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Optimization of Embankment Widening with Different Soils

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Abstract: ***Due to increasing in the population and vehicular volume the existing roads are becoming inadequate. To overcome this problem, widening of existing roads or embankments are obtained, which required a huge amount of soils of suitable properties but due to industrialization and urbanization the availability of good soils are getting reduced because of which the construction should be carried out with unsuitable or weaker soils of inadequate properties and also the widening process involves accumulation of large land area which results in uneconomic of*** *project.* ***In this study three different soils are considered to analyze the influence of weaker soils on embankment widening which involves the stability analysis and reinforcement contribution analysis. Also study involves optimization of embankment widening using Different embankment sections with different slope angles (via*** *1V:1H, 2V:1.5H, 2V:1H and 2.5V:1H)* ***and geo-synthetic reinforcement, which results in reductions of additional land required and backfill material but ensuring minimum factor of safety of 1.5. The analysis performed based on Limit equilibrium methods using SLOPE/W software.*** *The results shows that the* ***reinforcement mobilizes the stabilizing force in embankment which increases the stability and corresponding factor of safety of embankment and for the reinforced section the factor of safety value is a contribution of both reinforcement and shifted critical slip circle and percentage of contribution depends upon slope angle, soil properties & reinforcement. The cost analysis of embankment widening with different soils and different slope angles shows that steep section is the most economical section in all the cases.***

KEYWORDS: Road embankment; Widening; Different soils; Slope angles; Optimization; Geo-synthetic reinforcement;

I. INTRODUCTION

Widening of embankment is adopted to increase the carriage width of an embankment which can serve the purposes of increasing vehicular traffic volume adequately. Widening of embankment required a huge amount of suitable backfill material but now a day due to industrialization and urbanization the availability of good soils are getting reduced.

Yang et al. [4] made a study on differential deformation of embankment widening using PLAXIS software. In this analysis, different excavation schemes are used to know the influence of steps excavation in existing embankment. The results show that smaller steps give lesser deformation compared to large steps.

Wang et al. [9] study on reduction of differential settlement in widening embankment using anchorage bars and geogrid as reinforcement. The analysis is carried out by using different schemes of reinforcement combinations. The results show that combination of anchorage and geogrid are very effective to reduce differential settlement.

Ghosh et al. [7] made a study on stability of a slope using different limit equilibrium methods using Geo-slope software and results are compare. The results show that Janbu's method gives conservative factor of safety compared with other methods. **Jha et al. [3]** in their study optimize of geosynthetic reinforcement by curtailing from the face end and identify the effect shifting of the critical circle due to reinforcement and compare with unreinforced slopes. The results show that factor of safety is contribution of slip circle shift and reinforcement effect and due shifting of the critical slip the reinforcement length can be reduced by up to 16%.

In this paper an embankment of 6 m height and top width of 4 m with side slopes of 1V:2H is considered (Figure 1). The top width of the existing embankment which is of 4 m is extended by 12 m resulting in the extension of the base width to 40 m for the same existing side slopes. As the base width of extended embankment is occupying larger area, to reduce the land requirement and to study effect of weaker soils on stability of widening embankment the analysis is carried out by considering different soils with different slope angle and geo-synthetic reinforcement. Further reinforcement length is optimized and rate analysis is carried for each section and compared.

Objective: Optimization of embankment widening.

II. METHODOLOGY

In this study, the influence of different soils on stability and design of slopes of widening embankment are analyzed. The analysis is carried out by considering three different soils of different strength properties. Among which one of the soil (S1) is of same soil properties of existing embankment and other two soils (S2 & S3) are considered of weaker strength properties then soil properties of existing embankment (S1). The properties of different soils are tabulated in Table 01.

Table 1 Soil Properties

S.No.	Soil type	Cohesion	Angle of Shearing Resistance
1.	S_1	10 kPa	24^0
2.	S_2	9 kPa	25^0
3.	S_3	6 kPa	26^0

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2.1. Stability Analysis:

The embankment widening is carried out by providing steps cutting of 1 m height and 2 m width on the slope of the existing embankment which provides a bond between the existing and extended portions of embankment. Due to widening of the existing embankment the bottom width of embankment increases to large area. To optimize the bottom width, different slopes, viz., 1V: 1H, 2V: 1.5H, 2V: 1H and 2.5V: 1H are considered due to which the bottom width of occupies less area as shown in Figure 01

