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Performance of Geotextile Reinforced Slopes of Earthen Dam

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ABSTRACT: *Soil reinforcement is now well established technique for geotechnical applications in most parts of world. This paper presents the application of soil reinforcement technique for slope stability of earthen dams. The dam section designed by Water Resources Department of Maharashtra has been considered for the study. The slopes of dam are then considered to be reinforced with horizontal layers of geotextile and its effect on factor of safety has been studied. The various parameters of the reinforcement such as spacing, length and offset from the face are varied and its effect on the stability is evaluated by using Oasys Slope software. It is found that much steeper slopes may be provided to the earthen dams by providing geotextile reinforcing layers. The suitable length of reinforcing layers, spacing between them and offset from the face needs to be determined for the required slopes of dam. The economic analysis of the reinforced slopes of dam has also been carried out and found to be much economical. This technique may be particularly useful for high earthen dams and may result in lesser construction cost as well as construction time.*

KEYWORDS *: geotextile reinforcement, reinforced slopes, Oasys software*

I. INTRODUCTION

The conventional method of embankment dams to a stable slope for a given height may involve considerable expenses in material, plant, construction time and extension to the base area of embankment dam. While for low height dams this may not be of much concern, but for high dams provided with flatter slopes may involve considerable increase in cost of dam. Also in some cases, if the suitable construction material is not available nearby site, then there will be an additional increase in cost due to transportation of suitable material. One of the solutions to this issue is to make the dam slopes much steeper than obtained by conventional design procedure. The slopes of embankment dam can be made steeper by reinforcing them with suitable reinforcing material.

Reinforced soil is a technique where tensile elements are placed in soil to improve stability and control deformation. To be effective, the reinforcement must intersect the potential failure surface in the soil mass. Strains in the soil mass generate strains in the reinforcement, which in turn, generate tensile loads in the reinforcement. These tensile loads act to resist soil movements and thus impart additional shear strength. This results in composite soil reinforcement system having significantly greater shear strength than soil mass alone. Reinforced soil is very cost effective technique compared to other construction techniques. Literature clearly established that the reinforced soil technique provides cost effective solution with lesser construction period and higher stability of the completed structure.

A great number of reinforced soil structures, particularly for retaining walls, for railways and highways has been constructed in recent parts and showed successful performance even in the seismic loading condition. It is also recognized that the technology is useful to reinforce and rehabilitate soil structures to have higher stability, rainfall and water flow as well [1].Zhu et.al. [2] study the anti-seismic measure of geogrid of high earth rockfill dam, using dynamic elasto-plastic analysis method and suggested installing geogrid in dam slopes to have better performance during strong earthquakes. Amit srivastava and G. L. Shivkumar babu [1] presented a case study where the soil reinforcement technique has been used to reconstruct and stabilize the u/s slope of water impounding reservoir in Karnataka which was failed by sliding under sudden drawdown condition during rainy season. Using FEM analysis in the Plaxis 2D software, it was demonstrated that the provision of reinforcement provides higher stability to the structure. The adoption of soil reinforcement technology is found to highly efficient in terms of ensuring stability and also very cost effective.

1.1 Objectives

In the present paper, the soil reinforcing technique has been used to investigate the effect of horizontal planer reinforcement such as geotextile on strengthening of slopes of embankment dam so as to make them steeper as compared to those obtained by conventional design procedure. This will ultimately lead to economy and will also result in saving in construction material, cost, time and land width required for construction of dam. This may be particularly useful in case of high earthen dam. The main objective of the study was to decide the optimum parameters of the reinforcement such as length of reinforcing layers, spacing between geotextile layers and offsets to the layers from the faces of the dam. The designed section of the proposed Wasani dam to be constructed in Achalpur Taluka of Amravati district of Maharashtra has been considered for the study. The u/s and d/s slopes of the dam are considered to be provided with horizontal layers of woven geotextile. The analysis of slopes of the dam has been carried out by using Slope module which is available in the commercial software Oasys [3]. It is demonstrated that soil reinforced u/s and d/s slopes provides higher stability to the structure [4].

