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Stability of Sloped Soil Embankment for Seismic and Tidal Load Combination

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Abstract. The slope of soil embankment near the port subjected to fluctuation in water level, seismic load, dynamic vehicular load, and superstructure load. So the combined effect of these loading poses a threat to slope stability of soil embankment. In this study, dynamic vehicle load and superstructure load is not considered. This paper presents a common solution which is micropiles for slope stability when sloped soil embankment is subjected to either seismic loading or a combination of seismic and tidal loading. M-C criteria and Geoslope software are used for analysis. Slope stability theories namely Bishop, Fellenius, Janbu, Spencer are considered for finding factors of safety. JNPT, Mumbai bore log data, Mumbai tidal and seismic data is used for investigation. Using Bishop's theory variation in the factor of safety with a surcharge is examined at horizontal seismic coefficients 0.225 and 0.16 (zone III cities) respectively for seismic loading and combination of seismic and tidal loading. It is observed that a non-linear relationship exists between the factor of safety and surcharge for both cases.

Keywords: slope stability, seismic and tidal loading, micro-piles, surcharge effect

1 Introduction

Sloped soil embankment near the port faces fluctuation in water level due to tides in the sea, seismic action, dynamic vehicular load, and superstructure load. So the combined effect of these loading poses a threat to slope stability of soil embankment. In this study effect due to dynamic vehicle load and superstructure are not considered. In this paper, a sloped soil embankment is made with the help of Geoslope software. The stability of soil embankment is checked against seismic loading and a combination of seismic and tidal loading using M-C criteria. Fredlund and Krahn [3], explains various slope stability methods. However, in this paper, slope stability theories namely the Bishop method, Fellenius method, Spencer method, and Janbu method were considered to find a minimum factor of safety. Using Bishop's theory variation in the factor of safety with a surcharge is examined at horizontal seismic coefficients 0.225 and 0.16 (zone III cities) respectively for seismic loading and combination of seismic and tidal loading.

Duzceer [2] used the limit equilibrium method to test the stability of rock slope in Makkah, Saudi Arabia. Duzccer R used rock anchors to provide stability to the rock slope. Desai and Choudhury [1] studied the seismic ground response of different sites in Mumba using different peak horizontal acceleration. Misra A et al. [4] simplified the analysis method for micro support pullout behavior.

1.1. Equations used to find the factor of safety

Following equation are used to find the factor of safety as,

$$F_{improved} = ή \, F_{original} \quad (1)$$

$$ή = F_{original} / F_{improved} \quad (2)$$

Where $F_{improved}$ is a factor of safety after the application of micropiles. ή is a nondimensional improvement factor. $F_{original}$ is a factor of safety before providing any micropiles.

The equation to find $F_{original}$ [3] and $F_{improved}$ [as per Eq. (3-8)] are presented as,

A. Fellenius method

$$F = \frac{\sum\{c' \, l \, R + (P - ul) R \, \tan \emptyset'\}}{\sum wx - \sum Pf + \sum kwe \pm Aa + Ld} \quad (3)$$

B. Bishop Method

$$P = \left(W - \frac{C' l \, \sin\alpha}{F} + \frac{ul \, \sin\alpha \, \tan\emptyset'}{F}\right) \times \frac{1}{m_\alpha} \quad (4)$$

$$m_\alpha = \frac{\cos\alpha + (\sin\alpha \, \tan\emptyset')}{F} \quad (5)$$

C. Spencer method

$$F_f = \frac{\sum\{c' \, l \, \cos\alpha + (P - ul) \, \cos\alpha \, \tan\emptyset'\}}{\sum P \, \sin\alpha + \sum kW \pm A - L \cos\omega} \quad (6)$$

D. Janbu's Simplified Method

$$F_O = \frac{\sum\{c' \, l \, \cos\alpha + (P - ul) \, \cos\alpha \, \tan\emptyset'\}}{\sum P \, \sin\alpha + \sum kW \pm A - L \cos\omega} \quad (7)$$

$$F = f_o \times F_o \quad (8)$$

2 Analysis of Sloped Soil Embankment

A sloped soil embankment is made using Geoslopes software. The height and slope of soil embankment are 8 m and 60º respectively. Necessary details for analysis are taken from Jawaharlal Nehru Port, Mumbai [5]. From bore log data each soil layer's depth and unit weight is calculated [1]. The cohesion and the friction angle value for each layer are determined as given in Table 1.

Table 1. Material Properties

S.No	Material	Unit Weight (kN/m^3)	Cohesion (kPa)	Friction angle
1	Sand Embankment	12	12.26	2°
2	Marine Clay Layer 1	12.26	12	2°
3	Marine Clay Layer 2	12	12.26	2°
4	Marine Clay Layer 3	12.2	12.26	2°
5	Marine Clay Layer 4	12	12.26	2°

The two of the following cases are considered for analysis

a) Stability of sloped soil embankment against seismic loading
b) Stability of sloped soil embankment against seismic and tidal load combination

The following combination of micropiles was used for the analysis of slope stability in both cases.

