Slope Stability Analyses of Zoned Dam Under Steady State Condition/Case Study

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ABSTRACT--Earth and rock are the principal materials from which dams are constructed, these kinds of dams are called embankment dams. The conventional limit equilibrium method has dominated use over any other method for analyzing slope stability. In this paper, Spence, Morgenstern-price, the Ordinary method of slices, and Janbu simplified methods are used to find out how near, far Aquban dam from the verge failure which is in Erbil-Kurdistan/Iraq. In present study, the focus is mainly drawn on analyses of steady-state condition. To compute the factor of safety, the study utilized SLOPE/W software. The results show that there is no major difference in a safety factor and a critical slip surface position between all the methods which are used in the study. In addition, all used methods offered a more than the minimum required safety factory which is given by the U.S. Army Corps of Engineers, so this ensures that the dam against slope instability is on the safe side. According to the results obtained from this study, Janbu simplified method which considers only force equilibrium condition produced the lowest factor of safety, while the highest and almost identical factor of safety generated from the methods that satisfy all the static equilibrium condition (Spencer and Morgenstern-Price methods) give. Therefore, a reasonably reliable and higher value of safety factor is given by the methods which satisfy all static equilibrium conditions.

KEY WORDS: Factor of safety, steady state, slope analyses, slope/w

1. INTRODUCTION

In the study of slope stability, the key focus is on the determination of safety factor against slope failure [1]. According to [2] the contribution to the economical and safe design of embankment, excavation, and earth dams is the top focus of slope stability assessment. Therefore, the primary objectives of stability analysis are to prevent harm to infrastructure and human victims due to slope failure. Stability analysis is often done under static loading. The majority of approaches adopted to evaluate the slope stability in static condition are the approaches of limit equilibrium and finite element analysis approach [3]. Numerous limit equilibrium-based methods have been developed in the study of slope stability, however, (Duncan, 1996) offers a comprehensive overview of slope stability analysis equilibrium methods. According to (Duncan J. a., 1980), methods that satisfy all equilibrium conditions generate accurate results under all realistic conditions. These methods (Spencer and Morgenstern's, and Price's) provide FS values that vary by no more than 5% of the right solution, regardless of the assumptions they make. Baker and Garber's variational approach to evaluating the factor of safety does not require any assumptions about internal force distribution, however it is difficult to use even for a single failure surface (Baker R, 1978). Morgenstern and others have pointed out that the variables of safety FOS from various methods of analyses are

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identical for normal problems, so the assumptions on internal force distributions are not major issues for practical use except in a few situations (Morgenstern, 1992). The finite element method has the advantage of catching the behavior of the stress-strain relationship of soil and thus eliminate the assumptions required by limit equilibrium approaches to turn the static indeterminate problem into a statically determined one. Limit equilibrium methods, on the other hand, do not consider soil stress-strain behavior. Limit equilibrium methods to achieve a statically determined solution the soil mass typically divides into plenty of sections and presume the different interslice normal and shear forces. According to [4] some limit equilibrium methods fulfill all the conditions of static conditions such as Spencer and Morgenstern- Price methods, and some others satisfy partially static equilibrium conditions such as the Ordinary slice method (satisfy only moment equilibrium) and Janbu simplified method (satisfies only force equilibrium). Generally, all satisfactory static equilibrium condition methods appear to provide a more reliable factor of safety estimation than those that satisfy only force or moment equilibrium conditions. Consequently, Spencer, and Morgenstern- Price methods are more commonly utilized because they take all the static equilibrium conditions into consideration and produce a more reliable factor of safety. This paper presents a case study under the steady-state condition that involves different types of soil using Spencer, Morgenstern- Price, the Ordinary method of the slice, and Janbu simplified methods. The software SLOPE/W is used for all the methods.

2. METHODOLOGY

The case study shows the stability analyses carried out in the Aquban zoned dam, which is illustrated in Fig. 1 to assure the stability of the dam under the long-term condition.

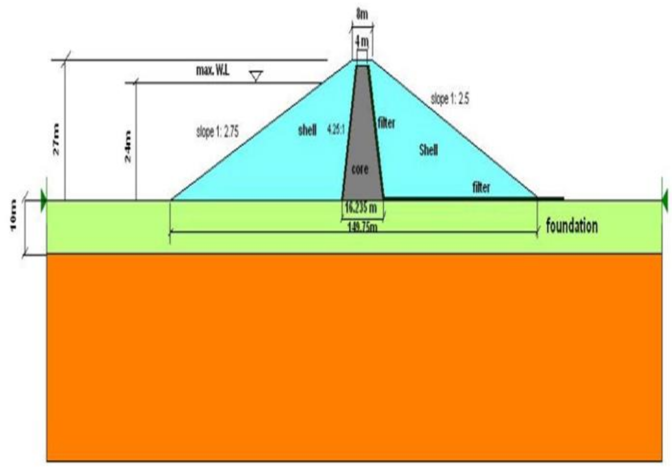

Fig. 1. Dam Section.

