Effect some parametric on optimum design of highway embankment with stone columns

تأثير بعض المحددات على التصميم الامثل للسداد الترابية مع الاعمدة الحجرية

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ABSTRACT:

in this paper will discussed the effect of some parametric on optimum design of stone column by using ANSYS program to define the model of highway embankment with stone column and find the optimum shape, these parametric are (height of highway embankment, surcharge load (traffic load), friction angle), from first parametric it can be noted with increase the height of highway embankment the diameter of stone column increase until reach (103%)between (H=3m and H=10m), from second parametric it can be noted with increase surcharge load the diameter of stone column increase, the percentage of increase in diameter of stone column with increase surcharge load from (0 KN/m^2 to 10 KN/m^2) for height of highway embankment (H=3m) about (2%) but for height of highway embankment (H=10m) equal to zero, and from last parametric it can be noted with increase friction angle of stone column the diameter of stone column decrease for same height of highway embankment. The percentage of decreasing in diameter of stone column reach to (31%) if increase fraction angle of stone column from (φ=38º to φ=50º) for height of highway embankment (H=10m).

Key word: stone columns, highway embankment, soft clay, diameter

الخلاصة

في هذا البحث سوف يناقش تأثير بعض المحددات على التصميم الامثل للاعمدة الحجرية بستخدام برنامج ال(ANSYS) لرسم نموذج السدة الترابية للطرق السريعة مع الاعمدة الحجرية وايجاد الشكل الامثل، وهذه المحددات هي (ارتفاع السدة الترابية ،احمال المرورية للطرق السريعة وزاوية الاحتكاك للاعمدة الحجرية)، من خلال دراسة اول محدد (ارتفاع السدة الترابية) يمكن ملاحظة مع زيادة ارتفاع السدة الترابية يزداد قطر الاعمدة الحجرية حتى تصل نسبة الزيادة الى (103%) بين ارتفاع (H=3m,H=10m) للسدة الترابية، ومن المحدد الثاني (الاحمال المرورية) يمكن ملاحظة مع زيادة الاحمال المرورية يزداد قطر الاعمدة الحجرية، ونسبة الزيادة بقطر الاعمدة الحجرية مع زيادة الاحمال المرورية من (0KN/m^2 to 10 KN/m^2) حوالي (2%) تقريبا لسدة ترابية ذات ارتفاع (H=3m) ولكن لسدة ترابية بارتفاع (H=10m) لا يحصل اي تغيير بقطر الاعمدة الحجرية، ومن خلال دراسة تاثير اخر محدد (زاوية الاحتكاك) وجد انه مع زيادة زاوية الاحتكاك للاعمدة الحجرية يقل قطر الاعمدة الحجرية لنفس الارتفاع من السدة الترابية ،ونسبة النقصان بقطر الاعمدة الحجرية يصل الى (31%) في حالة زيادة زاوية الاحتكاك من(φ=38º to φ=50º) لسدة ترابية ذات ارتفاع (H=10m).

1) INTRODUCTION

The purpose of optimization is to find the best possible solution among many potential solutions satisfying the chosen criteria. Designers often base their designs on the minimum cost as an objective, taking into account mainly the costs of the structure itself, safety, and serviceability.

An embankment is an artificial barrier that typically is used to hold back water or to support a roadway, railway, or canal. The material use in embankment can be naturel like (sand, rock….etc.) or manmade, in general any material can be use but non organic material. The highway embankment consists of soil that is placed on the embankment foundation in order to raise the level of the roadway to the correct grade and to provide adequate support for the layers of base and surface courses that make up the roadway. Since the embankment foundation and embankment provide the basic support of the entire roadway, it is very important that they be properly constructed in accordance with all plans and specifications. Grades, slopes, density, and all other controls must be accurately monitored. The highway embankment founded on soft clay soil. Soft clays an outstanding classification of tricky soils which are for the most part experienced under the type of kept layers in waterfront regions. A few issues are confronted when managing the investigation of delicate muds from field examination, soil portrayal, conduct demonstrating, and security of geotechnical structures up to ground change arrangements. Concentrate the conduct of soft clay particularly requires a careful assurance of their geotechnical parameters. In Iraq, the problems of this soil taken space from the attention of geologists and civil engineers, because about 35% of the Iraqi clay soils (especially southern Iraq) are weak[Dr. Hussein]. So, necessity to improve soil properties for road building has resulted in the use of various stabilizers. Ground improvement is normally understood as the modification of the existing physical properties of the ground beneath a site to sufficient depth to enable effective, economic, and safe permanent or temporary construction in practical timescales. Typical objectives would be one or a combination of the following:

1. Improve bearing capacity by increasing in shear strength or density.
2. Minimize total or differential settlements of buildings or structuresby reduction in compressibility.
3. Minimize flow of ground water to prevent inundation or water damage by reduction in permeability
4. Prevention of liquefaction or reduction in lateral spreading beneath or near both new and existing structures during earthquakes, employing densification, replacement with stronger materials, or deep drainage.
5. Conversely, an improvement in deep drainage in order to assist preloading or surcharge techniques.
6. Controlled displacement of the ground in order to dispel previous differential settlements or ground

The use of stone columns as a technique of soil reinforcement is frequently implemented in soft cohesive soil and have been successfully used to support isolated footing, large raft foundations and embankment. Besides, their use in soft clays has been found to provide moderate increases in load carrying capacity accompanied by significant reduction in settlement. Being granular and freely drained material, consolidation settlement is accelerated and post construction settlement is minimized [Klaus Kirsch].

