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Research Paper

CORROSION DAMAGE PREDICTION OF UNDERGROUND RC COLUMN NECKS EXPOSED TO SALT SOLUTIONS BY SEWAGE WATERS THROUGH CONFINED POROUS MEDIA

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Sulfate and chloride attack for underground RC constructions has been an important subject of many researchers. Chemical attack by aggressive waters specially sewage is one of the factors causing deterioration and corrosion damage of concrete in the undergroung RC column necks . The chemical resistance of RC column necks against salt attack induced by sewage waters is expressed by the percentage of their mechanical properties losses. Sulfate attack of concrete building foundations induced by sewage waters was studied. Effect of the diffused salts concentration by sewage waters from multiple seepage pits through an unconfined porous media on the load carrying capacity of underground RC column necks was analytically studied. But, the influence of chloride and sulfate salts concentration diffused by sewage waters through confined porous media on the deterioration and corrosion damage of underground RC elements with time, specially footings and column necks, was not enough studied. So, in this paper is presented and developed an analytic model for the effect of the induced salt solutions by sewage waters through confined porous media on the corrosion damage and deterioration of concrete in underground RC elements specially column necks. The finite difference technique is used and a computer program is developed and written in a basic language for the solution of the problem in confined porous media. Analysis of the numerical results shows that, the induced salt solutions by sewage waters through confined porous media have a great effect on the deterioration and corrosion damage of underground RC elements depending on the distance "ri" of the concrete structure from the sewage source, total relative concentration "Ca/CO" of diffused chloride and sulfate salts at that distance , soil porosity and permeability , time level and height of the sewage waters at that structure .

Keywords: Deterioration, concrete, Corrosion damage, Sewage water, Confined, Porous media, Chloride and sulfate attack, Underground, Dispersion, Salt solutions, Concentration, Analytic model, Correction factor, Porosity, Permeability, Compressive strength, Yield stress, Longitudinal strain

INTRODUCTION

Sulfate and chloride attack for underground RC constructions has been an important subject of many researchers. Chemical attack by

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aggressive waters, especially sewage, is one of the factors causing damage to the used concrete in underground RC column necks. Concrete can be deteriorated in many ways. One of the typical deterioration is caused by the corrosion of reinforcing steel and subsequent spalling of the concrete cover (Hughes, 1985). The use of seepage pits or deep wells for the disposal of partially treated sewage waters and waste products through confined or unconfined porous media are important aspects for sewage water disposal planning. These seepage pits are recognized as the chloride and sulfate sources due to the microorganism metabolism of sulfur and chloride compounds present in sewage. Consequences of this attack were very poor bond strength between cement paste and aggregates, which reduce compressive strength of concrete, a severe cracking of the concrete cover around steel reinforcement and corrosion damage of embedded reinforcement. The degradation effects increase with decreasing the distance of RC structures from these seepage pits or absorbing wells located in courtyard of the building (Negro and Mario, 2002).

The chemical resistance of RC elements against chloride and sulfate attack induced by sewage waters is expressed by the percentage of their mechanical properties losses. These losses are the reduction of concrete compressive strength and steel yield stress, increase of concrete strain and corrosion rate of steel with time compared with similar concrete not exposed to sewage waters (Negro and Mario, 2002; Rashwan, 1997). Sulfate attack of concrete building foundations induced by sewage waters was studied by Negro and Mario Collepardi (Negro and Mario, 2002). They concluded that, the degration of effects increased with decreasing the distance of concrete sructures from an absorbing well located in the courtyard of the building.

Some experimental studies were carried out to show the effect of sulfate attack on the damage of RC element (Rashwan, 1997). Deterioration of concrete by sulphuric acid produced from sewage is a long term process , but, poor quality concrete deteriorates at a much faster rate than good-quality ones (Fattuhi and Hughes, 1983). In addition, when a sulphuric attack is active, under a very low "pH", all hydrated products, hydrated silicate and aluminate phases and calcium hydroxide can easily be decomposed, leading to a severe disintergation of the concrete matrix (Torri and Kawamura, 1994). In fact, as previously stated [2,6], the etteringite expansion phenomenon is in adequate to explain the sulfate-generated deterioration of the concrete. Also, the ferrous chloride phenomenon in the presence of oxygen is in adequate to explain the generated corrosion damage of embedded steel bars.

Manu Santhanam, Menashi D Cohen (2002) investigated the effects of different concentrations of sodium and magnesum sulfate solutions on expansion and microstructure of different types of Portland cement mortars. They indicated that, the ultimate of failure of the specimen occurs as a result of the decalcification of the calcium silicate hydrate (C-S-H), and its conversion to magnesium silicate hydrate (M-S-H), after prolonged exposure to the solution.

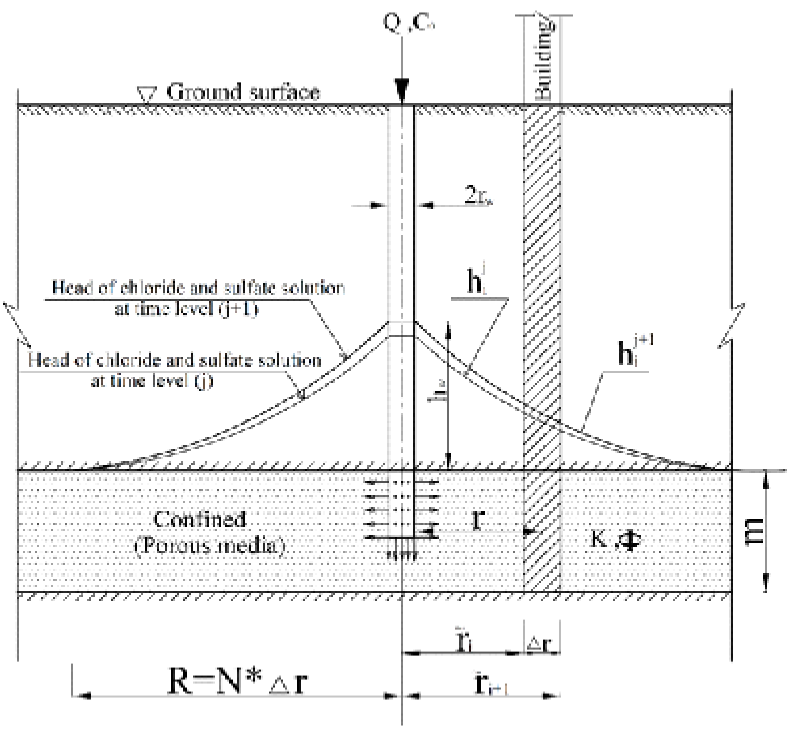
Adam Neville (2004) studied the mechanisms of attack on concrete by different sulfates – sodium, calcium and magnesium including the issue of topochemical and through solution reactions including the effect of soil properties.

The problem of unsteady radial flow to a well penetrating an unconfined porous media has been formulated mathematically by number of differential equations. Abdelsadek (1977) proposed new trend for the solution of differential equation of drawdown near a pumping well using the finite-difference technique. Recently, the dispersion of concentration of waste-waters through confined or unconfined porous media was studied by number of researchers among home were Abdelsadek Ali (1977) and Rashwan (1989), De Josselin (1958) and Yih (1960).

Some experimental studies were carried out to show the effect of sulfate and chloride attack on the damage of RC elements. Effect of diffused salt concentration by sewage waters, from multiple seepage pits, through aunconfined porous media on the load carrying capacity of underground RC column necks was analytically studied (Rashwan, 2005). But, the influence of salt solutions diffused by sewage waters through a confined porous media on the deterioration and corrosion damage of underground RC elements, specially footings and column necks, after a long period of time were not enough studied. These researches need more time to give us a relation between the relative concentration of these migrating salts and its damage effect on the properties of underground RC elements at any service time.

So, in this paper is presented and developed an analytic model for the effect of the induced salt solutions by sewage waters through a confined porous media on the corrosion damage and deterioration of concrete in underground RC elements specially column necks. The finite difference technique is used and a computer

Figure 1: Radial Flow Of Salt Solutions From A Recharge Sewage Source Penetrating A Confined Porous Media



program is developed for the solution of the problem in confined porous media. The correcti on factors of concrete compressive strength "CFc' and steel yield stress "CFs" , longitudinal strain of concrete and corrosion rate of steel bars are determined as a function of total relative concentration of salt solutions, time level, distance from the source of sewage disposal and soil properties and compared with the similar concrete elements not exposed to sewage waters.

THEORY

1) Single Recharge Sewage Resource

The problem of unsteady radial flow of salt solutions from a recharging sewage source penetrating a confined porous media (as shown in Figure 1) can be formulated mathematically by the following system of equations [10, 12, 13, 14, 16] .

