Probabilistic assessment for Analysis of Retaining Structures Supporting Cemented Sand Soil

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Abstract: This paper aims to quantify the uncertainty associated with the methods commonly used for calculating straining action values (mainly the bending moments) of retaining structures sections supporting cemented sand. The study is concerned with diaphragm wall supporting three kinds of cemented sand currently founded in the nature (Sand cemented with calcium carbonate, calcium sulphate and clay). A probabilistic approach based on Monte Carlo simulation technique is used to determine the increase in bending moment values and its probability of occurrence, due to change in soil characteristics from dry to soaked state as a result of exposure to water. This paper is useful in that it enables the designer to calculate the increase in straining action (Bending Moment)values relevant to the risk taken and its probability of occurrence, as a result the designer can calculate an economical retaining structures sections.

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Key words: Cemented Sands, Diaphragm walls, Probabilistic Approach, Monte Carlo simulation

1. Introduction

Cemented sands are found in many deserts all over the world. In Egypt Cemented sands cover extensive area of desert land where there is a very long dry season, and ground water table is at great depths. Now a days the probability of water existence in such cemented sand areas is high due to expansion in building new cities in these areas, due to water existence the cemented sands will lose part of its privilege of cementation and the soil shear strength parameters (C,ϕ) will degrade from dry state to wet state. Since any retaining structure serve generally to resist horizontal pressures due to soil and water. They derive their stability from the horizontal resistance of the ground into which they are driven and also from the horizontal support provided by any anchors, ties or struts placed at a higher level and hence both the retained soil and supporting soil characteristics has a great affect in the design of any retaining structure. This paper aims to propose a probabilistic-based methodology to assess straining actions (bending moments) of retaining structures supporting cemented sand soils (taking into account the degradation of shear strength parameters of cemented sands from a dry state to a wet state) specially when such retaining structures are used as temporary structure to get an economical design at reasonable risk.

2. Methodology

In order to conduct a probabilistic assessment of retaining structures straining actions, Monte Carlo simulation is applied. Monte Carlo simulation attempts to generate a random set of values from known or assumed probability distributions of some variables involved in a certain problem. Full details of the Monte Carlo technique are given by many authors (e.g. **Hammersley and Handscomb 1964; Rubinstein 1981).** With the help of Monte Carlo simulation the soil shear strength parameters (C, ϕ**)** (the value of each parameter and it's probability of occurrence) variations between soaked and dry state probability distribution can be assumed or obtained from in situ tests that can be performed in variety of soil types, degrees of wetting and geotechnical conditions.

These soil shear strength parameters can be used by any retaining structure analytical method to generate a set of retaining structure straining actions distribution and it's probability of occurrence. The generated set of retaining structure straining actions distribution and it's probability of occurrence are invaluable. For example it can be used by the designer to obtain the increase in the straining actions as a percent of its minimum value and its relation of cementing agent type, contents and soil Relative Density (RD). Hence the designer can get an economical design based on the site location, soil conditions, kind of the structure, its importance and the purpose of its construction (temporary or permanent).

3. Case Study

To illustrate the methodology proposed in this study a diaphragm wall with total height 9 meters, retained height equals 5 meters and penetration depth equals 4 meters as shown in figure (1). This wall is founded in cemented sand with three types of common cementing agents (calcium carbonate, calcium sulphate, and clay), Cementing agent's contents are 2% and 12%, and Relative densities are 0.2 and 0.8.

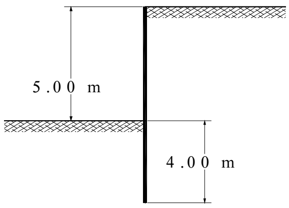

Fig.1. Diaphragm wall used in the study

The shear strength parameters for both dry and soaked conditions of the above three types of sand are found in [1] "Shear Strength of Cemented Sand", M.Sc. Thesis, Faculty of Engineering, Cairo University (1988).

A finite element program (PLAXIS - 2002) is used in the analysis of the proposed diaphragm wall. Table 1,2 and 3 show a sample of the soil parameters and their corresponding PLAXIS straining actions output used in the analysis.