2) Formulation of optimization process

2.1 Structural stability

Structural stability can be divided in the two type the first type with in embankment called (slope stability) and the second type within foundation of embankment called (bearing capacity)

2.1.1 Bearing capacity

$Qu = \sigma_v * \frac{\frac{\pi}{4} * D^2}{1.5}$(1)

$\sigma_v = \sigma_{rL} Kp_{col}$(2)

$\sigma_{rL} = p_p = \gamma * kp * z + 2 * cu * \sqrt{kp}$ (3)

Where :(σ_v) limiting axil stress,(σ_{rL}) limiting radial stress,(D)diameter of stone column,(Kp_{col})passive earth pressure (Kp= $\tan^2(45+\frac{\phi_c}{2})$,wherefriction angle of stone column),(p_p)passive pressure,(z) average bulge depth (2 time the column diameter),(cu)cohesion of soft clay,(k_p)passive pressure coefficient of soft clay($k_p=\tan^2(45+\phi/2)$,where ϕangle of friction of soft clay) and(1.5) factor of safety.

2.1.2 Slope stability

Bishopsuggestat (1955) a circular failure surface by divided the soil mass into slices. In this method normal forces for inter-slice are considered butshear forces are ignored for same slice. Also moment equilibrium is satisfy butthismethod is simplified because it assumes inter-slice shear forces resultantact on the sides of a slice are horizontal i.e. zero or X1-X2 = 0 (Figure1). Safety factor in this method for effective stress is given as follows:

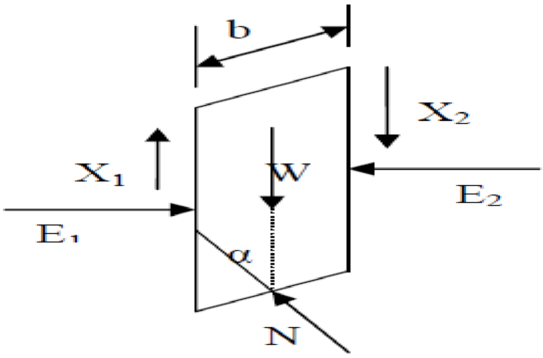


Figure (1) Bishop's method[Shyamal]

$$F=\frac{1}{\sum W\sin\alpha}\sum[\{c'b+W\tan\phi'\}\frac{\sec\alpha}{1+\frac{\tan\alpha\tan\phi'}{F}}] \qquad (4)$$

Where :(F) Factor of slope stability (for embankment must be ≥ 1.5), (*W*)weight of each slice, (c') cohesion of soil, (*b*) width of each slice, and (′) angle of friction

2.2 Settlement

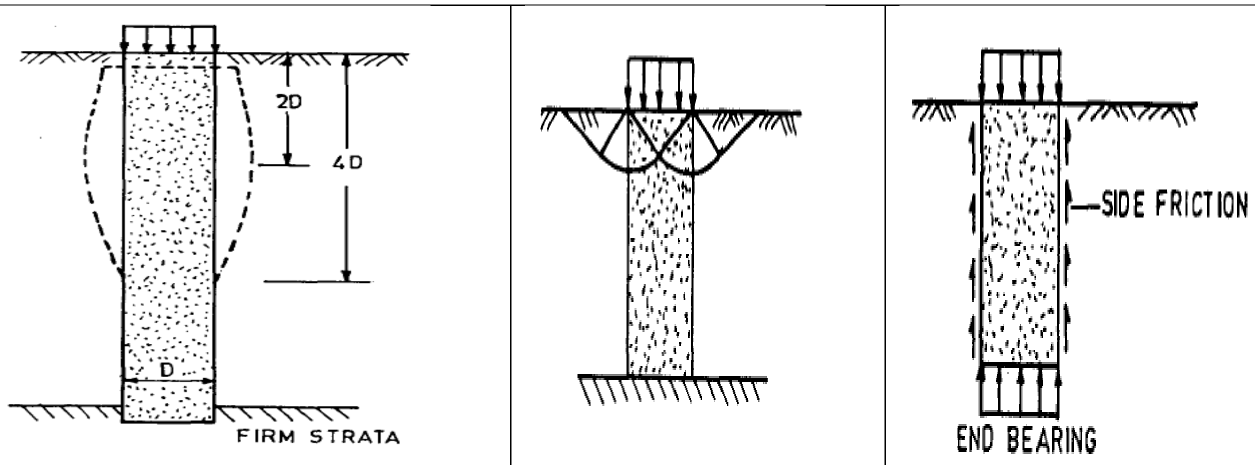
After construction the stone column and at the center of building the settlement for each layer i is expressed as follows:

$$S=\frac{hi*\sigma_t}{a_i*E_{col}+\{(1-a_i)*E_{soil}\}} \qquad (5)$$

Where: (a_i) the replacement ratio for layer i ($a_i=\frac{A}{Ac}$,A: total area within the unit cell ,A_c: area of stone column),(E_{col})young modulus of stone column, (E_{soil}) young modulus of soft clay, (σ_t)average of vertical stress exerted by building and (h_i) layer thickness

2.3 Mode failure of stone column

Mechanism of failure of a solitary stone column stacked over its zone essentially relies on the length of the segment. For segments having length more noteworthy than its basic length (that is around 4 times the segment distance across) and regardless whether it is end bearing or drifting, it flops by swelling (see Fig. 2,a). In any case, section shorter than the basic length are probably going to flop as a rule shear on the off chance that it is end bearing on an inflexible base (see Fig. 2,b) and in end bearing on the off chance that it is a skimming section as appeared in (Fig. 2,c).



(2,a) Long stone column with firm of floating support-bulging failure	(2,b)Short column with rigid base shear failure	(2,c)Short floating column Punching failure

Figure (2) failure mechanisms of a single stone column in a homogeneous softlayer[Indian Standard]

In practice, however, a stone column is generally stacked over a zone more prominent than its own (see Fig. 3) in which case it encounters altogether less protruding prompting to more noteworthy extreme load limit and diminished settlements since the heap is conveyed by both the stone segment and the encompassing soil [Indian Standard].

