BANKS RETREAT OF THE REGULATING LAKE OF MOSUL DAM

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Abstract

An increase in the shear stress that leads to bank failure in water bodies is commonly the result of rapid drawdown of water against bank face. The present research work introduces and discusses a local case study of bank failure of an artificial lake in Iraq (the regulating lake of Mosul dam). The bank susceptible to this failure extends about 4 kilometers long and 0.4 kilometers maximum width. The fluctuation of water level in the lake depends mainly on the daily release of water from Mosul main dam and on the requirement of daily flow in Tigris River. Thus, the lake banks have degraded seriously since the dam operation in 1985. The failures are generally associated with bank tension cracks. These failures are due to the rapid daily draw down of water in the lake causing imbalance condition between the hydrostatic pressure in the lake and the pore water pressure in the saturated bank. This imbalance results in insufficient shear strength against failure. Moreover, the wetting of bank materials causes an increase in its weight and decreases in its strength. The observed collapses are due to the degradation and erosion of cementing material formed of conglomerate terrace.

The average amount of bank retreat was found to be 0.144 m/month during the study period. Stability analysis showed high factor of safety at low water level and decreases as water level increases in the lake.

Introduction

The banks of an artificial regulating lake located in Mosul dam is subject to water level fluctuation resulting from the operation of a regulating dam, fig (1). This fluctuation in water level occurs daily to regulate the water discharge released to Tigris River. Erosion, degradation and failure of banks material were observed in many sites along the regulating lake.

Two basic types of bank failure can occur [1], either a thin soil layer sliding down a bank, or a large mass of soil that slips along curved path deep in the bank. In both types, a decrease in the shear strength of soil or an increase in the shear stress in the bank can individually or, in combination lead to bank failure. Janson, et.al. 2006 found that event peak excess shear stress is the best indicator of the bank erosion for moderately cohesive banks and, variability of excess shear stress is the best for minimally cohesive banks [2]. (Lohnes, et.al. 1968) investigated the relationship between the bank heights, slope angle and strength properties of banks formed in loess [3]. They identified two main mechanisms of failure, shear failure along planes of slip surface through the toe, and slab failure of vertical banks by tension cracking. (Bradford and Piest 1977) considered the stability of steep banks using water-filled trench in the field to rise the water table behind vertical bank and, observing failure as a function of pore water pressure [4]. Bradford and Piest 1980 reported three major mechanisms of failure, deep-seated circular arc toe failure, slab failure and "pop out" failure with shear failure of the remaining cantilever [5]. (Thorne,1982) observed tensile stress in the upper part of the bank leading to the development of vertical tension cracks, which promote failure by slab mechanism [6]. The presence of tension crack has a very important effect in limiting bank height. The results of Little,1982 showed great importance of the control of bank height through the control of channel bed degradation [7]. Okagbua and Abam,1986 concluded that, the engineering properties of soil, seasonal variation of precipitation, flooding, density of vegetation and the balance between the rates of sediment supply from failed material and their removal from bank toe, are the main factors, which affect the rate of bank retreat [8].

The present work aimed to predict the rate of bank face retreat of an artificial regulating lake and, the relationship between the rapid draw down of the lake water level with the stability of bank face.

Location and geology

The area chosen for this work is part of the Pliestocene – Resent age, [9]. It is located at about 55km. north-west of Mosul city. The area is about 4 km. long and, 0.4 km. maximum width fig. (1). The bank which is 5.2m.high is formed by the fourth stage of Tigris River terrace which is the only stage of the Quaternary deposits found in the area[9]. These river terraces disappear towards the south and replaced by silty loam deposits. These deposits consist mainly of sub rounded and occasionally sub angular to rounded pebbles, which do not exceed 20cm. length and 15 cm width. The majority of these pebbled are of sedimentary and metamorphic origin and rarely of igneous origin. Those of metamorphic origin are mainly quartzite and schist, where as those of sedimentary origin are mainly limestone, chert, and sandstone. These river terraces overlay by soil, which consists of brown silty loam when wet, and pale brown when dry. Extensive burrowing are noticed with average size of 3cm. in diameter as well as extensive root plants were noticed in the upper most 20cm of the top soil.

