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# Comparison of different design concepts in slope stability analysis of geosynthetic reinforced slopes

Erol Güler, Muhannad Ismeik & Yaman Görken
*Boğaziçi University, Istanbul, Turkey*

ABSTRACT: In this paper the design method proposed by the Federal Highway Administration manual and the ones developed basically by Jewell, which are called the Chart methods, for the design of geosynthetic reinforced slopes are compared to each other. The FHWA method foresees that when a geotextile is used as a reinforcement, the effect of the flexibility of the reinforcement must be considered in the analysis. A computer program ISMEIK is developed for the design concept of FHWA method, which follows all the internal design steps. The program gives the force coefficient values for combination of various slopes and internal friction angles for extensible reinforcement, thus developing a new chart for extensible reinforcement. The newly developed chart is compared with existing methods and similarities and differences are discussed.

## 1 INTRODUCTION

Geosynthetic reinforced soil is recently one of the most commonly used soil improvement techniques to increase the stability of unreinforced natural slopes. The increased use of this composite engineering material is because of its versatility, cost effectiveness and ease of construction.

Reinforced slopes are currently analyzed using modified versions of the classical limit equilibrium slope stability methods proposed by Murray (1982), Leshchinsky and Reinschmidt (1985), Verduin and Holtz (1989), among others. All these methods try to fulfill the required criterion's in order to secure the stability of the slope on an assumed failure surface which could be a circle, log spiral or two wedge part.

Schmertmann, et al. (1987) and Jewell (1984) developed user friendly charts to calculate maximum tensile forces per unit width of slopes for inextensible reinforcements. Jewell (1990) revised his charts by improving the analysis technique. Though the charts are one set, independent of reinforcement type, it is stated that it can be used for extensible and inextensible reinforcement. The revised charts incorporate around 30 % savings as compared to the previous ones. The Federal Highway Administration manual (Christopher et al. 1990), however, distinguishes between extensible and inextensible reinforcement. Jewell's Charts and FHWA method will be briefly described below.

## 2 A GENERAL OVERVIEW OF THE DESIGN CONCEPT OF FHWA

The FHWA method (Christopher et al. 1990), uses limit equilibrium theory in the stability analysis of reinforced slopes. Potential failure surface is assumed circular and the relationship between driving and resisting moments of the most critical slip circle, which requires the maximum amount of reinforcement, determines the unreinforced factor of safety $F_{S_u}$ which is calculated by Bishop's (1955) method. Then The target factor of safety $F_{S_r}$ of the reinforced slope is formulated as:

$$F_{S_r} = F_{S_u} + \frac{T_s \cdot D}{M_D} \quad (1)$$

where $M_D$ is defined as the driving moment of the critical surface, $T_s$ is the required tensile force to hold the slope in equilibrium and D is the moment arm which depends on the extensibility of the reinforcement.

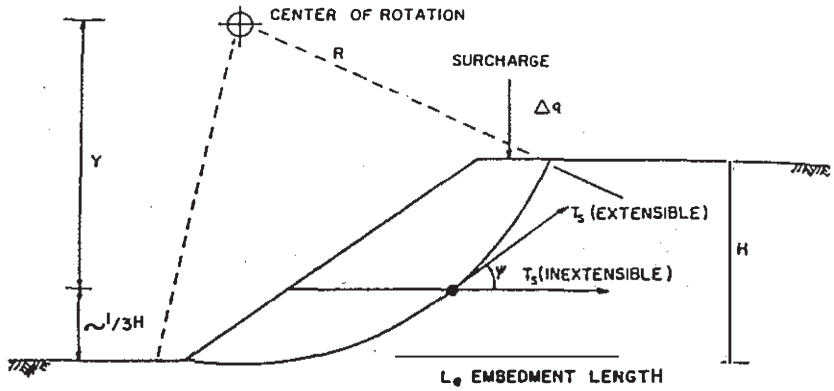


Figure 1 Orientation of the tensile forces used in the FHWA method (Christopher et al. 1990)

The moment arm is equal to the radius R for extensible reinforcements and equals to the vertical distance Y for inextensible reinforcement as illustrated in Figure 1.