II. COMPUTATIONAL ANALYSIS

Details of the designed slopes and berms of Wasani dam are presented in TABLE I.

Table I: Details of the Designed Slopes and Berms of Wasani Dam

Top/ Lower Berm Widths (m)			***Slope H:V***	
R.L.	*u/s*	*d/s*	*U/S*	*D/S*
339.90	6.5	6.5	2.5:1	3.0:1
333.90	6.0	7.0	2.5:1	3.5:1
327.90	5.0	14.0	3.0:1	3.5:1

The model of the Wasani dam has been developed in Slope module of Oasys software as shown in Fig 1. The properties assigned to the dam material are presented in TABLE II.

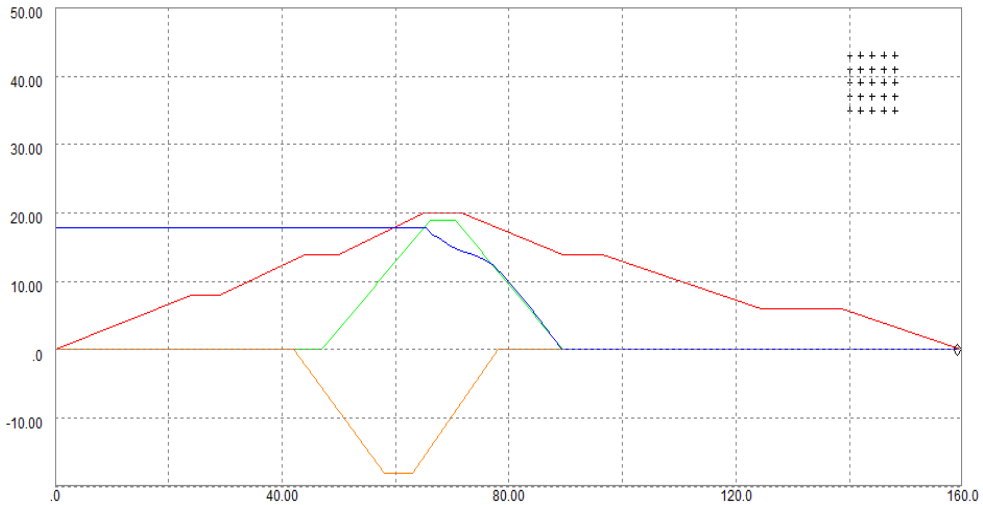

Figure 1: Model developed in oasys software

Table II: Properties of Dam Materials

Sr. No.	***Particulars***	***Unit Weight (kN/m^3)***	***Angle of Friction***	***Cohesion (kN/m^2)***
01	Casing	15.8	25.17	7
02	Hearting	15.16	14.57	18.5
03	Foundation	14.98	16.69	18

The tensile strength of the geotextile reinforcement to be provided for reinforcing the slopes of dam is considered as 200 kN/m. Dam section is analyzed using Bishop's method of analysis. The minimum FOS for the

given section, reinforced or unreinforced, is determined by the software by selecting centre of critical slip surface which is automatically selected by the software. The broad steps in the analysis are as follows:

[1] Selecting the general parameters such as slip surface type (circular or non-circular), type of analysis (static or pseudo static), direction of slip (downhill, increasing x or decreasing x), value of horizontal acceleration (%g),
[2] Selecting method of analysis namely Swedish slip circle method, Bishop Method or Janbu method,
[3] Assigning material properties such as unit weight, conditions (drained linear strength, drained power curved strength, drained hyperbolic curved strength), cohesion and angle of friction,
[4] Setting ground water level,
[5] Drawing strata for various components of dam such as casing, hearting, cut off trench and foundation,
[6] Defining the slip surface (circle centre specification, circle radius specification, centres of grid and features of grid),
[7] Analysis and data checking,
[8] Viewing the results,
[9] Graphical output.

III. RESULTS AND DISCUSSIONS

3.1 Stability Analysis of Unreinforced Slopes of Wasani Dam

The stability analysis of Wasani Earth Dam designed by Water Resources Department of Maharashtra State and the results obtained in the present study are presented in TABLE III.