Table 1 Soil Parameters and corresponding diaphragm wall's straining actions (Case of Calcium Carbonate Cementation)

Cementing Content	Relative Density	ϕ	Soil State	C KN/m^2	E KN/m2	Angle of dilatancy (ψ)	γ_{dry} KN/m^3	Poisson's Ratio	B.M. Values KN.m
2%	0.2	33	Soaked	5*	18500*	3*	15.52*	0.35*	37.64
		33		10	37000	3	15.52	0.35	36.87
		33		15	55500	3	15.52	0.35	35.06
		33	Dry	20*	74000*	3*	15.52*	0.35*	35.03
	0.8	39*	Soaked	15*	150000*	9*	17.34*	0.35*	25.13
		39.5		20	215000	9.5	17.34	0.35	24.63
		40.5		25	400000	10.5	17.34	0.35	23.63
		41*	Dry	30*	600000*	11*	17.34*	0.35*	23.13
12%	0.2	29*	Soaked	30*	17250	0*	15.06*	0.35*	41.1
		29.3		35	34500	0	15.06	0.35	40.35
		30		45	75000	0	15.06	0.35	38.85
		↓		↓					
		31*	Dry	60*	11000	1*	15.06*	0.35*	36.6
	0.8	36*	Soaked	40*	23833*	6*	17.76*	0.35*	53.93
		36.3		45	26812	6.28	17.76	0.35	52.45
		36.6		50	29791	6.56	17.76	0.35	51.4
		40.5	Dry	120*	71500*	10.5*	17.76*	0.35*	37.7

Table 2. Soil Parameters and corresponding diaphragm wall's straining actions (Case of Calcium Sulphate Cementation)

Cementation Content	Relative Density	ϕ	Soil State	C KN/m^2	E KN/m2	Angle of dilatancy (ψ)	γ_{dry} KN/m^3	Poisson's Ratio	B.M. Values KN.m
2%	0.2	32*	Soaked	25*	60000*	2	15.3	0.35	34.64
		32		30	80000	2	15.3	0.35	34.26
		32		35	150000	2	15.3	0.35	33.57
		32*	Dry	80*	260000*	2	15.3	0.35	29.76
	0.8	32.5*	Soaked	45*	41210*	7	17.33	0.35	38.38
		32.67		50	45789.48	7.23	17.33	0.35	37.65
		32.83		55	50368.42	7.45	17.33	0.35	37.48
		37*	Dry	180*	133636.36*	2.5	15.07	0.35	28.57
12%	0.2	30*	Soaked	70*	51969.7	0	15.07	0.35	39.57
		30.11		75	55681.82	0.11	15.07	0.35	39.12
		30.23		80	59393.94	0.23	15.07	0.35	38.36
		32.5*	Dry	180*	133636.36	2.5	15.07	0.35	28.57
	0.8	35*	Soaked	110*	10000	5	18.04	0.35	38.25
		35.12		115	15000	5.12	18.04	0.35	37.93
		35.24		120	20000	5.24	18.04	0.35	37.45
		40*	Dry	320*	141875	10	18.04	0.35	25.65

Table 3. Soil Parameters and corresponding diaphragm wall's straining actions (Case of Clay Cementation)

Cementation Content	Relative Density	φ	Soil State	C KN/m²	E KN/m2	Angle of dilatancy (ψ)	γ_{dry} KN/m³	Poisson's Ratio	B.M. Values KN.m
2%	0.2	33*	Soaked	10*	10000*	3	15.25	0.35	45.91
		33		15	60000	3	15.25	0.35	44.82
		33		20	110000	3	15.25	0.35	43.73
		33*	Dry	75*	495000*	3	15.25	0.35	31.74
	0.8	39*	Soaked	25*	40000*	9	17.15	0.35	34.18
		39.17		30	105000	9.17	17.15	0.35	33.97
		39.33		35	187000	9.33	17.15	0.35	33.76
		41*	Dry	85*	365000*	11	17.15	0.35	25.54
12%	0.2	30*	Soaked	5*	13529.41*	0.06	15.22	0.35	46.88
		30.06		10	27058.82	0.11	15.22	0.35	46.38
		30.12		15	40588.24	0.18	15.22	0.35	45.88
		32*	Dry	170*	460000*	2	15.22	0.35	30.44
	0.8	35*	Soaked	45*	5000*	5	17.72	0.35	43.58
		35.11		50	18000	5.11	17.72	0.35	43.32
		35.21		55	30000	5.21	17.72	0.35	43.06
		40*	Dry	280*	255000*	10	17.72	0.35	31.36

N.B. The parameters with * mark is the soaked and dry soil parameters found in [1], other parameters are intermediate values calculated between the marked values.

