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Effect of Core Geometry on Earth Dam Slope Stability

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Abstract: Embankment dams are widely constructed due to their suitability with different types of foundation, and it is constructed from the available material at the site. A zoned earth dam consists of a clay core at the center to control seepage supported by a shell. This paper investigated the impacts of side slopes, top width, and shape on upstream and downstream slope stability during different cases. Slide 6.0 software was used to evaluate the factor of safety of side slopes of an earth dam, and its result was validated. Different side slopes range from 0H:1V to 2 H:1V, and crest widths from 3m to 10 m were examined. In addition, for the slanting core case, several cases with varying angles of inclination were provided. The results indicated that by increasing the side slopes of the core, the factor of safety was reduced, especially in the steady state and rapid drawdown conditions. Increasing the top width also reduced the safety factor in the steady state condition. This reduction was because the core material had lower shear strength than the shell material. In addition, in a steady state and rapid drawdown conditions, the cohesion of core material sharply reduced. Compared with the vertical case, increasing the slanting core slopes influenced the slope stability insignificantly during the steady state. The slanting core had benefits in the steady state when the reservoir was full since, in this case, increasing core side slopes affected the slope stability insignificantly. The maximum core side slope in the earth dam and maximum top width, which insignificantly affected the dam's slope stability, were 0.8:1 and 5 m, respectively.

تأثير شكل اللب على إستقرار الميل الجانبي للسد الترابي

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قسم الموارد المائية / كلية الهندسة / جامعة صلاح الدين – اربيل / العراق.

الخلاصة
يتم بناء السدود الاملائية على نطاق واسع بسبب ملاءمتها لأنواع مختلفة من الأساسات، حيث تبنى من المواد المتاحة في الموقع. يتكون السد الترابي ذو الطبقات من لب طيني في المركز للسيطرة على التسرب ويحاط بغلاف. في هذا البحث تم دراسة تأثيرات المنحدرات الجانبية للب، عرض قمة السد، والشكل على استقرار المنحدرات في المقدم والمؤخر خلال حالات مختلفة. تم استخدام برنامج Slide 6.0 لتقييم معامل أمان المنحدرات الجانبية للسد ترابي، وتم التحقق من صحته. تم اختبار عدة منحدرات جانبية مختلفة للب تراوحت مابين (H:1V0) إلى (H:1V2) وعرض قمة من 3م إلى 10م. بالإضافة إلى ذلك، بالنسبة للحالة الأساسية المائلة، تم توفير العديد من الحالات بزوايا ميل مختلفة. أشارت النتائج إلى أنه من خلال زيادة المنحدرات الجانبية للب فإن معامل الأمان انخفض، خاصة في ظروف الحالة المستقرة او حالة الهبوط المفاجيء لمنسوب مياه السد. تؤدي زيادة العرض العلوي أيضًا إلى تقليل معامل الأمان في حالة الاستقرار. إن هذا النقصان في معامل الامان هو بسبب أن مادة اللب لديها مقاومة قص أقل من مادة الغلاف. بالإضافة إلى ذلك، في حالة الاستقرار وظروف الهبوط السريع لمياه السد انخفض تماسك المواد الأساسية بشكل كبير. مقارنة بالحالة العمودية، فإن زيادة ميل اللب المائل أثر على استقرار ميول السد بشكل ضئيل أثناء الحالة المستقرة. بينت النتائج أن اللب المائل له فوائد في الحالة المستقرة عندما يكون الخزان ممتلئًا، لأنه في هذه الحالة، أثرت زيادة ميل اللب المائل على استقرار المنحدر بشكل ضئيل. كان الحد الأقصى للميل الجانبي للب في السد الترابي والحد الأقصى لعرض قمة السد والذي أثر بشكل ضئيل على استقرار منحدر السد هو (0.8:1) و 5 أمتار على التوالي.

الكلمات الدالة: السد الترابي ذو الطبقات، استقرارية المنحدرات، اللب الطيني.