NOTE — the above disappointment components apply to stone sections introduced in homogeneous soils. Down to earth circumstances may emerge where disengaged zones of delicate durable soils may bring about critical protruding at both shallow and profound profundities and subsequently, this ought to be properly considered wherever essential.

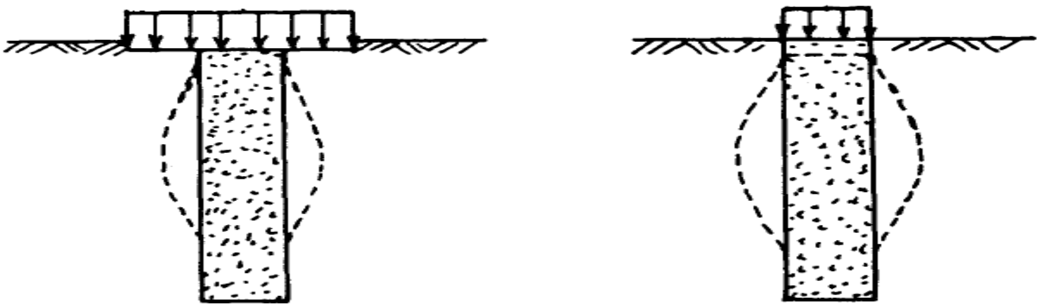


Figure (3) different type of loadings applied to stone columns [Indian Standard]

Wherever interlayering of sand and clay occurs, and if the sand layer is thick enough as compared to the size of the loaded area, the general compaction achieved by the action of the installation of the stone columns may provide adequate rigidity to effectively disperse the applied stresses thereby controlling the settlement of the weak layer. However, effective reduction in settlement may be brought about by carrying out the treatment of stone columns through the compressible layer.

When clay is present in the form of lenses and if the ratio of the thickness of the lenses to the stone column diameter is less than or equal to 1, the settlement due to presence of lenses maybe insignificant.

In mixed soils, the failure of stone columns should be checked both for predominantly sandy soils as well as the clayey soil, the governing value being lower of the two calculated values.

2.3.1 Maximum allowable stress for stone column

It is need todetermine the vertical stress-rupture point (qr) for an isolated column at firstto calculate the maximum allowable stress, based on characteristic of column and the soil after treatment and according to possible mode of failure[G. Billoet].

1. Bulging failure

   $qre = \sigma_{rL} * kp_{col}$ (6)

- (σ_{rL}) calculate as equation (3) above

2. General shear failure

   It can be studied when the characteristic of stone column closely resemble those of soil. This occur only very rarely and the corresponding calculation does not appear in this paper.

3. Punching effect shear failure

The vertical shear within the column is most intense at top and decreases as it moves down.

$q_{rp} = 9 * Cu + L_c(2 * \frac{Cu}{R_c} - \gamma_c)$ (7)

where :

γ_c: unit weight of stone column material

L_c:length of column

R_c: average radius of the column

- Vertical failure stress (qr) within the column equal to :
  qr = min(q_{re} , q_{rp} , 1.6 Mpa)
- At the service limit state (SLS), the allowable vertical stress (q_{aSLS}) within the column is obtained by applying safety factor of 2 to the vertical failure stress (qr) :
  q_{aSLS}= qr/2 = min (q_{re}/2 , q_{rp}/2 ,0.8 Mpa)
- Value of stress within column at the layer i (σ_{ci}) can be expressed as :

$$\sigma_{ci} = \frac{E_{col} * \sigma_t}{a_i * E_{col} + \{(1-a_i) * E_{soil}\}} \quad (8)$$

2.4 Stress in Subsoil due to Loading

To determine thesettlement and bearing capacity of foundation, it is necessary to determine the stress of increasing with depth of foundation soil due to an incremental load. In the case of a highway embankment stresses are developed as a result of the embankment and traffic loads.

2.4.1 Embankment loading

The increase of vertical stress to a depth *z* from the ground surface due to embankment loading can be determined from Osterberg's equation (Das, 2004) as follows:

$$\Delta\sigma_{av} = \frac{q_o}{\pi} [\left(\frac{B_1+B_2}{B_2}\right)(\alpha_1 + \alpha_2) - \frac{B_1}{B_2}(\alpha_2)] \quad (9)$$

Where ($q_o = \gamma H$),(γ) unit weight of the embankment soil,and (H)height of the embankment

$\alpha_1 = \tan^{-1}(\frac{B_1+B_2}{Z}) - \tan^{-1}(\frac{B_1}{Z})$ (10)

$\alpha_2 = \tan^{-1}(\frac{B_1}{Z})$(11)

notes that (α_1 , α_2) in radians

B_1 , B_2 ,z shown in figure (4)

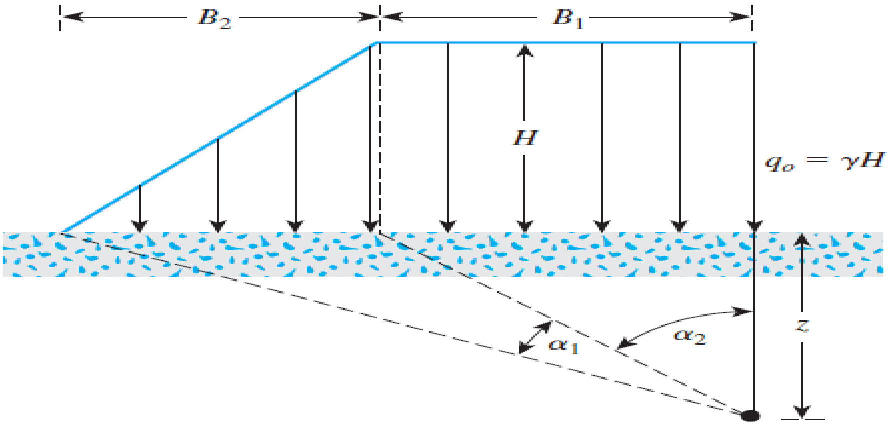


Figure (4) Embankment loading[Das, 2004]

