Behaviour of normal reinforced concrete columns exposed to different soils

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Abstract. Concrete resistance to sulfate attack is one of the most important characteristics for maintaining the durability of concrete. In this study, the effect of the attack of sulfate salts on normal reinforced concrete column was investigated by burying these columns in two types of soils (sandy and clayey) in two pits at a depth of 3 m in one of the agricultural areas in the holy city of Karbala, one containing sandy soil ($SO_3 = 10.609\%$) and the other containing clayey soil with ($SO_3 = 2.61\%$). The tests were used (pure axial compression test of reinforced concrete columns, compressive strength test, and splitting tensile strength test, absorption, voids ratio and finally density). It's found that the strength of RC columns decreasing by (12.51%) for age (240 days), for columns buried in clayey soil, where the strength increased by (11.71%) for the same period, for columns buried in sandy soils, with respect to the reference column.

1 Introduction

Sulfate ions are found in groundwater and soil in southern parts of Iraq. Concrete structures in the regions of this part subjected to attack from sulfates may suffer from two types of damage; loss of strength of the matrix due to degradation of calcium-silicate-hydrate (C-S-H), and volumetric expansion due to formation of gypsum or ettringite that leads to cracking [1]. Protecting against sulfate attack requires reducing the permeability of concrete, whereby low permeability characteristics of concrete can prolong the service life of a structure that is subjected to severe exposure conditions [2]. The present study includes an attempt to produce reinforced concrete mix that can stand up against sulfate attack investigating, Normal reinforced concrete was used to study the strength and durability performance of this type of concrete. The main aim of the present work is to evaluate the effect of sulfate salts in groundwater and soil on strength and durability characteristics of normal reinforced concrete columns under pure axial compression force. Through this investigation (7) reinforced concrete columns are tested, where a (42) cubes are performed to cover a compressive strength, absorption, density, and voids tests. Splitting tensile strength are undertaken on (21) cylinders. The specimens are buried in sandy and clayey soils, for up to (240) days, in aggressive solution containing ($Cl^- + SO_4^{2-}$) at

concentration identical to those present in soil and groundwater in the southern parts of Iraq.

2 Experimental work

2.1 Experimental program

All groups of columns, were identical in size, (150x150) mm square section and overall height (1080 mm). They were casted in a vertical direction and hardened in fresh water conditions until 28-days. After that, they were buried and hardened in soils with different concentrations of sulfate and chloride solutions for a period of 60, 150, and 240 days. Then, all groups of columns were tested under axial static load by mechanical machine with electrical seal load in period 60, 150, and 240 days as shown in *Figure 1* and mechanical and electronic dial gauges. The capacity of machine was (1000 kN), it had a rigid structure frame, and the capacity of mechanical gauges (2 cm) and (5 cm) for electronic dial gauge Test started with the application of 7 kN/m² load to set and check dial gauge. Then initial reading of dial gauges is obtained. The load was applied in stages. At each load increment, observations of crack development on the concrete columns traced. Also, at each test, the first visible cracking load and reading of dial gauges were recorded. The process of reading the gauges and crack observations took about five to ten minutes. Once this process got completed, loading

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resumed to the next load step. The same procedure was followed. The load was continued until ultimate load that recorded. All columns were divided into two groups, one buried in clayey soils and other buried in sandy soil, the main details of the mix used throughout this investigation in Table 1. The columns have the same

amount of longitudinal reinforcement of 4 Ø 8 mm and stirrups of 7 Ø 6mm/m ($A_s=0.00893 A_g$), as shown in Figure 1, which is less than the smallest percentage allowed in the ACI code by (0.0011) to observe the effect of sulfates.

Table 1. The main details of the mixes used throughout this investigation.

Mix Designation	Cement (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	W/C
Normal	336	760	1044	0.55

Fig. 1. Details of RC. tested columns and method of measuring their deformations.