Equation of piezometric head of the salt solutions:

The piezometric head of induced sulfate and chloride salt solutions by sewage waters through a confined porous media at any point in the flow field of a recharging sewage source can be given by the following partial differential equation:

$$\partial^2 h/\partial r^2 + 1/r*\partial h/\partial r = S/T*\partial h/\partial t \quad ...(1)$$

Where "h" = piezometric head," r" = radial distance from the center line of a sewage source to the point at which required the piezometric head "h", "S" = storage coefficient," T" = coefficient of transmissibility of the porous media and "t "= time at which required the head of the salt solutions .

2) Equation of dispersion of concentration of salt solutions:

The dispersion of salt solutions concentration "C" of miscible of sewage water through confined porous media at any point at a radial distance "r" from the sewage source may be expressed as:

$$1/r*\partial/\partial r(r.\ k_r.\partial C/\partial r)-1/r*\partial/\partial r\ (r.U.C)=\partial C/\ \partial t \quad ...(2)$$

In which: U = the pore velocity, which may be given in the form:

$$U = k/\Phi*\partial h/\partial r \quad ...(3)$$

where: k = coefficient of permeability, Φ = porosity of the soil and k_r = radial dispersion coefficient which is a function of both pore velocity and the grain size of the soil "ds" and it can be given in the form: $k_r = 0.86$ ds . U, m = thickness of porous media.

At any point in the flow field of sewage source where the pore velocity and the dispersion coefficient are constants, Equation. (2) may be expressed as:

$$K_r*\partial^2 C/\partial r^2-U*\partial C/\partial r=\partial C/\partial t \quad ...(4)$$

The initial and boundary conditions are:

$h (r , 0) = 0$

$h (\infty, t) = 0 \quad t \geq 0$ for piezometric head equation

lime $2\Pi.r.T\ \partial h / \partial r = Q \qquad t \geq 0$

$C (r, 0) = 0$

$C (r_w, t) = Co \qquad t \geq 0$

$C (\infty, t) = 0 \qquad t \geq 0$

r_w = radius of the sewage source or well

The solution of the piezometric head or surface equation (Eqn .1) of the salt solution was obtained by Theis [10] for homogenous aquifers in the form:

$$h (r, t) = (Q / 4\Pi T) * W (u) \quad ... (5)$$

where: Q = recharge value of the sewage source,

$$W(u) = -Ei(u) = +\int_u^{\infty} (e^{-u}/u)\,du \qquad ...(5, a)$$

$$U = r^2 * h / (4 T.\, t) \qquad ...(5, b)$$

Abdelsadek (1977) proposed the following theory for the determination of the drawdown near a recharge well under unsteady state conditions using the finite-difference technique. The theory is applied for both confined and unconfined aquifers. Divide the flow field to "N" blocks radically from the well or sewage source to the radius of influence "R":

$$R = 1.5\sqrt{.(T/S)}\,.\, t \qquad ...(6)$$

where: t = time at which steady state occurs. Then find "Δr" = R / N, as shown in Figures (1 and 2). The time increment "Δt" can be determined from the following relation:

$$T.\Delta t/(S.\Delta r^2) < 5 \qquad ...(7)$$

The balance equation at the "i" block can be written in finite-difference form as:

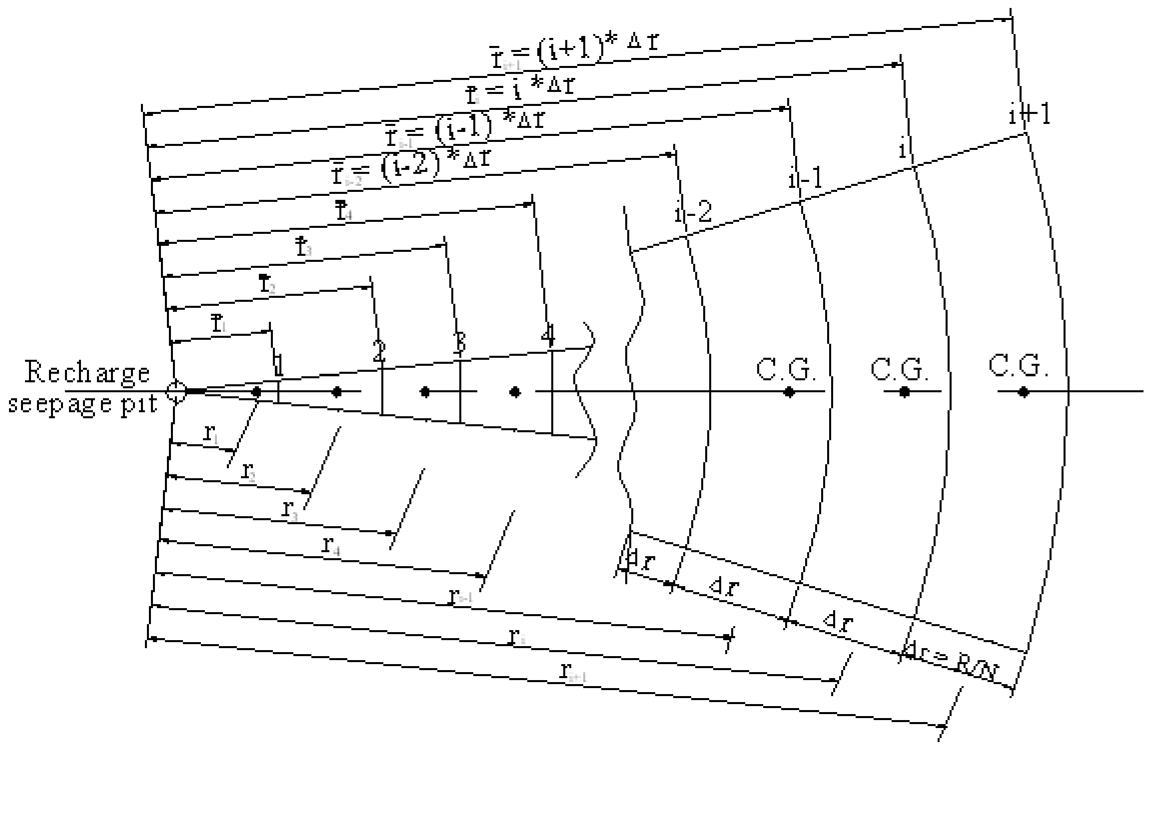
J J+1 J+1 J J+1 J+1

2.".T * [(h - h) / ln (r $_{i+1}$/ r $_i$)] + 2".T [(h - h) / ln (r $_i$ / r $_{i-1}$)] =

I , i+1 I + 1 I I , I- 1 I , I -1 I-1

2 2 J+1 J J

Figure 2: Division Of Flow Field Of Salt Solutions Dispersion To "N" Blocks



= “.(r – r) * (h - h) * S / “t ...(8)

I I-1 I II

Which:

T = Coefficient of transmissibility = k . h for unconfined porous media,

h = Drawdown of salt solutions flow at block “I” and time level “J” .

Equation (8) may be written as:

J J+1 J+1 J J+1 J+1 J J+1 J

a (h - h) + a * (h - h) = b *(h - h) …(8a)

I I+1 I I-1 I-1 I III

J+1

where: h = drawdown of salt solutions flow at block “I” and time level “J+1”.

a = 2Π.T/ln(r/r) ...(9)

J J

a = 2".T / ln (r / r) ,

...(9a)

I-1 I , I-1 II-1

J JJJ

b = “(r - r) * S / “ t

...(9b)

I I I-1 I

And assuming:

where : r $_{I+1}$, r $_{I}$, r $_{I-1}$ are the radius to the center of the” I+1" , “I” , “I-1” blocks as shown in Figure (2).