In order to conduct a probabilistic assessment of diaphragm wall straining actions, Monte Carlo simulation is applied. In this paper @Risk program **(Palisade 2002)** is used to generate an assumed predefined normal distribution of soil shear strength parameters (C, ϕ) variations between soaked and dry state probability distribution as shown in figure 2. These soil parameters are used in the analysis of diaphragm wall.

The PlAXIS straining actions output for the diaphragm wall (maximum bending moment and maximum shearing force) are correlated to its corresponding predefined soil shear strength parameters (c). Using these correlated output values and by the help of @Risk, a random set of diaphragm wall straining actions are generated. As a result the **@Risk program** (2002) output is a set of straining actions values and its probability of occurrence distribution as shown in figure 3.

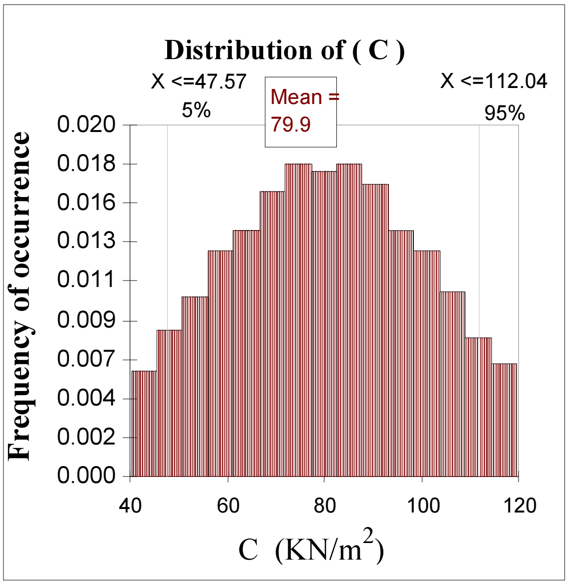

Fig. 2. Soil parameter (C) probability predefined distribution. Case of Calcium Carbonate Cementation

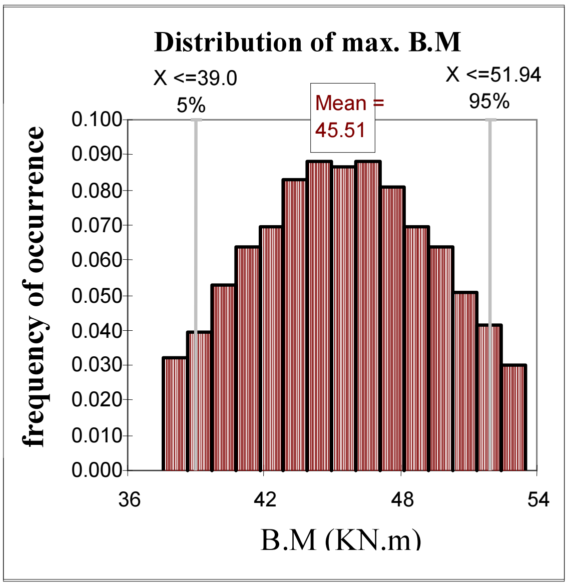

Fig. 3. Diaphragm wall max. B. M. probability distribution. Case of Calcium Carbonate Cementation

In this paper, a suggested referenced dry state straining action values is taken to study the effect of cemented sands shear strength parameters decreasing due to wetting on the increasing of diaphragm walls maximum straining actions (mainly bending moment) and its probability of occurrence, hence the percentage of increase in the bending moment is calculated as follows:

$$\% \text{ increase in max. B.M} = \frac{\text{max.B.M (at soaked state)} - \text{max.B.M (at dry state)}}{\text{max.B.M (at dry state)}}$$

4. Analysis and Discussion of Results

Effect of Cementing Agent

The effect of cementing agent on diaphragm wall maximum bending moment increasing due to wetting at probability of occurrence equal 95% and less (i.e. the risk to exceed this increase equal 5%) is studied and the result of this study is shown in table 4 and figure 4.