1.INTRODUCTION

Earth dams are barriers constructed across rivers to store water. They are constructed from fragmental natural materials available at the site, and the earth dams are classified into homogeneous and zoned earth dams [1]. The zoned earth dam consists of a central impervious core supported by a shell of previous material, and a transition filter is provided between the shell and core. The main problems of earth dams are excessive seepage and sliding of side slopes USBR [2]1988). The core and shell dimensions are usually determined by the types of soils and their available quantities at the dam site [3]. Mainly the core dimensions should have an insignificant influence on the slope stability and control seepage quantity. [4] (Datta & Gulhati, 1991) analyzed the influence of the core's side slopes and top width on the earth dam slope stability. In addition, the study provided a limit for the core side slope, which beyond this limit, it has a significant influence on the slope stability. Furthermore, to control the seepage core at the zoned earth dams, they were provided with different shapes, such as vertical and slanting with different side slopes, Which vertical and slanting have their advantages and disadvantages [5]. The inclined core behaved better thn he vertical core, especially important settlements during the dam body construction. [6] (Rajesh et al, 2011) investigated the effect of a vertical core side slope on slope stability. The authors concluded that the factor of safety of upstream and downstream slopes was reduced by increasing the side slopes to more than 1:1.5V. The safety factor of the zoned earth dam side slopes increased as the core width reduced because the core material had lower shear strength than the shell material and had higher pore water pressure [7]. The present study investigated the effect of side slopes, top width, and shape of the core (slanting and vertical) of core material on the slope stability of upstream and downstream slopes for different cases. Different side slopes, top widths, and slanting shapes were analyzed using Slide 6.0 software.

2.MATERIAL AND METHODS

2.1.Slide 6.0 Software

To investigate the effect of the core side slopes in vertical and slanting cases on upstream and downstream slope stability during different cases, Slide 6.0 was utilized. The 2D software is based on limit equilibrium for the estimation factor of safety for circular and non-circular failure surfaces [8]. The software analyzes slip surfaces using vertical and non-vertical slices. In addition, it has many methods to analyze groundwater. The software uses finite element analysis to predict a water table in earth dams and any hydraulic structure.

2.2.Description of the Dam

In this study, the Degala earth fill dam analyzed the side slope effect and the core shape on the upstream and downstream slope stability. Degala dam is located in Degala village on Koya road, about 35 km from Erbil city center (Fig.1). The dam is a zoned earth fill dam with a 32 m height; its cross-section is shown in Fig. 2. It consists of a clay core supported by a shell with an upstream slope of 1V:2.5H and a downstream slope of 1V:2.75H. There is a transition filter with 0.8m between the dam's core and shell. The properties of the Degala dam materials are presented in Table 1. In the present study, the vertical core's different side slopes ranged from 0H:1V to 2H:1V, and seven different top widths were considered. In addition, for the slanting (inclined) core, eleven cases were considered with different upstream side slopes.

Fig. 1 Degala Dam View.

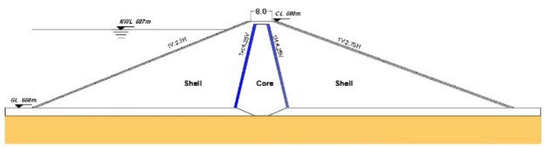

Fig. 2 Cross Section of Degala Dam.

Table 1 Degal Dam Material Properties.

Materials	End of Construction		Steady State		K
	C (KN/m²)	Φ (Degree)	C (kN/m²)	Φ (Degree)	m/s
Shell	3	41	3	41	$1*10^{-4}$
Core	200	0	80	5	$9.8*10^{-7}$
Filter	0	32	0	32	$1*10^{-3}$
Foundation 1	100	5	100	5	$2.5*10^{-5}$
Foundation 2	3000	0	3000	0	$1*10^{-7}$

3.RESULTS AND DISCUSSION

3.1.Validation of Results

To validate and evaluate the applicability of the software used in the present study, the results were compared with some methods from the literature. The slope stability results predicted by Slide 6.0 were compared with two analyses performed for the construction condition end of the Clearance Cannon dam section. The dam cross-section consists of two phases of compacted clay. The analysis was performed by [9, 10]. The results comparison of the factor of safety of the downstream slope for end construction condition is shown in Table 2. The comparison showed a good agreement between results. The Slide 6.0 software result was very close to other methods, and the software accurately evaluated the slope stability.