Table 2. Combination of micropiles

Combination of micropiles	No of supports	Length (meter)	Angle with horizontal	Shear force [4] (kN)	Shear reduction factor
Set A	1	7	0°	500	1
Set B	3	6	15°	400	1
Set C	3	6.5	20°	300	1
Set D	2	7	15°	400	1
Set E	2	8	0°	500	1
Set F	2	8.5	0°	350	1

To recommend a solution for slope stability it must satisfy the following conditions

a) It must ensure the safety of sloped soil embankment in both cases
b) The factor of safety calculated from all considered slope stability theory must be 2 or more than 2 after the application of micropiles

Theoretically, a factor of safety more than 1 is considered safe but for all practical purposes, designers consider the factor of safety two or more than two. Hence we also set the bar at 2.

2.1. Sloped soil embankment under horizontal seismic loading

A sloped soil embankment is subject to seismic loading. The coefficient of horizontal seismic loading (k_h) is taken as 0.225 [1]. The factor of safety is calculated by Bishop method, Fellenius method, Janbu simplified method, Spencer method using M-C criteria. All considered combinations of micropiles were tested by all four theories and improvement in the factor of safety is recorded.

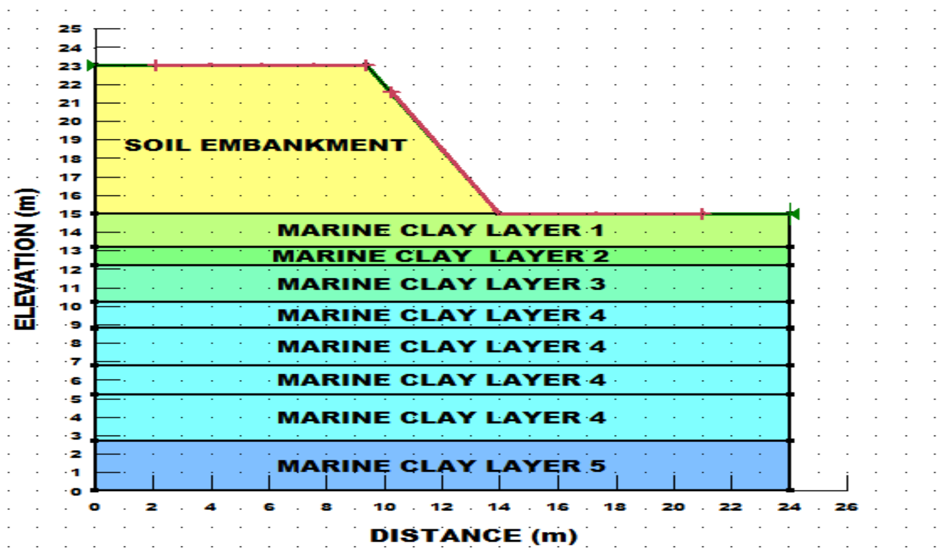

Fig.1. Soil embankment of 8 mt height and slope of 60° subjected to seismic loading with soil profile details up to 15 m depth.

Results for the considered combination of micropiles are as follows.

Table 3. The factor of safety for all considered combination of micropiles using slope stability theories

Description	Fellenius	Bishop	Janbu simplified	Spencer
No Micropile	0.555	0.554	0.552	0.554
Provided	0.555	0.554	0.552	0.554
Set A*	0.580	0.578	0.567	0.578
Set B*	0.611	1.680	1.566	1.677
Set C*	0.611	2.727	2.368	2.727
Set D*	0.611	2.768	2.582	2.767
Set E*	2.769	2.768	2.582	2.767
Set F*				

*Refer Table 2

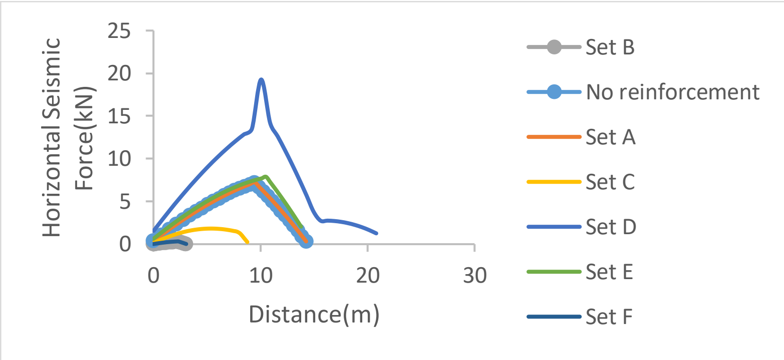

Fig.2. Horizontal seismic force variation with distance for critical surface (Bishop method) when soil embankment subject to seismic loading