Table III: Results Obtained by Water Resources Department and Oasys Software

Sr. No.	***Conditions***	***Factor of Safety (FOS)***	
		Obtained by Irrigation Department	*Obtained by Slopes Software*
01	Steady seepage without Earthquake	1.501	1.777
02	Sudden Drawdown without Earthquake	1.319	1.460

3.2 Stability Analysis of Reinforced d/s Slope for Steady Seepage Condition

The d/s slope of the Wasani dam is then considered to be reinforced with horizontal layers of geotextile. As the provision of reinforcing layers of geotextile would result in increase in factor of safety, the steeper slopes may be provided to the d/s side of the dam. The d/s slope of the dam is therefore reduced in increment by 0.25 H: 1V.The spacing between layers (z) was varied from 0.9 to 3 m for each case. Analysis is then carried out for each case separately. During analysis of each case the length of reinforcing layer (L) and their offset (x) from the d/s face of dam was varied in such a way that the reinforcing layers remains activated i.e. intersect the potential failure surface and governing criteria of failure for the reinforcing layers remains as tensile. This ensures the maximum utilization of reinforcing layers and results in economy. Typical graphical output obtained from software is presented in Fig. 2.

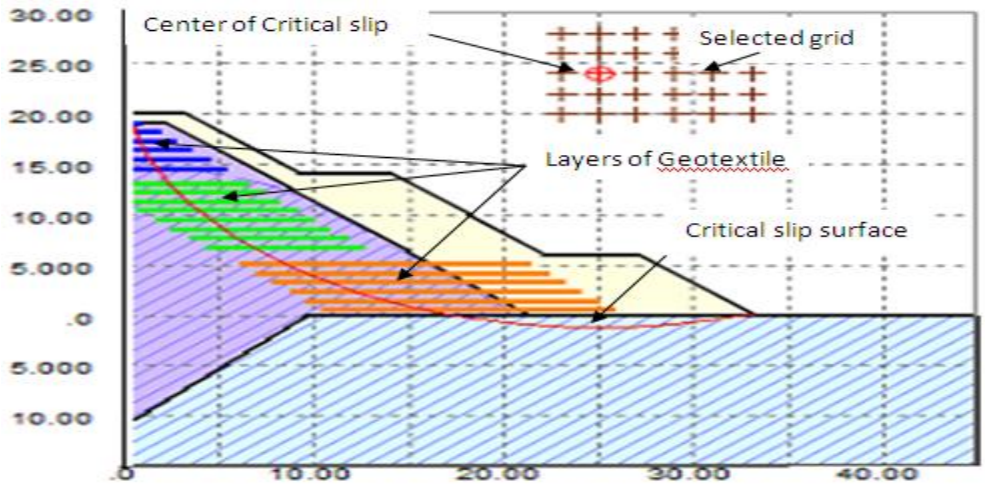

Figure 2: Typical graphical output of d/s slope

The results of analysis are presented in Fig. 3.