2.2 Materials

In this research Portland Sulfate Resist Cement (ASTM-Type V) [3] manufactured by United Cement Company commercially known (AL-GESR) was used. The adopted cement confirms to the Iraqi Specifications No.5/1984 [4]. The fine aggregate from Al-Ekadir region was used throughout this work, it was within the requirements of (IQS No.45/ 1984) [5]. Black crushed stones of 20 mm maximum size from Al-Nebai quarry

2.3 Soils

Two types of soil were used to bury the specimens and RC columns models in clayey soil and sandy soil. Two pits were excavated in an agricultural land located to a location (1.5 km) west of Karbala centre. The pit's

were used as a coarse aggregate in all mixes. which confirms to the Iraqi specification (IQS No.45/ 1984) [5]. The water used in the mix design was potable water from the water-supply network system; so, it was free from suspended solids and organic materials, which might have affected the properties of the fresh and hardened concrete. Deformed steel bars (8 and 6) mm diameter were used as reinforcement to test column specimens obtained from Turkish production. The steel reinforcement was tested according to ASTM-A615/A-615M-05a.

dimension was (2×2×3) m. The reinforced concrete columns models and their attached specimens were buried in the pits, then one pit was filled with the sandy soil, while the other pit was filled with the clayey soil, see Table 2. The ground water at August appeared in the pits in level 1.75 m, which had the properties shown in the Table 3.

Table 2. Physical and chemical properties for clayey and sandy soils.

Soil Type	SiO ₂ %	Fe ₂ O ₃ %	Al ₂ O ₃ %	CaO %	MgO %	SO ₃ ⁼ %	Na ₂ O %	K ₂ O %	Cl ⁻ %	O.M %	PH	GS
Sandy	18.31	2.95	4.55	26.86	5.87	10.60	4.24	0.64	1.95	0.62	8.15	2.6
Clayey	33.79	6.40	12.43	12.49	7.79	2.61	2.20	1.35	0.78	0.83	8.3	2.5

Table 3. Chemical properties for ground water

SO ₄ ⁼ ppm	4675.5
Cl ⁻ ppm	11182.5
PH	8.45

3 Results and discussion

3.1 Results of hardened concrete properties

The compressive strength of specimens decreased in clayey soil with time and increased in sandy soil. The tensile strength of concrete cylinders showed that it has increased over time, this may be due to the salt affected to improve bonds between the concrete particles. The absorption has decreased with time, the maximum increment in the absorption was recorded in cubes buried

in the sandy soil for (240 days) by 5.09%, and in cubes buried in the clayey soil by 9.83 % for (240 days) compared with the reference cubes. It was also noted that the percentage of voids in the cubes had also decreased with time in all concrete mixes, specifically in the polymer mix, where the increase was 4.57% in cubes buried in sandy soil and 7.79% in cubes buried in the clayey soil for (240 days). A decrease in the percentage of voids and the absorption ratio in the normal mix was observed. This is due to the crystallization in the normal mix because of the presence of salts, which led to the closure of pores and reduced the percentage of voids and absorption in this mix and it was expected over time that the crystallization would increase the stresses in concrete, thus increase absorption rate and voids again *Table 6* provides a summary of cubes and cylinders tests such as compression strength, tensile strength, absorption, voids ratio and density.

Table 4. Percentage of sulfates and chlorides in clayey and sandy soil over time.

Soil Type	Salt (%)	Time of buried (days)			
		0	60	150	240
Clayey	Sulfate (SO ₄ ⁼)	2.61	4.41	3.50	3.04
	Chloride (Cl ⁻)	0.78	0.78	1.99	0.78
Sandy	Sulfate (SO ₄ ⁼)	10.6	9.5	9.0	9.6
	Chloride (Cl ⁻)	1.95	1.95	1.24	1.07

Table 5. Results of the Experimentally Tested Columns

Group Name	Soil Type	Designation Name	Time of Test (days)	Cracking Load (Pc), (kN)	Failure Load (Pu), (kN)	Long. Def. (mm)	Lateral. Def. (mm)
Nc	Ref.	RS1	28	142.92	495	4.8	0.61
	Clayey	N2	60	327.24	490.32	3.45	1.63
		N3	150	440.23	509.76	4.79	0.525
		N4	240	254.16	433.08	3.75	0.98
Ns	Sandy	NS2	60	158.4	439.2	7.43	1.56
		NS3	150	111.24	529.56	5.23	0.74
		NS4	240	552.96	552.96	3.25	1.28

Table 6. Results of the Experimentally Tested Cubes and Cylinders.

