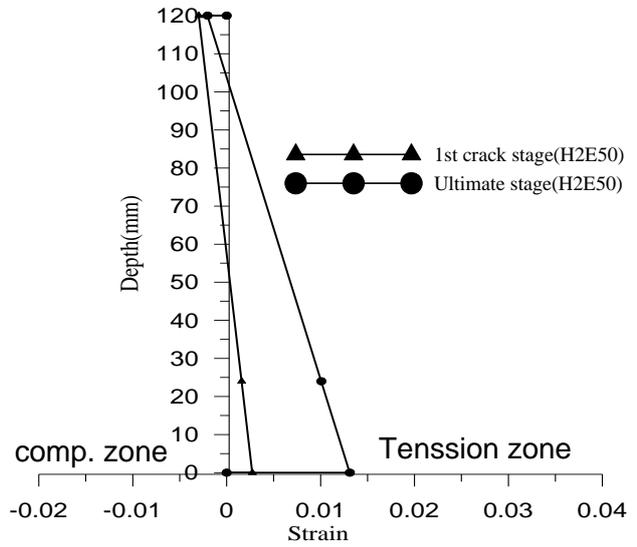
a'-curing in chloride water



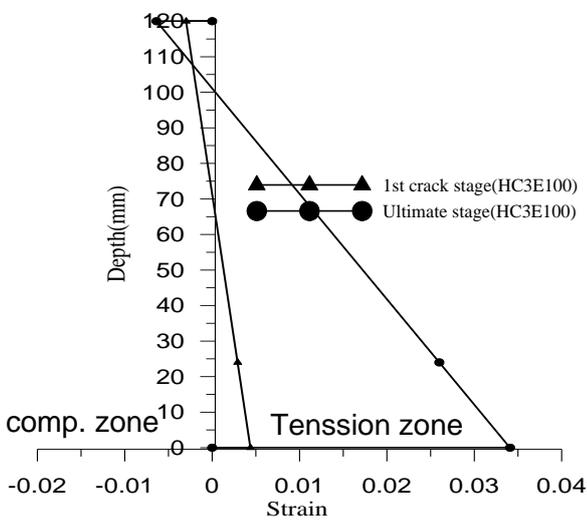
a'-curing in tap water



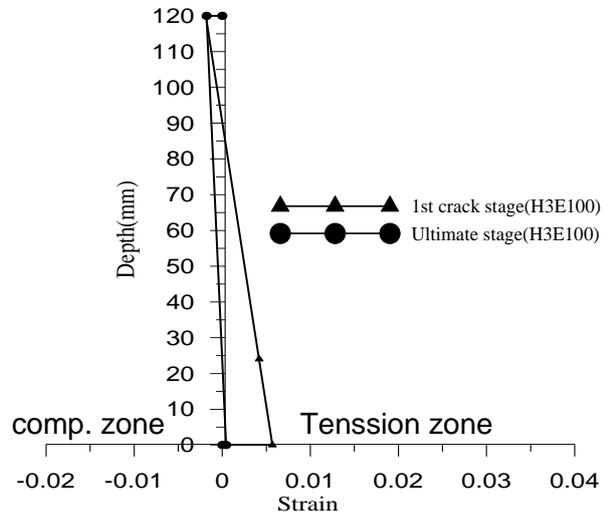
b'-curing in chloride water



b'-curing in tap water



c'-curing in chloride water



c'-curing in tap water

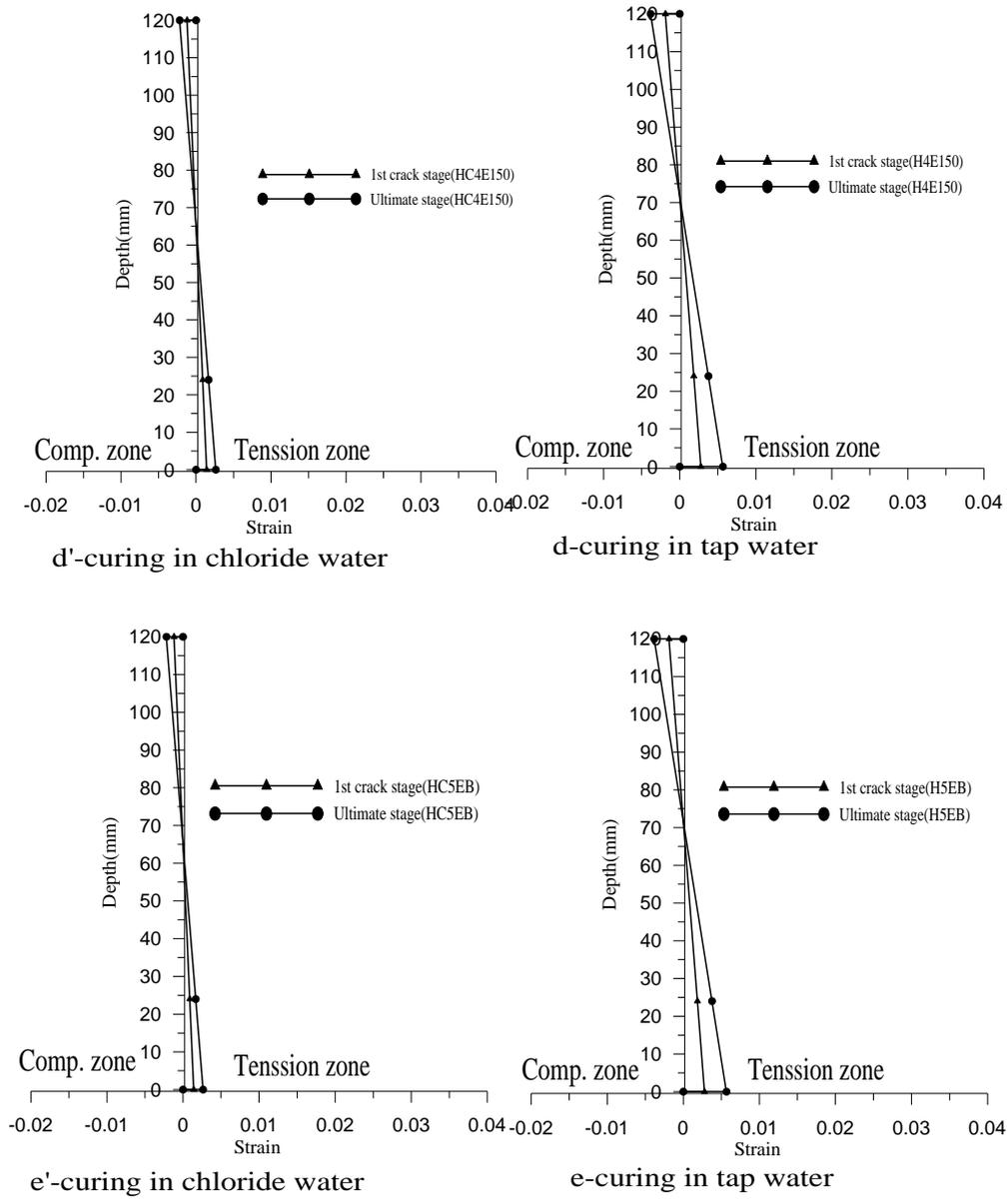


Figure 9. Strain Profile Along Depth of HFRPC Columns.