## 3 A GENERAL OVERVIEW OF THE CHART METHODS

It is a simplified method based on a two part wedge type failure surface (Jewell 1984, 1990). The method presents a design procedure for determining the maximum tensile force required to hold a slope stable by the inclusion of geogrid strips for embankments, with slope angles ranging from 45° to 80° in chart form, as shown in Figure 2 and Figure 3 receptively. The main steps in the chart design procedure in order to determine the maximum tensile force required to hold the section in equilibrium, are summarized below:

- A factored angle of internal friction $\phi_f$ which is smaller than the real angle of internal friction $\phi$ is defined as:

$$\phi_f = \tan^{-1}\left(\frac{\tan\phi}{F_{S_r}}\right) \qquad (2)$$

- The force coefficient K is determined from Figure 2 with the slope angle $\beta$ and $\phi_f$.
- The maximum horizontal force T required to hold the slope in equilibrium is calculated as:

$$T = \frac{1}{2} \cdot K \cdot \gamma \cdot H^2 \qquad (3)$$

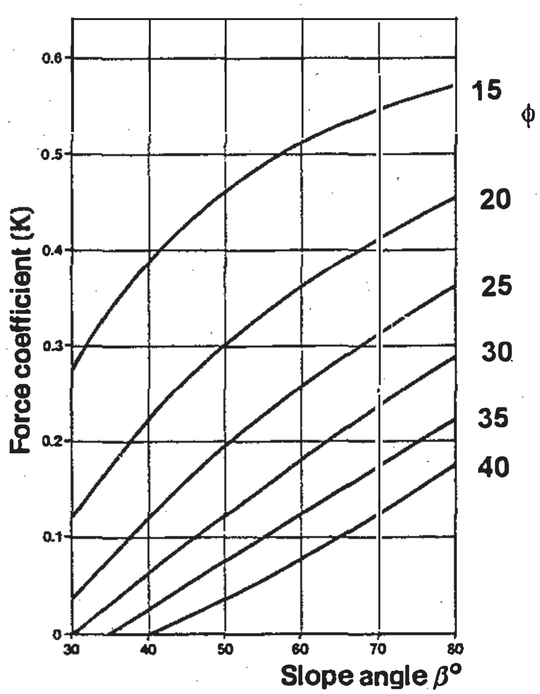


Figure 2 Jewell's Chart (1984) for geogrid reinforcement

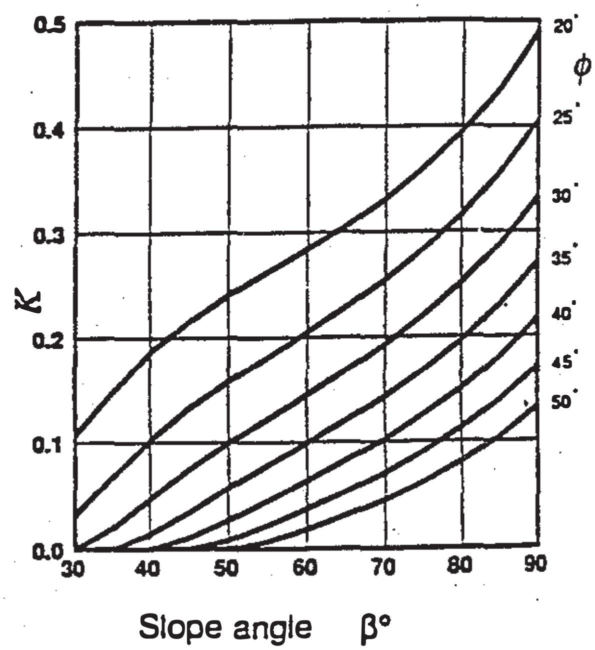


Figure 3 Jewell's revised Chart (1990) for all types of reinforcement

## 4 THE COMPUTER PROGRAM ISMEIK

A computer program is developed following the design method of FHWA, (Ismeik, 1992). The program first searches for all possible failure surfaces. In each iteration it calculates the factor of safety and the corresponding required tensile force which will produce the target factor of safety. The program can consider both extensible and inextensible reinforcements. It can also include a uniform traffic surcharge load.

A typical output of the program, is the location of the critical circle which gives the maximum reinforcement tensile force, the magnitude of this force, the distribution of the reinforcements and embedment length as well as the total length of each reinforcement.