Table 4.percentage of increase in the maximum bending moment at probability of occurrence equal 95% and less (Case of Cementing content equal 2% and Relative Density equal 0.2)

Cementing Agent	C (KN/m^2)			B.M. (KN.m)		% increase in B.M
	Soaked	Dry	Difference	Soaked	Dry	
Calcium Carbonate	5	20	15	37.507	35.03	7.07%
Calcium Sulphate	25	80	55	34.64	29.76	16.40%
Clay	10	75	65	45.91	31.74	44.64%

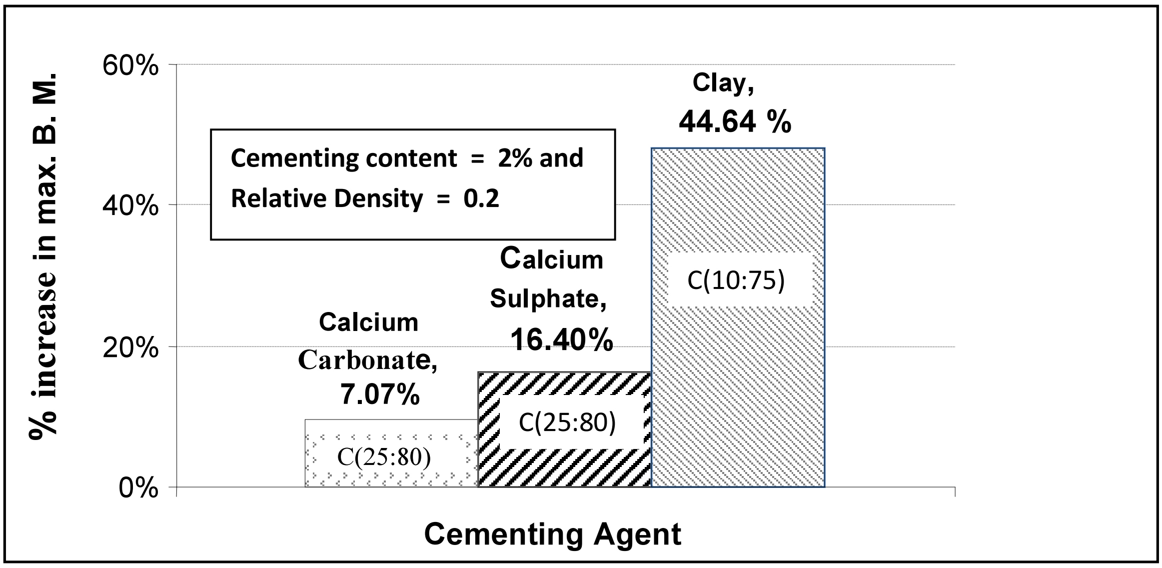

Fig. 4. Relation between C and percentage of increase in the maximum bending moment for three kinds of cemented sand at cementing content of 2 % and relative density of 0.2

From table 4 and figure 4 it is clear for the same cementing content and relative density (case of cementing content equal 2% and relative density equal 0.2) that the percentage of increase in the maximum bending moment at probability of occurrence 95% and less (i.e. the risk to exceed this increase equal 5%) is more in case of clay agent than that of calcium sulphate and calcium carbonate respectively. This is because the difference between cohesion (C) at the dry state and cohesion (C) at the wet state is higher in case of clay agent than that of calcium sulphate and calcium carbonate respectively.

Effect of cementing content

The effect of cementing content on diaphragm wall's maximum bending moment due to wetting at probability of occurrence 95% and less is studied and the results of this study are shown in table 5a, 5b and 5c and figure 5.

