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Stability of railway embankment reinforced (geosynthetic) under static and seismic conditions: A case study

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ABSTRACT

The expansion of railway lines is a symbol for development of nation. However it is equally challenging due to soft soils at the formation. The development demands high speed and heavy loaded wagons and which in turn dictates need for ground improvement. Embankments constructed on soft foundation soils are unstable due to the outward lateral earth pressure forces developed within the fill coupled with sliding moment of soil at slippage. While these forces are resisted by the shear strength of soil to some extent, the problem will be attenuated in seismic zones. These seismic forces which act in both horizontal and vertical direction for a short period can cause more instability. A viable solution for these problems can be through provision of reinforcement, stone column for the entire base width. The basal reinforcement resists some or all of the lateral pressures from within the embankment and restricts lateral deformations of the foundation; thereby increasing the latter's bearing capacity and stability.

This paper discusses stability analysis (Bishops) of reinforced embankment on soft soil under pseudo static seismic condition. A railway embankment is proposed for new railway line proposed at Srikakulam railway station, A.P , India. Soil samples are collected from site and are tested in the laboratory. Using the properties, the embankment is designed as per IRC of practice. The slope stability is computed using program Geoslope. Parametric studies are carried out for varying embankment slope, tensile capacity of geosynthetic reinforcement, seismic acceleration coefficients, stone columns in ground. A comparison is made based on test results. It is observed that, stone columns and reinforcement is very effective in increasing Fs even in seismic cases.

Keywords: soft soil, geo-synthetic, reinforcement, stability, stone columns.

I.INTRODUCTION

1.1 Basal reinforced embankments on Soft Soils

For embankments constructed on soft foundation soils because of the low strength of foundation soil, the stability will be a concern. Reinforced Soil concept (Vidal, 1969b) using geosynthetics proved as the best technique, which can be used to enhance the strength and deformation behavior of soil in difficult situations. In basal reinforced embankments a layer of geosynthetics material provided horizontally at the interface of the embankment soil and foundation soil extending for the full width and length of the embankment. The basal

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IJARSE
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reinforcement can serve to resist some or all of the earth pressure within the embankment and to resist the lateral deformations of the foundation, thereby increasing bearing capacity and stability, Jewell (1988**).**

1.2 Stability of Geosynthetic - Reinforced Embankment on soft soils.

Limit equilibrium methods and programs developed through FEM have been used to asses short term stability (undrained) stability of reinforced embankments constructed on soft foundation soils (Rowe 1984, Rowe et.al 1985a, 2002**).** Geometry of embankment and thickness of soft soil influences collapse height (Rowe et.al.1999, 2005). The stability of reinforced embankment depends on several factors namely, drainage conditions, rate of construction of embankment, strain in reinforcement, tensile strength of reinforcement, type of soil etc (Rowe et.al 1984,1985a, 2002, 2005). Chakravarthi et al. 2007, 2009, Narasimha reddy 2008.)

1.3 Reinforced embankments-Kinematics of reinforcement-backfill response

Kinematics of the deformation (Fig. 2) dictates typical failure of reinforced soil structures. At failure of soil mass the reinforcement is subjected to pull. Almost all the available design methods incorporate only the axial pullout mechanism Jewell, 1992 (Fig. 3). The contribution of pull in reinforcement is quantified by many authors for various Geosynthetic reinforced structures namely embankments, Retaining walls. Etc. (

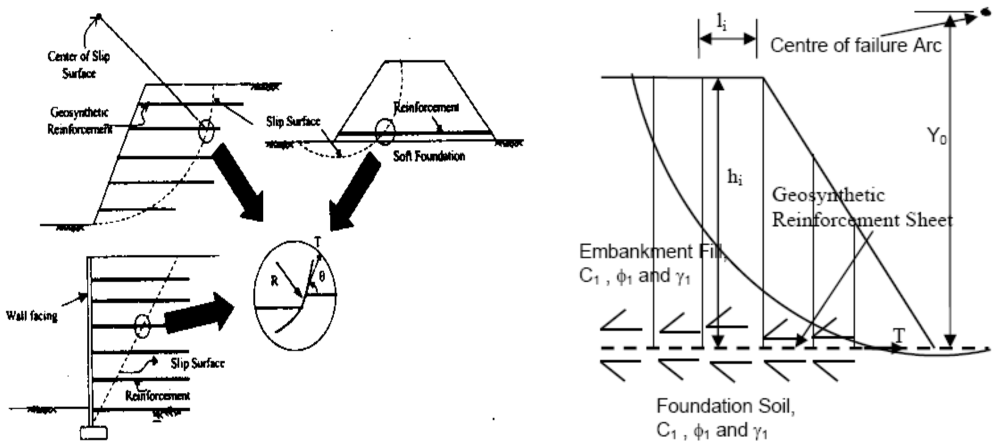


Fig. Typical slip surface and kinematics of Reinforcement and Soil Interaction- axial pull

II.DETAILS OF STUDY AREA, PROBLEM FORMULATION, METHODOLOGY AND ANALYSIS

The study area considered is Railway station near Amadalavalasa, where new line is proposed for expansion of platform through constructing a new embankment. The length of embankment is approximately 1 Km and of which 100m is taken for study. The cross-section of embankment is chosen as per IR specifications and stability is computed under the conditions of loading namely static, seismic with surcharge. Necessity of reinforcing with geosynthetics and stone columns is exercised.