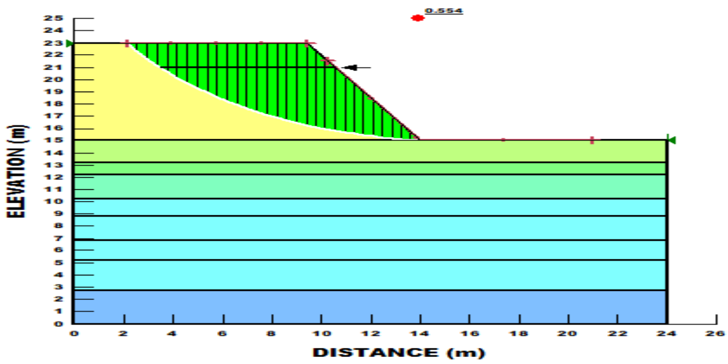

Fig.3. Arrangement of micropile (set A) and corresponding critical surface (Bishop method) For seismic loading

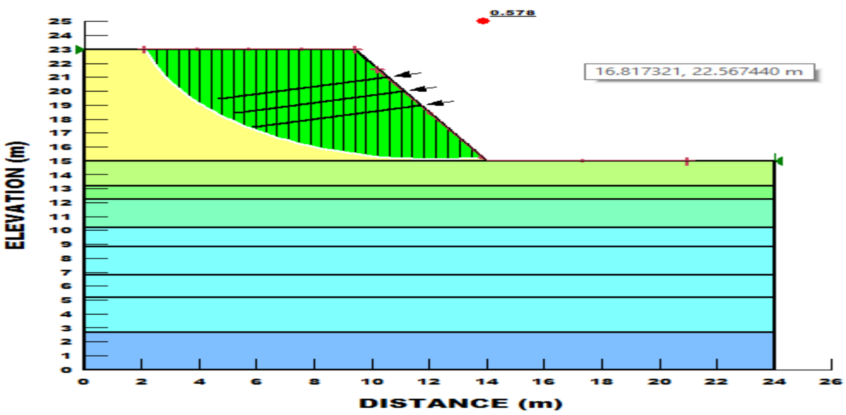

Fig.4. Arrangement of micropile (set B) and corresponding critical surface (Bishop method) for seismic loading

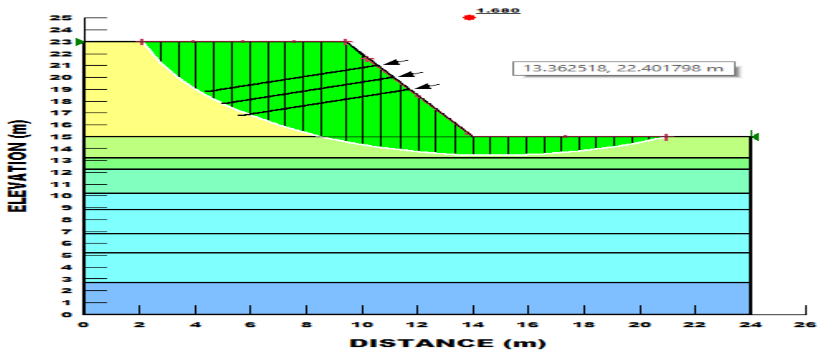

Fig.5. Arrangement of micropile (set C) and corresponding critical surface (Bishop method) for seismic loading

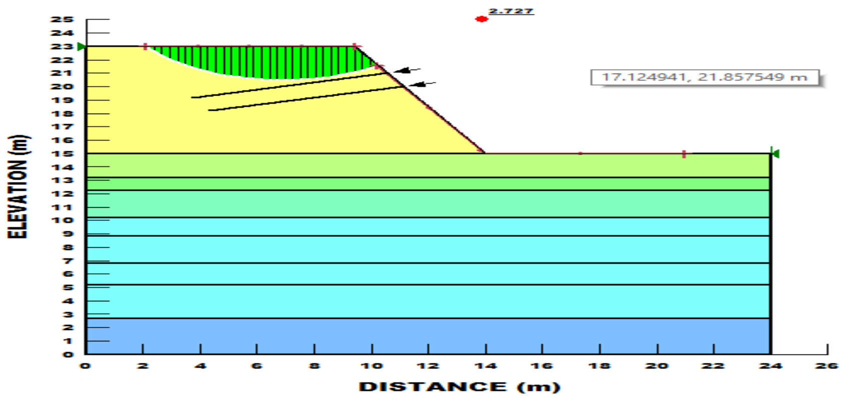

Fig.6. Arrangement of micropile (set D) and corresponding critical surface (Bishop method) for seismic loading

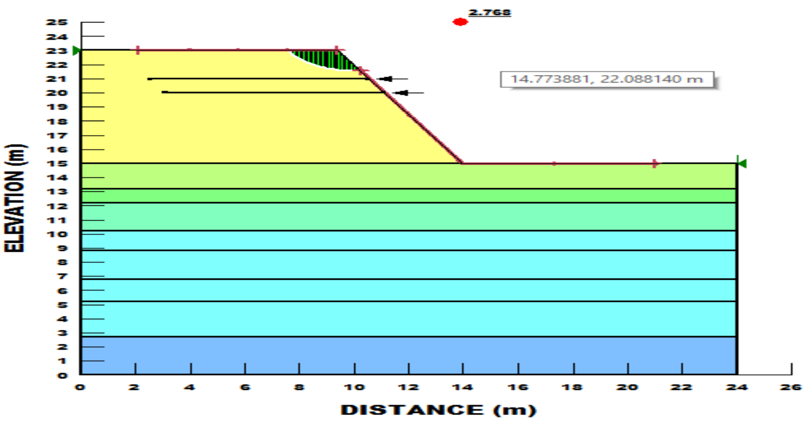

Fig.7. Arrangement of micropile (set E) and corresponding critical surface (Bishop method) for seismic loading