In the program, equation 3 was rearranged in a non dimensional form giving the value of K in a very useful form so that it could be compared independently of any specific height or unit weight as:

$$K = \frac{2 \cdot T}{\gamma \cdot H^2} \qquad (4)$$

T in the above equation is determined by rearranging equation 1 and solving for the total reinforcement tension $T_{max} = T_S$ required to obtain the target factor of safety $F_{S_r}$ for the most critical slip circle. This results in:

$$T_S = \left(F_{S_r} - F_{S_u}\right) \cdot \frac{M_D}{D} \qquad (5)$$

It is obvious that, the reinforcements should compensate the maximum tensile force per width of the slope in order to provide the stability of the slope for an adequate factor of safety, namely for the target safety factor. Therefore, the sum of all resisting forces of the reinforcements should be equal to $T_{max}$ value, which is calculated with this target factor of safety.

Many analyses proved that the determination of K coefficients is independent of the height and unit weight, but mostly dependent on pore water pressure and effective soil cohesion both effect the magnitude of K among many other factors.

## 5 APPLICATION OF THE SAFETY FACTOR

Before proceeding further, the effect of the application of the safety factor in the FHWA and the Chart Method on the final results were investigated. As an example, the force coefficient K for a soil of internal friction angle of 30° is determined for various values of slope angles ranging from 45° to 80° with a factor of safety of 1.5. The results showed that the required amount of reinforcement deviated significantly depending on the design method used as illustrated in Figure 4.

This leads to the question of how it is possible to duplicate the Jewell 1984 Chart by using the FHWA method. It is recognized that the difference is due to the difference of application the safety factor in the two methods. Namely in the Chart Method the safety factor is applied to the strength property of the soil, where in the FHWA method the safety factor is applied to the stability of the slope.

In the FHWA method the used angle of internal friction is exactly the original one without any reduction.

However, in the Chart Method the factor of safety is applied to the internal friction angle of the reinforced soil at the first step as defined in equation 2 and then

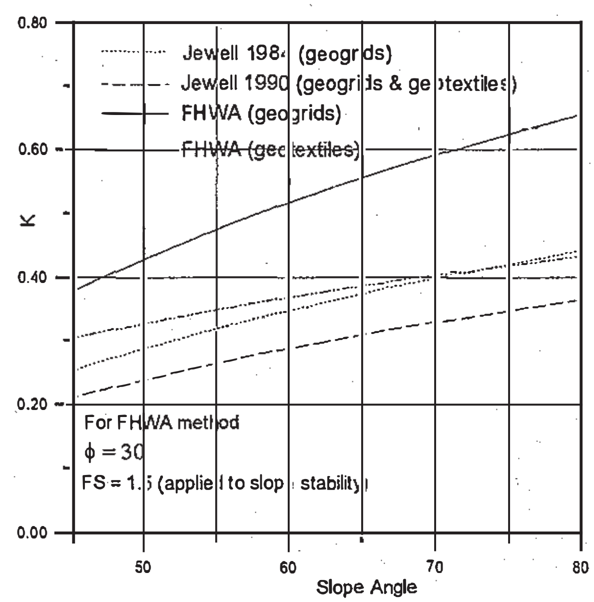


Figure 4 Comparison between Chart Methods and FHWA design method.

with this factored internal friction angle value, it begins to calculate the maximum tensile force by using the chart.

So a factored $\phi_f$ and $F_{Sr}$ of unity applied to the strength property of the soil were used as an input data for the program ISMEIK. The internal friction angle of the reinforced soil is determined by using equation 2 where the $F_{Sr}$ value is chosen to be 1.5. Since the internal friction angle $\phi$ was 30° and the target factor of safety $F_{Sr}$ was 1.5 in the original analysis, new values of these parameters are calculated as 21° and 1.0.

Force coefficients K for all methods which are calculated from maximum tensile forces by using the equation 5 are presented in Figure 5.

The difference between the results of Jewell 1984 and FHWA geogrids methods for different slope angles is very small. This proves the validity of the correspondence between FHWA method and the Jewell 1984 Chart Method results, when the factor of safety is applied to soil properties rather than slope stability.

## 6 DEVELOPMENT OF A CHART FOR GEOTEXTILE REINFORCEMENT

Comparison of both procedures was the first step for the development of the K against $\beta$ chart. To get accurate results and to obtain the correct chart, the compatibility between the results of the Chart Method and the FHWA method was checked using the computer program ISMEIK.

At this stage, it is possible to develop a new design chart for K-values against $\beta$ angles utilizing extensible reinforcements (Görken, 1995), i.e. geotextiles contrary to Jewell's Chart (1984).