Methodology includes collection of UD Soil samples from site and from borrow pit. The samples are tested in lab for their index and engineering properties. The results are presented in the subsequent headings. The embankment is reinforced with geosynthetics and stone columns in the ground. The slope stability is computed using geoslope software and parametric study is carried out. .

For study, the following nomenclature is adopted. The formation width B, height He, side slope 1vtl.:n htl ,cohesion c and phi Ø, borrow pit fill having cohesion c_e and angle of friction $Ø_e$.

2.1 Geometry of embankment, modeled Cross section for geoslope:

The Cross section railway embankment is presented in fig.2 and modeled embankment is presented in fig.3 A typical slip circle generated using geo slope is given in fig.4 The surcharge is taken as 3 kg/ sq.cm and single lane width recommended by IRC is considered. The analysis is carried out for unreinforced embankment, reinforced embankment on ground with and without stone columns. The effect of stone columns is presented by considering equivalent ground. The ranges and parametric study are shown in tables 1 to 5.

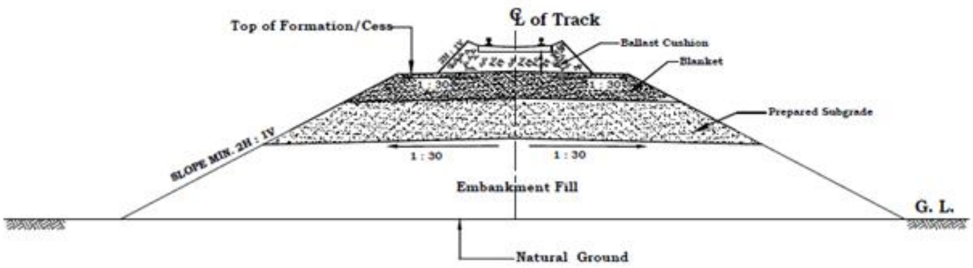


Fig.2. Cross section requirements for embankments as per IRC

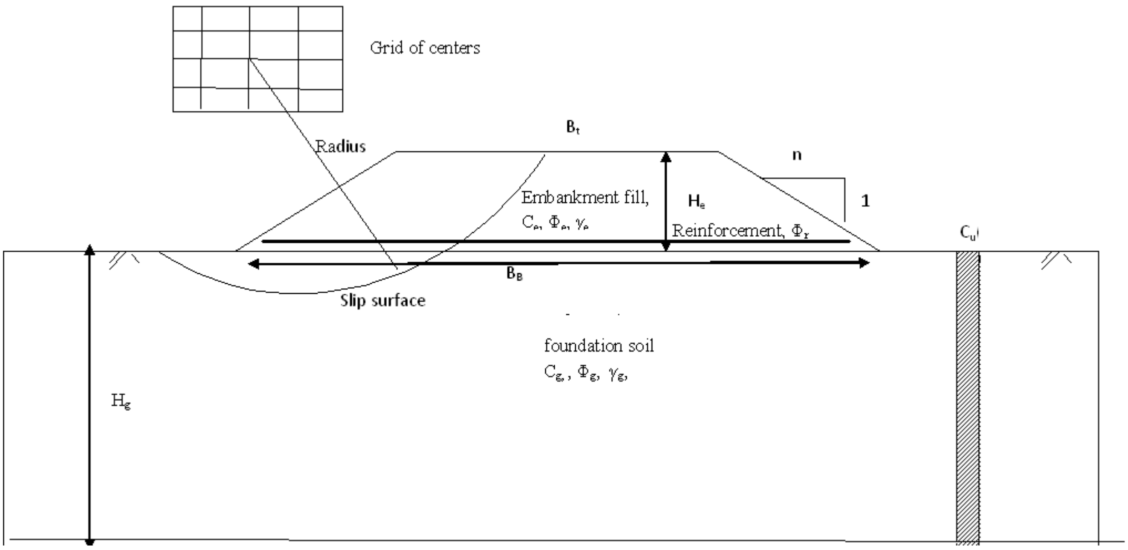


Fig.3 Cross-section of embankment and slip circle considered

Table.1 Embankment Properties for study

Parameter	*Range*
Top width(as per IRC for single lane)	8m
Bottom width	Varying
Side slope (1: n), n	1.5,2, 2.5
Height of embankment He	5m