- As loading is symmetrical the vertical stress at the Centre of embankment is twice that of half of the section

2.4.2 Traffic load

Traffic load consider as live load and the minimum load (11.5 KN/m^2) from AASHTO recommendation. To calculate the allowable stress (Qall) on foundation of soft clay and stone column it need to know the residual value of traffic load to be as surcharge load on foundation because the traffic load disappeared gradually with height of embankment, to calculate the residual value of traffic load use Stress Increase under rectangular area as shown in equation below:

$$\Delta\sigma = \left(\frac{3qz^3}{2\pi}\right) \int_0^b \int_0^a \frac{dxdy}{(z^2+y^2+x^2)^{\frac{5}{2}}} \qquad (12)$$

Where :($\Delta\sigma$) : increase in stress under rectangular area (kpa), (q) surcharge load (traffic load) (kpa), (z) depthof point which calculated stress increase (m) , and(a,b) dimension of plane area (m)

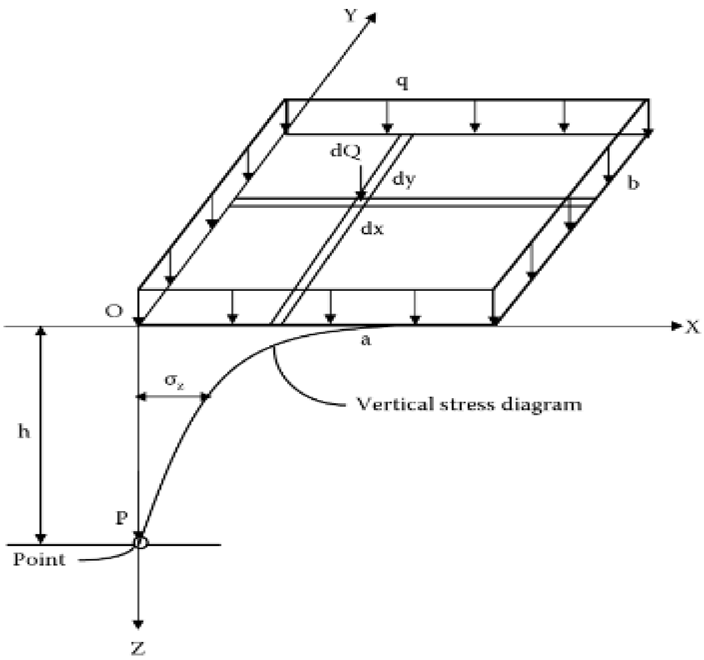


Figure (5) vertical stress under a uniform load intensity [Timothy]

Integration equation (12) above gave:

$$\Delta\sigma = \frac{q}{2\pi}\left(\frac{abz(A^2+B^2)}{A^2B^2C} + \frac{\pi}{2} - arctan\left(\frac{zC}{ab}\right)\right) \quad (13)$$

In which:

$A = (z^2 + a^2)^{0.5}$; $B = (z^2 + b^2)^{0.5}$; $C = (z^2 + a^2 + b^2)^{0.5}$

2.5 The design variables

The design variables (which are virtually the decision variables in the optimization model) represent the dimensions that characterize the respective sectional shape.in this paper the design variable is diameter of stone column (D) and slope of highway embankment (m).

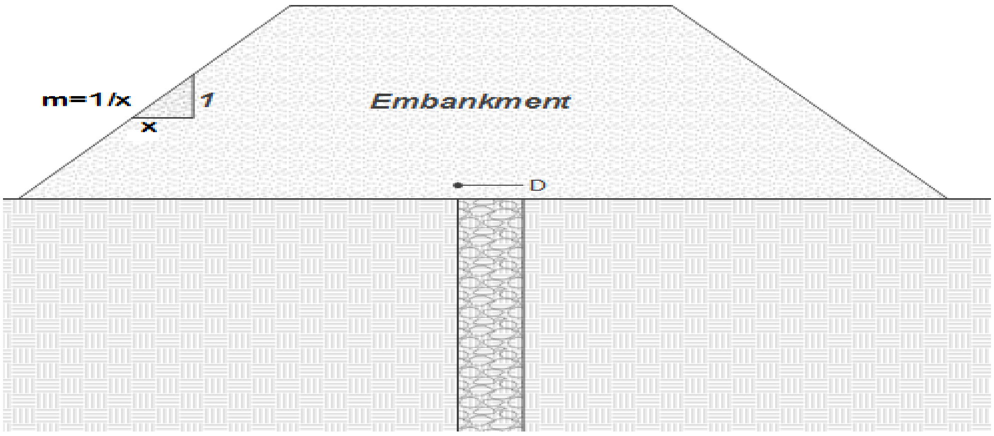


Figure (6) design variable for model of highway embankment with improvement

2.6 The objective function

The objective function for embankment is based on minimum cost for this purpose the area of embankment should be minimize. It can be formulated as follow:

Min. $A = H*(b + H/m) + \frac{\pi}{4}D^2$

Where:
H: embankment height (m)
b : top width of embankment (m)
m:slope of embankment
D: diameter of stone column (m)

2.7 The constraints

The objective function is minimized subject to a set of constraints. Some of these constraints can be explicitly defined in terms of the design variables (i.e., side constraints), such as dimensions, while others are implicitly related to design variables.