Table 5a.Percentage of increase in the maximum bending moment at different cementing content and different relative densities (Case of Calcium Carbonate Cementation)

Cementing Content	Relative Density	ϕ			C			B.M. (KN.M)		% increase
		Soaked	Dry	Difference	Soaked	Dry	Difference	Soaked	Dry	
2%	0.2	33	33	0	5	20	15	37.507	35.03	7.07%
	0.8	39	41	2	15	30	15	25.13	23.13	8.65%
12%	0.2	29	31	2	30	60	30	40.51	36.6	10.67 %
	0.8	36	40.5	4.5	40	120	80	37.7	53.93	43.05%

Table 5b.Percentage of increase in the maximum bending moment at different cementing- content and different relative densities (Case of Calcium Sulphate Cementation)

Cementing Content	Relative Density	ϕ			C			B.M. (KN.M)		% increase
		Soaked	Dry	Difference	Soaked	Dry	Difference	Soaked	Dry	
2%	0.2	32	32	0	25	80	55	34.64	29.76	16.40%
	0.8	32.5	37	4.5	45	180	135	38.38	28.57	34.34%
12%	0.2	30	32.5	2.5	70	180	110	39.57	28.57	38.50%
	0.8	35	40	5	110	320	210	38.25	25.65	49.12%

Table 5c. Percentage of increase in the maximum bending moment at different cementing- content and different relative densities (Case of Clay Cementation)

Cementing Content	Relative Density	ϕ			C			B.M. (KN.M)		% increase
		Soaked	Dry	Difference	Soaked	Dry	Difference	Soaked	Dry	
2%	0.2	33	33	0	10	75	65	45.91	31.7	44.83%
	0.8	39	41	2	25	85	60	38.2	25.54	49.57%
12%	0.2	30	32.5	2.5	5	170	165	46.88	30.44	54.01%
	0.8	35	40	5	45	280	235	43.58	26.54	64.20%

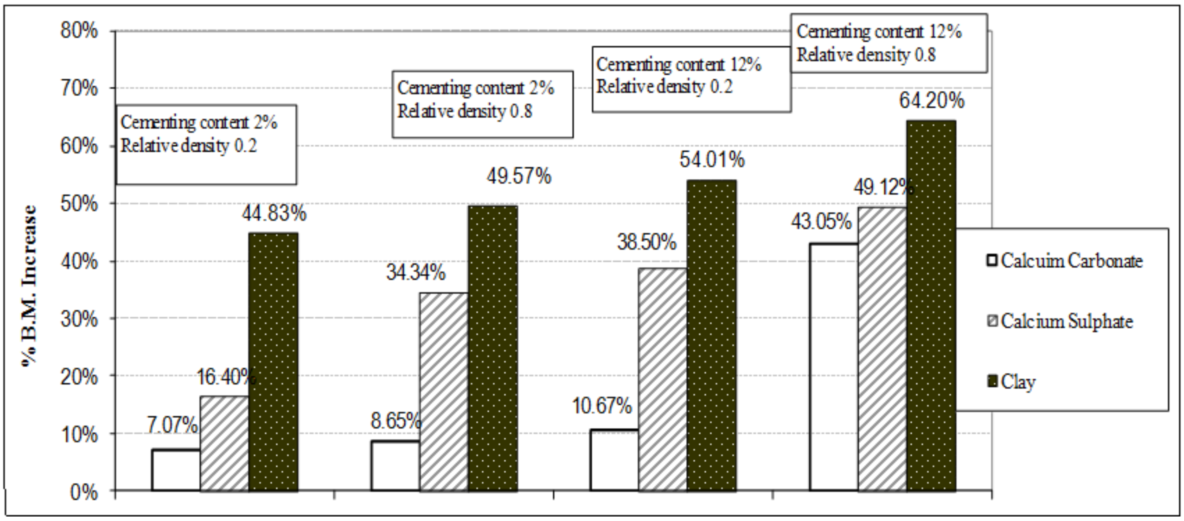

Fig.5 Relation between cementing content, relative density and percentage increase in maximum bending moment for three kinds of cemented sand

From Tables 5a, 5b&5c and figure 5 it can be deduced for all kinds of cementing agents with relative density 0.2 or 0.8 that the increase in the maximum bending moment is more for the case of cementing content 12% than that for the case of cementing content 2%, and it is also clear that this increase is significant in the case of relative density 0.8. This is due to the increase in the difference between both (C) and (ϕ) at dry state and those at wet state with increase of both cementing content and relative density.