The new chart includes the force coefficients for different internal friction angles and slope angles. Calculations have been done for $\phi$ = 15°, 20°, 30° and 40°. These values are the most encountered internal friction angles in practice.

In order to determine the required K-values, maximum tensile forces have been calculated by using the computer program ISMEIK with a unity target safety factor and reduced $\phi_f$. Force coefficients have been determined by using equation 5.

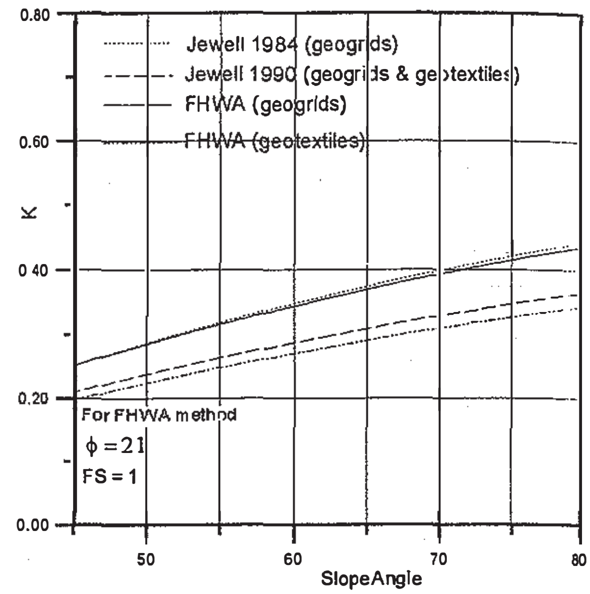


Figure 5 K values of Chart Method for a backfill with $\phi$= 30 versus FHWA for $\phi_f$= 21 and $F_{Sr}$ = 1.0

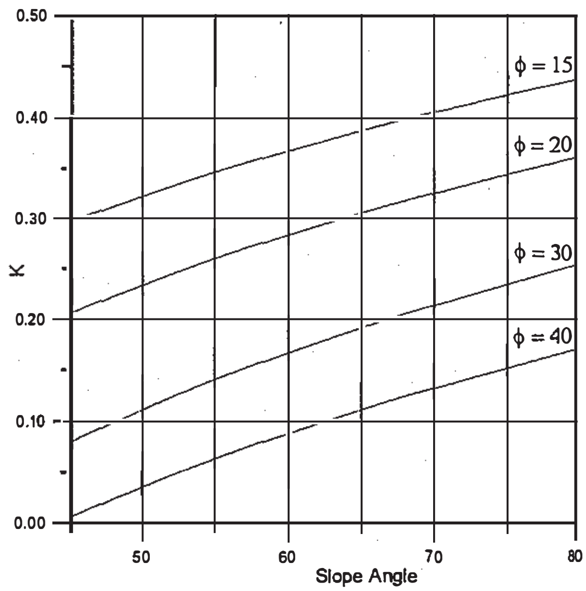


Figure 6 The new chart for geotextiles reinforcement

Calculations has been done for a slope height of nine meters and for slope angles of 45°, 50°, 55°, 60°, 65°, 70°, 75°, 80°. The choice of 9 m height is arbitrary since the K coefficients are independent of the height.
Maximum tensile forces are obtained from the computer outputs and then converted to force

coefficients which are used in the development of the chart.

The new chart is illustrated in Figure 6 and it is the combination of K against $\beta$ values for all four internal friction angles. This chart is developed for dry conditions and cohesionless soil fill and for extensible reinforcements. Similar charts for different pore water pressure could be obtained.

The uniform surcharge load in both steps of the analyses for the development of the chart is taken to be zero. In case of an existing surcharge load condition, its effect to the calculations can be analyzed by increasing the height by an extra amount equals to the surcharge value divided by the unit weight. The same procedure used in the Chart Method should be also followed here when using the new developed chart (for instance, instead of $\phi$ angle new $\phi_r$ value should be determined in order to use the chart correctly to obtain the force coefficient K for the examined slope). As a result, the new chart represents the FHWA method for designing geotextile reinforced steep slopes.

## 7 COMPARISON BETWEEN THE NEW DEVELOPED CHART AND OTHER METHODS

It is possible now to compare and plot on the same graph the slope angle $\beta$ and the K coefficient for the new developed chart, and the ones developed by Jewell (1984, 1990). This is done for two angles of internal friction, 20° and 30° for side slope $\beta$ ranging from 45° to 80° as illustrated in Figures 7 and 8 respectively.