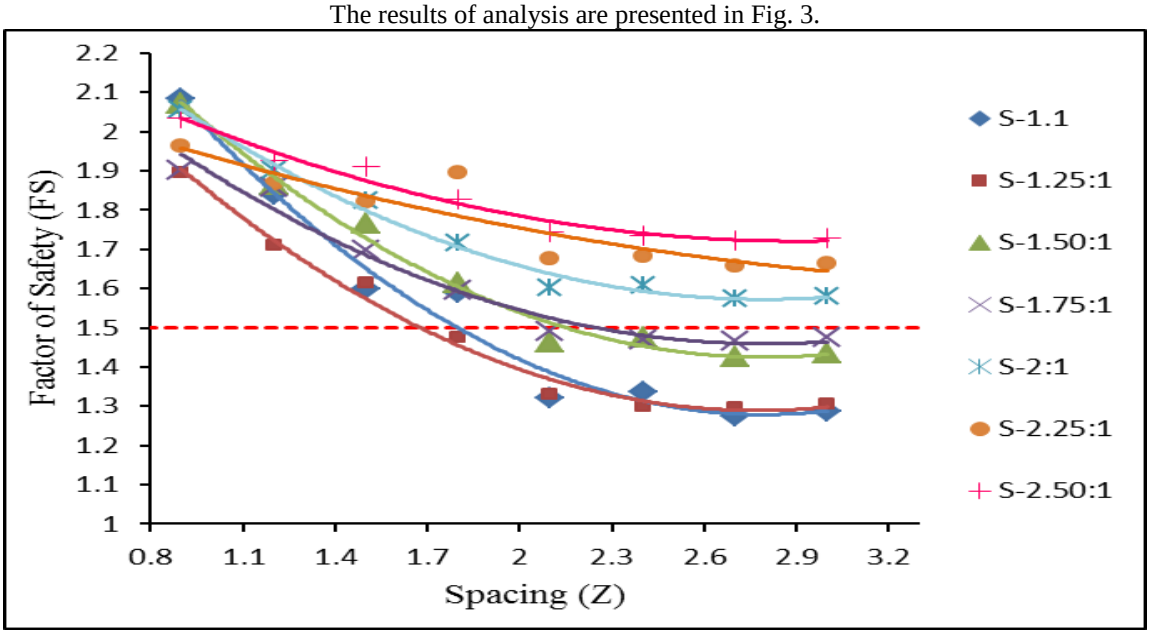

Figure 3: Variation of factor of safety with respect to spacing between geotextile layers for steady seepage condition

From the Fig. it is observed that by providing the geotextile layers at spacing of 3.0 m the d/s slopes of dam can be made steeper up to 2:1. For more steeper slopes, the vertical spacing between geotextile layers is required to be reduced up 1. 5 m. The length of the geotextile layers required for reinforcing the d/s slopes are found to be in the range of 4 m to 16 m and offset from d/s slope are found to be in the range of 3 m to 45 m depending upon the location of geotextile layers.

3.3 Stability Analysis of Reinforced u/s Slope for Sudden Drawdown Condition

The u/s slope of the Wasani dam is then considered to be reinforced with horizontal layers of geotextile. As the provision of reinforcing layer of geotextile would result in increasing F.S., the steeper slopes may be provided on the u/s of dam. The u/s slope is reduced by 0.25 H: 1V in increments. The spacing between layers (z) was varied from 0.9 to 3 m for each case. Analysis is then carried out for each case separately. During analysis of each case the length of reinforcing layer (L) and their offset (x) from the u/s face of dam was varied in such a way that the reinforcing layers remains activated i.e. intersect the potential failure surface and governing criteria of failure for the reinforcing layers remains as tensile. This ensures the maximum utilization of reinforcing layers and results in economy. Typical graphical output obtained from software is presented in Fig. 4.

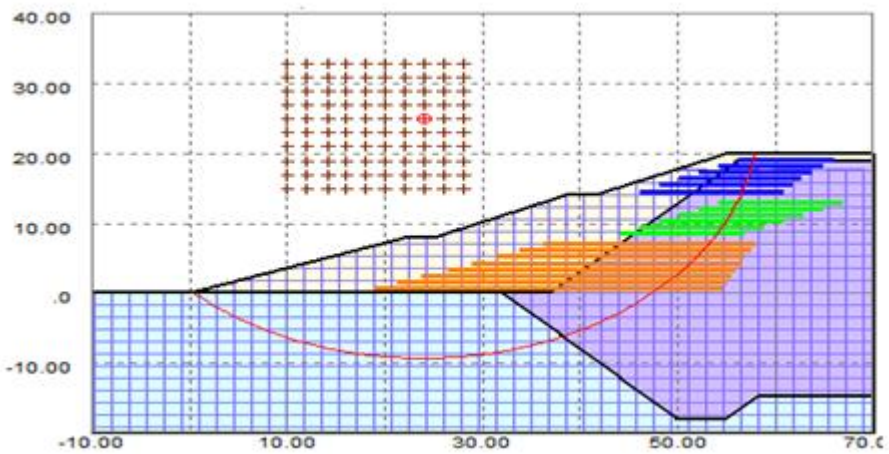

Figure 4: Typical output for u/s slope

The results of analysis are presented in Fig. 5.