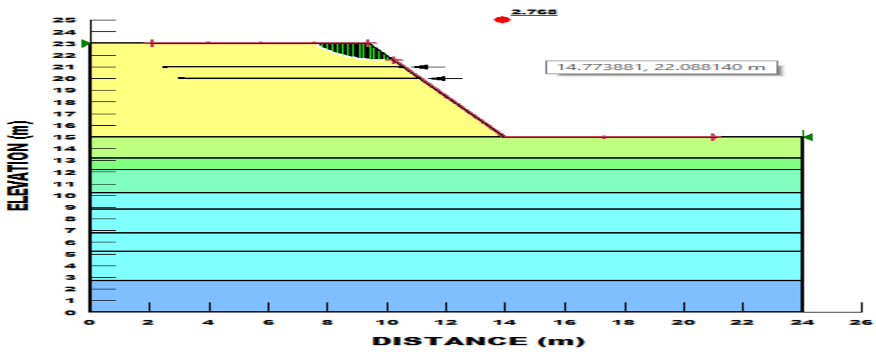

Fig.8. Arrangement of micropile (set F) and corresponding critical surface (Bishop method) for seismic loading.

2.2. Sloped soil embankment under horizontal seismic and tidal load combination

A sloped soil embankment is subject to a combination of seismic and tidal loading. The coefficient of horizontal seismic loading (k_h) is taken as 0.225 [1] and the water level is taken as 5.8 meters [5]. The factor of safety is calculated by Bishop method, Fellenius method, Janbu simplified method, Spencer method using M-C criteria. All considered combinations of micropiles were tested by all four theories and improvement in the factor of safety is recorded

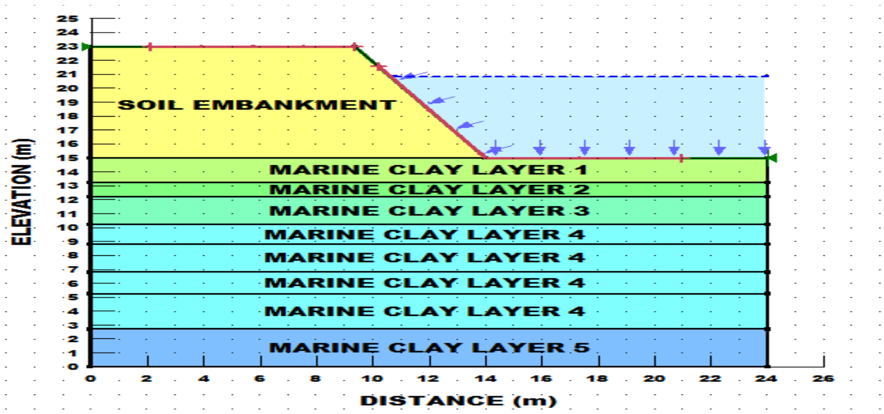

Fig.9. Soil embankment of 8 mt height and slope of 60^0 subjected to a combination seismic and tidal loading with soil profile details up to 15 m depth

slope stability analysis is done for seismic and tidal load combination and the result for the factor of safety is as follows.

Table 4. The factor of safety under all considered combination of micropiles using slope stability theories

Description	Fellenius	Bishop	Janbu simplified	Spencer
No Micropiles	0.855	0.862	0.818	0.861
Provided	0.855	0.862	0.818	0.861
Set A*	0.891	0.905	0.858	1.053
Set B*	0.973	2.727	2.368	2.727
Set C*	0.973	2.727	2.368	2.727
Set D*	0.973	2.768	2.582	2.767
Set E*	2.769	2.768	2.582	2.767
Set F*				

*Refer table number 2

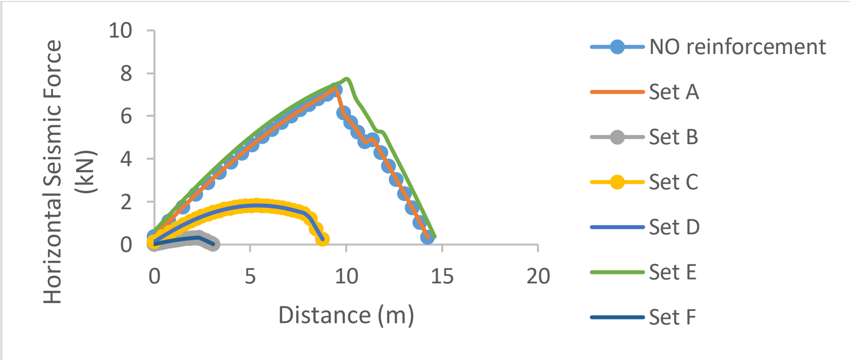

Fig.10. Horizontal seismic force variation with distance for critical surface (Bishop method) when soil embankment subjected seismic and tidal load combination

