Stability analysis of a fly ash embankment on soft soil

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ABSTRACT

Stability analysis is the important aspect before construction of an embankment.Stability of slope of any embankment always depends on the properties of the material used in the embankment. The factors chosen for suitability of materials depend on locally availability, economic and sustainability criteria. Public Works (Roads) Department under Government of West Bengal in India decided to construct the approach road embankment of Moyna Bridge with fly ash material.Due to non-availability of good quality oflocal earth,Department has taken a decision for use of fly ash material as substitute of earth for construction of the embankment. Moyna Bridge connects Tamluk- Pingla major district road in the Purba Midnapore district of the State West Bengal in India. The portionbelow EGL will act as foundation. From geotechnical investigation it is revealed that down to 7.0m below the EGL embankment yellowish grey silty clay isobserved. At first slope stability analysis is carried out for fly ash embankment and subsequently failure surface and critical factor of safety at static condition are evaluated..After that bearing capacity and settlementare also being checked. The embankment will be constructed through stage construction method. Factor of safety against bearing capacity is obtained which is much higher than permissible valueof 1.5 as per IRC: 75-2015. Factor of safety for seismic condition and the total settlement calculation in two stages are being calculated and finalized. This approach embankment being constructed for an important bridge like this in the vicinity will set a very good example of sustainable development using fly ash as a waste resource.

Keywords: Slope stability, Embankment, Fly Ash, Factor of safety

1 INTRODUCTION

The infrastructure development is just in initial stage in India and it is likely to remain for a very long period in the country.The countryalthough still a developing nation but very soon to become a developed nation.The investment in infrastructure started quite late. The use of waste material from burning of coal in power plant is a challenging task for the nation. Construction of fly ash embankment with clay blanket for engineering purposes is as modern as civilization itself. Until the advent of soil mechanics, the design and construction of embankment was more an art than a science. Experience, intuition and engineering judgment no doubt continue to play important part in the design of embankment but developments in soil mechanics have provided a framework through which one can approach the subject in a rational manner. In recent years,demands on the performance of fly ash embankment have become more exacting. Embankments are required to be constructed on poor foundation materials with a wide variety of soils and to considerable heights.Construction of an embankment involves stability analysis which is an important aspect for such construction.The failure of a slope could be slippage of fill material mass along a slip surface (generally circular). All the methods of slope stability analysis in practice consider discretization of failure zone into slices.

2 LOCATION AND DESCRIPTION OF SITE

The present paper deals with the stability analysis of a fly ash embankment constructed for the approach road of Moyna bridge at Purba Medinipur,West Bengal, India. Due to non availability of good quality earth material, locally available fly ash from nearby thermal power plant will be used as substitute of earth for construction of the embankment.The thermal power plant is situated at Kolaghat, Purba Medinipur district of the state of West Bengal which is about 30 to 35Km from the project site. This bridge will connect Tamluk-Pingla major district road. The embankment will be situated between chainage of1492.7Km (near abutment end) to chainage 2500kM of Tmluk-Pingla road. Maximum height of the embankment is proposed to be 6.5m above EGL. Top width of embankment 12m and bottom width will be 38m (slope2H:1V). The portion below EGL will serve as foundation. The fly ash embankment will be placed at a depth of 1.5m below existing ground level (EGL) and 1m wide clay blanket on both sides will be provided.From detailed geotechnical investigation report, it is revealed that the soil consists of soft yellowish grey silty clay upto the depth of 7.5mbelow EGL.This layer is underlain by loose to medium dense sand. Water table is situated at EGL.

