Applicability of the Field Deformation Measurement Data in Predicting the Stability of Embankment Slopes

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ABSTRACT: Matsuo chart, which is based on the field measurement of the settlement at the center of an embankment and the lateral deformation at the toe, is widely used in practice in evaluating the stability of embankments. However, the applicability and the accuracy of the Matsuo chart in evaluating the stability of embankment slopes under varying geometrical and subsoil conditions needs further investigations. Therefore, the current study aimed at investigating the above using the finite element method and limit equilibrium approach. Stability of different embankments including several case histories were analyzed by varying the embankment height, width and the sub soil parameters and factor of safety values were determined by the use of Matsuo chart, finite element method and the limit equilibrium method. Results of the current study suggest that Matsuo chart can reasonably predict the stability of embankment slopes under varying embankment conditions.

1 INTRODUCTION

In order to construct a safe and operational embankment, it is essential to evaluate the stability of the embankment during the construction and after the construction. Stability of the embankment can be evaluated by using available analytical methods and using field monitoring data. Analytical methods include the limit equilibrium method and finite element method. Choice of correct analysis method depends on both site condition and the potential mode of failure.

In Finite Element Method (FEM), soil mass is divided into number of small elements and appropriate stress- strain behavior is assumed for the soil element. In FEM, stability of the embankment slopes can be evaluated by using phi – c reduction method. Here strength parameters (ϕ and c) of the soil are successively reduced until failure of the structure occurs. Both of the factor of safety value and the deformation characteristics of the embankment can be obtained by using FEM. In Limit Equilibrium method (LEM),numbers of appropriate failure surfaces are assumed and their factor of safety (FoS) values can be determined. The minimum FoSvalue is taken as the factor of safety value of the slope and the corresponding failure surface is taken as the critical failure surface.

Use of field monitoring data to evaluate the stability of the embankment is easy and more practicable than the use of analytical methods.

Embankment over soft ground is usually constructed with a smaller safety factor compared to the other structures. The evaluation of the stability of such embankment can be done quickly and easily by using practically possible measurements. Matsuo and Kawamura (1977) proposed a prediction method of failure of soft ground by observing the settlement at the center of the embankment and lateral displacement at the toe of the embankment as shown in Fig. 1.

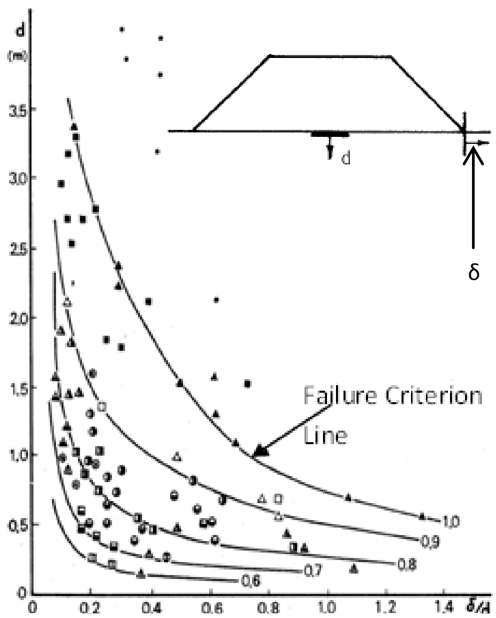


Fig. 1 (δ /d – d) diagram for prediction of failure

This is an observational method that links closely with the failure of the embankment, since deformation of the ground is closely related to the failure of the embankment. On the other hand, observation of deformation is easier and more accurate than monitoring of earth pressure.

However, applicability and the accuracy of the Matsuo chart in evaluating the stability of the embankment slopes under varying geometrical and subsoil conditions needs further investigations. Therefore, present study is aimed at investigating the above using advanced numerical tools.

2 BACKGROUND

Matsuo and Kawamura (1977) evaluated the several failed embankments using (d, δ/d) plot and they found that those embankments failed near the failure criterion line.

Premalal et al (2012) evaluated the stability of three failed embankments using Matsuo chart. According to the Matsuo chart two embankments showed this instability condition and other failed section didn't show this instability condition. Premalal et al (2012) stated that it may be a sudden failure due to stockpiling of the fill material on the embankment or any other reason.

Influence of the mechanical and geometrical condition on the deformation characteristics on the (d, δ/d) plot was investigated by the Matsuo and Kawamura (1977). They mentioned that deformation characteristics are strongly influenced by the ratio of the loading width and the thickness of the soft ground and influence of the soil properties can be neglected.

3 METHODOLOGY

A hypothetical embankment on peaty clay was selected as shown in Fig. 2 and the effect of the embankment height (H), embankment width (B) and the sub soil parameters (Cohesion/c_u) on the FOS of the embankment were analyzed.Thickness of the peaty clay layer was taken as 10m with the water table at the existing ground level. Embankment height, embankment width and the sub soil parameters were varied as shown in Table 1. Stability of each embankment was analyzed by using Finite Element Method, Limit equilibrium method and the Matsuo chart incorporating the deformations obtained from the finite element analysis. Soil properties of the sub soil strata are presented in Table 2.