The distance “r $_{I}$” is given by:

r$_{I}$ = r $_{I-1+}$ [(r $_{I}$ – r $_{I-1}$) / 2]

+ (r $_{I}$ – r $_{I-1}$) ^{2} / 6 (r $_{I}$ – r $_{I-1}$) ...(10)

where: r $_{I}$ = I. Δ r

r $_{I-1}$ = (I– 1) * Δ r, and

I = 1 , 2 , 3 , 4 , ... N blocks ...(10b)

The first boundary condition at the sewage source can be fulfilled by writing the balance equation at the first block in the form :

J J+1 J+1 J J J+1 J

a *(h - h) = Q + b * (h - h) ...(11)

1 2 1 1 1 1 1

The second boundary condition at “r” = R is: h $_{N+1}$ = 0 for t e” 0 ...(11a)

Therefore, equation (8a) can be written in the form:

J+1 J J+1 J+1

h = A * h + B ...(12)

I I+1 I+1I+1

Where : J JJJJ

A = a / (f - A * a) ...(12a)

I+1 I II I-1

J+1 J JJ J+1 J J

B = (A / a) * (a * B + b * h) ...(12b)

I+1 I+1 I I-1 I II

Similarly, at the first block, Eqn. (11) may be expressed in the form:

J+1 J J+1 J+1

h = A * h + B , ...(13)

1 2 2 2

where : J JJJ

A = a / (a - b) , and ...(13a)

2 1 1 1

J+1 J JJJJ

B = (A / a) * (h * b - Q) ...(13b)

i 2 1 1 1 1

J JJJJ

The values of " a , b , f " are determined by knowing " T , S " . Then, the

I IIII

J J

Values of " A , B J+1 can be calculated from Eqns.(13a) and (13b) . Knowing A

J+1 2 2 J J+1 J J+1 2

B , the values of " A , B , ……., A , B " can be calculated . Using the

2 3 3 J+1 N+1 N+1

Lower boundary condition (h = 0) and the obtained coefficients, the known

J+1J+1 N+1 J+1

Values of " h , h , …………….., h " at all blocks in the backward direction at

N N-1 1

time level "J+1" can be obtained . The calculations are continued to find the values of the drawdown of unsteady salt solutions flow near each seepage pit at any time level for a case of confined aquifer.

The solution of the pore velocity equation (Eqn. 3), by using finite-difference method (backward - difference), can be written as follows:

J+1 J+1J+1

U = - k / ô [h - h] / " r ...(14)

I I I-1

In line with Abdelsadek [8], the solution of Eqn. (2) using the finite- difference method may be expressed as :

J+1 J J J+1 J+1J+1 J J+1 J+1

(C - C) / " t = kr * (C - 2 C + C) / " r2 – U * (C - C) / 2 " r ...(15)

I II I+1 I I-1 I I+1 I-1

J J

Where: kr , U are the radial dispersion coefficient and pore velocity of the salt

I I

solutions flow at a block "I" and time level "J" respectively , whose values depend on the type of soil . Equation (15) may be expressed at the "I" block in the form:

J+1 J J+1 J+1

C = A * C + B ...(16)

I I I+1 I+1

Where : J JJJJ

A = b / (f - a * A) ...(16a)

I+1 I III

J+1 J JJ J+1 J J

B = (A / b) * [a * B + (f - 2) * C] ...(16b)

I+1 I+1 I IIII

J

C = concentration of diffused salt solutions at block "I" and time level "J" ,

I

J+1

C = concentration of diffused salt solutions at block "I" and time level "J+1"

I

J JJ

The values of "a , b , f " can be expressed in dimensionless form as : " z = " r / R

III

J J

"ô = " t * k_r/ (ô. R ^{2})

I I

JJJJJJJ

G = U * R / k_r= ô. U. R / ô. k = U * R / k ………………. (17)

I IIIII

Where :

J

k = dispersion coefficient at block "I" and time level "J" ,

I

J J

a = 1.0 + (G * " z) / 2.0 ...(18)

I I

J J

b = 1.0 - (G * " z) / 2.0 ...(18a)

I I

J J

f = (" z ^{2} / " ô) - 2.0 ...(18b)

I I

Similarly, at the first block, Eqn. (16) can be written in the form:

C(1 , J +1) = A (2 , J) * C (2 , J+1) + B (2 , J+1)

...(19)

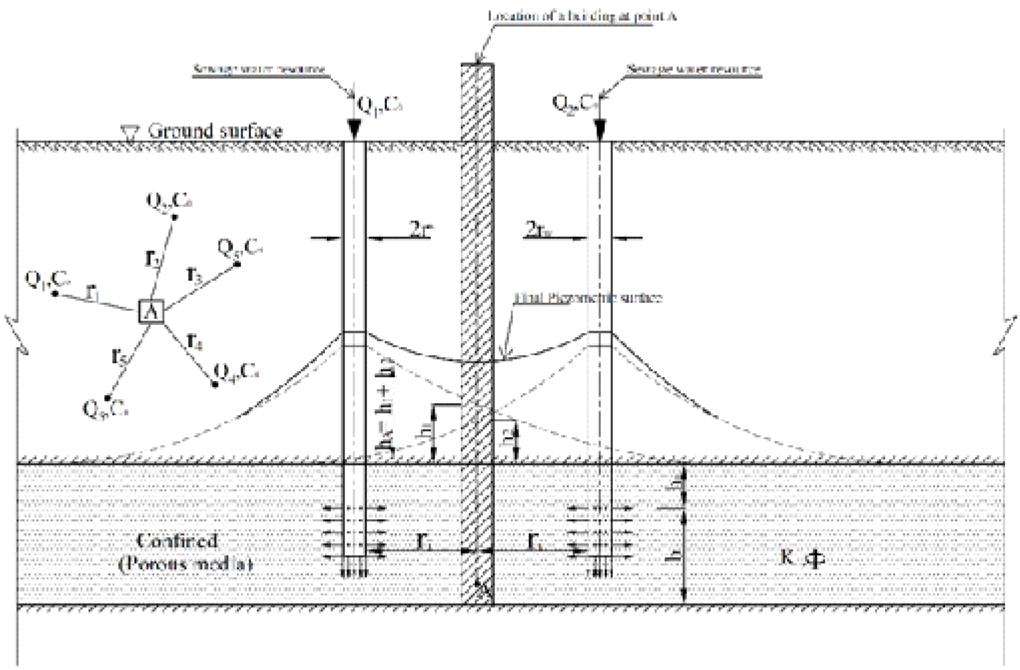
Where: A (2 , J) = b (1 , J) / [b (1 , J) – f (1 , J)] ...(19a)

B(2 , J+1) = [- A (2 , J) / b (1, J)] / [(f (1, J) – 2) * C (1, J)] ...(19b)

For the solution of the system of equation (16) written at the nodes 1 , 2 ,3 , N , N-1, the values of a(I , J) , b(I , J) , f(I , J) should be firstly determined from the previous given values of k_r (I , J) , U(I , J) . Then: A (2 , J) , B(2 , J+1) are calculated by using equations (19a) and (19b) , then A(3 , J) , B(3 , J+19) , A(4 , J) , B(4 , J+1) , ……A(N+1 , J) , B(N+! , J+1) can be determined.

Using the lower boundary condition [C(N+1 , J+1) = 0] and the obtained coefficients , the known values of C(N , J+1) , C(N-1 , J+1) , …..C(1 , J+1) at all nodes in the backward direction at the level "J+1" can be determined . Similarly, the calculations are continued to find C(I , J+2) , C(I ,

Figure 3: Drawdown Curve Of Diffused Sulfate and Chloride Salt Solutions Flow From Multiple Sewage Sources



J+3) , …..C(I , J+M) at time levels “J+2” , “J+3” , ….and “J+M” respectively . A computer program was developed and written to formulate the model.

II) Multiple recharge sewage sources penetrating a confined porous media

When a group of sewage sources situating near each other’s are recharging, their drawdown curves intersect within their radius of influence. The total piezometric head of salt solutions at any underground building at a point “A” in their flow field (as shown in Figure 3) is equaling to the sum of the piezometric heads caused by each sewage source individually . Thus:

$$h_A = h_1 + h_2 + h_3 + \ldots\ldots h_n \qquad ...(20)$$

In which “n” = number of interfered sewage sources.

Similarly, the concentration of diffused salt solutions at point “A” in the flow field of “n” sewage sources is:

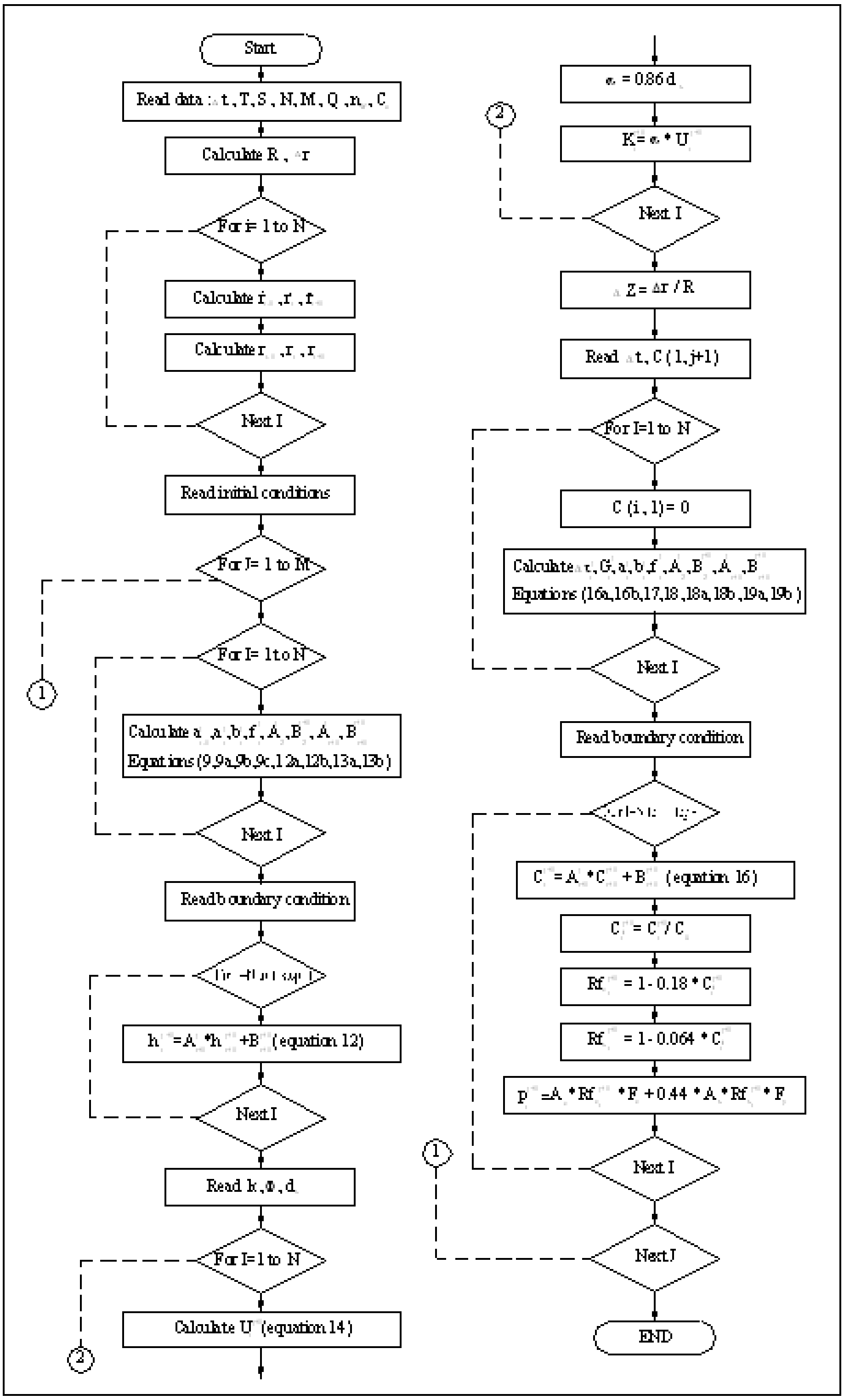
$$C_A = C_1 + C_2 + C_3 + ... + C_n \ldots \qquad ...(21)$$

From the foregoing, it is appeared that, the concentration of diffused salts at any point in the flow field of interfered recharge sewage sources “C_A” is a function of the initial concentration “C_o” , the soil permeability coefficient “k”, the soil porosity “Π” , the diameter of the soil particles “d_s”, the radial distance from the source and the time “t”. Therefore:

$$C_A = f\,(C_o, k, \Phi, d_s , r, t\,) \qquad ...(22)$$

3) Equations of the mechanical properties losses of underground R.C. columns in a building at point “A” in the flow field of the induced sulfate and chloride salt solutions by sewage waters through confined porous media .

Figure 4: Flow Chart for Computer Program



After calculating the total concentration of sulfate and chloride salt solutions C_T(I, J) at any block "I" and time level "J" or C_T(I, J+1) at time level "J+1" , the total relative concentration "C_R"at a building at point "A" can be determined from the following equation :

$$C_R(I , J+1) = C_T (I , J+1) / C_o \qquad ...(23)$$

where: C_o = initial concentration of sulfate & chloride salts at each sewage source ,

C_T(I , J+1) = total concentration of diffused salts at block "I" and time level "J+1"

The corrosion rate of embedded steel bars "C_r", correction factors of concrete compressive strength "CF_c" and steel yield stress "CF_s" and longitudinal strain of concrete " $•_c$" for underground R.C. columns in a building at at a point "A" in the flow field of multiple sewage sources at any service time " t " of the building can be determined from the following equation depending on the experimental results from the work of Rashwan and Sadeek (1997):

$$Cr(I , J+1) = [0.1 \text{“ } t * 0.27C_R (I , J+1)] +0.579 \qquad ...(24)$$

$$CFc(I , J+1) = [1.0 – 0.12 * \text{“}Cr(I , J+1)] \qquad ...(25)$$

$$CFs (I , J+1) = [1.0 – 0.062 *\text{”}Cr (I , J+1)] \qquad ...(26)$$

$$•c (I , J+1) = [3.266x10^{-4} + 6.92x10^{-7} * Cr(I,J+1)\sqrt{t}] \qquad ...(27)$$

The actual compressive strength of concrete Fc(I , J+1) and yield stress of steel bars Fy (I , J+1) of underground R.C. columns situated in the chosen building at a point "A" at block "I" and distance "ri" from multiple sewage sources can be determined at any time level "J+1" from the following equations :

$$Fc(I , J+1) = [CFc(I , J+1) * Fcu] \qquad ...(28)$$

$$Fs(I , J+1) = [CFs(I , J+1) * Fy] \qquad ...(29)$$

where:

Fcu = cubic compressive strength of concrete after 28 days,

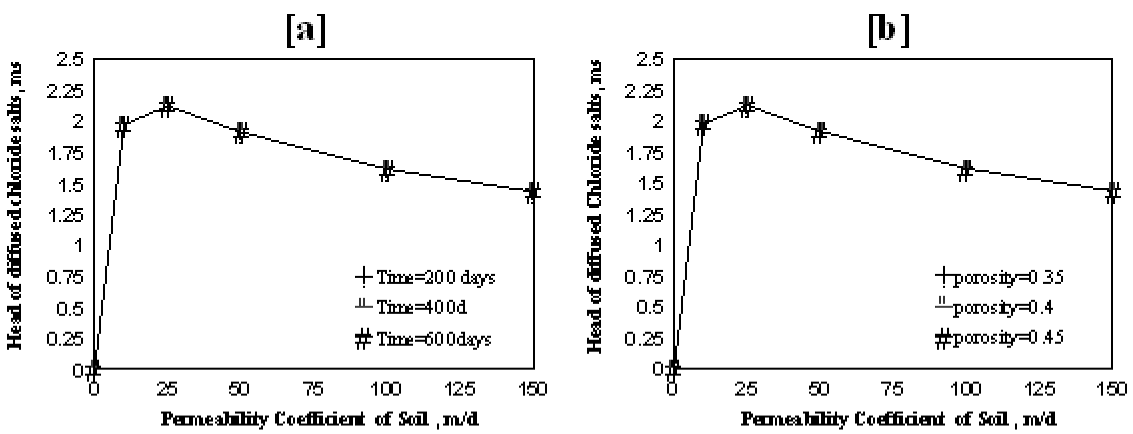
Fy= yield stress of steel reinforcement of RC column

COMPUTER IMPLEMENTATION

i) **Computer program:** A computer program was written for use with IBM personal computer. Figure 4 shows the flow chart of essential features of the program.

ii) **Range of variable parameters:** The number of multiple sewage water sources, surrounding a chosen building at point referred to "A" changes from 1 to 5 (as shown in Figure 3). The sewage sources, that having recharge values of $Q_1=2Q_2 = 4Q_3 = 10 Q_4 = 20 Q_5 = 200 m^3/day$ are at a variable distances (r_1 =250ms, r_2 =204 ms, r_3 =160 ms, r_4 =113 ms, r_5 = 45 ms) from the chosen building at point "A". The diameter of the soil particles "ds" equals to 0.6 mm with different values of soil porosity Φ = 0.35, 0.40, 0.45. The permeability coefficient of soil "k" is changed from 10 m/day to 150 m/day. The storage coefficient "S" is assumed to be constant at 0.007. The transmissibility coefficient [T(I , J)] for confined aquifer is taken as a function of head value [h(I, J)] of salt solutions and permeability coefficient at any point at a radial distance "r_i" from the sewage source. The initial

Figure 5: Effect Of Soil Properties And Time On The Total Piezometric Head " H_a"Of Sulfate And Chloride Salt Solutions Induced By Multiple Sewage Water Resources Through Confined Porous Media At The Chosen Under Ground Building At Point "A"



concentration "Co' of the sulfate and chloride salt solutions at each sewage source is assumed to be costant and equals 3000 p.p.m.

RESULTS AND DISCUSSION

In the model, the time increment (Δt) and the number of divisions (N) have great influence on the consistency of computation of the total head of salt solutions flow and hence on their concentration values. After number of trials, the numeric calculations are performed using Δt = 0.5 days and "N" = 30 blocks which having an accuracy for the computed total head values after the decimal point.