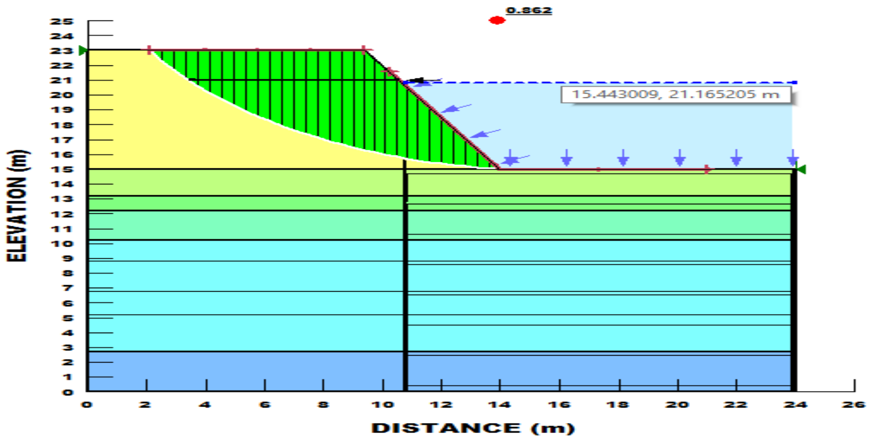

Fig.11. Arrangement of micropile (set A) and corresponding critical surface (Bishop method) for seismic and tidal load combination

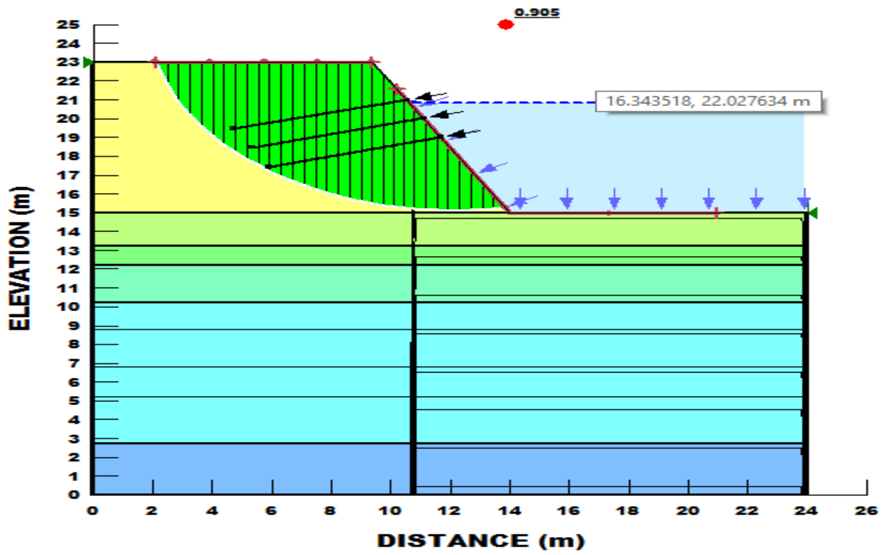

Fig.12. Arrangement of micropile (set B) and corresponding critical surface (Bishop method) for seismic and tidal load combination

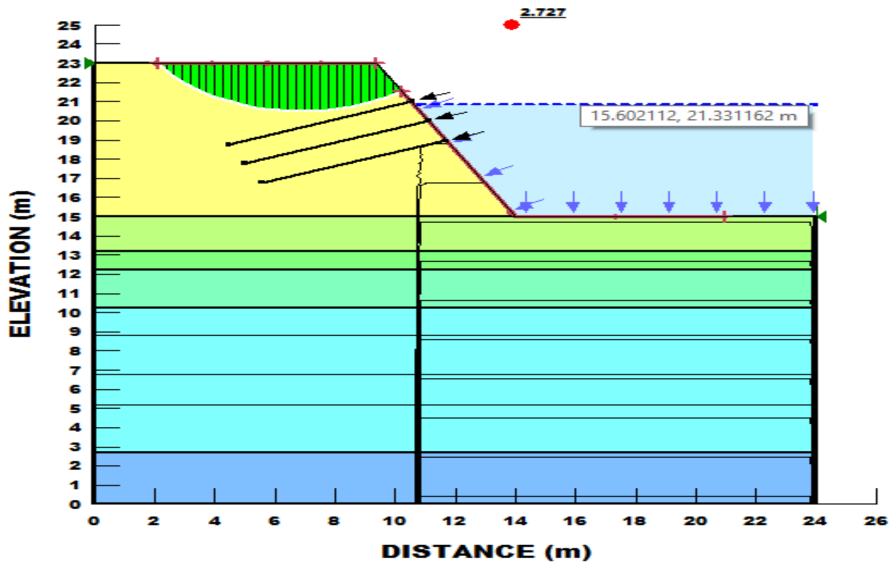

Fig.13. Arrangement of micropile (set C) and corresponding critical surface (Bishop method) for seismic and tidal load combination