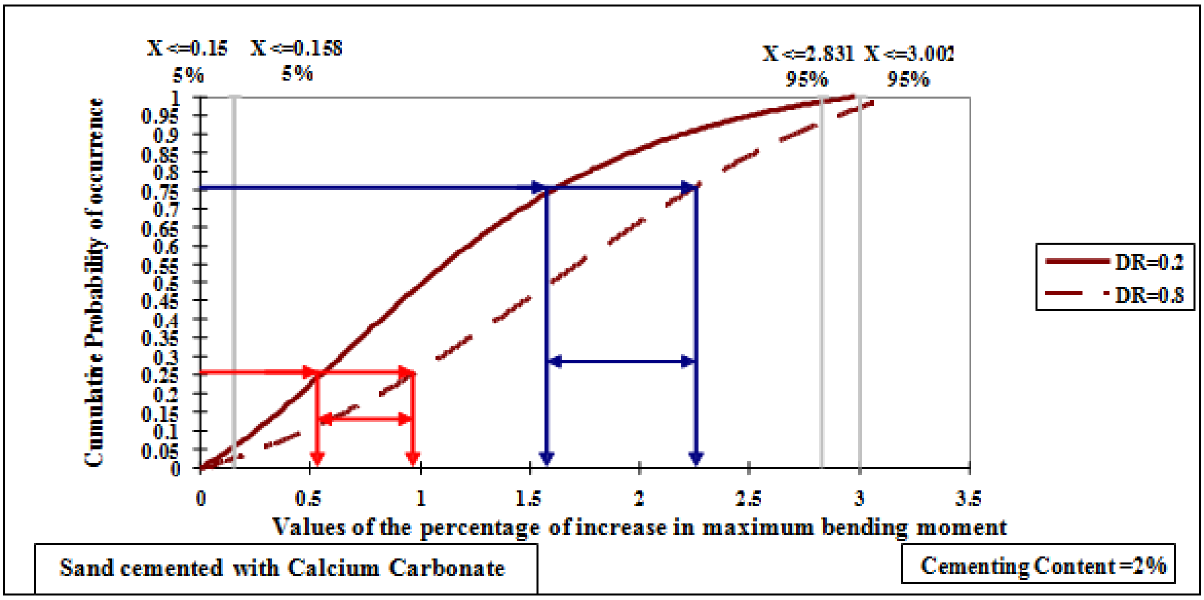

Figure 6.a Relation between maximum increase in maximum bending moment and its probability of occurrence for sand cemented with 2 % calcium carbonate