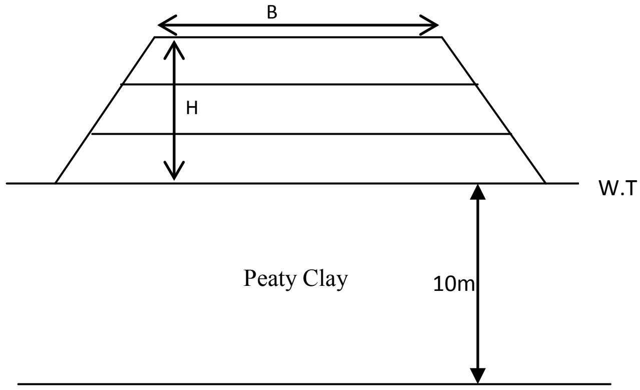


Fig. 2 Geometry of the hypothetical embankment

Table1. Variation of embankment height (H), width (B) and the un-drained shear strength (c_u)

B (m)	H (m)	c_u (kN/m^2)
3	3	5,15,25
	4	5,15,25
	5	5,15,25
	6	5,15,25
5	3	5,15,25
	4	5,15,25
	5	5,15,25
	6	5,15,25
8	3	5,15,25
	4	5,15,25
	5	5,15,25
	6	5,15,25

Table 2. Soil parameters employed in the analysis

	Peaty Clay	Fill
Model	SSC	MC
Condition	Un – drained	Drain
γ_{unsat} (kN/m^3)	11	18
γ_{sat}(kN/m^3)	11	20
Φ_u/ Φ'	0.1	30
c_u / c'(kN/m^2)	5,15,25	5
kx (m/day)	$2*10^{-3}$	1
ky (m/day)	$1*10^{-3}$	1
E (kN/m^2)	350	20000
v	0.35	0.3
e_0	1.5	-
Cc	0.75	-
Cr	0.075	-
Cα	0.05	-

3.1 *Finite element method*

Finite Element Analysis was carried out by using PLAXIS 8.2 commercial software and plain strain 15 nodes elements were used to model the embankment. Stability of the embankment was evaluated by using updated mesh analysis and factor of safety values (FOS) were gained using phi-c reduction technique.

Filling was carried out in three layers and each layer was subjected to 5 days of working period and the 200 days of consolidation period when the fill height is 3m, 4m and 5m. For the 6m fill height 15 days of working period and 200 days of consolidation period was selected.

Soft Soil Creep (SSC) model was used to model the behavior of peaty clay layer. Input parameters are presented in Table 2. Fill was modeled by using Mohr Coulomb (MC) model.

In addition to the FOS values, vertical settlement at the center of the embankment and the lateral displacement at the toe of the embankment were also obtained from the finite element analysis. Those values were used to read the Matsuo chart.

3.2 *Limit equilibrium method*

SLOPE/W 6.0 software was used to conduct the Limit equilibrium analysis. Morgentsern and Price method was used in obtaining the FoS values. Factor of safety values were obtained using grid and radius method.

3.3 *Analysis of the embankment using Matsuo chart*

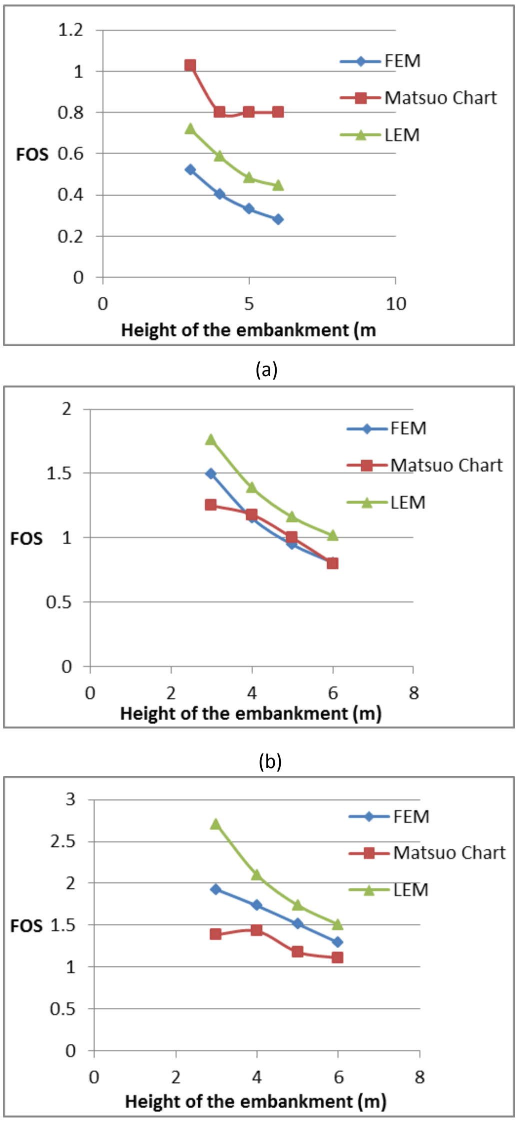
Vertical settlement at the center of the embankment (d) and the lateral displacement (δ) at the toe of the embankment were used as input parameters. These displacement values were obtained from the FEM analysis as explained before.