1. $m \leq ½$, $0.5m \leq D \leq 1.2m$
2. F.s (factor of slope stability) ≥ 1.5
3. Safety factor of bearing capacity of stone column is (1.5) (Spacing between column 1.5 D center to center)
4. The stresses should remain below maximum allowable values ($\sigma_{ci} < q_{aSLS}$)
5. The total settlement ($\sum S$) should remain below the values set by the operation condition.

3) Plot model by ANSYS

For design optimization model in ANSYS should be built the model to get optimum shape and dimensions for embankment, this built include drawing shape define material, element used with meshing for finite element process, boundary condition and load applied.

1. Drawing model : it suggested symmetrical model, is drawn after defining the initial values of variable which draw the initial shape of embankment and stone column and then hole model configuration as shown in figure(5).

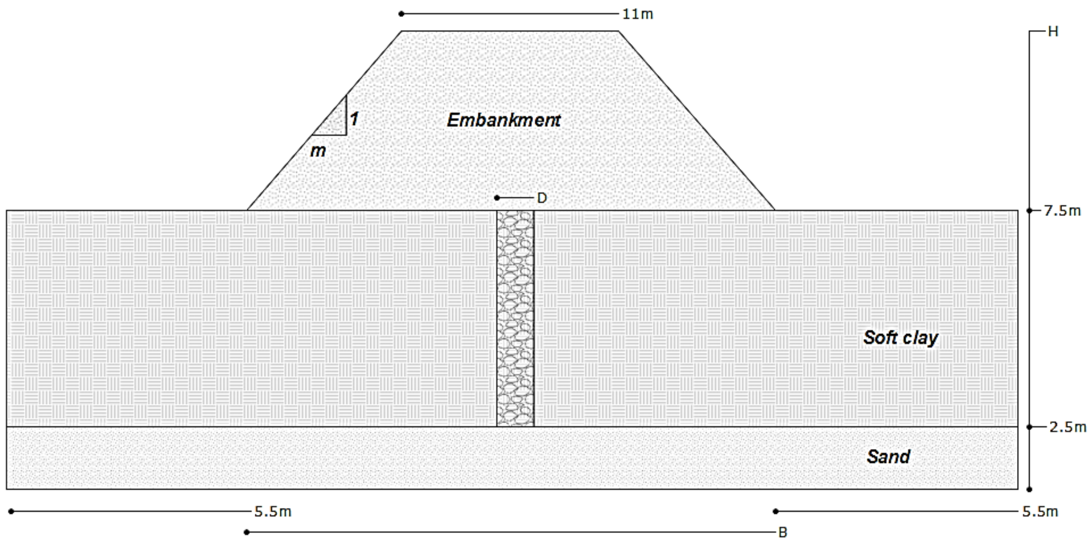


Figure (7) model of highway embankment with stone column

dimensions	Initial value
Slope of embankment (m)	½ (take steeper value for slope to get minimum area)
Top width (b) (constant)	11m (two way highway and it is remain constant in every model.
Height of embankment (h)	2 to 10m (change height for model to get minimum slope for every height)
Bottom width (B)	B = (2*h/m +11)
Depth of foundation(d)	10m (from ground surface to 7.5m depth soft clay, from 7.5 to 10m sand soil.
Width of foundation(B_f)	B_f =B+b
Diameter of stone column(D)	0.5m (take minimum value)
Length of stone column(L)	7.5m (soft clay depth)

Table (1) shown dimensions of embankment model.

2. Define properties of material :the properties of material used in optimum design of highway embankment with stone column as shown in table below:

material	Yong modulus(E) (mpa)	Poassion ratio(ϒ)	Density (γ) (kn/m^2)	Cohesion (cu) (kn/m^2)	ϕ
Embankment	80	0.3	20	5	30
Soft clay	2.4	0.4	17.7	15.8	11
Sand clay	50	0.3	18.3	5	25
subbase	400	0.35	22	------	---
asphalt	5000	0.35	23.5	------	---
Stone column	60	0.3	19	0	44

Figure (2) shown properties of material used in design

- The properties of soft clay material were taken nearby Korek company Building Al-Hilla City.

Figure (8) shown Korek Company Building Al-HillaCity[Ahmed]

The material it can be divided to linear and nonlinear material, Basically, for linear analysis it is assuming that Hooke's Law holds (i.e. linear relationship between stress and strain), other material properties (e.g. CTE, etc) are constant, and deformations are covered by small deflection theory (i.e. plane sections remain plane, etc). Nonlinear analysis allows for nonlinear stress-strain relationships (i.e. beyond yield) and material properties that are temperature dependent. In addition, non-linear analysis allows for the accurate modeling of structures that undergo large deformation.

In this thesis the assumption made that the embankment, stone column and pavement is linear material and foundation soil as nonlinear material

3. Chose element: PLANE 82 is used for 2-D modeling of solid structures.PLANE82 is a higher order version of the 2-D, four-node element (PLANE42). It provides more accurate results for mixed (quadrilateral-triangular) automatic meshes and can tolerate irregular shapes without as much loss of accuracy. The 8-node elements have compatible displacement shapes and are well suited to model curved boundaries. The 8-node element is defined by eight nodes having two degrees of freedom at each node: translations in the nodal x and y directions. The element may be used as a plane element or as an axisymmetric element. The element has plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities. Various printout options are also available.