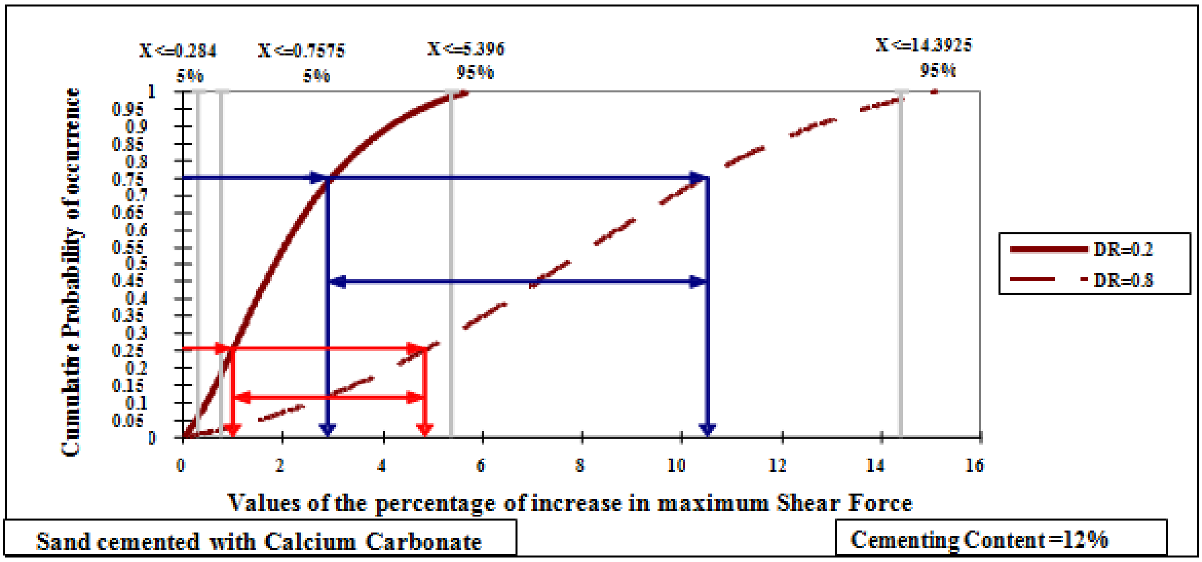

Figure 6.b Relation between maximum increase in maximum bending moment and its probability of occurrence for sand cemented with 12% calcium carbonate

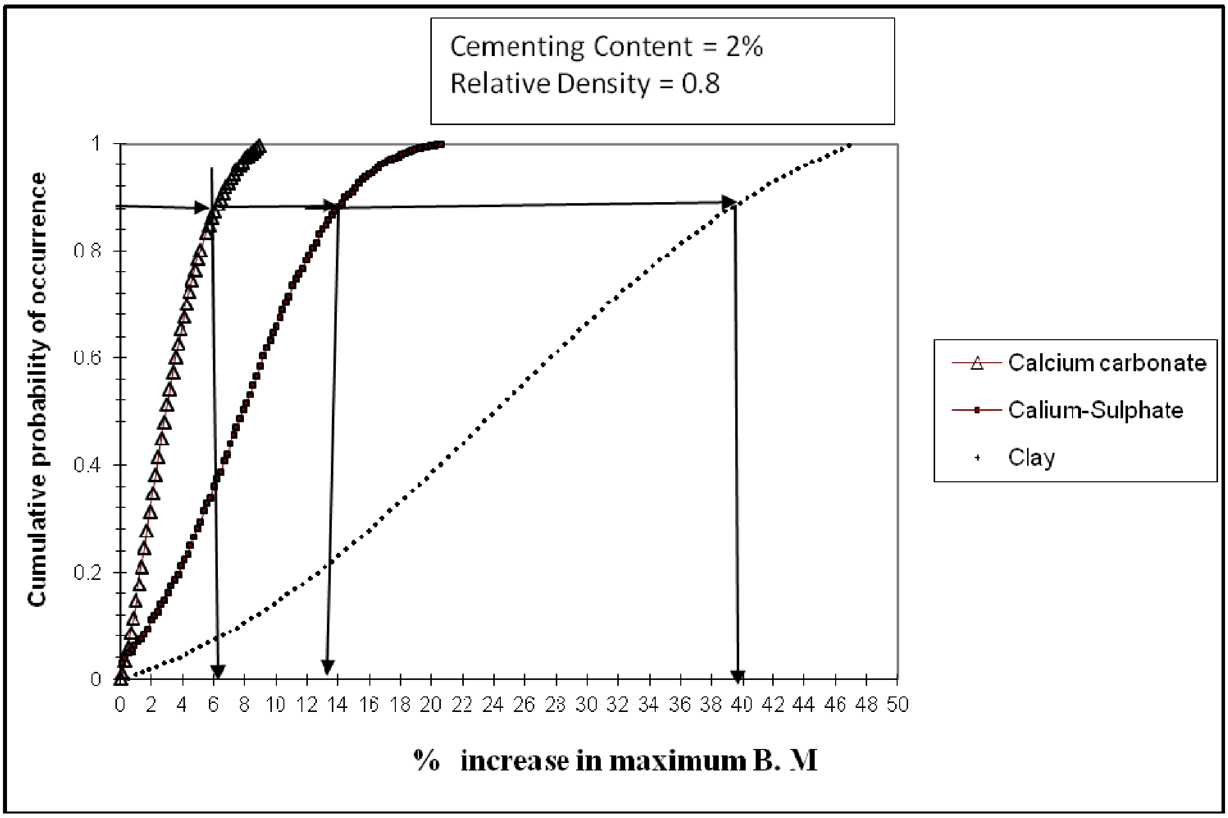

Fig. 6.c Relation between maximum increase in maximum bending moment and its probability of occurrence for sand cemented with 2% content of three kinds of cemented sand