Effect of time and soil properties (k & Φ) on the total head of salt solutions, induced by multiple sewage water resources through confined porous media, at an underground RC building situating in their flow field

Effect of soil properties (k & Φ) and time of exposure of any underground RC building to salt solutions, induced by five multiple sewage water resources penetrating an unconfined porous media, on their total piezometric head is analytically studied. The numerical results are determined for different values of soil properties (K=10, 25, 50, 100 and 150 m/day, Φ= 0.35, 0.4, and 0.45), diameter of soil particles "ds" = 0.6 mm, and for different times. The results are plotted in Figure 5 assuming the previous suggested data of the chosen building and sewage sources.

Figure (5a) shows that, the total head of diffused salt solutions by sewage waters at the chosen underground building is clearly affected by the soil permeability at the same porosity of soil. It is largely increased by increasing soil permeability to 25 m/day and slowly decreased by increasing soil permeability to 150m/day at any time. It is necessary to notice that, the soil porosity "Φ" and time of exposure to these salts "t" have no any influence on the value of total head of salt solutions at the chosen building (as shown in Figure 5b). This may be explained that, by increasing permeability coefficient, the pore velocity increases which leads to the decrease of salt solutions head.

A comparison between the effect of confined and unconfined porous media on the total head

Figure 6: Effect Of Soil Properties And Time On The Total Relative Concentration "C_a/C_o" Of Sulfate And Chloride Salt Solutions Induced By Multiple Sewage Water Resources Through A Confined Porous Media At The Chosen Under Ground Building At Point "A"

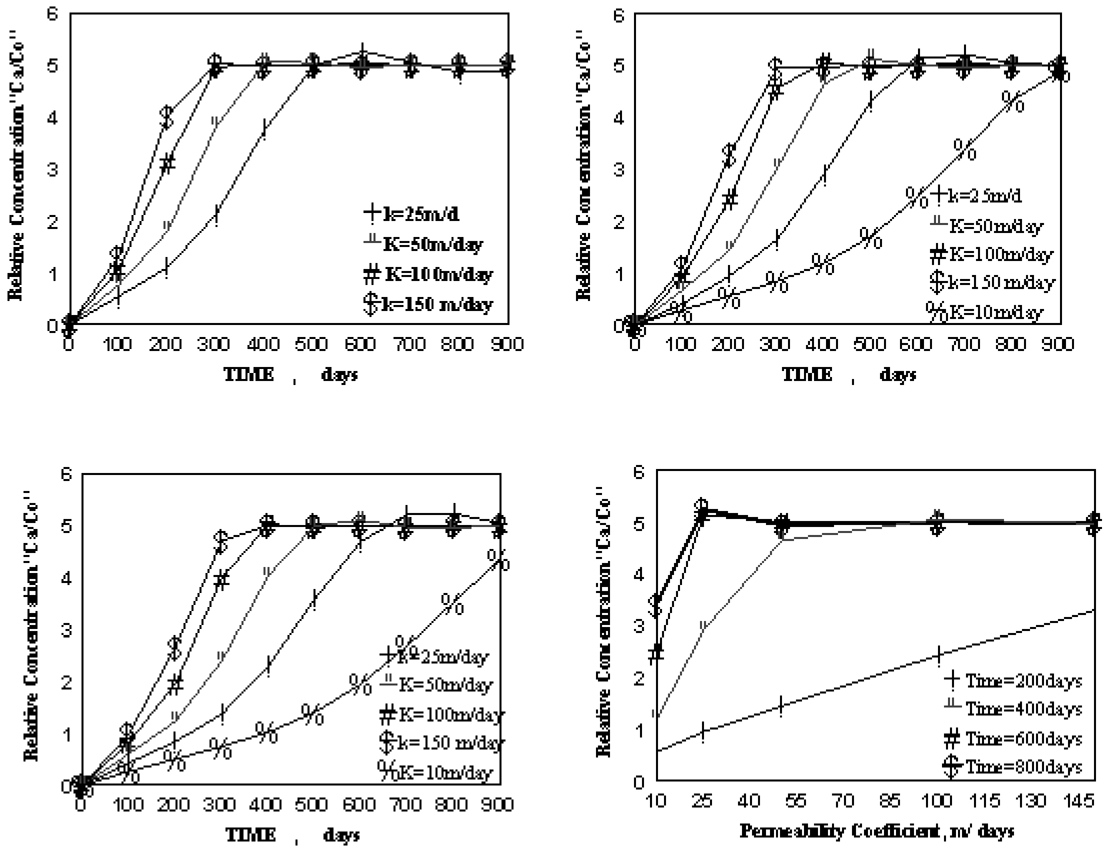


Table 1: Effect Of Soil Porosity "Φ" On The Relative Concentration Of The Diffused Salts From 5 Sewage Water Resources Through A Confined Porous Media (k =100m/Day)

Soil porosity	Relative concentration "C_A / C_o" at time, days							
	100	200	300	400	500	600	700	800
Φ = 0.35	1.063	3.11	4.96	4.99	4.99	5.02	4.99	5.0
Φ = 0.4	0.986	2.434	4.563	5.05	4.96	5.0	5.01	4.99
Φ = 0.45	0.83	1.96	3.99	5.01	5.0	5.0	5.0	5.0

of salt solutions at the same building and for the same soil properties (permeability coefficients k = 10 $\rightarrow$ 150 m/day, porosity Φ = 0.4 and ds = 0.6 mm), is determined and the results are plotted in Figure (5c). it is clear that, the unconfined porous media has a great and large effect an the total piezometric head of salt solutions at the same building and for the same soil properties than the confined . It increases the total head of salt solutions to 2.12 m depending on the soil properties. But, in the case of confined porous media, the total head is constant and equals to 0.4ms and it is not affected by soil permeability. This is explained by the constant value of the soil transmissibility coefficient "T" in the case of confined porous media.

a) " h_a " versus soil permeability at different times (=0.4),

b) "h_a " versus soil permeability at different at different values of soil porosity

Influence of time and soil properties (k & Π) on the total relative concentration "C_A/C_O" of salt solutions, induced by multiple sewage water resources through a confined porous media, at any underground RC building situating in their flow field.

The same suggested data are used to determine the total relative concentration "C_A/Co" of the diffused salt solutions from five multiple sewage resources through unconfined porous media to the chosen building at point "A" in their flow field taking the effect of soil properties and time of exposure to these salts into consideration. The numerical results are determined and plotted in Figure 6 and Table 1.

In Figure (6.a, b, c) are shown plotting of the relative concentration of the induced sulfate and chloride salts solutions, from five sewage water resources at a building at point "A" situating in the flow field, versus time at different permeability coefficients and porosity of soil (Π= 0.35, 0.4, 0.45) respectively. As expected, the total relative concentration of the diffused salts at the chosen underground building increases gradually and rapidly with the time approaching the unity or bigger than that value after a time depending mainly on the permeability coefficient and porosity of soil and radial distance from the sewage resource.

Again, the numerical results of "C_A/C_o" are plotted in Figure (6.d) against soil permeability for different times and constant soil porosity (Π= 0.4). Obviously, the total relative concentration of the proposed salts at the chosen building rapidly increases (from 1.19 to 4.97) by increasing soil permeability from 10 m/day to 150 m/day at time level equals one year. But, after 2 years, "C_A/C_o" increases from 3.41 to 5 for the same values of soil permeability. It is necessary to notice that, the soil porosity has a small effect on the values of "C_A/C_o" compared to the soil permeability. The relative concentration increases by decreasing the value of soil porosity. At time =200 days, and k= 100 m/day, "C_A/C_o" increases from 1.96 to 3.11 by decreasing porosity of soil from 0.45 to 0.35 (as shown in Table 1). Obviously, the total relative concentration at the chosen building reaches the number of sewage water resources after a nearly 2 years for the suggested properties of the confined porous media. This may be explained by the good effect of soil permeability and porosity on increasing pore velocity and diffusion of sodium sulfate and chloride.