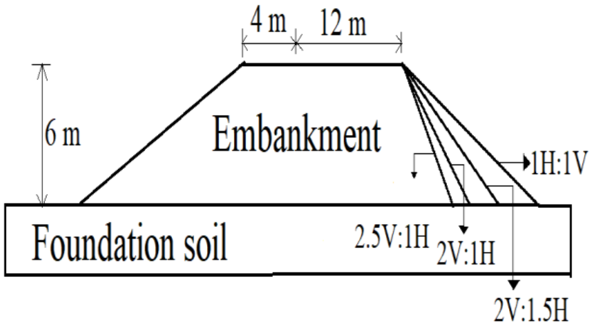

Fig. 1 Widened Embankment with different slope angles

The widening of embankment with each different soil using different Slopes viz., 1V:1H, 2V:1.5H, 2V:1H and 2.5V:1H are analyzed using Slope/W software of Geostudio 2012. (Figures. 2 to 4)

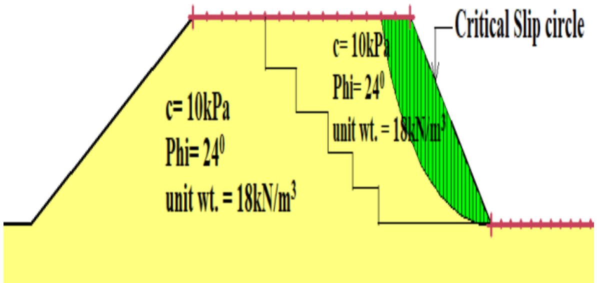

Fig. 2 Widened Embankment Section with S_1 Soil

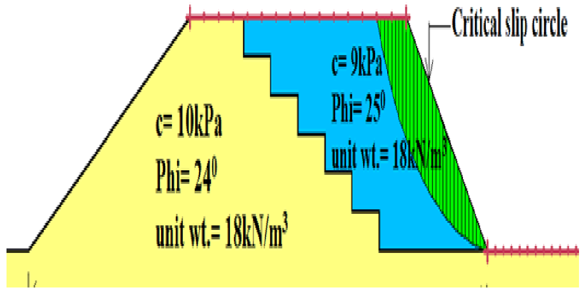

Fig. 3 Widened Embankment Section with S_2 Soil

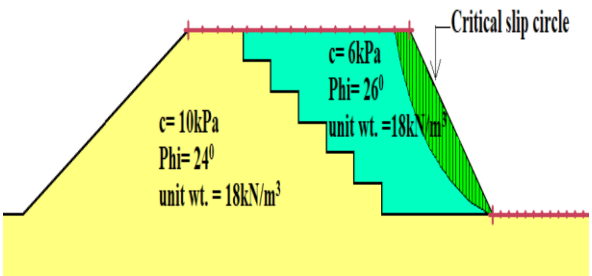

Fig. 4 Widened Embankment Section with S_3 Soil

Minimum factor of safety obtanied from the analysis for different soils are summarized in table.

Table 2 FS Values of Unreinforced Embankment Widened with Different Soils

S.No.	Section	For S_1soil	For S_2 Soil	For S_3 Soil
		Factor of Safety	Factor of Safety	Factor of Safety
1.	1V:1H	1.32	1.3	1.12
2.	2V:1.5H	1.16	1.14	0.97
3.	2V:1H	1.00	1.0	0.82
4.	2.5V:1H	1.05	0.97	0.76

The above results show that the none of the above slopes are stable since the FS is less than 1.5 (required for long term stability). The slopes are reinforced with geosynthetic reinforcement (geogirds/geotextiles) to obtain a minimum factor of safety of 1.5 in each case

2.2. *Design and Optimization of Reinforcement:*

Geo-synthetic reinforcement of ultimate tensile strength 80 kN/m and the allowable tensile resistance of 40 kN/m with a reduction factor of 2 is used as reinforcement. Initially for all the slopes the reinforcement is provided to the full possible length (i.e. the face cutting edge of steps to the slope face of the widened/extended portion) with spacing of 1 m as shown in Figure 5.

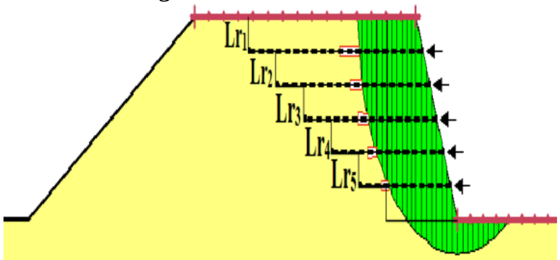

Fig. 5 Slope provided with reinforcement of fully possible lengths with 1 m spacing.