Group Name	Soil Type	Time of Test (days)	Comp. Strength (Cube), (MPa)	Tensile Strength (Cylinder), (MPa)	Absorption %	Voids %	Density Mg/m ³
Nc	Ref.	28	27.75	2.712	5.2061	11.566	2.3457
	Clayey	60	27.365	2.034	3.1967	7.3703	2.383
		150	26.723	3.3502	4.6073	9.7224	2.2076
		240	24.48	3.3815	4.6942	10.665	2.3755
Ns	Sandy	60	27.767	2.0865	3.3125	7.5891	2.3665
		150	27.013	2.7194	4.3789	9.3165	2.2212
		240	29.75	3.9142	4.9412	11.037	2.3435

3.2 Effect of aggressive solution of clayey soil

To understand the effect of sulfate and chloride on normal reinforced concrete columns, specimens buried for 60, 150, and 240 days in clayey soil to investigate its behavior. First visible crack was observed in the Normal Reinforced concrete columns group (Nc) at top and bottom of these columns at applied load of (142.92, 327.32, 440.32, and 254.16) kN for columns (RS1, N2, N3, and N4) respectively, as shown in *Figure 2*. The cracks propagated and grew, through the load progressing. At the final stages of loading the columns reached ultimate loads at (495, 490.32, 509.76, and 433.08) kN for columns (RS1, N2, N3, and N4) respectively. The failure occurred gradually with increased loads in the developed ages while the longitudinal deflection decreased, thus decrease in the

area under the curve of load - deformation, which led to the columns became less tough and ductile with time, *Figure 3* shows that the deflection was decreased with increasing buried time for the columns tested under the same loading, which means decreasing the ductility and toughness. As seen in the *Figure 4* the lateral deflection increased over time at the same load for example (400 kN), these increments were the reflection of the decrements in the longitudinal direction. From *Table 5*, it can be seen that, the ultimate load lightly enhanced until 150 days of buried time, while the harmful effected of sulfate and chloride was seen after this time, where the cracking load, and failure load of N2, N3 and N4 with respect to RS1 were (229, 308, and 171 %), and (99, 103 and 87%) respectively.

Fig. 2. First cracks for group (Nc) (* the load factored by 3.6)

A possible reason for this increment in the lateral and longitudinal deflection is the effect of the sulfate and

chloride in clayey soil on the strength of columns during the buried time.

Fig. 3. Load – Longitudinal Deflection behaviour of **Normal** RC. column buried in clayey soil

Fig. 4. Load – Lateral Deflection behaviour of **Normal** RC. column buried in clayey soil

After 60 days columns in the clayey soil, the normal mix remained conservative on its behavior and was not affected by sulfate salts during duration of 60 days. Visually there is no penetration of sulfate inside columns in this age. At the age of 150 days buried in the soil it notes an improvement in the strength of the concrete columns of the normal mix with a decrease in ductility, this may be due to the low proportion of sulfates in the soil at this age. The percentage of increase of normal

mix strength was 2.98% with respect to reference column (RS1). By visual vision there is a penetration of sulfates in the normal column for depth (3 cm). At the age of 240 days of burial in the clayey soil, the concrete specimen's strength decreasing due to the high percentage of sulfates in the soil as in *Table 4*. The decreasing percentage of the strength in normal columns was 12.51% with respect to reference columns. Visually there is a penetration of sulfates for depth (3.5 cm).