Table 2. Embankments fill properties for study

Parameter	*Range*
Ce	15kPa
Φe	15
Unit weight	18 kN/cu.m

Table 3. Foundation soil properties for study

Parameter	*Range*
Thickness H	10m
Cu(kPa)	3.7
Φ	13
Unit weight	17 kN/cu.m

Table 4. Reinforcement details

Parameter	*Range*
Type	Geosynthetic geo grid
Location	In the embankment
Length	Vertical distribution
Tensile capacity(allowable), T	50,100,150, 200,300 kN/m
Transfer efficiency	0.6
Interface friction Φr	7.8

Table 5. Seismic coefficient values

Parameter	*Range*
Horizontal acceln. coefficient k_h	0, 0.05, 0.1, 0.15
Acceleration coeff. ratio (k_v/k_h)	0.5

Table 6. Stone column details

Parameter	*Range*
Type	
Phi of stone	32 to 47
Cohesion	0 kPa
Density	20 kN/cu.m
Diameter	1.5m
Spacing	3m
Pattern	Triangular
Length	10m
Stress ratio,n	5

III. PRESENTATION OF RESULTS AND DISCUSSION

3.1 Details of soil properties:

The soil samples collected from site are tested in lab and the results are presented in table.7.

Table.7 properties of samples collected from site.

Property	Borrow pit	Sample Up lane	Sample down lane
Natural Moisture content, NMC(%)	-	-	21.37
Gravel(%)	21.1	23.8	12.1
Sand(%)	76.8	74.5	84.5
Fines(%)	6.945	7.197	6.175
Liquid limit, w_l	41.94	49.72	36.16
Plastic limit, w_p	18.18	20.00	33.33
Plasticity Index, PI	23.78	29.72	2.83
Classification as per IS	SC	SC	SM
OMC	10.5	13.8	12.5
MDD kn/m	2.07	1.69	1.74
Cohesion, c kPa	15.7	3.7	12
Phi	15	13	13

3.2 Presentation of results for reinforced embankment under static and pseudo static case without surcharge:

The slip circle obtained is presented in figs. 4 and 5. The results are tabulated in table.8. Typical variation of Fs with Kh is presented in fig.6 and fig.7.