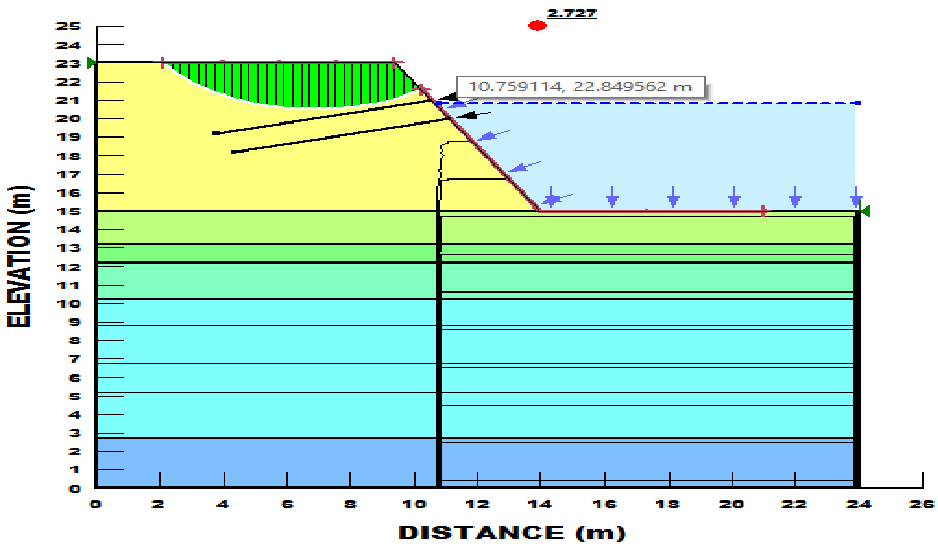

Fig.14. Arrangement of micropile (set D) and corresponding critical surface (Bishop method) for seismic and tidal load combination

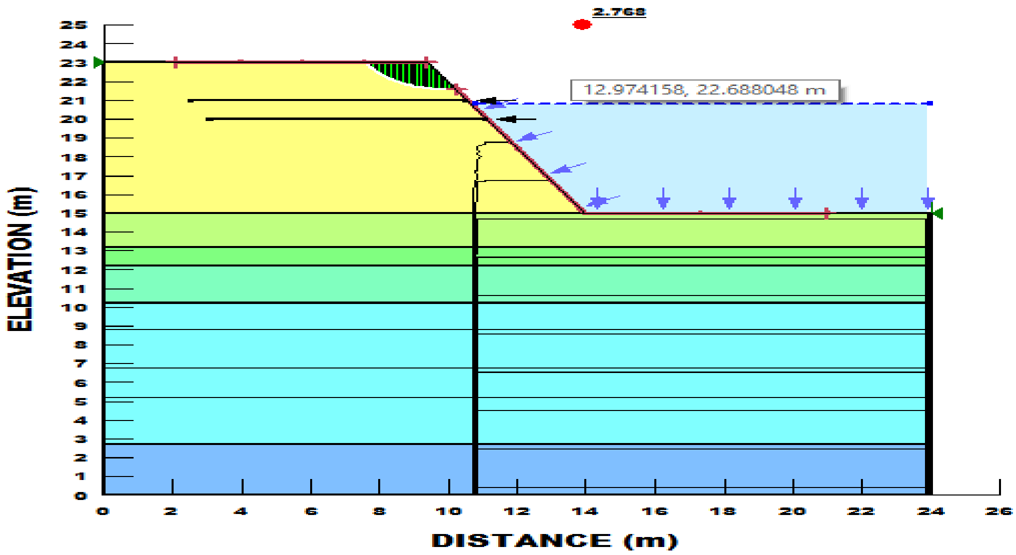

Fig.15. Arrangement of micropile (set E) and corresponding critical surface (Bishop method) for seismic and tidal load combination