2.1 Materials and analysis

Stability of slope of any embankment is always dependent on the properties of the materials used in the embankment.The embankment core was constructed of fly ash derived from nearby thermal power plant as discussed earlier. Besides there was a clay blanket along the periphery of the embankment.Here Mohr Coulomb material model is used in SLOPE/W of GeoSlope software. The material i.e, Fly ash, Clay blanket used in embankment and silty clay used in foundation of embankment are tested as per IRC:SP:58-2001and SP36(Part1):1987 at soil laboratory of Construction Engineering Department of Jadavpur University and Central Laboratory of Mackintosh BurnLimited.The geotechnical properties of the embankment and foundation materials are given below:

2.2 Embankment Fill Material : Fly ash

Bulk density: 12kN/m^3
Angle of internal friction (φ_f) =30°
Cohesion: 0 kPa

2.3 Clay blanket

Bulk density: 17kN/m^3
Angle of internal friction (φ_b) =0°
Cohesion (c_b): 22 kPa

2.4 Foundation material : Silty clay

Bulk density: 17.5kN/m^3
Angle of internal friction (φ) =3.5°
Cohesion (c)=31.86 kPa, Liquid limit(LL) =41%
Coefficient of consolidation (C_v)=0.018cm^2/sec, Initial void ratio, e_o =0.935,

In Slope W (2007) software Bishop Ordinary and Janbu method is used for analysis of static stability purposes. None of the the present methods of slope stability analysis takes into consideration the strain compatibility of the slices within the zone of failure. All the methods are covered within the ambit of limit equilibrium analysis which comprises of moment equilibrium and force equilibrium and provide moment factor of safety andforce factor of safety depending on the method of analysis. The primary assumptions of the Bishop simplified method (1960) are that ignores inter slice shear forces and satisfies only moment equilibrium. In generalized limit equilibrium terminology isnot considered shear forces and satisfies only moment equilibrium i.e, means λ is zero. Janbu's simplified method (1954) also ignores inter slice shear forces ie, means λ is also zero and only satisfies force equilibrium. The interslice shear forces in general equilibrium method are handled with an equation (Eq.1)

$$X = E\,\lambda f(x) \tag{1}$$

Where f(x) is function, E is inter slice normal force and X is the interslice shear force. As per SlopeW(2007) manual the value of lambda (λ) percentage in decimal form for a typical slice is the ratio of ordinate of applied function (lower curve) to the value of f(x) read from specified function(upper curve) in Fig.1.Lamda versus factor of safety relation for different methods is shown in Fig.2.

In general limit equilibrium method in Slope W can accommodate a wide range of different interstice function. In this analysis half sine function is used(Fig.1). Half sine function value for any chosen no ofslices can be obtained and used in the computation. The value of specified function f(x) itself varies from slice to slice in half sine function.

Slope W connects a point along the entry area with a point along the exit area to form a line. At the midpoint of this connecting line Slope W creates a perpendicular line.Radius points along the

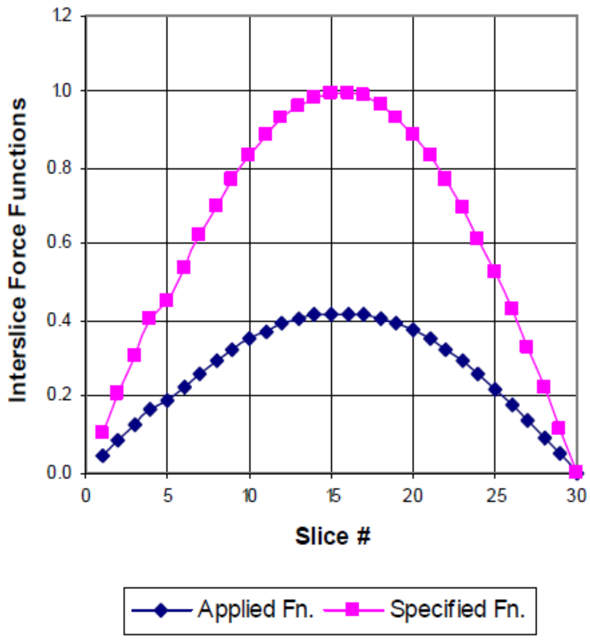

Fig.1.Interslice Applied and Specified Function.