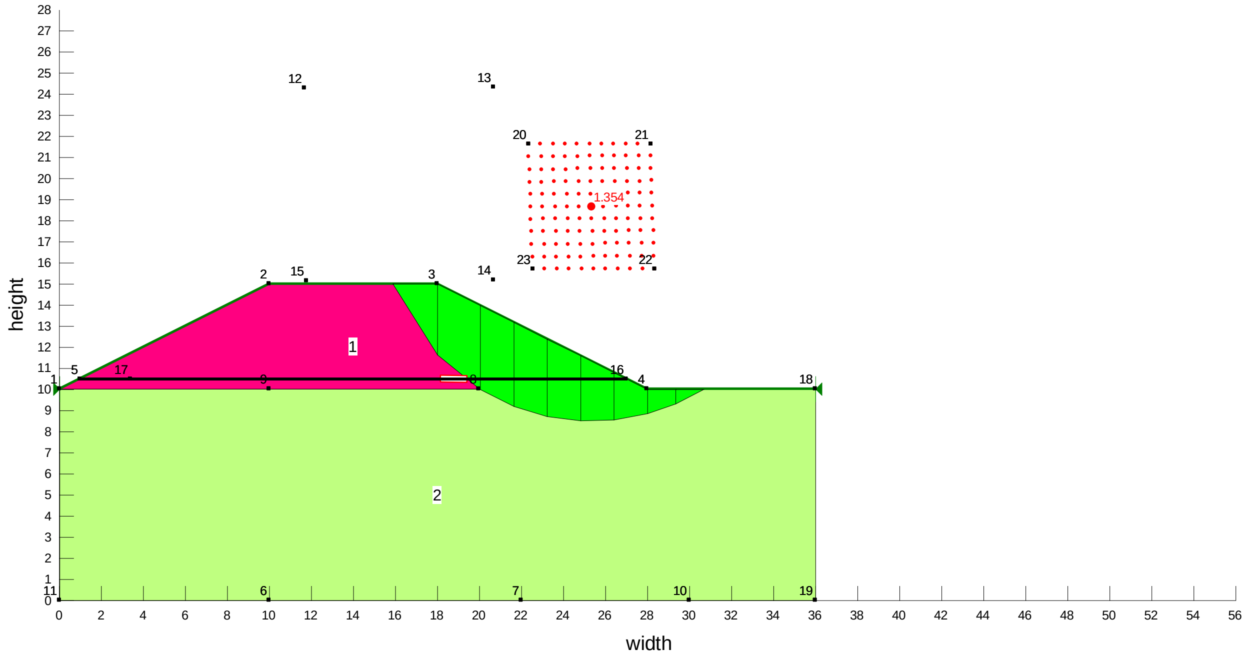
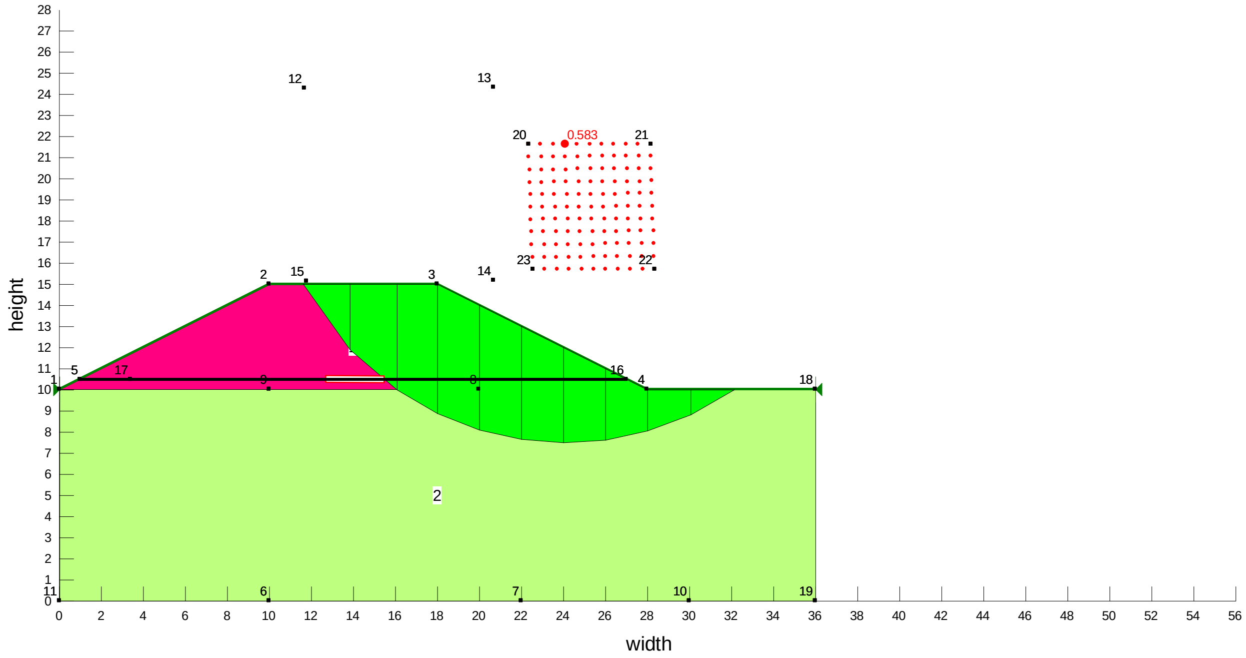


Fig.4 Geo slope modeled embankment and slip circle for static and reinforced case



Pseudo static

Fig.5 G**eo slope modeled embankment and slip circle for seismic and reinforced case**

Table- 8 FoS for embankment under seismic conditions

IJARSE
ISSN: 2319-8354

T	kh	Fs			
T=0 kN/m	0	1.555	1.609	1.666	1.829
	0.1	1.212	1.24	1.255	1.344
	0.2	0.987	1.005	1.023	1.07
	0.3	0.835	0.843	0.156	0.881
T=50 kN/m	0.0	1.555	1.731	1.81	1.957
	0.1	1.285	1.324	1.359	1.429
	0.2	1.05	1.069	1.091	1.127
	0.3	0.886	0.897	0.905	0.904
T=100 kN/m	0	1.756	1.853	1.95	2.085
	0.1	1.38	1.416	1.464	1.511
	0.2	1.117	1.135	1.161	1.18
	0.3	0.941	0.947	0.961	0.968
T=150 kN/m	0	1.915	1.975	2.089	2.213
	0.1	1.487	1.496	1.551	1.591
	0.2	1.185	1.198	1.223	1.235
	0.3	0.995	0.995	1.004	1.01
	0.4	0.86	0.854	0.87	0.864