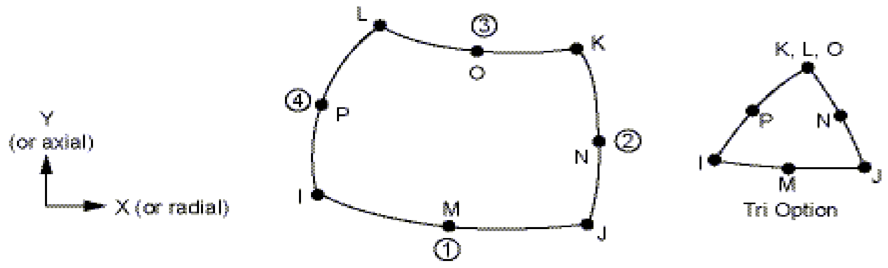


Figure (9) PLANE82 Geometry[ANSYS manual]

For embankment and soft clay used Plane strain (Z strain = 0.0), for stone column used Axisymmetric.To contact between embankment and soft clay used contact element 172, CONTA172 is used to represent contact and sliding between 2-D "target" surfaces (TARGE169) and a deformable surface, defined by this element. The element is applicable to 2-D structural and coupled field contact analyses.The mesh of embankment model with stone column shown in figure (10).

4. Boundary condition: the foundation of embankment model is fixed at bottom and sides in which no translation permissible in X and y directions as shown in figure (10).

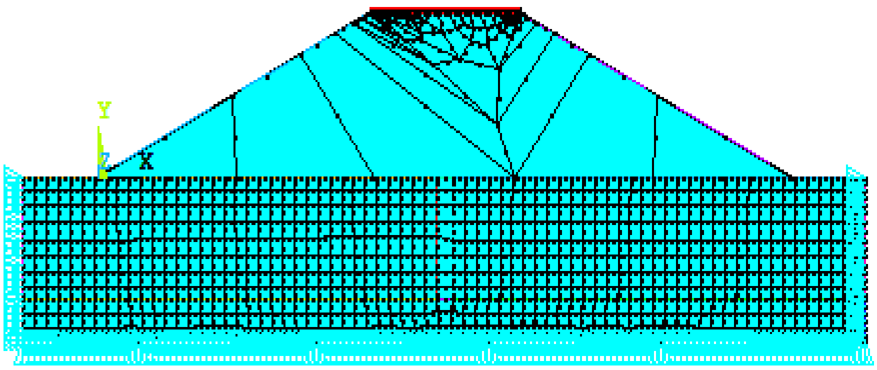


Figure (10) shown the mesh and boundary condition

5. Applied load: the surcharge load (traffic load) applied at the top of embankment model as pressure (uniform distribution pressure) as shown in figure (11).

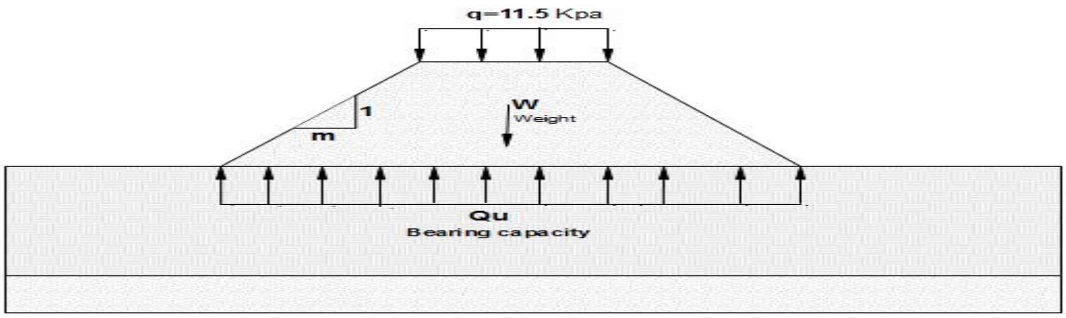


Figure (11) the distribution of load

6. Static analysis:A static investigation ascertains the impacts of unfaltering stacking conditions on a structure, while overlooking dormancy and damping impacts, for example, those brought about by time-differing loads. A static investigation can, in any case, incorporate unfaltering inactivity burdens, (for example, gravity and rotational speed), and time-fluctuating burdens that can be approximated as static proportional burdens, (for example, the static proportionate wind and seismic loads ordinarily characterized in many construction regulations). Static examination

decides the relocations, stresses, strains, and powers in structures or segments brought on by burdens that don't prompt critical dormancy and damping impacts. Relentless stacking and reaction conditions are accepted; that is, the heaps and the structure's reaction are expected to shift gradually regarding time. The sorts of stacking that can be connected in a static investigation include:

- Externally connected strengths and weights
- Steady-state inertial strengths, (for example, gravity or rotational speed)
- Imposed (nonzero) removals
- Temperatures (for warm strain)
- Fluences (for atomic swelling)

4) **Results and discussion**

4.1 Effect the height on design:

With increasing the height of embankment the applied load on foundation of stone columns increase until the foundation cannot carry the load applied on it for certain diameter of stone columns this is meaning the bearing capacity for stone columns is less than the required value (allowable stress of embankment), in this case its need to increase the diameter of stone columns until the bearing capacity of foundation became greater than the allowable stress of embankment with minimum diameter of stone columns can achieve that as shown in figure (12) below:

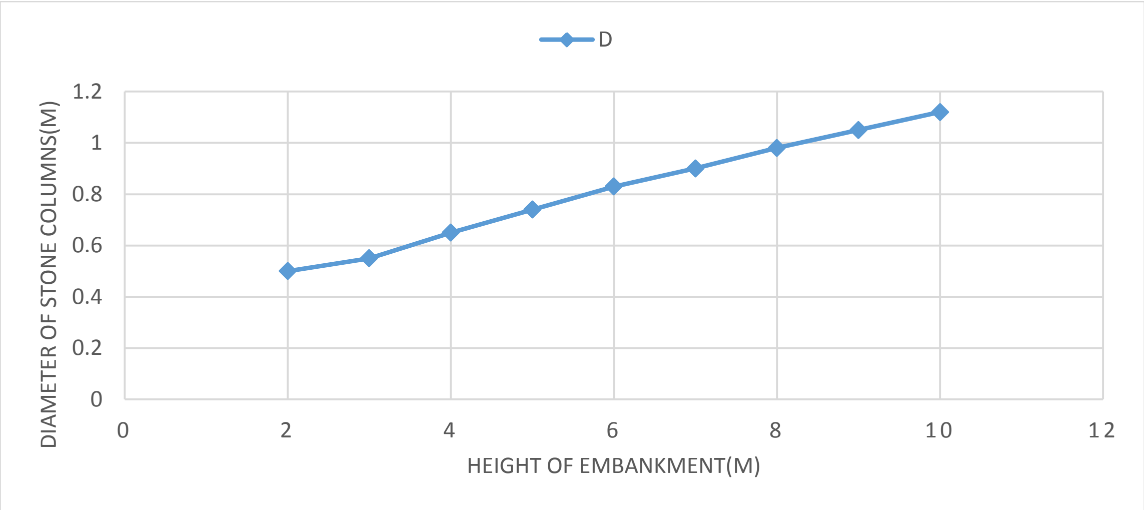


Figure (12) effect the height embankment on diameter of stone columns

From figure above notes with increasing the height of embankment the diameter of stone columns increase for the same properties of stone columns. The percentage of increasing in diameter of stone columns with height shown in equation below:

Increasing in diameter%= $\frac{D_2-D_1}{D_1} * 100\%$

Increase in diameter of stone columns between heights of embankment (H=3m and H=4m) equal to(18.18%), that is meaning its need to increase (18.18%) in the diameter of stone columns for height of embankment (H=3m) to improve bearing capacity to carry the load applied on it form height of embankment (H=4m).

The percentage of increasing in diameter of stone columns between heights of embankment (H=3m and H=10m) equal to (103.63%), this is the percentage of increasing in diameter of stone columns which is required for achieving the bearing capacity in height of embankment (H=10m).

4.2 Effect the surcharge on design

With increasing the surcharge load (traffic load) the diameter of stone columns increase because the allowable stress applied on foundation of stone columns increase this mean its need to increase bearing capacity of stone columns to carry the applied load but this increasing unremarkable and whenever the height of embankment increase the effect of surcharge became more unremarkable until disappeared in high heights because the highway embankment with pavement working as foundation for traffic load and the load disappeared in the soil of highway embankment with the height for same surcharge load, as shown in figure (13).

The figure shown the effect of surcharge on diameter of stone columns for each height of the highway embankment.

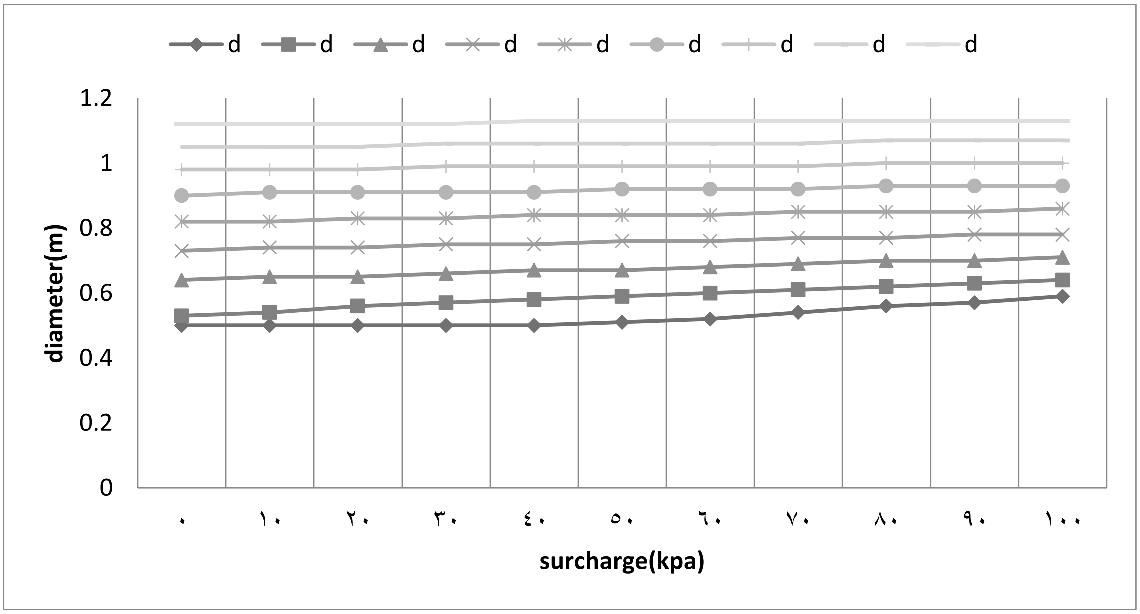


Figure (13) effect the surcharge on diameter of stone columns

From figure (13) above notes increasing in diameter with height this increase decrease with the height of embankment, at height of embankment (H=2m) it can be noted there is no effect for surcharge load on diameter of stone column until the surcharge reach (qu=50KN/m^2) the diameter of stone columns began increase linearly because at beginning not need to increase bearing capacity of stone column and the initial section can carry the allowable stress applied on foundation. At height of embankment (H=10m) it can be noted no increase in diameter until the surcharge reach (qu=40KN/m^2) the diameter of stone columns increase one centimeter and stay constant for anther surcharge because the effect of surcharge decreases gradually with the height of embankment until disappeared, and in this height of embankment the effect of surcharge too low for this reason the change in diameter unremarkable.

Increasing in diameter for height of embankment (H=3m), between (qu=0 and qu=10 KN/m^2) equal to (1.88%). Between (qu=0 and qu=100 KN/m^2) equal to (60.37%). Increasing in diameter for height of embankment (H=10m), between (qu=0 and qu=10 KN/m^2) equal to(0%), between (qu=0 and qu=40 KN/m^2) equal to (0.89%), between (qu=40 and qu=100 KN/m^2)equal to(0%)

It can note at height of embankment (H=3m) the percentage of increase in diameter of stone columns between surcharge load (qu=0 and qu=10 kn/m^2) just (1.88%) but when increase the surcharge load to (qu=100kn/m^2) the percentage increase to (60.37%), but when increase the height of embankment to (H=10m) the increase so small (0.89%).