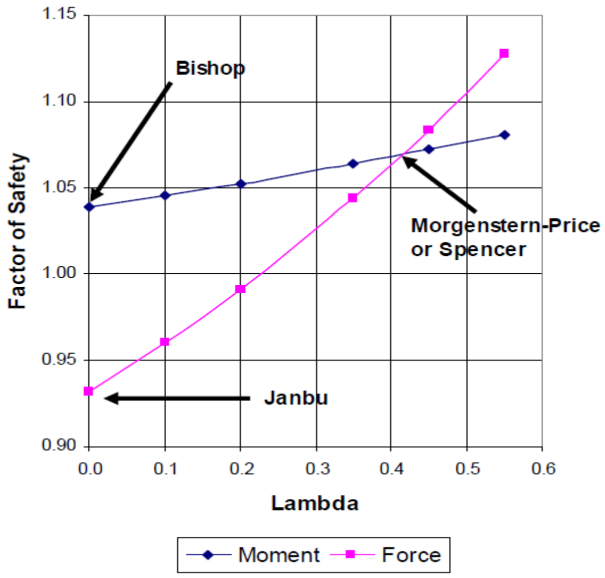

Fig.2. Factor of Safety versus Lambda((λ) Plot.

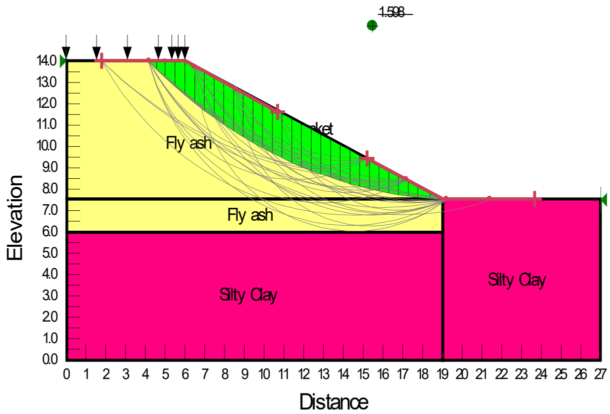

Fig .3. Static Slope Stability output with Geo Slope.

Perpendicular lines are created to form the required third point of a circle. In this analysis tension crack option is ignored. Direction of movement of slip surface is considered left to right.

The search for the critical surface i.e. the surface with the lowest factor of safety or yield acceleration may have to be repeated because the critical surface from the static analysis is not necessarily the same as the critical surface for the dynamic analysis. Pseudo static limit equilibrium analysis is performed for seismic slope stability analysis.In the pseudo static limit equilibrium analysis a seismic coefficient is used to represent the effect of the inertia forces imposed by the earthquake upon the potential failure mass. Simplifications made in using pseudo static limit equilibrium method includes replacing the cyclic earthquake motion with a constant horizontal acceleration equal to k_HX g where 'k_H' is the horizontal seismic coefficient and 'g is' acceleration due to gravity and assuming that this steady acceleration induces an inertia force k_HW through the center of gravity of the potential failure mass where 'W' is the weight of the potential failure mass.

2.5 Computation of Factor of safety

At the outset slope stability analysis is carried out for fly ash embankment. Subsequently failure surface and critical factor of safety are evaluated for various cases.Here both static and seismic slope stability analysis ofthe fly ash embankment with both sides clay blanket are done by Slope W Geo Slope software separately and shown in . After that bearing capacity and settlement will also be checked.Minimum factor of safety for slope stability against static condition is assumed as 1.25 and 1.0 for seismic condition as per IRC: SP: 53.As per FHWA-SA-97-076(1997), Seed(1979) also recommended that for earthquake of magnitude 6.5 or less a horizontal seismic coefficient (k_H) 0.10 combined with a factor of safety of1.15 should be used. It is proposed to construct the embankment through stage construction method.Consequently bearing capacity calculation is done and the factor of safety evaluated is 2.72. As the permissible value of factor of safety against bearing capacity is 1.5 as per IRC-75-2015, this is considered safe. As per Indian Roads Congress codal provision,IRC-75-2015, live load(external) for traffic is considered as 24kN/m^2. Surcharge load is assumed(24-18)x0.6kN/m^2= 3.6 kN/$m^2$to act across the width of carriageway where unit weight of 600 mm cutting earth and replaced hard crust are 18 and 24 kN/m^3respectively. In static case,Dead + live load combinationand in seismic case, Dead load+0.5 Live load+seismic load combination has been examined as per IRC-6. For static case factor of safety is obtained as1.598 which is higher than 1.25 and is considered safe.