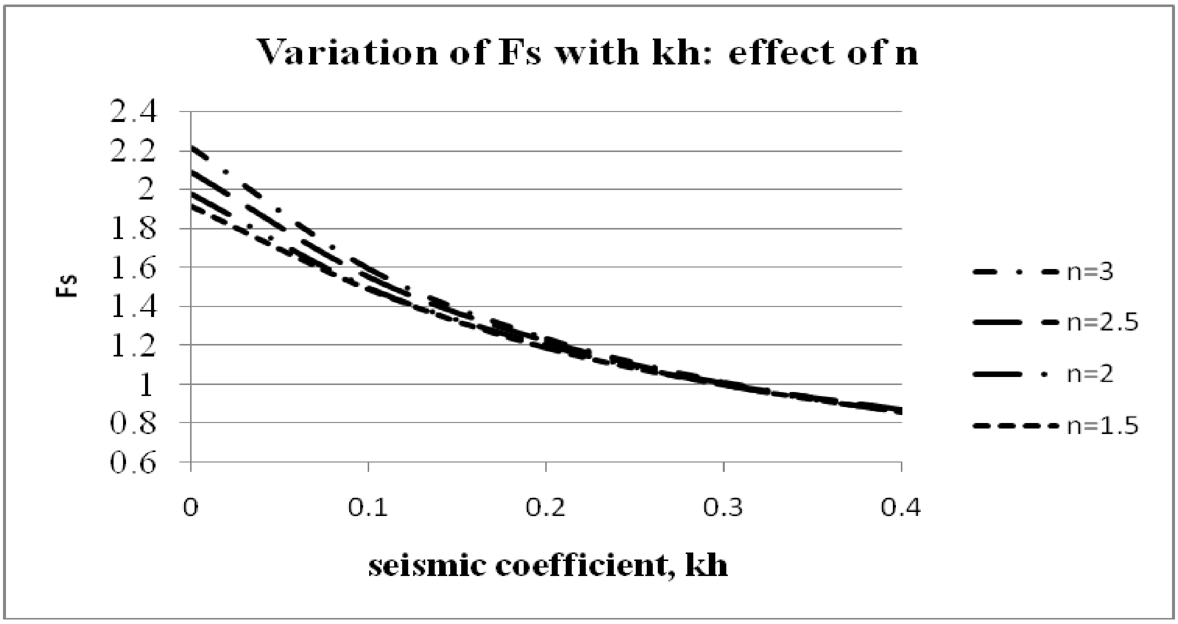


Fig.6 variation of Fs with kh: effect of n

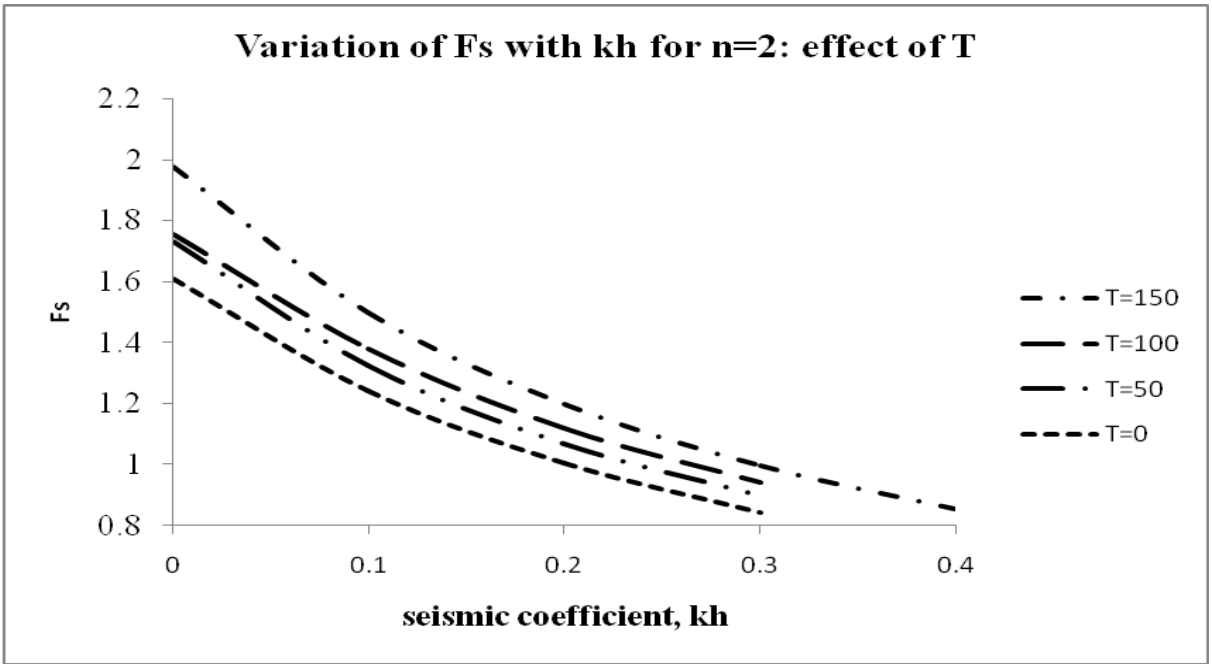


Fig.7 variation of Fs with kh for n=2: effect of T

3.3 Presentation of results for embankment with surcharge of 3 kg/ sq.cm under static conditions:

The reinforced embankment with surcharge modeled with geoslope and is shown in fig. 8 The typical slip circle indicates Fs ranges are low between 0.8 to 0.6. Hence the embankment is unstable for surcharge under static loading and hence seismic loading is beyond its capacity. The results are same for even higher tensile capacity of reinforcement.