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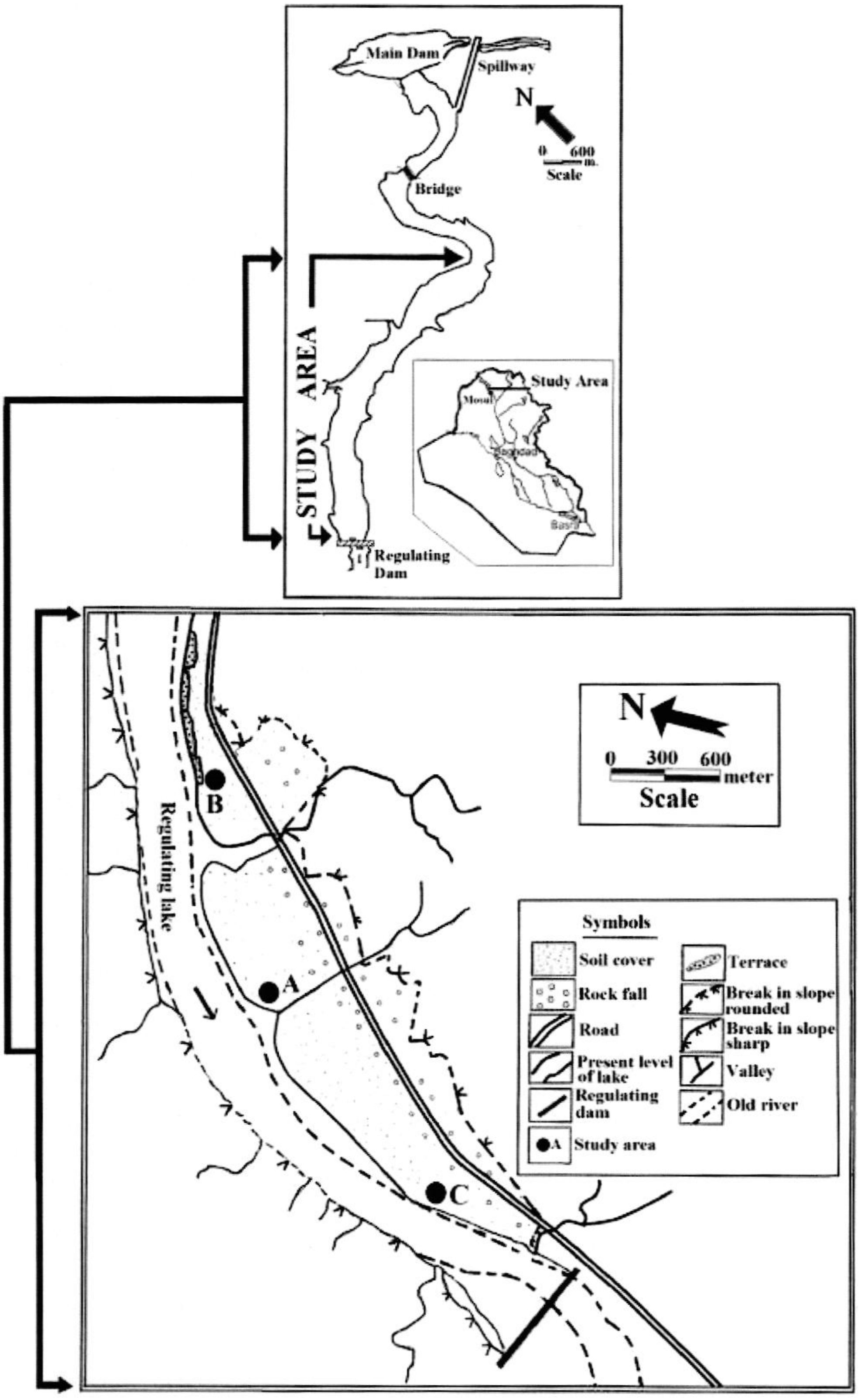

Figure 1 Location and layout of study area, modified from AL-Hamdani 1997.

Methodology

The method employed for this work is to predict the instability of the artificial regulating lake bank at Mosul dam.

Fieldwork

The basic aim of the fieldwork is to record accurately the changes in the geometry of the bank of the regulating lake and to measure the amount of bank face retreat. A topographical map scale 1: 200,000 was used for this purpose. Topographical sections of the bank face were drawn using Abney level, measuring tape and compass (fig.2). These sections represent the banks face drawn from the crown down to the lake water surface level (m.a.s.l.)l. The maximum and the minimum water levels were fixed.

Metal pins of 30-cm. length hammered into the ground at different distances behind the bank face to determine the amount of bank retreat. Two sets of pins used at three localities chosen for this study. One set put as stand by to avoid any disturbance by vandals. Measurements of the distance from the bank face were done nearly every month..

Laboratory work

The laboratory work includes measurement of grain size distribution of the silty loam and gravel deposits using Hydrometer and sieve test respectively. Hydraulic conductivity test was carried out using constant head permemeter. Bromhead ring shear machine [11] was used to determine the shear strength parameters of the bank material.

Results

The results of the amount of retreat in the studied area are listed in table (1). The total amount of retreat for the study period in areas A, B, and C are 0.79m, 0.5m, and 0.45m respectively, while the average rate of retreat are 0.197, 0.125 and 0.112 m/month for the same areas respectively

Table (1) explains the percentages of grain size analysis of the silty loam and gravels. The results show that, for location A and C at figure (1) the percentages of sand are 40% and 32% respectively, while silt percentages are 60% and 68% respectively. Clay and gravel percentages are zero for both areas. For area B, the sand percentage is 6%, silt 8% and gravel 86%. Fig.(3) reflect the grain size distribution of the three areas A, B, and C. Table (1) contains the hydraulic conductivity values of the silty loam and gravel deposits. The silty loam hydraulic conductivity values are (0.32, 0.57) cm/hr for areas A and C respectively, while for area B the gravel gave hydraulic conductivity values of 36cm/hr.