3.3 Effect of Aggressive Solution of Sandy Soil

The columns were buried for 60, 150, and 240 days in sandy soil to understand the effect of sulfate on reinforced concrete columns. The first visible crack in the normal Reinforced concrete columns group (Ns) was observed at top and bottom of these columns at applied load of (142.92, 158.4, 111.24, and 552.96) kN for columns (RS1, NS2, NS3, and NS4) respectively, NS4 failed suddenly without appearing cracks, with load sequence cracks grow and became wider. With continuous loading, the columns reached ultimate loads at (495, 439.2, 529.56, and 552.96) kN for columns (RS1, NS2, NS3, and NS4). See *Figure 5*.

Gradually failure occurred except column (NS4) which failed suddenly, it was observed for 60 days age of the column the compressive strength decreased and then it increased in the developed ages to reach its large strength at 240 days age. This means there was improvement in strength with 6.98% and 11.71% in 150

and 240 days ages respectively compared with reference strength, these happened because the concentration of sulfate decreased in sandy soil at 150 and 240 days as shown in *Table 4*. In the developed ages deflection decreased in longitudinal directions with time, due to which the columns became less tough and ductile because of the decrease in the area under the curve of load - deformation, so at last age it was found that for the same loading values, there is a decrease in the longitudinal deflection due to decrease in the toughness and ductility, these conclusions were covered by *Figure 6*. As seen in the *Figure 7* the lateral deflection increases over time at the same load for example (380 kN), these increments were the reflection the decrements in the longitudinal direction. From *Table 5*, it can be seen that, cracking load, and failure load of NS2, NS3 and NS4 with respect to RS1 are (118, 77, and 386 %), and (88, 106 and 111%) respectively. The effect of the sulfate in sandy soil on the strength of columns during the time of buried is a possible reason for this increment in the lateral and longitudinal deflection.

Fig. 5. Failure pattern for group (Ns) (* the load factored by 3.6)

Fig. 6. Load – Longitudinal Deflection behaviour of **Normal** RC. column buried in sandy soil

Fig. 7. Load – Lateral Deflection behaviour of **Normal** RC. column buried in sandy soil

At test age of 60 days high strength decreasing was recorded for normal reinforced concrete columns which reached to 11.27% compared to the reference strength, the failure was gradual in concrete columns. There is no penetration of sulfate inside columns in this test age. At 150 days the strength was enhanced, the increase became 6.98 %. From figures of load-deformation curves it can be seen the failure happened gradually. There was

penetration for sulfate to the columns and its value was (4) cm. Finally, at 240 days the increasing in strength was 11.71%, the failure was suddenly, and the penetration was (5 cm).

3.4 The Effect of Different Soils

The columns in sandy soil were more ductile than the columns in clayey soil but, generally the behavior of columns was relatively similar with a difference in the value of deformation and compressive strength recorded in each test, these are shown in *Figure 8 to 10*.

Fig. 8. Load – Longitudinal Deflection behavior of **Normal** RC. column buried in clayey and sandy soil for **60 days**

Fig. 9. Load – Longitudinal Deflection behavior of **Normal** RC. column buried in clayey and sandy soil for **150 days**

Fig. 10. Load – Longitudinal Deflection behaviour of **Normal** RC. column buried in clayey and sandy soil for **240** days

4 Conclusions

Based on the test results obtained from experimental program and the dissection of the results, the following conclusions can be drawn:

1. Ductility decreased with time, for models buried in clayey and sandy soils.
2. Strength of normal RC. columns decreased by (12.51%) for age (240 days) and increased it by (2.98%) for age (150 days), while it's not effected at age (60 days), all these changes were for columns buried in clayey soil, where the strength decreased by (11.27) % for age (60) days while it enhanced in age (150, 240) days (6.98, 11.71) % respectively, compared with reference columns, for columns buried in sandy soils.
3. The failure was gradual failure in normal RC. columns.
4. Decreasing the percentage of absorption ratio with time in normal concrete cubes, the highest ratio recorded at (240 days) age were (5.09, 9.83)

% for sandy and clayey soils respectively, compared with reference cubes.

5. Decreasing the voids ratio with time in normal concrete cubes, the highest ratio recorded at (240 days) age were (4.57, 7.79) % for sandy and clayey soils respectively, compared with reference cubes.

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