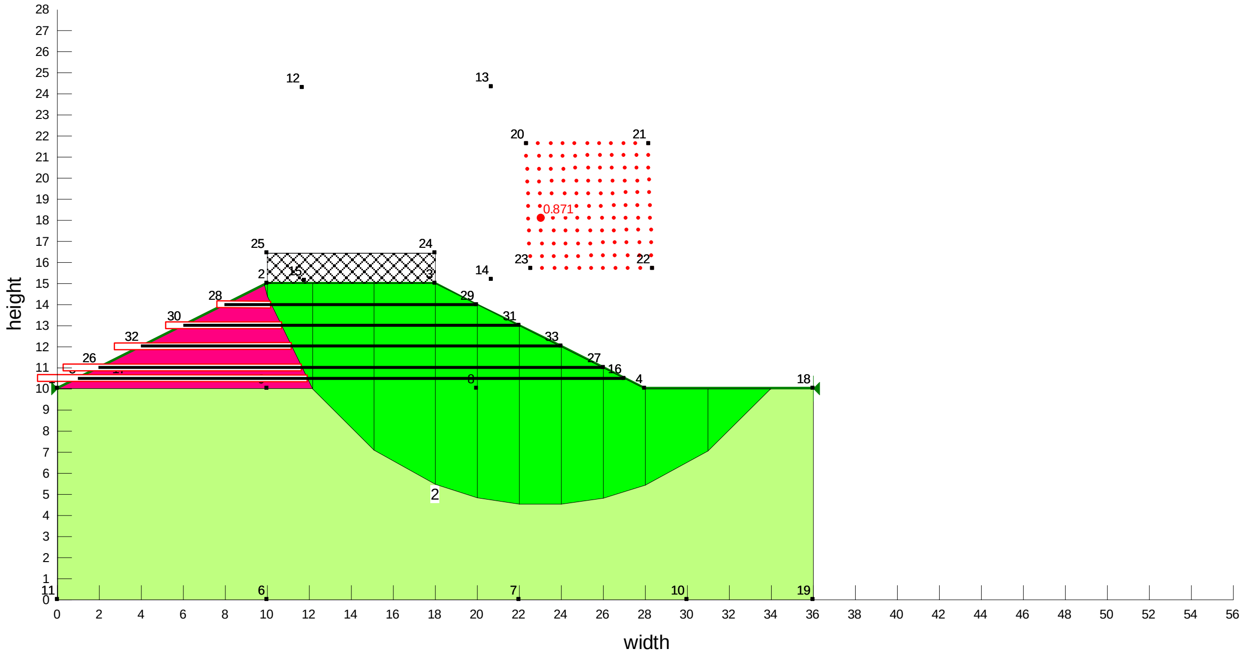


Fig.8 Slip circle with surcharge for reinforced embankment.

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3.4 Pseudo static seismic stability results on stone column reinforced ground considering surcharge of 3 kg/sq.cm.

As mentioned in 3.2 and 3.3 the embankment is unstable in seismic plus surcharge load combination. An attempt is made to reinforce ground with stone columns and observe stability. A typical stone column supported embankment is shown in fig.9(a) and layout is presented in fig.9(b) The stone columns will have a combined effect on stiffness and strength of ground. Homogenized ground properties are arrived with stone columns using formulation described below. The results of stability on composite ground are presented in table .9