4 RESULTS AND DISCUSSION

4.1 *Variation of the factor of safety values with the embankment height*

Fig. 3 shows the variation of the factor of safety values with the embankment height for various shear strength parameters of the sub soil. According to the Fig. 3 it can be seen that factor of safety values decrease with the increase of the embankment height.

It can be observed that it is not reliable to use Matsuo chart to predict the stability of embankments on week sub soils. Because, large values of “d’’ and ‘’δ/d’’ represent a point beyond the failure criterion line and it is difficult to find an exact value for the FOS.



(c)

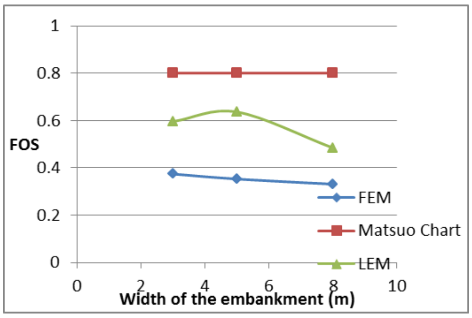
Fig. 3 Variation of factor of safety values with embankment height(a) c_u=5kN/m^2 (b) c_u=15kN/m^2(c) c_u=25kN/m^2

For lower un-drained shear strength values Matsuo chart gives higher factor of safety values than the LEM and FEM. And for higher shear strength values it gives lower factor of safety values than the LEM and FEM. In addition, it can be observed that the factor of safety values obtained through the LEM is higher than that of FEM.

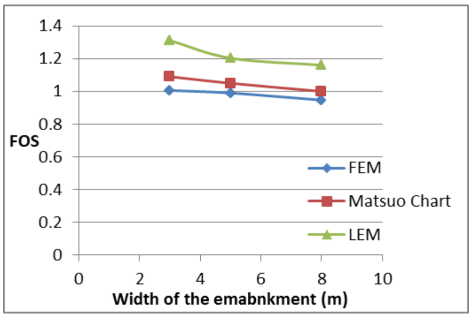
Further, it can be seen that the FOS values obtained from the Matsuo chart (based on “d” and “δ” obtained from the finite element analysis) and the FOS values obtained using Phi-c reduction method gives similar results for larger c_u values.

4.2 *Variation of the factor of safety values with the embankment width*

Variation of the factor of safety values with the embankment width is shown in Fig.4. It can be seen that there's no significant variation of the FOS values with the embankment width. So, increase of the embankment width will not significantly affect the stability of the embankment. Similar to the previous case for lower un-drained shear strength values, Matsuo chart gives higher factor of safety values than the LEM and FEM and for higher shear strength values it gives lower factor of safety values than the LEM and FEM.Thedifference between the FOS values obtained from the FEM and LEM is higher for sub soil with lower shear strength.



(a)



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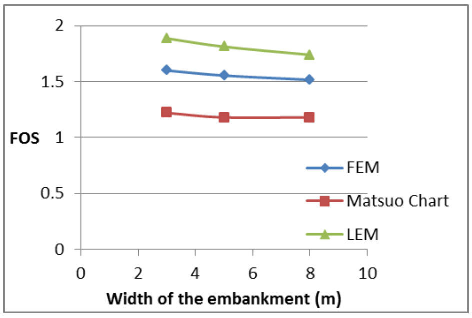

(a)

Fig. 4 variation of factor of safety values with embankment width(a) c_u=5kN/m^2 (b) c_u=15kN/m^2 (c) c_u=25kN/m^2

5 CONCLUSIONS

The following conclusions can be drawn from the results of the analysis.

Factor of safety values are decreasing with the increment of embankment height, however there is no significant variation in the factor of safety values with the embankment width.

Factor of safety values given by the Matsuo chart are higher for subsoil with lower shear strength than those given by FEM and LEM methods. However, for higher shear strength values, it gives lower FOS values than those obtained through FEM and LEM. For very weak soils, Matsuo chart cannot be used to find an exact factor of safety value since it only represents the instability condition (FOS<1). In all the analysis the FoS values obtained by LEM is greater thanthose obtained through FE analysis.

REFERENCES

Premalal, R.P.D.S., Jayasinghe, T.W.A.S.L., Indrachapa, K.R.T.H., &Thilakasiri H.S. (2012). Use of the observational approach for embankment construction on organic soil deposits in Sri Lanka: Kandy *2012,* Proceeding of the 2nd International Conference on Sustainable Built Environments.

Matsuo, M., and Kawamura, K., (1977)., Diagram for construction control of embankment on soft ground, Journal of soils and foundations, 17:37-52.