Probability distribution for percentage increase in the bending moment

With the help of **@risk program** a set of maximum bending moment values and its frequency distribution for cases of different cementing agent are produced, As a result the increase in maximum bending moment and its probability of occurrence is calculated. Figures 6.a&b shows the increase in maximum bending moment and its probability of occurrence for case of same cementing agent (calcium carbonate) with different cementing contents (cementing contents equal 2% and 12%, with relative density (RD) 0.2 and 0.8), While Figure 6.c shows the increase in maximum bending and its probability of occurrence for case of sand cemented with different cementing agents and with constant cementing content equal 2% and relative density (RD) equal 0.8.

From figures 6.a and 6.b for all probabilities of occurrence (i.e. for all risk values) it can be observed for the same cementing content 12% that the percentage of the increase in maximum bending moment values at relative density 0.8 is significantly greater than those values of relative density equals 0.2. But the difference of the percentage of the increase in maximum bending moment values in the case of cementing content 12% is greater than that difference in the case of cementing content of 2%. It can also be noticed that for case of cementing content 2% the difference between the percentage of the increase in bending moment values for relative density 0.2 and 0.8 at probability of occurrence less than 50% is approximately equal to that difference for probability of occurrence more than 50%.On the other hand in the case of cementing content 12% the difference between the percentage of the increase in bending moment values for relative density 0.2 and 0.8 at probability of occurrence the more than 50% is significantly greater than that difference for probability of occurrences less than 50%.

It is also clear from figure 6.c that for the same cementing content, relative density and for all probabilities of occurrence (i.e. for all risk values) the percentage of increase in maximum bending moment in case of sand cemented with clay is more than that for cases of sand cemented with calcium sulphate and calcium carbonate respectively.

Conclusions

For the same probability of occurrence equal 95% or less and for all kinds of cementing agents:-

a. The larger the cementing content, the larger the percentage of the increase in maximum bending moment.
b. For the same content of cementation equal 2% the percentage of the increase in maximum bending moment values at relative density equal 0.8 are slightly greater than those of relative density equal 0.2.
c. For the same content of cementation equal 12% the percentage of the increase in maximum bending moment values at relative density equal 0.8 are significantly greater than those of relative density equal 0.2.

For any probability of occurrence and for all kinds of cementing agents:-

d. At a cementing content equals 2%, the difference between the percentage of increase in maximum bending moment values for relative density equal to 0.2 and to 0.8 at probability of occurrence of less than 50% is approximately equal to that difference for probability of occurrence more than 50%.
e. At a cementing content equals 12% the difference between the percentage of increase in maximum bending moment values for relative density equal 0.2 and 0.8 at probability of occurrence of more than 50% is significantly greater than that difference for probability of occurrences of less than 50%.
f. For the same cementing content and same relative density the percentage of increase in maximum bending moment in case of sand cemented with clay is more than that for cases of sand cemented with calcium sulphate and calcium carbonate respectively.

Recommendations

As a result from the above conclusions, the maximum bending moment values for retaining structures supporting cemented sand will probably increase if the cemented sand soil is exposed to water. This increase should be considered in the design retaining structures sections. The designer has to decide on the acceptable risk for the likelihood of the seepage of water according to the site surrounding circumstances, and according to the type of cemented sand soil found in the site. According to the risk decided by the designer and with the help of this paper, the designer can calculate the percentage of the increase in the maximum bending moment values relevant to the risk taken and its probability of occurrence. As a result the designer can obtain an economical retaining structures sections.

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References

1. Abouleid. A.F, El Mamlouk .H.H and Hussein. A.K. (1988), "Shear Strength of Cemented Sand", M.Sc. Thesis, Faculty of Engineering, Cairo University.
2. Palisade. (2000), @Risk: Risk analysis and simulation (version 4.5 2002) Palisade corp. New York.
3. Plaxis program (finite element) version 8.2 2002.
4. Rubinstein, R.Y. (1981), Simulation and the Monte Carlo method. Wiley Press. New York.
5. @RISK program (Risk Analysis and Simulation) version 4.5 2002.
6. Hammersley, J. M. and Handscomb, D. C. (1964). Monte Carlo methods, Wiley Press, New York.

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