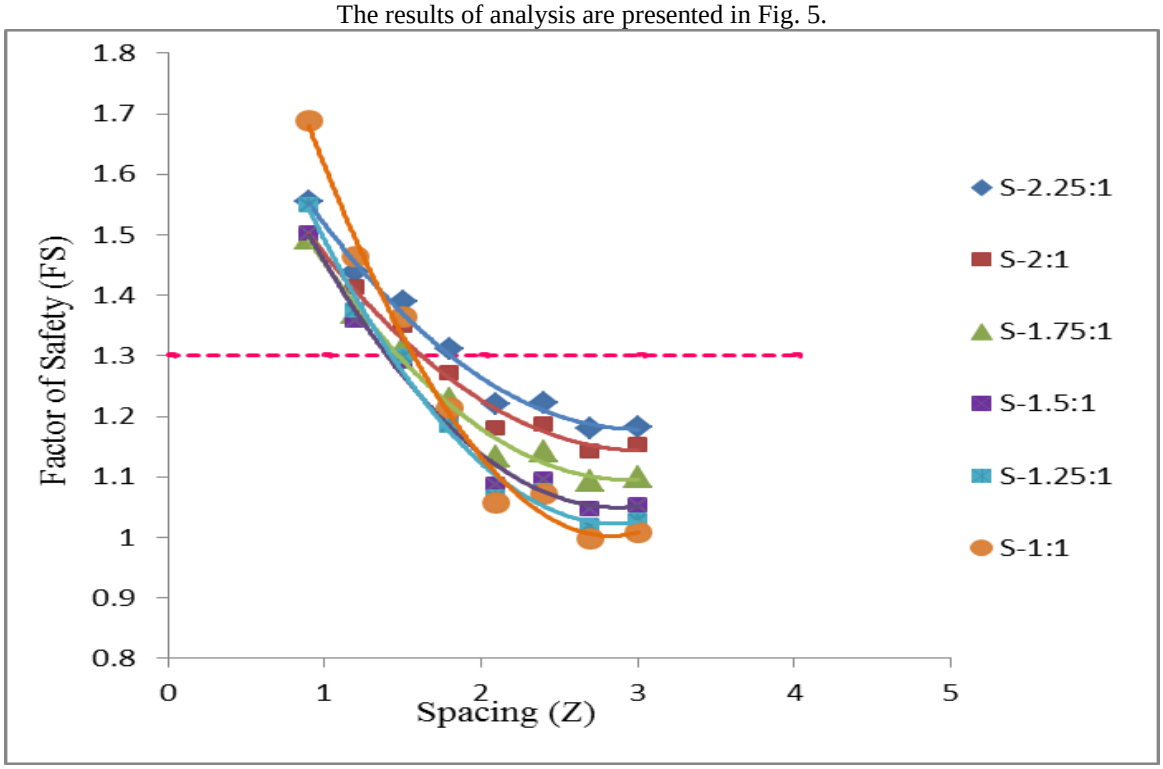

Figure 5: Variation of factor of safety with respect to spacing between geotextile layers for sudden drawdown condition

From the Figure, it is observed that a factor of safety decreases with increase in spacing between geotextile layers. It is also observed that by providing geotextile layers at spacing of 1.5 m, the u/s slope as steep as 1:1 can be provided. The length of the geotextile layers required for reinforcing the u/s slopes are found to be in the range of 4 m to 27 m and offset from u/s slope are found to be in the range of 3 m to 18 m depending upon the location of geotextile layers.

IV. ECONOMIC ANALYSIS

The economical analysis of the dam reinforcement has been carried out and compared with the unreinforced dam section. From the analysis it is observed that the reinforced dam section is 36% more economical.

V. CONCLUSIONS

In the present study, soil reinforcement technology using geotextile reinforcement has been adopted for strengthening the u/s and d/s slopes of the earthen dam. It is found that much steeper slopes may be provided by providing the geotextile reinforcement. A spacing of 1.5 m between geotextile layers is found to be suitable for safe section of dam in all cases. In order to utilize the full strength of geotextile layers, geotextile layers of sufficient length and at appropriate offsets need to be provided. The economic analysis of the reinforced dam section indicates saving of about 36% in the cost.

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