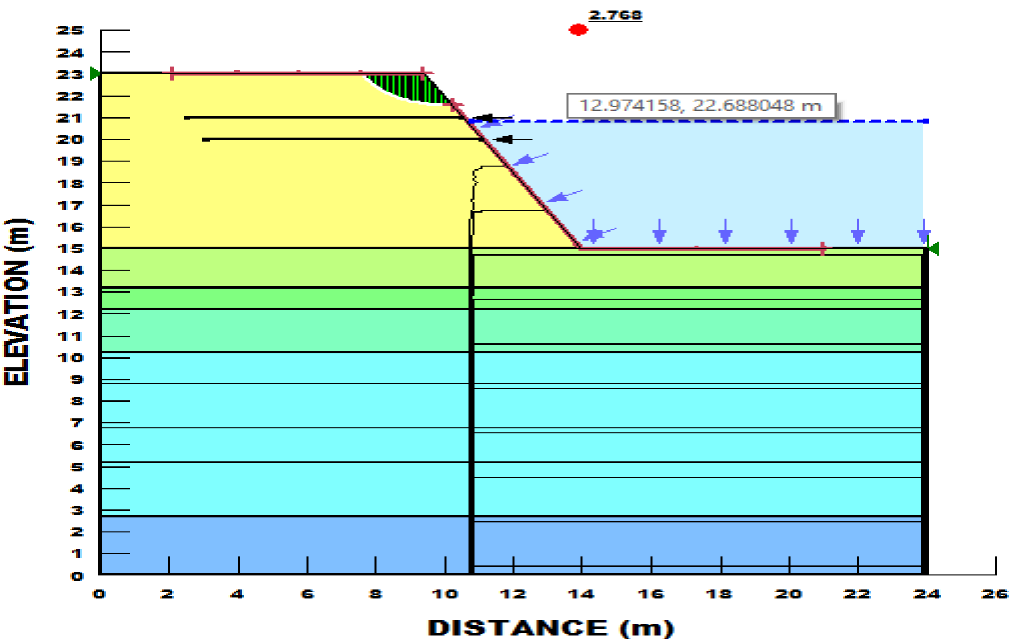

Fig.16. Arrangement of micropile (set F) and corresponding critical surface (Bishop method) for seismic and tidal loading

3 Effect of Surcharge on The Factor of Safety

The effect of the surcharge load on the factor of safety is analyzed for the recommended solution when sloped soil embankment is subjected to seismic loading and a combination of seismic and tidal loading.

3.1. Sloped soil embankment subjected to seismic loading

Once an adequate solution is prepared for slope stability, it is tested for surcharge loading. Surcharge load of 6 m length, 2 m height is applied to sloped soil embankment. Surcharge load density varies from 0 kN/m³ to 12 kN/m³. The factor of safety is calculated for the horizontal seismic coefficient of 0.225 and 0.16 (for zone III cities) respectively at a different density.

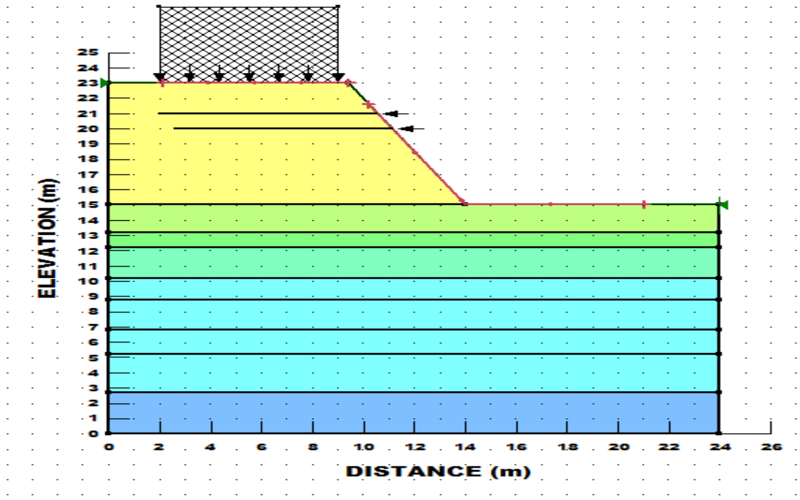

Fig.17. Surcharge load on sloped soil embankment for recommended set F (Table 2) subject to the seismic loading

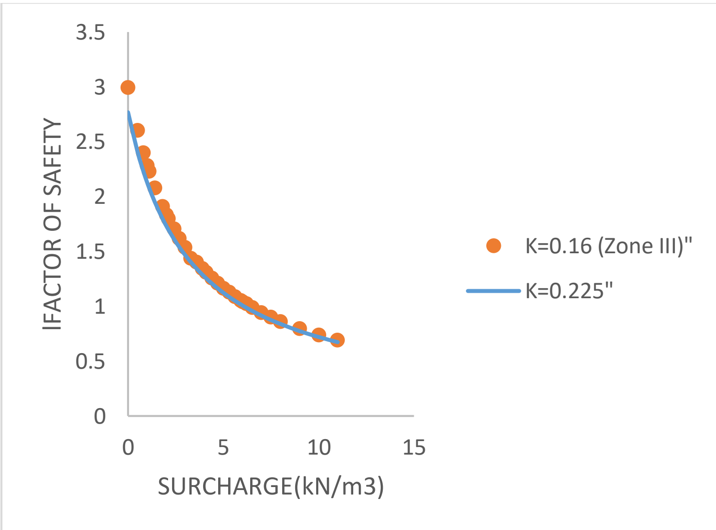

Fig.18. Variation in the factor of safety with the surcharge when soil embankment subjected to seismic loading for set F (Table 2)

For the recommended solution, sloped soil embankment subjected to seismic loading is analyzed for the surcharge load. When the horizontal seismic coefficient is 0.225 then the factor of safety is less than 1 for a surcharge load density of 6.2 kN/m³. When the horizontal seismic coefficient is 0.16 then the factor of safety is less than 1 for a surcharge load density of 7 kN/m³. But after 5.6 kN/m³ difference between the factor of safety for both seismic coefficient is less hence 5.6 kN/m³ should be the upper limit for surcharge loading.