The slopes provided with full length reinforcement at minimum spacing of 1 m for different soils are analyzed and results are as shown in table. The results indicate that the provided reinforcement is much higher than required to maintain a factor of safety 1.5.

Table 3 FS Values of Reinforced Embankment for Fully Extended Reinforcement

S.No.	Section	For S_1soil	For S_2 Soil	For S_3 Soil
		Factor of Safety	Factor of Safety	Factor of Safety
1.	1V:1H	1.93	1.91	1.9
2.	2V:1.5H	1.87	1.84	1.81
3.	2V:1H	1.81	1.80	1.77
4.	2.5V:1H	1.78	1.74	1.75

Further analysis is done by varying spacing of reinforcement layers and location of reinforcement at different depths. Much iteration is carried out for different combinations of spacing and location of reinforcement and it is found that reinforcement provided in the bottom half of the embankment (i.e., depths of 3 m to 6 m) is preferable with minimum spacing of 1 m.

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By considering the above results, reinforcement is provided at spacing of 1 m, and placed at the lower half of the embankment for embankments with different slope angles and different soils to obtain minimum FS of 1.5. Figure 6.

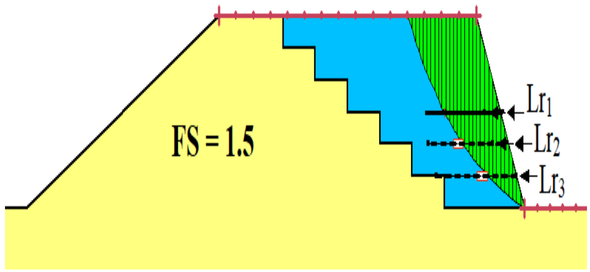

Fig. 6 Slope with Reinforcement Provided at Bottom Half of Embankment to maintain FS of 1.5

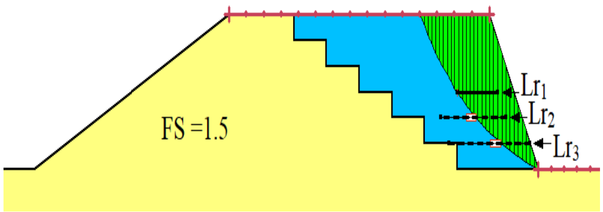

Fig. 7 Slope with Optimized length Reinforcement to maintain FS of 1.5

Further the optimization of reinforcement length is carried out by using curtailing of reinforcement layers from both the ends without causing the change in the factor of safety value of 1.5. the curtailing for both the ends are continued till a point, which further reduction length of reinforcement results in reduction of factor of safety value as shown in Figure 7

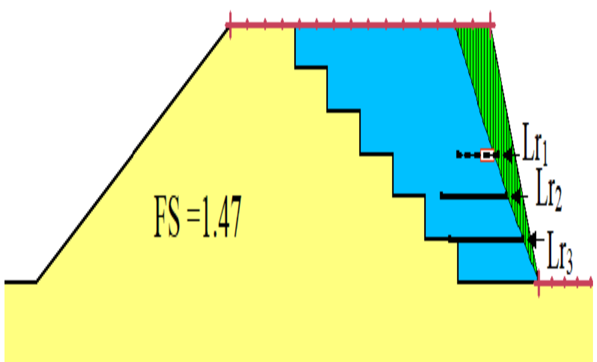

Fig. 8 Failure of Slope on reduction of reinforcement length beyond length of optimization

2.3. *Shifting of critical slip surface*

In reinforced embankment due to the effect of reinforcement the critical slip surface of slope shifts deep into the slope when compared to that of unreinforced slope. Thus resulting a lager soil mass contribution for increasing stability of slope

Figure 8 illustrates the shifting of critical slip surface due to effect of reinforcement. BC and AC represent the critical circles of unreinforced and reinforced slopes. AC get deeper inside the slope, the sliding mass has large weight which results in increase of stabilizing force. Consequently, the force mobilized in the reinforcement gets reduced as the stability zone increases. However, the overall factor of safety still remains same (i.e., ≥ 1.5)

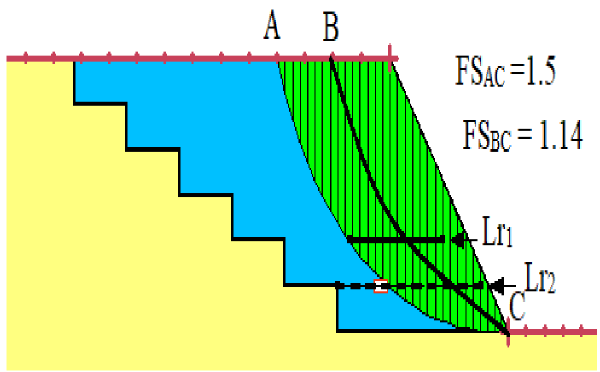

Fig. 9 Critical slip circles for Unreinforced and Reinforced Slope; AC and BC- critical slip circles for reinforced and unreinforced slopes.