a) "C_A/C_o" versus time at different permeability coefficients (Φ = 0.35),

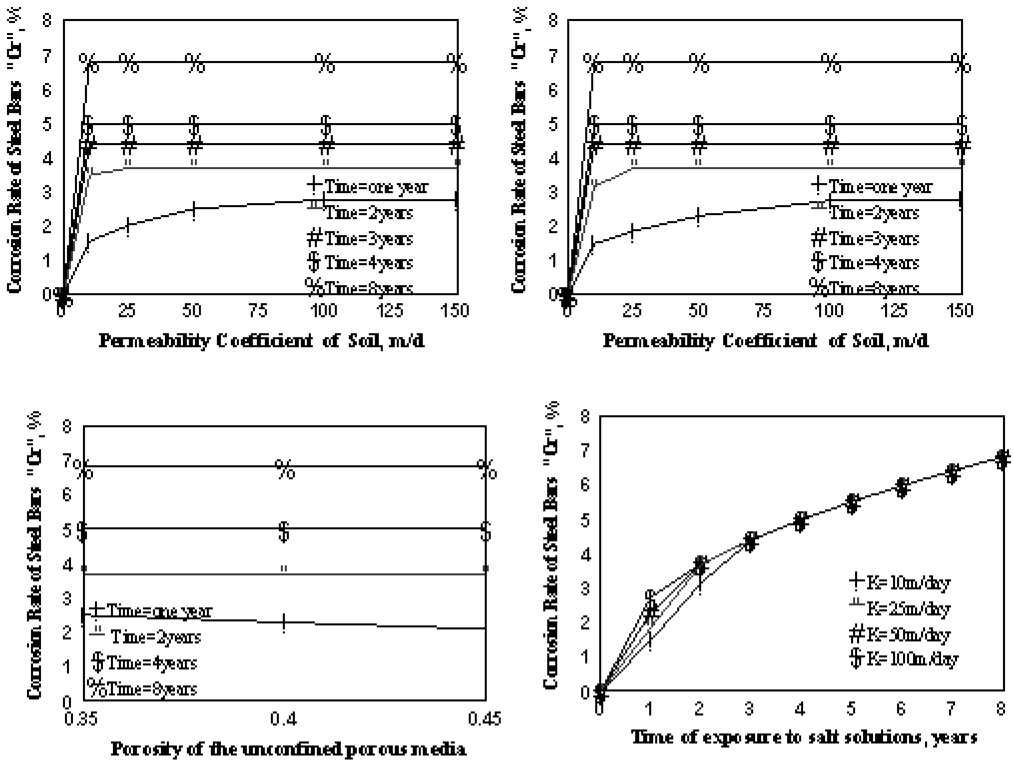
b) "C_A/C_o" versus time at different permeability coefficients (Φ = 0.4),

c) "C_A/C_o" versus time at different permeability coefficients (Φ = 0.45), and

d) "C_A/C_o" versus soil permeability at different times, (Φ = 0.4)

Influence of time and properties of confined porous media on the corrosion rate of steel bars and deterioration of concerete in the underground RC building damaged by sodium sulfate and chloride salt solutions, induced by multiple sewage water resources penetrating

Figure 7: Effect Of Soil Properties And Time On The Corrosion Rate " Cr "Of Embedded Steel Bars In R.c. Columns Damaged By Sulfate And Chloride Salt Solutions Induced By Multiple Sewage Water Resources Through A Confined Porous Media



this porous media.

The chemical resistance of underground RC elements exposed to sulfate and chloride salt solutions, induced by sewage water resources through a confined porous media, is expressed by the percentage of their mechanical properties losses. These disadvantages are the increase of corrosion rate of embedded steel bars, increase of strain and deformation of concrete, decrease of concrete compressive strength and steel yield stress and cracking of the concrete cover.

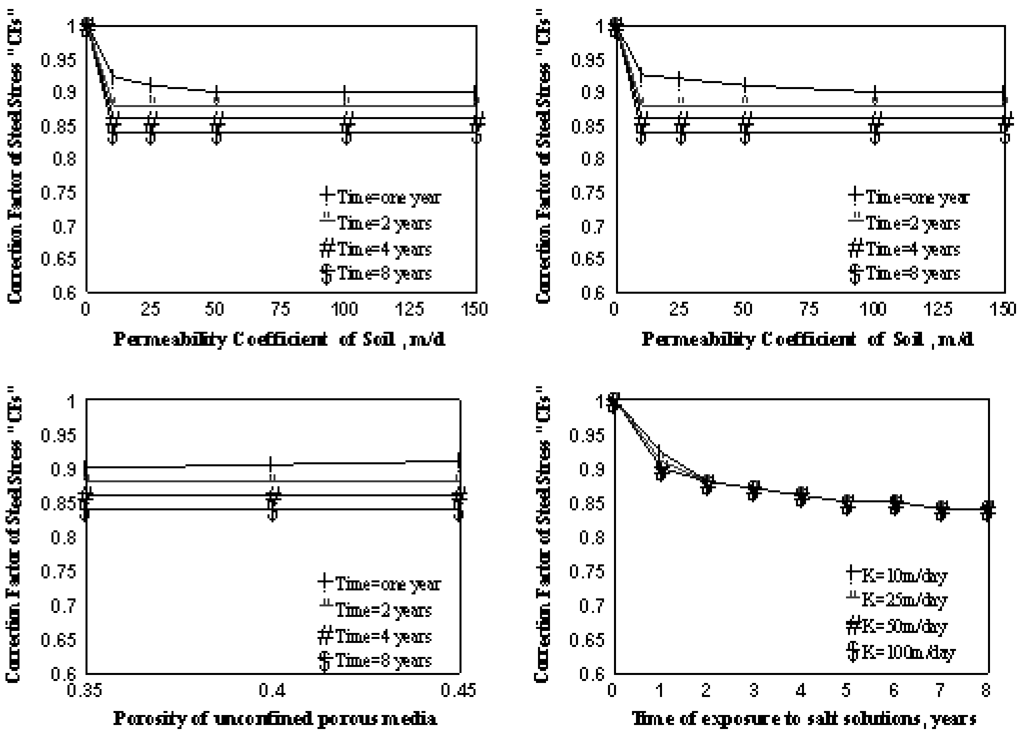
[3.a] Corrosion damage of embedded steel bars

[3.a.1] Corrosion rate of embedded steel bars Cr(I, J)

The same previous data are used and numerical calculations are extended to find the effect of the confined porous media properties and time of exposure of the chosen underground RC building to the suggested salt solutions on the corrosion rate of embedded steel bars .The results are determined at any time level, depending on the development of some experimental results (Rashwan, 1997) from Equation (24) and plotted in Figure 7.

In Figure (7a, b) are shown plotting of the corrosion rate of embedded steel bars, in the underground RC building damaged by the flow of salt solutions from multiple sewage resources, versus soil permeability at different times and for soil porosity equals 0.35 and 0.45 respectively.

Figure 8: Effect Of Confined Porous Media Properties And Time Of Exposure Of The Chosen Underground Building To Sodium Sulfate &Chloride Salt Solutions Flow On The Correction Factor Of Future Steel Yield Stress Of Its RC Columns



As expected, corrosion rate of embedded steel bars of the RC columns in the chosen underground building is clearly affected by the total relative concentration of salt solutions "C_A/C_o", time of exposure to these salts "t", and properties of the confined porous media until 2 years. After 2 years, the effect of soil permeability is neglected. It is necessary to notice that, the time of exposure to these salts have a large effect on increasing corrosion damage of steel bars specially after 2 years. At soil properties (K= 100 m/d, Φ = 0.4 and ds = 0.6 mm), corrosion rate of embedded steel bars in RC columns increases by about 2.74%, by weight, after one year. It increases by about 6.8%, by weight, after 8 years for the proposed data in the problem in this research.

Figure (7c) shows the effect of soil porosity "Φ = 0.35, 0.4 and 0.45" on the corrosion rate of steel bars in the chosen underground building and for different values of soil permeability. Obviously, the soil porosity has a small effect on the corrosion rate of embedded steel bars compared to the effect of permeability coefficient at the same time and the same previous data of salts and building situation. After one year, corrosion rate, by the reduction of weight, slowly decreases from 2.77 to 2.54% by increasing soil porosity from 0.35 to 0.45 with constant k = 100 m/day. It is necessary to notice that, the effect of the properties of the confined porous media (k, Φ) on the corrosion rate of steel bars is neglected after 2 years of exposure of the chosen building to the suggested salt solutions flow from sewage waters. But, the actual parameter affecting the corrosion rate of steel is the long time of exposure to these salts (as shown in Figure 7d). From which is clear the effectiveness of long time on increasing corrosion rate of steel bars "Cr' and at the same time, the effect of soil properties disappeared. This may be explained as previously stated, the ferrous chloride phenomenon in the presence of oxygen is in adequate to explain the generated corrosion damage of embedded steel bars. This consequently leads to appearance of internal cracks, which affect on the mechanical properties of concrete.

a) " Cr " versus permeability coefficients at different times (Φ = 0.35),

b) " Cr " versus permeability coefficients at different times (Φ = 0.40),

c) " Cr " versus porosity of soil at different times (k = 50 m/day), and

d) " Cr "versus time at different soil permeability (Φ = 0.4)