For computation of factor of safety for seismic condition result of Pseudo Static analysis as per IRC:75-2015 is shown in Table.1. Factor of safety for seismic condition are found to be 1.469 as per IRC:75-2015 and 1.302 from Slope W analysis which both are safe

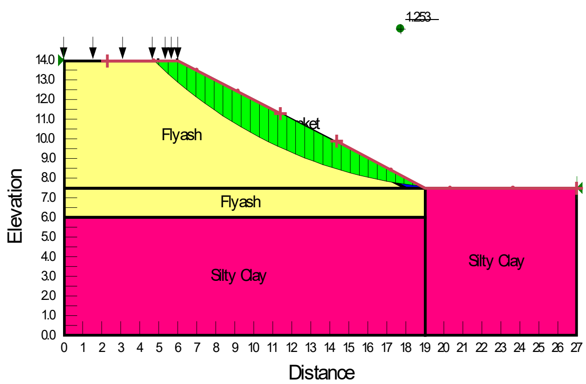

Fig .4. Seismic Slope Stability output with Geo Slope.

because it is higher than required value 1.0 or 1.15 asper Seed(1979) of FHWA-SA-97-076(1997) and the total settlement calculation for two stages are being made and finalised.

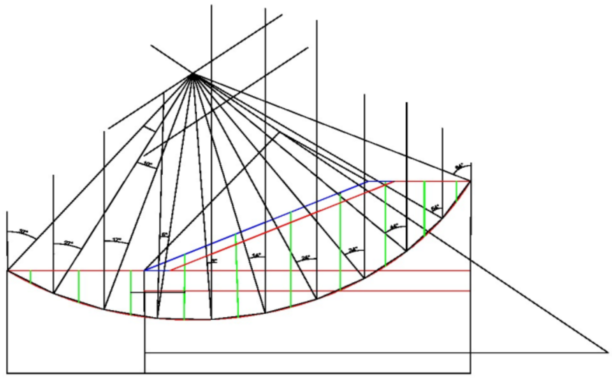

Fig.5. Seismic Slope Stability Analysis by method of Slices.

Table 1. Computation of Pseudo Static Factor of Safety for Seismic Condition

Slice no	k_H	α	N =Wcosα (kN/m)	Wsinα (kN/m)	N tanφ (kN/m)	WsinαtanφkH (kN/m)	Wcosα kH (kN/m)	cL (kN/m)
1		64	7.472	15.320	4.311	0.884	0.747	For
2		54	49.026	67.478	28.288	3.893	4.903	Embankment
3		44	119.346	115.251	68.863	6.650	11.935	c= 0kPa
4		34	264.875	178.660	116.631	7.867	26.487	L=8.50m
5		24	313.237	139.462	120.990	5.387	31.324	&
6	0.10	14	331.183	82.573	110.074	2.744	33.118	For
7		3	280.179	14.684	76.771	0.402	28.018	Foundation
8		5	173.299	15.162	33.348	0.292	17.330	c= 31.86 kPa
9		17	93.274	28.517	5.690	0.174	9.327	L=23.165m
10		27	59.867	30.504	3.652	0.186	5.987	Resisting
11		37	16.547	12.469	1.009	0.076	1.655	Force=0x8.50 +31.86x23.16
				∑700.079	∑569.627	∑28.556	∑170.830	∑738.0369

Total Resisting Force = (ΣcL+ΣNtanφ)-Σ(WsinαtanφkH) = (738.0369+569.627)-(28.556) = 1279.109kN
Total Driving Force = ΣWsinsα +ΣWcosαkH= (700.079+170.830) =870.910 kN
FOS = 1279.109/870.910 = 1.469 >1.0 Hence O.K.