Table 2 Comparison Results between Slide 6.0 and Two other Methods.

Model	Minimum Downstream FOS
Hassan and Wolf (1999)	2.647
Bhattacharya et al, (2003)	2.612
Slide 6.0	2.61

3.2.Effect of Core Slope on the Vertical Case Slope Stability

The upstream and downstream slopes of the dam were tested for different core slopes during different cases, i.e., end of construction for upstream and downstream, Steady state downstream, and rapid drawdown of upstream. This analysis examined 17 different core slopes, ranging from (0H:1V to 2H:1V) . Two cases of the sloping upstream and downstream and vertical core are shown in Figs. (2, 3). The summary of the slope stability results for different cases is presented in Table 3.

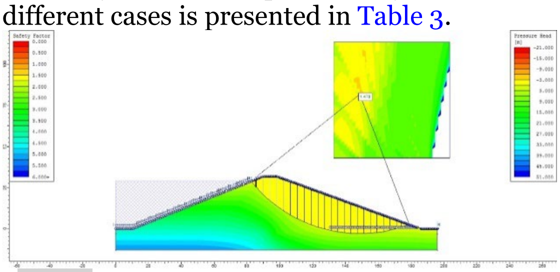

Fig. 2 Steady-State Condition (Vertical Core 1.1H:1V).

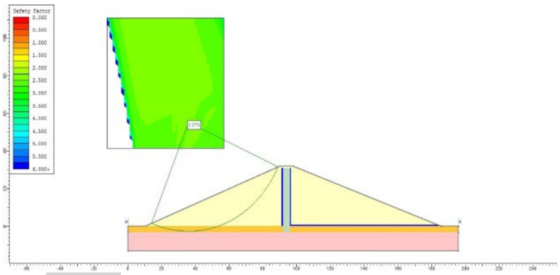

Fig. 3 After Construction Condition DS (Vertical Core 0H:1V).

Table 3 Results of FOS Changing Core Side slopes.

Core Slope	After Construction		Steady State	Rapid drawdown
	US	DS	DS	US
0H:1V	2.273	2.332	2.274	1.111
0.1H:1V	2.273	2.331	2.186	1.111
0.2H:1V	2.271	2.331	2.032	1.11
0.3H:1V	2.271	2.33	1.873	1.103
0.4H:1V	2.251	2.327	1.765	1.102
0.5H:1V	2.197	2.305	1.676	1.103
0.6H:1V	2.132	2.257	1.599	1.102
0.7H:1V	2.101	2.225	1.545	1.103
0.8H:1V	2.103	2.207	1.505	1.103
0.9H:1V	2.124	2.213	1.482	1.102
1H:1V	2.152	2.238	1.476	1.18
1.1H:1V	2.177	2.265	1.478	1.11
1.2H:1V	2.201	2.213	1.479	1.115
1.4H:1V	2.245	2.269	1.481	1.082
1.6H:1V	2.22	2.344	1.482	1.049
1.8H:1V	2.172	2.296	1.481	1.023
2H:1V	2.134	2.199	1.478	0.999

As can be observed from Table 3, initially, as the core upstream and downstream slope increased, the safety factor reduced because the shear strength of the core material was lower than the shell material shear strength. The reduction of safety factor (FOS) with respect to all cases was different. From after construction loading condition, the minimum factor of safety corresponding to maximum core side slope is greater than critical value of safety factor. However, in the steady state case, the reduction was significant, and the factor of safety was less than the critical value at core side slopes (0.9H:1V). At rapid drawdown, the safety factor insignificantly reduced as the core side slope increased; its value was less than the critical value at the core side slopes (1.4H:1V). The summary of results showed that the core side slope of (0.8H:1V) was a critical value, and more than this value, the slope became unstable.

3.3. Effect of Top Width of Core on Slope Stability

In this case, the top width of the clay core was changed, while the sides slopes were fixed. The results showed that increasing the top width insignificant influenced the slope stability at the upstream and downstream slope during the end of construction and upstream slope during rapid drawdown. However, in the steady state case, the FOS reduced as the top width increased due to increasing the core area, which had lower shear strength while higher pore water pressure. Also, this case was much more sensitive than other cases, such as rapid drawdown for changing material properties (Table 4).