[3.a.2] Correction factor of future steel yield stress CFs(I, J) at the chosen building at distance "r_i" and time level "J"

The numerical results are determined, for the same data of the chosen underground building, to find the effect of the porous media properties (k, Π) and time of its exposure to the suggested salt solutions flow on the future yield stress "Fy_f' of embedded steel bars in its RC columns. The results are calculated at the chosen building and plotted in Figure 8 at any time level from the following equation:

Fyf (I, J) = CFs(I, J) * Fy , where: CFs (I, J) =correction factor of steel yield stress at and distance from the sewage source and any time. It is determined from the following equation, developed from some previous experimental works:

CFs(I, J) = 1.0 – 0.062 " Cr(I, J)

a) "CFs" versus permeability coefficients at different times (Φ = 0.35),

b) "CFs" versus permeability coefficients at different times (Φ = 0.45),

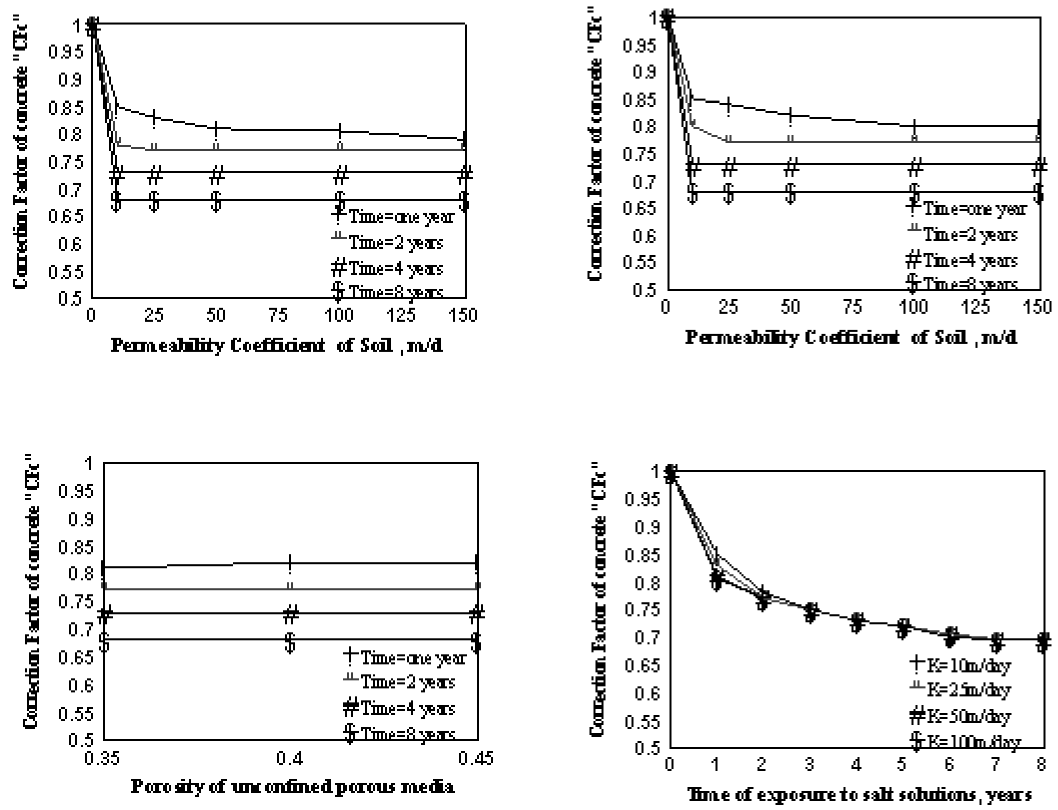
c) "CFs" versus porosity of soil at different times (k = 50 m/day), and

d) "CFs" versus time at different soil permeability coefficients (Φ = 0.4)

In Figure (8.a, b) are shown plotting of the correction factor of future yield stress of steel "CFs" embedded in RC columns in the chosen building, damaged by the flow of suggested salt solutions, versus soil permeability at different times and for soil porosity Π = 0.35 and 0.45 respectively. Obviously, "CFs" is small affected by the porous media properties (k, Φ) untill two years and the clearly effect occurs with soil permeability. As the soil permeability increases from 10m/day to 150m/day, "CFs" decreases from 0.92 to 0.90 after one year and for soil porosity = 0.4. After 2 years, "CFs" decreases by about 12% for different values of soil properties compared to the same type of concrete not exposed to these salts. It is necessary to notice that, the soil porosity has a neglected effect on this factor at any time and for different values of soil permeability (as shown in Figure 8c).

Figure (8d) shows the influence of a long time of exposure of the chosen building to the suggested salts on the correction factor of yield stress of its damage column reinforcement. It is clear the effectiveness of the long time of exposure to these salt solutions on decreasing "CFs" compared to the effect of soil properties, which are neglected after 2 years. "CFs" decreases by about 16% (from 1.0 to 0.84) after

Figure 9: Effect Of Confined Porous Media Properties And Time Of Exposure Of The Chosen Underground Building To Salt Solutions Flow On The Correction Factor Of Future Compressive Strength " CFC " Of Its RC Columns



8 years compared to the same type of concrete (C250) not exposed to these salts induced by sewage waters. This may be explained by the effect of the long time of exposure to these salts on increasing corrosion rate and pitting corrosion of embedded reinforcement, which decreases its future yield stress.

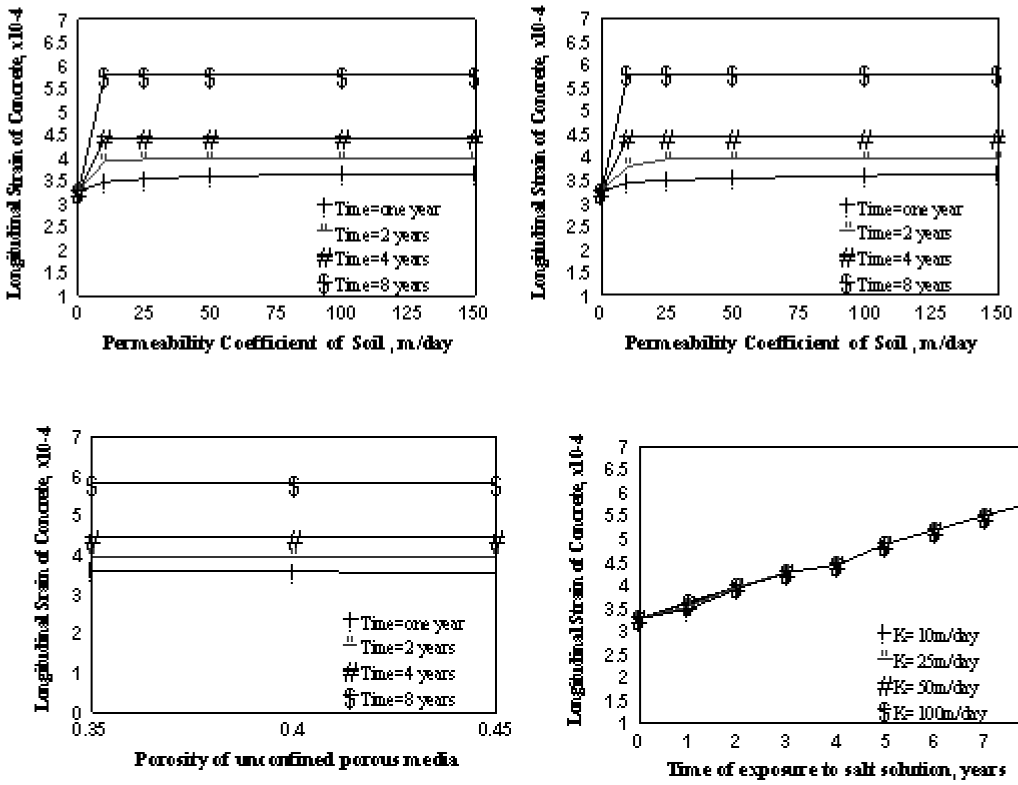
[3.b] Deterioration of concrete in the underground RC column necks (C250) damaged by salt solutions induced by multiple sewage water resources through a confined porous media

[3.b.1] Correction Factor of concrete future compressive strength "CFc" at the chosen underground column necks at distance "ri" and at any time level "J"

The numerical calculations are extended, for the same previous data of the chosen underground building, to find the effect of the porous media properties (k, Φ) and time of its exposure to the suggested salt solutions flow on the future compressive strength "Fc_f' of concrete in its R.C. column necks. The numerical results are determined at the chosen RC building and plotted in Figure 9 at any time level from the following equation:

Fc_f (I, J) = CFc(I, J) * Fc_{28} , where: CFc(I, J) =correction factor of concrete compressive strength at any distance from the sewage resource and at any time. It is determined from

Figure 10: Effect Of Confined Porous Media Properties And Time Of Exposure Of The Chosen Underground Building To Salt Solutions Flow On The Future Longitudinal Strain Of Concrete "ϵc_f" Of Its RC Columns



the following equation, developed from some previous experimental works.