Thus, it is established that the resulting FS is a contribution of due to shift of critical slip surface and reinforcement force. The percentage contributions FS of these two factors are estimated.

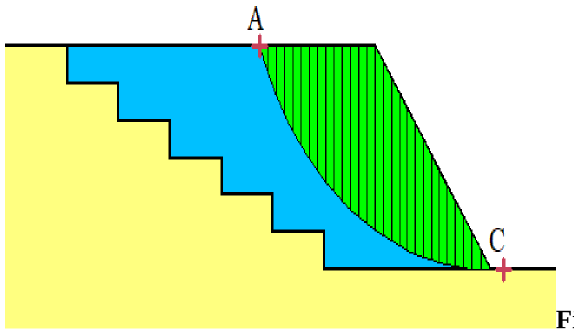

Fig. 10 FS of Reinforced Slope excluding effect of reinforcement. AC = critical slip circle of reinforced slope

Figure 09 illustrate the effect of shifted critical circle on Factor of safety value by excluding the effect of reinforcement. FS of this critical circle is estimated without considering effect of reinforcement. FS value obtained from the above scenario only due to shifted critical circle.

Similarly, FS values of different slope angles and different soils are estimated and summarized in Table 2.

Table 4 Factors of Safety

S. No.	Sections	For S_1soil		
		FS_U	FS_{RE}	FS_{ER}
1.	1V:1H	1.32	1.59	1.39
2.	2V:1.5H	1.16	1.50	1.25
3.	2V:1H	1.00	1.50	1.04
4.	2.5V:1H	1.05	1.50	1.13

Table 5 Factors of Safety

S. No.	Sections	For S_3soil		
		FS_U	FS_{RE}	FS_{ER}
1.	1V:1H	1.30	1.56	1.33
2.	2V:1.5H	1.14	1.54	1.37
3.	2V:1H	1.00	1.51	1.12
4.	2.5V:1H	0.97	1.50	1.20

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Table 6 Factors of Safety

S. No.	Sections	For S_3soil		
		FS_U	FS_{RE}	FS_{ER}
1.	1V:1H	1.12	1.57	1.37
2.	2V:1.5H	0.97	1.50	1.34
3.	2V:1H	0.82	1.54	1.23
4.	2.5V:1H	0.76	1.52	1.01

FS_U = factor of safety of unreinforced embankment; FS_{RE} = factor of safety for reinforced embankment; FS_{ER}=factor of safety for reinforced embankment due to shifting of critical circle, excluding contribution of reinforcement.

The following ratios are used to determine the effects of reinforcement and shifting of critical surface. Relative overall improvement ratio, ΔFS_{RS} in factor of safety of reinforced slope

$$\Delta FS_{RS} = \frac{FS_{RE} - FS_u}{FS_u} \quad (1)$$

and ΔFS_{Sh} = relative improvement in factor of safety exclusively due to shifting of critical circle

$$\Delta FS_{Sh} = \frac{FS_{ER} - FS_u}{FS_u} \quad (2)$$

The net relative contribution of reinforcement is the difference between the two relative ΔFS_{RS} & ΔFS_{Sh} improvements.

2.4. *Rate analysis:*

The rate analysis is carried for the each reinforced section of widened embankment with different slope angle and different soils. Rate analysis of embankment widening involves the cost of additional land to be acquired for construction to estimate the overall economy. The major items for costing are (i) Land cost, (ii) Ground preparation/ Clearance, (iii) Excavation, (iv) Earth work, (v) Transportation of materials and (vi) Reinforcement.