It can be noticed clearly that the force coefficient for extensible reinforcements are in general less than the ones for inextensible reinforcements. This is to say that, the maximum tensile force obtained from Jewell method (1984) is greater than the one obtained from FHWA for the same soil properties and geometry. Therefore, a slope may require more inextensible reinforcements than extensible ones if both have the same geometrical and physical properties. Also, it is noted that the new developed charts results for extensible reinforcement are in fair agreement with the ones obtained from Jewell (1990). Generally for good quality backfills, the deviation between the methods tends to decrease as seen in Figure 7 and 8.

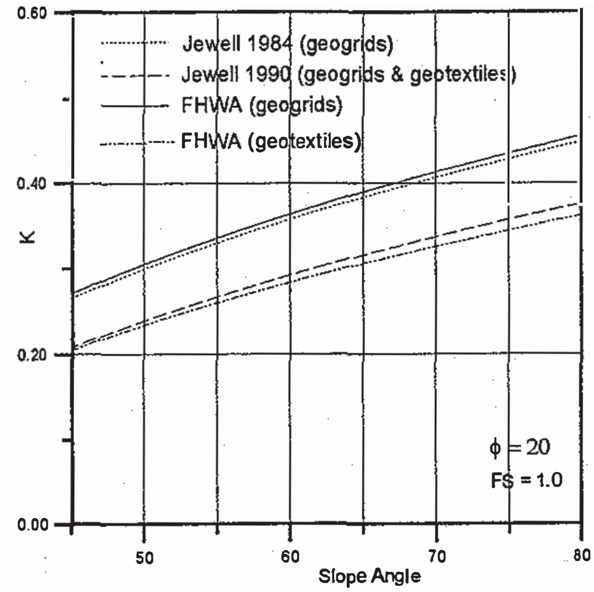


Figure 7 Comparison between the new chart and the Jewell Chart $\phi$ = 20°

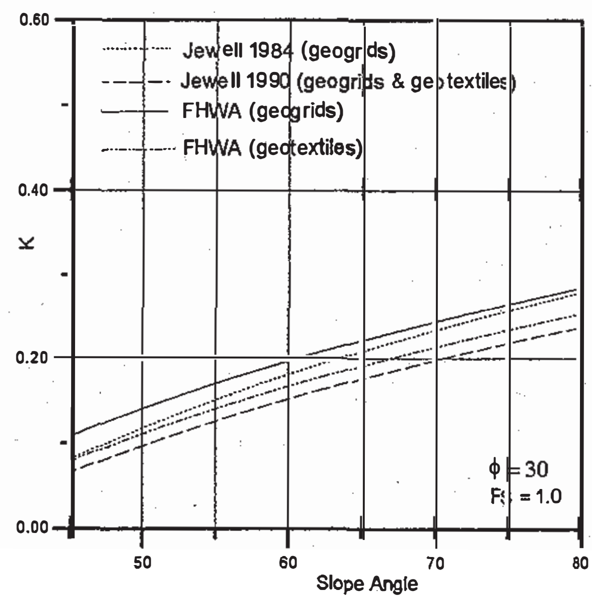


Figure 8 Comparison between the new chart and the Jewell Chart $\phi$ = 30°

## 8 CONCLUSIONS

1. The computer program ISMEIK has been developed following the Federal Highway Administration procedure.

2. The horizontal force coefficient value K is independent of the height and unit weight of the embankment, but it changes with the level of saturation, cohesion and slope angle.
3. It is shown that the computer program ISMEIK can represent both the method proposed by the FHWA and Jewell (1984) Chart.
4. The application of the safety factor is on the material property for the Chart Methods, where in the FHWA method, the safety factor is applied to the slope stability analysis. The two methods only give similar results, if the safety factor is applied to the internal friction angle in both analysis methods.
5. The newly developed chart for extensible reinforcement gives lower force coefficient values than the Jewell's (1984) Chart, however it is in close agreement with Jewell's (1990) Chart for the same soil and slope.
6. The use of geotextiles instead of geogrids in reinforced slope designs is more economical since the amount of geotextile reinforcement needed will be less than the required amount of geogrids.
7. It is important to recognize, however, that there is no generally accepted universal design methodology and much research should be carried out for standardization the methods in order to produce a unique design methodology.

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