4.3 Effect the angle of fraction of stone columns on design

With increase the angle of fraction of stone columns the diameter of stone columns decrease because the passive earth pressure of stone columns (kp_{col}) increase that is mean increase in bearing capacity of stone columns lead to decrease in diameter of stone columns for same height of embankment as shown in figure (14) below:

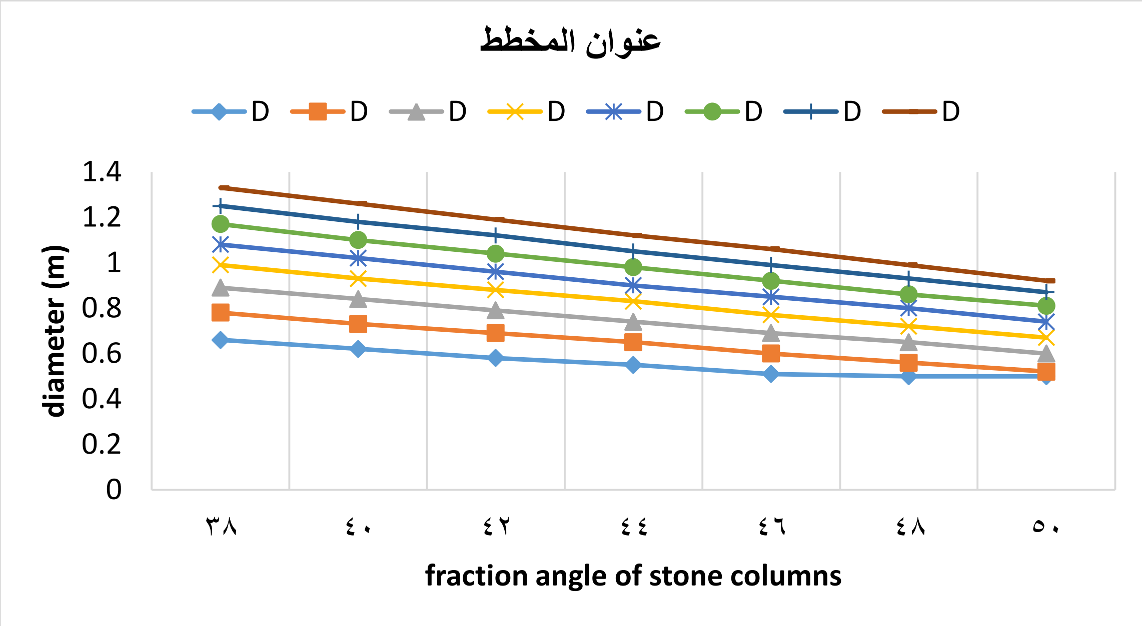


Figure (14) effect fraction angle of stone columns on diameter

From figure (14) above it can be noted the linear decreasing in diameter with increase the fraction angle of stone columns, but at height of embankment (H=3m) and at fraction angle (φ=48º and φ=50º) there is no decrease in diameter because the diameter of stone columns reach to minimum level.

The percentage of decreasing in diameter of stone columns with increase the fraction angle of stone for height of embankment (H=3m), between (φ=38º and φ=40º) equal to (6.06%) and between (φ=38º and φ=50º) equal to(≈ 24.24%). Decreasing in diameter for height of embankment (H=10m) between (φ=38º and φ=40º) equal to (≈ 5.26%) and between (φ=38º and φ=50º) equal to (≈30.8%).

It can be noted increase in percentage of decreasing in diameter of stone columns with increase the fraction angle of stone columns where up about (30%) at fraction angle (φ=50º).

5) CONCLUSIONS

1. The ANSYS APDL is efficient tool to simulate highway embankment foundation interaction problem and optimization process.
2. The individual-accumulative optimization technique used in this researcher gives reasonable procedure to carry out the factor of safety individually.
3. The initial section of highway embankment with stone column that is provide according to initial variables is not representing the optimum section because it is failed by factors of safeties.
4. The soft clay soil in southern of Iraq cannot carry the applied load and it is failed by bearing capacity and excessive settlement for that it is necessary to improve it by suitable method before construction of highway embankment to avoid failed it by bearing capacity and excessive settlement
5. Increase in diameter of stone columns with increasing height of highway embankment because with increasing the height of highway embankment the allowable stress increase and it is need to increase bearing capacity of foundation of stone columns until reach the required value. Increase in diameter of stone column between initial section and optimum section for height of highway embankment (H = 3m) equal to (10%), and for height of highway embankment (H =10m) equal to (124%) for certain fraction angle of stone column (φ = 44º). Percentage of Increasing in diameter of stone column between height of highway embankment (H=3m and H=10m) about (103%) because increasing in allowable stress about (200%).
6. Increase the diameter of stone column with increase surcharge load (traffic load) because with increase surcharge load the allowable stress applied on foundation increase for this reason it is

need to increase bearing capacity of stone column by increase diameter of stone column but this increase in allowable stress decrease with height of highway embankment because the effect of surcharge load disappear gradually inside of embankment soil with height of it until reach the ground surface of foundation.

7. Linear decreasing in diameter of stone column with increase fraction angle of stone column for same height of highway embankmentbecause the passive earth pressure of stone columns (kp_{col}) increase that is mean increase in bearing capacity. The percentage of decreasing in diameter of stone column reach to (31%) if increase fraction angle of stone column from (φ=38º to φ=50º) for height of highway embankment (H=10m).

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