Table 4 Results of the FOS Changing Core Top Width.

Core Width (m)	After Construction		Steady State	Rapid drawdown
	US	DS	DS	US
3	2.239	2.345	2.037	1.109
4	2.239	2.345	2.013	1.109
5	2.237	2.345	1.984	1.109
6	2.273	2.345	1.959	1.109
7	2.273	2.345	1.942	1.109
8	2.273	2.358	1.927	1.109
9	2.273	2.358	1.911	1.109
10	2.273	2.358	1.89	1.109

3.4. Effect of Core Slope on Slope Stability in Slanting Case

To investigate the effect of the core shape on slope stability, several runs were performed for inclined cores with different upstream and downstream side slopes. In the analysis, 11 core cases were investigated by changing the upstream core slope from (0.1H:1V) to (2.2H:1V) and fixing the downstream core slope. It started from a slope of 0.12H:1V for case 1 and to a slope of 2.2H:1V for case 11. The results of the factor of safety for different side slopes of the inclined core are presented in Table 5.

Table 5 Results of the FOS Slanting Core Cases.

Slanting Core cases	After Construction		Steady State	Rapid drawdown
	US	DS	DS	US
1	2.273	2.332	2.275	1.143
2	2.273	2.332	2.275	1.141
3	2.273	2.384	2.275	1.111
4	2.245	2.332	2.275	1.109
5	2.173	2.332	2.237	1.049
6	2.032	2.332	2.275	1.141
7	2.009	2.332	2.275	1.109
8	2.045	2.332	2.275	1.137
9	2.083	2.332	2.275	1.092
10	2.152	2.332	2.275	1.003
11	2.103	2.332	2.275	0.993

It is clear that from the results of the factor of safety for different cases of inclined core, during the end of construction condition, changing the slope of the upstream core had an insignificant effect on the downstream slope; however, the factor of safety for the upstream part reduced by increasing the upstream slope of the core. For steady state condition, the factor of safety was almost constant since, in the inclined core case, all the core sections were located at the upstream part of the dam section, so changing the side slope had an insignificant effect on the downstream slope. During the rapid drawdown condition, by increasing the core's upstream slope, the factor of safety decreased because of increasing the core area at upstream and pore water pressure. Compared with the vertical case, the FOS during the steady state through changing slope of the core was constant. However, in the vertical case, FOS was reduced by changing the core slope (Fig. 4).

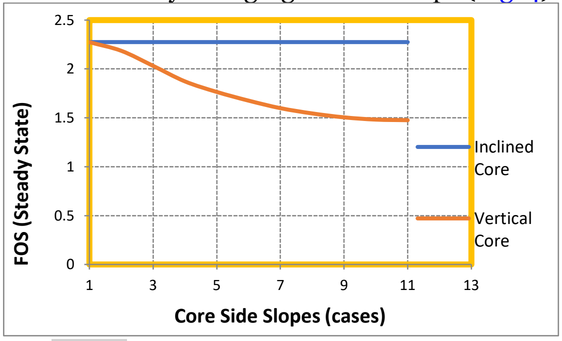

Fig. 4 FOS During the Steady State for Inclined and Vertical Core.

4. CONCLUSIONS

The present study investigated the effects of core shape and dimensions on different cases of slope stability upstream and downstream of the dam. The summary of conclusions is summarized below:

1. Increasing the core side slopes in the vertical cases reduced the factor of safety of both upstream and downstream slopes. The reduction was more significant in the steady state case since the core material had lower shear strength than the shell material. Also, a significant pore water pressure developed in the core caused this reduction.
2. Providing a slanting core had an insignificant effect on the downstream slope stability during the steady state and end of construction; however, it influenced the upstream slope during rapid drawdown and the end of construction conditions.
3. The core side slopes can be increased up to 0.8H: 1V because it had an insignificant effect on the slope stability.
4. The downstream stability reduced during the steady state as the core top width increased.
5. The slanting core shape had advantages over the vertical core since the factor of safety remained constant in the steady state condition by increasing the core material area.

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