2.6 Bearing capacity Analysis

Top width of embankment = 12m
Height of embankment =6.5m
Side slope =2H: 1V
Base width of embankment = (12+2x6.5x2) =38m
Depth of silty clay =7.5m
B/D =38/7.5 =5.06 >2.0
Hence as per IRC:75-2015, (Eq. 2)

$$Nc = [4.14+0.5*(B/D)] \tag{2}$$

=6.67
Overburden pressure due to 6.5m embankment fill material((Δσ) =12x6.5 =78kN/m^2
Net ultimate Bearing capacity (Eq.3.)

$$cNc \tag{3}$$

= 31.86x6.67= 212.50 kN/m^2
Factor of safety against bearing capacity = 212.50/78 = 2.72> 1.5,Hence O.K.

2.7 Settlement Analysis

Compression index (Cc) is calculated from Eq. (4) as:

$$Cc=0.009(LL-10) \tag{4}$$

= 0.009(41-10) =0.279
Effective pressure p_0 at centre of the H =7.5m thick clay layer
=(17.5-10)x7.5/2 =28.12kN/m^2.
Settlements due to 6.5m height embankmentfill
=((0.279×7.5)/(1+0.935))*log$_{10}$((28.12+78)/28.12)
=623mm
Hence 4m height at first stage and 2.75m at second stage was constructed.
Overburden pressure due to 4.0m embankment fill material(($\Delta\sigma_{4m}$) =12x4.0 =48kN/m^2
Settlement for 1st stage of construction(4m height)
=(0.279×7.5)/((1+0.935)) log$_{10}$ ((28.12+48))/28.12
= 467mm
Settlement for 2nd stage construction (6.5-4= 2.5m height
=((0.279 X 7.5)/(1+0.935))*Log$_{10}$((76.12+30)/(76.12))= 156mm where,
p'_0= (28.12+48) = 76.12 kN/m^2
Overburden pressure due to 2.5m embankment fill material
($\Delta\sigma_{2.5m}$) =12x2.5 =30kN/m^2

If 80% consolidation (0.8x467mm) is consideredafter 1st stage construction of embankment therefore time (t) required for achieving 80% consolidation, Time factor,
$T_V = -0.9332*\log_{10}(1-(80/100)) -0.85=0.567$
$t=(H^2)*Tv/C_v$
$=((7.5\times100)/2)^2)*(0.567)/ (0.018*24*3600) =51$ days
Therefore we allow total settlement after 2nd stage construction=(467-0.8x467+156) mm =249mm<300mm Hence O.K.

CONCLUSION

In the present investigation stability analysis has been carried out for a fly ash embankment considering both static and seismic conditions besides bearing capacity and settlement are also checked. Here the embankment is proposed to be built in stage construction method. The analysis has been carried out using Slope W software applying Bishop's ordinary and Janbu method. Here it is found that FOS in static condition is 1.598 and that for seismic condition is 1.469 as per IRC:75-2015 and 1.236 from Slope W analysis which are higher than permissible values of 1.25 and 1.0 or 1.15(as per Seed,1979 respectively. Bearing capacity is also found to be safe as per IRC:75-2015. The settlement analysis shows that during the first stage of construction (467-0.8x467)mm i.e.93mm and for second stage construction it is 249mm both of which are less than permissible value of 300mm. It is concluded that stability analysis is successfully made complying the relevant codal provisions and the fly ash embankment so constructed will be safe.

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