The dam is a 27-meters height, with a 24-meters height of the water, and 149.75 m width. The different shear strength parameter of different materials was used as given Core–cohesion= 50 KPa, the Phi equal with 20º and density with 17.4 kg/m3, Dam body (Shell) with C = 25 KPa, Ø = 41º and a density of 20.2 kg/m3, Filter with cohesion = 0 KPa and Ø = 32º density= 19 kg/m3 and for Foundation, gives 40 KPa for the cohesion and friction angle = 22º density 19.5 kg/m3.

2.1 Stability analysis method

Conventional slope stability analysis approaches which are basically built on the concepts of static equilibrium of forces and/or moments have traditionally been used to perform analyses of slope stability [5] The importance of limit equilibrium methods is reasonably reliable in assessing the stability of slopes and minimal input parameters, but have the ability to conduct a comprehensive trial and error check for the critical shear surface. In these methods, it is used to compute the factor of safety by dividing the mass of the slope into different vertical slices. These methods are included:

2.1.1 Spencer's Method

This is a very detailed approach that fulfills both the conditions of forces and moments and works for any slip surface form. The basic principle used in this approach is that for all the slices, the inclinations of the side forces are the same. For interslice forces, Spencer assumes a constant inclination and the safety factor is calculated [6].

2.1.2 Morgenstern-Price Method

Morgenstern and Price began the development of the system in 1995 [7]. The technique is considered one of the techniques that satisfy all conditions of equilibrium. Shear forces between slices relate to the normal forces, as per this approach.

2.1.3 Ordinary method of slices

The ordinary slice method is considered to be among the straightforward stability methods. It satisfies partially equilibrium condition (the only moment) for a circular slip surface, due to parallel to the base of each slice both the inter-slice normal and shear forces are ignored [8]. In this method, no iteration is required to calculate the factor of safety, so it can be directly calculated.

2.1.4 Janbu's simplified method

The moment equilibrium has not been taken into consideration in this technique and considers interslice normal forces (E) but ignores the shear forces (X). Horizontal force equilibrium determines the safety factor.

Table 1. Summary of various limit equilibrium methods.

Methods	Circular	Non-circular	$\sum M = 0$	$\sum F x = 0$	$\sum F y = 0$	X and E Assumptions
Ordinary method	√	×	√	×	×	Ignore both E and X
Janbu simplified	√	×	√	√	×	Considers E, but ignore X
Spencer	√	√	√	√	√	$X = \tan\theta \times E$
Morgenstern-Price	√	√	√	√	√	$X = f(x). \lambda .E$

SLOPE/W is a software developed by GEOSLOPE (Geo-Studio). The software utilizes limit equilibrium-based theories and principles to compute the factor of safety. Due to SLOPE/W 's detailed formulation straightforward and complex slope stability problems can be easily evaluated using different approaches to determine the factor of safety. In this paper, (SLPOE/W 2018) was used to compute the factor of safety in long-term stable condition.

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3. RESULTS

In this paper, static force and/or moment equilibrium based 2D slope stability methods are modeled which are used by Spencer, Morgenstern–Prices, the Ordinary method of slices, and Janbu simplified methods based on the fundamental principles of limit equilibrium. The soil properties (cohesion, internal friction angle, and soil unit weight) are used to assess the minimum safety factor value and to define the critical slip surface. The values of the factor of safety calculated by these four methods to cover all the conditions. Since all the static equilibrium conditions composed of moment and force equations are satisfied by the first and second methods, thereby providing a greater validity for the safety factor, while the third one satisfies only the moment equilibrium and the last method satisfy only force equilibrium. In the case of steady-state, focuses are on the downstream slope. Fig. 2 to 5 illustrate the stability analyses of the dam in regards to a factor of safety and the critical slip surface.

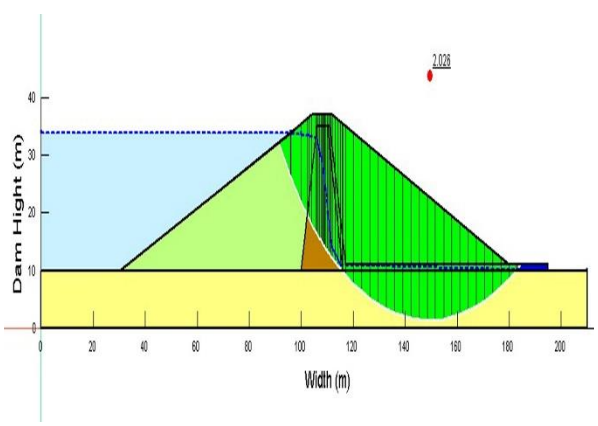

Fig. 2. Stability analysis using Spencer method.