Unit rates of these items are taken as per the standard PWD schedule of rates (Table 5)

Table 7 Schedule of Rates

S. NO.	ITEMS	UNITS	RATE (Rs)
1	Ground clearance	cum	30
2	Excavation	cum	38.5
3	Earth work	cum	135
4	Transportation charges	cum	98
5	Land cost	sqm	4500
6	Reinforcement	sqm	250

III. RESULTS AND DISCUSSION

The analysis shows that the stability of the widened embankment can be enhanced by providing reinforcement which results in increment of factor of safety value. In reinforced slopes the mass of slide portion increases due to the effect of the provided reinforcement in slopes, which results in stability of embankment. The results show that stability of a reinforced embankment is a contribution of reinforcement and shifting of slip circle deep inside.

The analysis is carried out to calculate the percentage contribution of factor of safety due to reinforcement and due to shifting of slip surface for different soil properties and slope angles. The different contribution percentages of factor of safety are calculated and tabulated in table 06

Table 8 Individual Contributions of Factor of Safety

S. No.	Section	For S_1Soil	
		Due to Shifting of Slip Circle	Due to Reinforcement effect
1.	1V:1H	6%	17.56%
2.	2V:1.5H	5 %	25.04 %
3.	2V:1H	6.67 %	42.68 %
4.	2.5V:1H	7 %	46.50 %

Table 9 Individual Contributions of Factor of Safety

S. No.	Section	For S_2Soil	
		Due to Shifting of Slip Circle	Due to Reinforcement effect
1.	1V:1H	16%	17%
2.	2V:1.5H	20 %	15%
3.	2V:1H	11.8 %	38.6 %
4.	2.5V:1H	12 %	40.5%

Table 10 Individual Contributions of Factor of Safety

S. No.	Section	For S_3Soil	
		Due to Shifting of Slip Circle	Due to Reinforcement effect
1.	1V:1H	22.3%	16.7%
2.	2V:1.5H	38 %	14 %
3.	2V:1H	50.2 %	37.8 %
4.	2.5V:1H	25 %	38 %

The result shows that percentage contribution of reinforcement and shifted critical circle depends on soil properties (i.e., C & Ø) and varies for each sections of slope angle.

Later rate analysis is carried out by calculating the total quantities of each item required for each different section and different soils, which are multiplied with rates of unit quantity to obtain total cost for each section of embankment widening. The total cost of each section with different soils and varying slope angle are estimated and compared with corresponding cost of unreinforced embankment widening section, give the percentage reduction in cost of each section.

Table 11 Cost Analysis per Unit Length of Embankment

S. No.	Section	For S_1Soil	
		Total Cost (Rs)	Total Cost (Rs)
1	Original section	73,567	-
2	1V:1H	38,024	48%
3	2V:1.5H	30,990	57.8%
4	2V:1H	24,057	67.2%
5	2.5V:1H	22,007	70%

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Table 12 Cost Analysis per Unit Length of Embankment

S. No.	Section	For S_2 Soil	
		Total Cost (Rs)	Total Cost (Rs)
1	Original section	95,780	-
2	1V:1H	52,090	45.6%
3	2V:1.5H	44,685	53.3 %
4	2V:1H	36,995	61.3%
5	2.5V:1H	34,063	64.4 %

Table 13 Cost Analysis per Unit Length of Embankment

S. No	Section	For S_1 Soil	
		Total Cost (Rs)	Cost Reduction (%)
1	Original section	95,780	-
2	1V:1H	53,410	44%
3	2V:1.5H	44,795	53.2 %
4	2V:1H	37,985	60.3%
5	2.5V:1H	35,273	63.2 %

IV. CONCLUSIONS

An analysis is carried out to study the influence of weaker soils on the stability of the widened embankment. Different slope angles analysis and optimization of reinforcement length using curtailing techniques are carried out to design a most economical section. Finally rate analysis is carried out for reinforced slopes.

- The reinforcement mobilizes the stabilizing force in embankment which increases the stability and corresponding factor of safety of embankment.
- For the reinforced section the factor of safety value is a contribution of both reinforcement and shifted critical slip circle and percentage of contribution depends upon slope angle, soil properties & reinforcement.
- Percentage contribution of reinforcement & critical circle for factor of safety provided. FS contribution due to shifting of critical circle increases with increase angle of shearing resistance Ø but contribution of reinforcement decreases with increase angle of shearing resistance Ø
- The length of the reinforcement can be reduced up to 28%, 20% and 12% by curtailing for widening of embankment with soil type S_1, S_2, S_3 respectively.
- A significant reduction of 24% of additional land area requirement for widening can be achieved by using steeper slope angle and geosynthetic reinforcement.
- The cost analysis of embankment widening with different soils and different slope angles shows that steep section is the most economical section in all the cases.

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