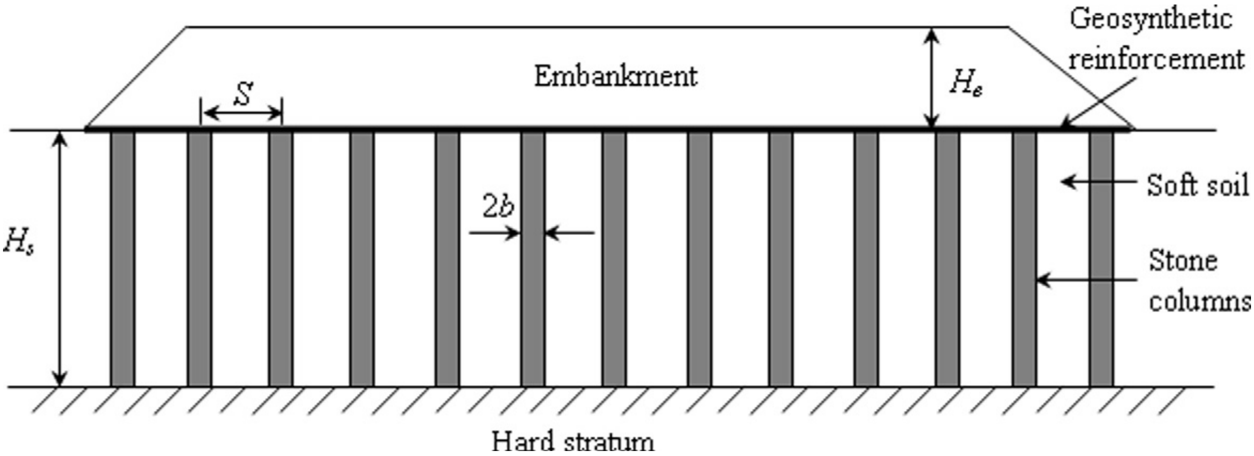

Fig 9(a)

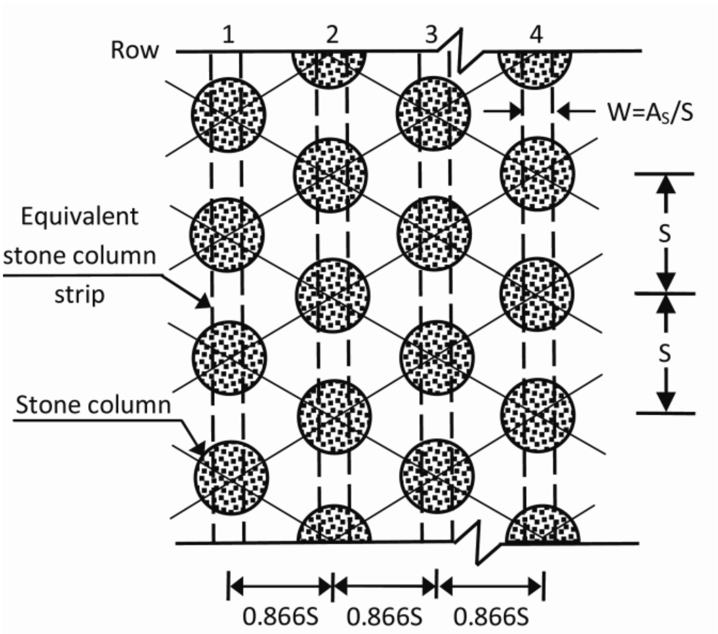

Fig 9(b)

Computation of equivalent area (homogenized area) with stone columns:

IJARSE
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$$C_{ave} = C_c(1-A_r) + c_s A_r$$

$$= C_c(1-A_r), \text{since } c_s = 0 \text{ for stone column}$$

$$\tan\phi_{avg.} = \frac{((1-A_r)\tan\phi_c + S_r A_r \tan\phi_s)}{1 + A_r(S_r - 1)}$$

$$S_r = 1 + (S_{rv} - 1)\cos\alpha$$

$$\gamma_{avg} = (1-A_r)\gamma_c + A_r\gamma_s$$

$$\mu_s = S_{rv} / ((1 + (S_{rv} - 1)A_r)$$

$$A_r = \pi d^2 / 4s^2 \quad \text{for square array}$$

$$A_r = \pi d^2 / 4s^2 \cos 30^0 \text{ for triangular array}$$

$$s_{rv} = \sigma_s / \sigma_c$$, stress ratio, range between 1 to 5

$c_{avg.}$ = average cohesion for treated soil

c_c = cohesion of the insitu soil

c_s= cohesion of stone

γ_s = unit weight of material of stone column

γ_c = unit weight of material of stone column

$\tau_{avg.}$= average shear strength of soil

$Ø_s$ = internal friction angle of stone

$Ø_{avg.}$ = average friction angle of treated soil

$\gamma_{avg.}$ = average unit weight of treated soil

$Ø_{c.}$ = internal friction angle of insitu soil

σ_s = effective vertical stress due to weight of column and applied loading ,

= τ_s z + sm_s

σ_c = vertical stress in the insitu soil

Table 9. Properties of homogenized ground

csoil	cstone	phi soil	phi stone	gamma soil	gamma stone	Composite ground		
						cavg.	phi. Avg.	gamma avg.
6	0	12	32	16	20	5.3954	21.97569	16.40307
6	0	12	35	16	20	5.3954	23.22612	16.40307
6	0	12	38	17	20	5.3954	24.54613	16.40307
6	0	12	41	17	20	5.3954	25.94805	16.40307

IJARSE
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6	0	12	44	17	20	5.3954	27.44638	16.40307
6	0	12	47	17	20	5.3954	29.05825	16.40307

3.5 Presentation of results for reinforced embankment on stone column ground:

The slip circle for seismic cases with surcharge is shown in fig.10 for homogenized ground. Variation of Fs with Kh for homogenized ground is presented in fig. 11. We can observe the Fos is 1.186 for highest seismic load, hence stable in all aspects.