CFc(I, J) = 1.0 – 0.12 " Cr(I, J)

In Figure (9.a, b) are shown plotting of the correction factor of future compressive strength of concrete "CFc" of RC columns in the chosen building, damaged by the flow of suggested salt solutions, versus soil permeability at different times and for soil porosity Π = 0.35 and 0.45 respectively. Obviously, "CFc" is clearly affected by the corrosion rate of steel bars, which affected by the relative concentration of diffused salts and the porous media properties (k, Π) untill two years. As the soil permeability increases from 10 m/day to 150m/day, "CFc" decreases from 0.85 to 0.79 after one year and for soil porosity = 0.35.But, for soil porosity= 0.45, it decreases from 0.85 to 0.80 after one year. So, the effect of soil permeability is greater than the soil porosity. It is necessary to notice that, the effect of soil properties is neglected after 2 years (as shown in Figure 9c). From this figure it is clearly the negligable effect of the soil porosity on the factor "CFc" at the same permeability coefficient.

Figure (9d) shows the relation between "CFc" and along period of time of exposure to these salts at different permeability coefficients and for soil porosity Π = 0.35. Obviously, the effectiveness of the long time of exposure to these salt solutions on decreasing " CFc " compared to the effect of porous media properties, which are neglected after 2 years. After 8 years, "CFc" decreases by about 31.4% (from 1 to 0.686) for different values of soil properties and compared to the same type of concrete (C250) not exposed to these salts. This may be explained by the effect of the long time of exposure to these salts on increasing corrosion rate and pitting corrosion of embedded reinforcement, internal cracks of concrete and deterioration of concrete cover due to sulphric acids and chloride ions, which consequently decreases its future compressive strength.

a) "CFc" versus permeability coefficients at different times (Φ = 0.35),

b) "CFc" versus permeability coefficients at different times (Φ = 0.45),

c) "CFc" versus porosity of soil at different times (k = 50 m/day), and

d) "CFc" versus time at different soil permeability coefficients (Φ = 0.4)

[3.b.2] Longitudinal concrete strain of the underground RC columns (C250) in the chosen building damaged by salt solutions induced by multiple sewage water resources through a confined porous media

The investigations are continued, for the same previous data of the chosen underground building, to find the effect of the porous media properties (k, Φ) and time of its exposure to the suggested salt solutions flow on the future longitudinal strain "$\in c_f$" of concrete in its RC columns. The numerical results are determined at the chosen RC building and plotted in Figure 10 at any time level from the following equation developed from some previous experimental works:

$$\in c_f(I, J) = 3.27x10^{-4} + 6.92x10^{-7} *Cr(I, J) * \sqrt{t}$$,

where: t= time in days

In Figure (10.a, b) are shown plotting of the future longitudinal strain of concrete "$\in c_f$" of RC columns in the chosen building, damaged by the flow of suggested salt solutions, versus soil permeability at different times and for soil porosity Φ = 0.35 and 0.45 respectively. Obviously, "$\in c_f$" is clearly affected by the corrosion rate of steel

a) "$\in c_f$" versus permeability coefficients at different times (Π = 0.35),

b) "$\in c_f$" versus permeability coefficients at different times (Π = 0.45),

c) "$\in c_f$" versus porosity of soil at different times (k = 50 m/day), and

d) "$\in c_f$" versus time at different soil permeability coefficients (Π = 0.4)

bars, which affected by the relative concentration of diffused salts and the porous media properties (k, Π) untill two years. As the soil permeability increases from 10 m/day to 150 m/day, "$\in c_f$" increases from $3.47x10^{-4}$ to $3.64x10^{-4}$ after one year and for soil porosity = 0.35. After 2 years, "$\in c_f$" increases from $3.92x10^{-4}$ to $3.96x10^{-4}$ by increasing soil permeability from 10 to 150 m/day. So, the effect of soil permeability decreases by increasing time of exposure of the chosen building to these salt solutions. But, as the soil porosity increases from 0.35 to 0.45, "$\in c_f$" slowly decreases from $3.47x10^{-4}$ to $3.46x 10^{-4}$ after two years for soil permeability k= 50 m/day. So, the effect of soil permeability is greater than the soil porosity. It is necessary to notice that, the effect of soil properties is neglected after 2 years (as shown in Figure 10c). From this figure it is clearly the negligable effect of the soil porosity on the factor "$\in c_f$" at the same permeability coefficient. This may be explained that, after 2 years total relative concentration of the diffused salt solutions reaches the maximum value and becomes constant and equals the number of sewage water resources. This leads to the constant value of corrosion rate at that time and consequently constant values of concrete strain.

Figure (10d) shows the relation between "$\in c_f$" and a long period of time of building exposure to these salts at different permeability coefficients and for soil porosity Φ = 0.35. Obviously, the effectiveness of the long time of exposure to these salt solutions on increasing "$\in c_f$" of RC columns compared to the effect of porous media properties, which are neglected after 2 years. "$\in c_f$" increases by about 20% (from 3.27 to $3.92x10^{-4}$) after two years. But, after 8 years, "$\in c_f$" increases by about 77% (from 3.27×10^{-4} to 5.8×10^{-4}) for different values of soil properties and compared to the same type of concrete (C250) not exposed to these salt solutions. This may be explained by the effect of the long time of exposure to these salts on generaing corrosion rate and pitting corrosion of embedded reinforcement, internal cracks of concrete and deterioration of concrete cover due to sulphric acids and chloride ions, which consequently increases deformation of the damaged concrete.

CONCLUSION

The main conclusions may be summarized as follows:

1. A numerical method using the finite-difference technique is successfully be used for the solution of partial differential equations representing the dispersion of salt solutions concentration from multiple seepage pits through a confined porous media and its effect on the reduction factors values of concrete and steel stresses of underground RC columns.
2. The total relative concentration of diffused salt solutions "C_A/C_o" at a building situating in the flow field of multiple seepage pits, penetrating a confined aquifer, increases gradually with the time approaching the unity or bigger than that value depending mainly on the soil properties , recharge value of each seepage pit and radial distance from the chosen building to them .
3. The total relative concentration of diffused salt solutions "C_A/C_o" at the proposed building rapidly increases by about 211% as the soil permeability coefficient increases from 50 m/day to 150 m/day after two years. But, "CA/Co" rapidly decreases for soils of higher porosity. It decreases by about 60% as the soil porosity increases from 0.30 to 0.45 at time level "t = 200 days".
4. The grain size of the porous media "ds" has a negligible effect on the value of total relative concentration of diffused salt solutions at the proposed building at any time or any radial distance from the multiple seepage pits, penetrating a confined aquifer, keeping the remaining parameters constant.
5. The value of the reduction factors of concrete compressive strength "Rfc" and steel yield stress "Rfs" of underground RC columns in the chosen building decreases gradually by increasing time level for different permeability coefficients and soil porosity. The large decrease occurs with higher values of soil permeability and lower values of soil porosity.
6. "Rfc" and "Rfs" decrease respectively by about 21% and 11% by increasing permeability coefficient from 50 m/day to 150 m/day after two years. Also , they decrease by about 28% and 15% respectively by increasing time level from 0.0 to 2 years for soil of permeability

coefficient "k = 100 m/day" .

7. The soil porosity has a clear influence on the values of the reduction factors of concrete and steel stresses of the underground R.C. columns in the chosen building situating in the flow field of salt solutions dispersion from multiple seepage pits. "Rfc" and "Rfs" of these columns decrease by about 10% and 5% respectively by reducing soil porosity from 0.45 to 0.30 at any time level, keeping the remaining parameters constant.

8. The maximum load carrying capacity [P(I , J)] of the underground RC columns in the proposed building situating in the flow field of diffused salt solutions from multiple seepage pits, penetrating a confined aquifer , can determined at any radial distance "r_i" from the pits and time level "j" from the following equation :

P (I, J) = Ac * [Rfc(I , J) * Fc_{28}] + 0.44* As *[Rfs (I , J) * Fy] . Where:

- Rfc(I , J) = reduction factor of concrete design compressive strength of R.C. columns (Fc_{28}) at any radial distance "ri" from the pits and at any time level "j'
- Rfs(I , J) = reduction factor of steel design yield stress of R.C. columns reinforcement "Fy" at any radial distance "ri" from the pits and at any time level "j',
- Ac = concrete cross sectional area of R.C. columns,
- As = area of steel reinforcement of R.C. columns.

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