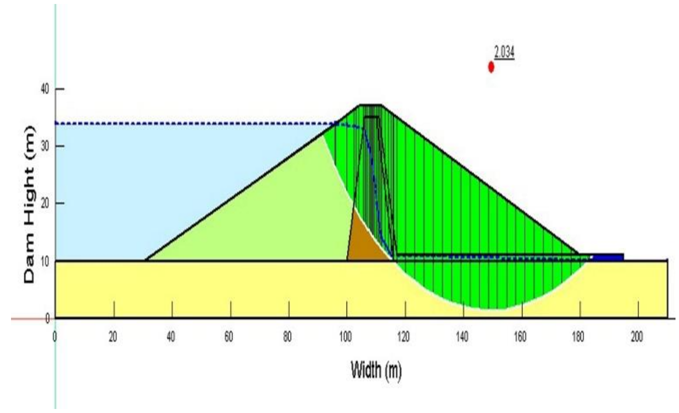

Fig. 3. Stability analysis using Morgenstern-Price method.

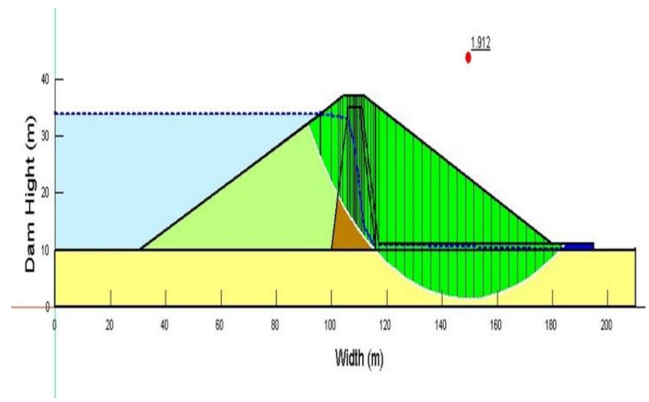

Fig. 4. Stability analysis using Ordinary method of slices.

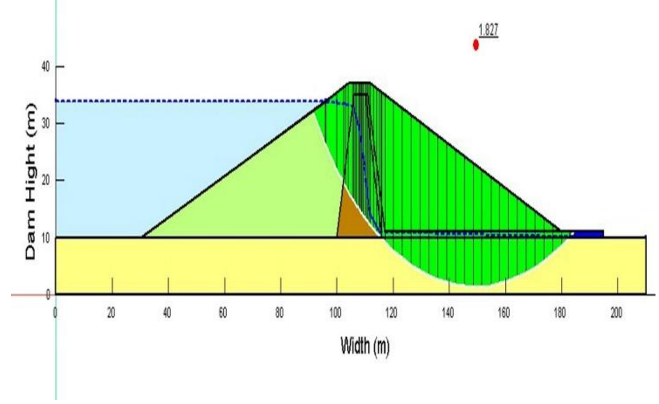

Fig. 5. Stability analysis using Janbu simplified method.

The results from Fig. 2, 3,4, and 5 show that in long-term conditions all methods indicate a factor of safety greater than 1.5 with the presence of water. To comparison, Table 2 addressed the minimum safety factor obtained from the methods. It is evident that the Janbu simplified method which satisfies force equilibrium condition appears to generate the lowest safety factor, while Spencer and Morgenstern-Price

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methods which fulfil all the static equilibrium condition tend to have the highest and almost an identical factor of safety. The moment equilibrium satisfactory method (Ordinary Method of Slices) computes a factor of safety that is higher than the force equilibrium satisfactory method and lower than the methods which satisfy both force and moment equilibrium conditions. It is also worth noting that the critical slip surface passes through the same location in all the methods.

Table 2. The computed factor of safety using various limit equilibrium-based methods

Method	Factor of Safety
Spencer	2.026
Morgenstern- Price	2.034
Ordinary Method of Slices	1.912
Janbu	1.827

4. CONCLUSIONS

In this paper, the methods of limit equilibrium are used to perform the stability analyses of an earth dam with the presence of water in its reservoir. Particularly, three different satisfactory conventional limit equilibrium condition methods were used to conduct the analyses, which are: Spencer, Morgenstern- Price, the Ordinary method of Slices, and Jabnu simplified methods. The study's purpose is to analyze the slope stability of an earthen dam in the steady-state condition. The findings of all methods show that the safety factor against dam instability is adequate, however, Janbu's simplified method generated more critical but adequate safety factor than the other methods. In addition, the methods that consider all static equilibrium conditions give a greater safety factor. In contrast, the methods that satisfy only the force equilibrium condition obtained the lowest factor of safety. In addition, the presence of the core and the filters guarantee that the dam stays stabile, limiting seepage and the problems that arise due to structural issues. In order to consider the economic and technical aspects of the construction process, I suggest the mean values of the safety factor obtained from all the methods.

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