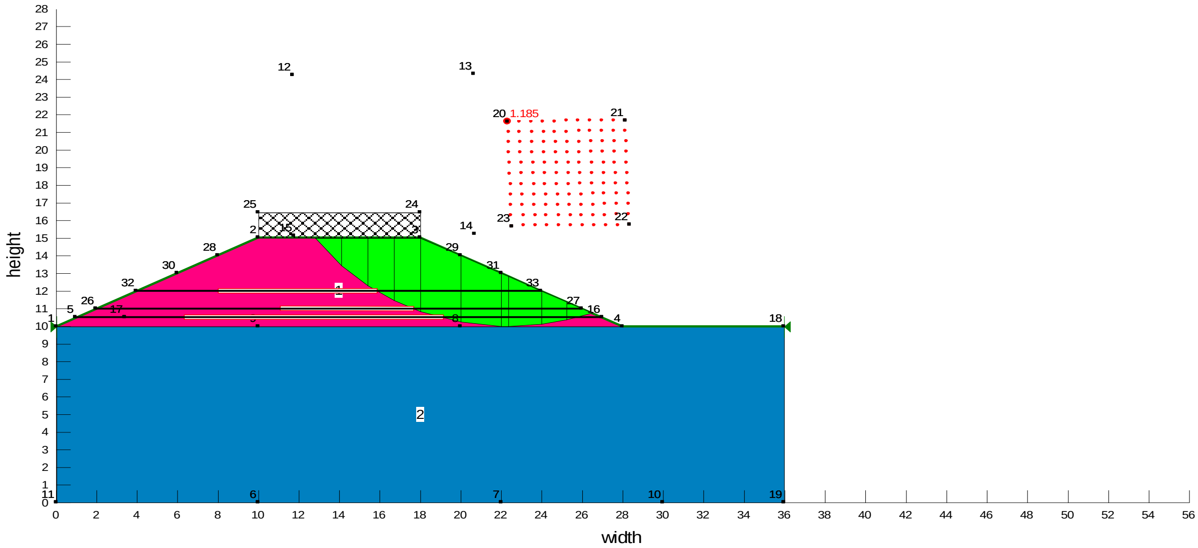
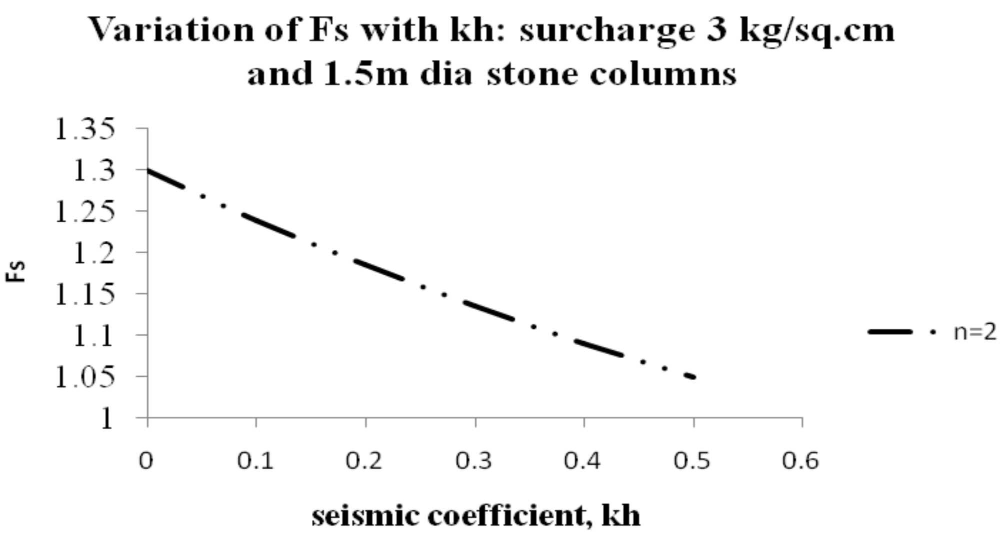


Fig 10. Geo slope model for seismic case and surcharge for embankment on homogenized ground



11 Variation of Fs with kh for embankment on homogenized ground Fig.

IV. CONCLUSIONS

From the study the following conclusions are made;

i) The effect of reinforcement on Fs in seismic conditions is marginal

.ii) Stone column effect in increases Ø of ground. An increase upto 1.2 times in Ø is observed.

iii) The proposed embankment for railway can be constructed using locally fill and 10m long stone columns of 1.5 dia spaced at 3m. which is safe in all conditions.

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