3.2. Sloped soil embankment subjected to a combination of seismic and tidal loading

Once an adequate solution is prepared for slope stability, it is tested for surcharge loading. Surcharge load of 6 m length, 2 m height is applied to sloped soil embankment. Surcharge load density varies from 0 kN/m³ to 12 kN/m³. The factor of safety is calculated for the horizontal seismic coefficient of 0.225 and 0.16 (for zone III cities) respectively at a different density.

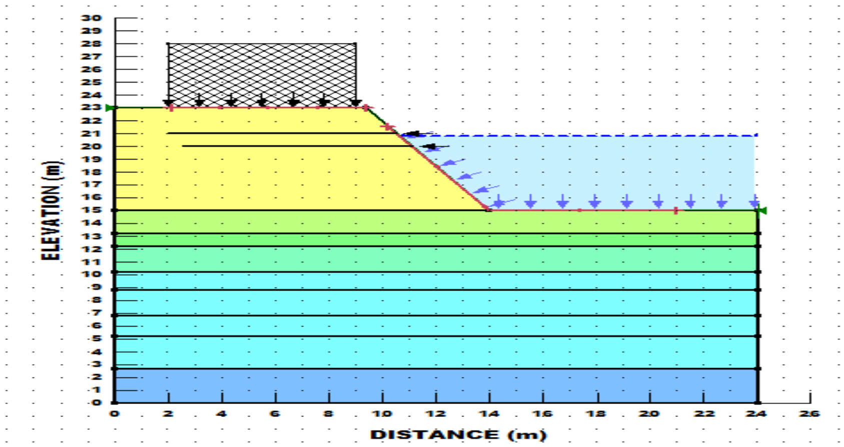

Fig.19. Variation in the factor of safety with the surcharge when soil embankment subjected to seismic and tidal load combination for set F (Table 2)

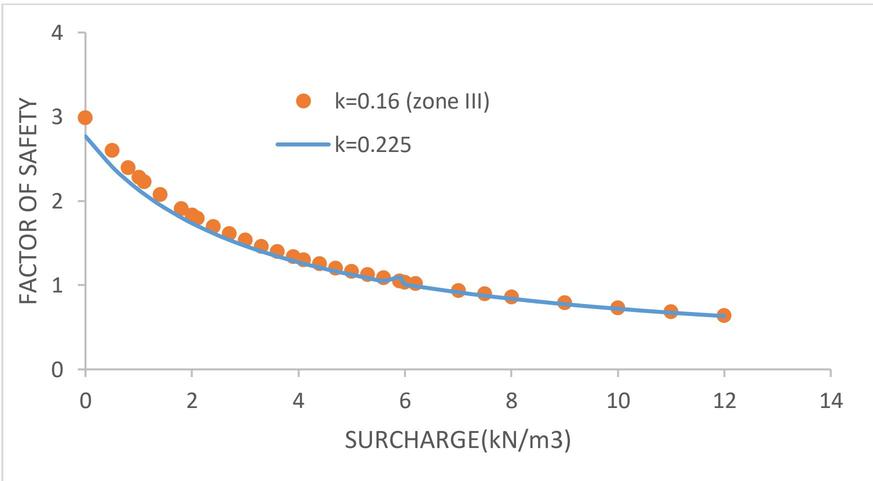

Fig.20. Variation in the factor of safety with the surcharge when soil embankment subjected to seismic and tidal load combination for set F (Table 2)

For the recommended solution, sloped soil embankment subjected to a seismic and tidal load combination is analyzed for the surcharge load. When the horizontal seismic coefficient is 0.225 then the factor of safety is less than 1 for a surcharge load density of 6.2 kN/m³. When the horizontal seismic coefficient is 0.16 then the factor of safety is less than 1 for a surcharge load density of 7 kN/m³. But after 5.6 kN/m³ difference between the factor of safety for both seismic coefficient is less hence 5.6 kN/m³ should be the upper limit for surcharge loading.

4 Conclusions

1. It is recommended to use a set of micropile having 2 micropiles at 0° angle with horizontal. Length, shear force, and shear reduction factor is 8.5 m, 350 kN, 1 respectively when slope embankment is subjected to either seismic loading or a combination of seismic and tidal loading.
2. The effect of surcharge on the factor of safety is as follows
   a) For the recommended solution, sloped soil embankment subjected to seismic loading is analyzed for the surcharge load. When the horizontal seismic coefficient is 0.225 then the factor of safety is less than 1 for a surcharge load density of 6.2 kN/m³. When the horizontal seismic coefficient is 0.16 then the factor of safety is less than 1 for a surcharge load density of 7 kN/m³. But after 5.6 kN/m³ difference between the factor of safety for both seismic coefficient is less hence 5.6 kN/m³ should be the upper limit for surcharge loading.
   b) For the recommended solution, sloped soil embankment subjected to seismic loading is analyzed for the surcharge load. When the horizontal seismic coefficient is 0.225 then the factor of safety is less than 1 for a surcharge load density of 6.2 kN/m³. When the horizontal seismic coefficient is 0.16 then the factor of safety is less than 1 for a surcharge load density of 7 kN/m³. But after 5.6 kN/m³ difference between the factor of safety for both seismic coefficient is less hence 5.6 kN/m³ should be the upper limit for surcharge loading.

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