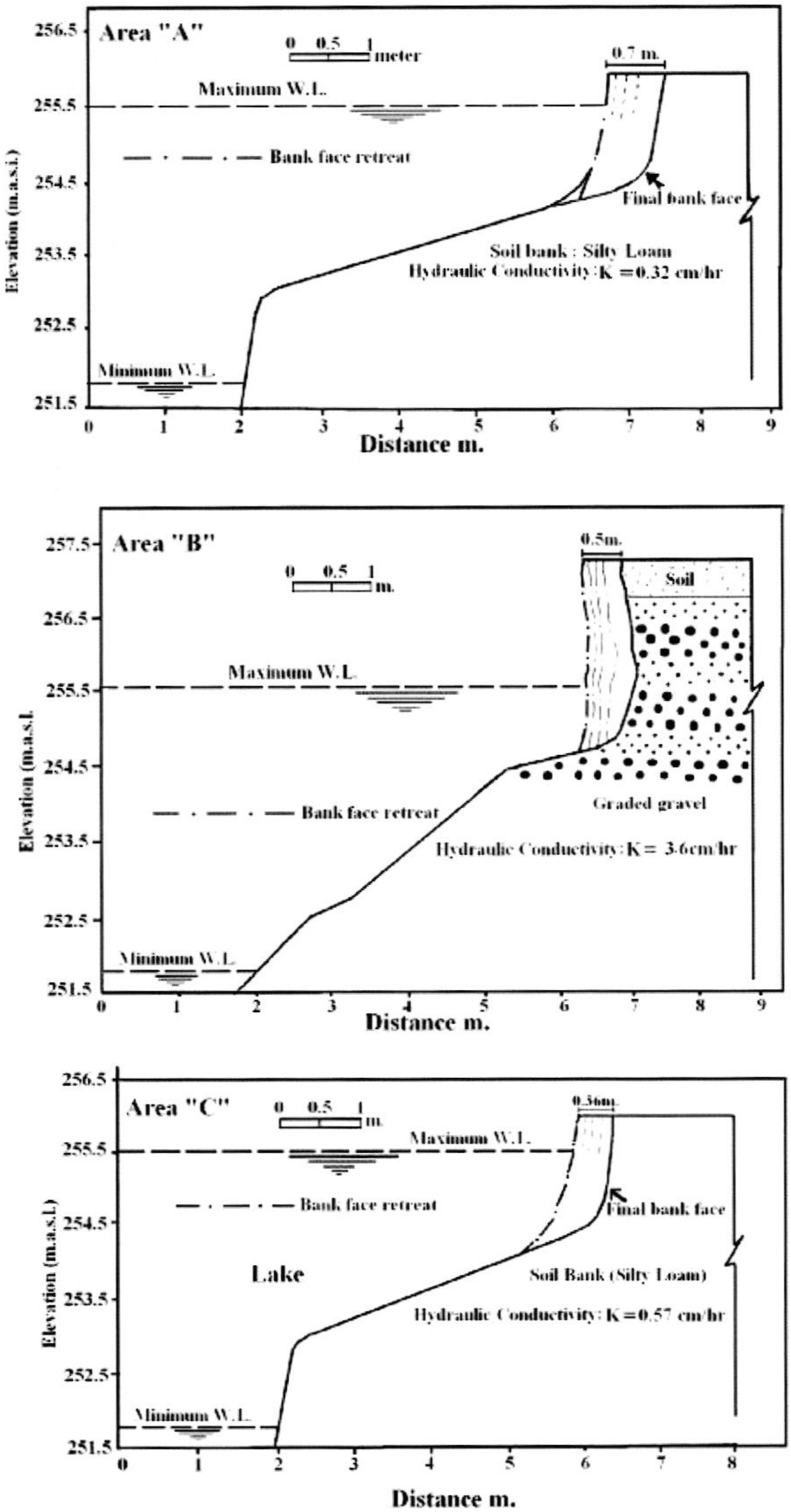

Figure 2 The cross sections of the studied areas along the bank of the regulating dam.

Table 1. Physical properties of the soil and the amount of banks retreat in the studied areas.

Site No.	Run No.	Date	Bank Retreat m.	Clay %	Silt %	Sand %	Gravel %	Texture	Hydraulic conductivity cm/hr
A	1	Dec.	0.45	0	60	40	0	Silty loam	0.32
	2	Jan.	0.19						
	3	Mar.	0.1						
	4	Apr.	0.05						
B	1	Dec.	0.15	0	8	6	86	Gravel	3.6
	2	Jan.	0.05						
	3	Mar.	0.05						
	4	Apr.	0.25						
C	1	Dec.	0.1	0	68	32	0	Silty loam	0.57
	2	Jan.	0.07						
	3	Mar.	0.08						
	4	Apr.	0.2						
Maximum water level fluctuation of the lake = 3 m Average water level fluctuation of the lake = 2 m									

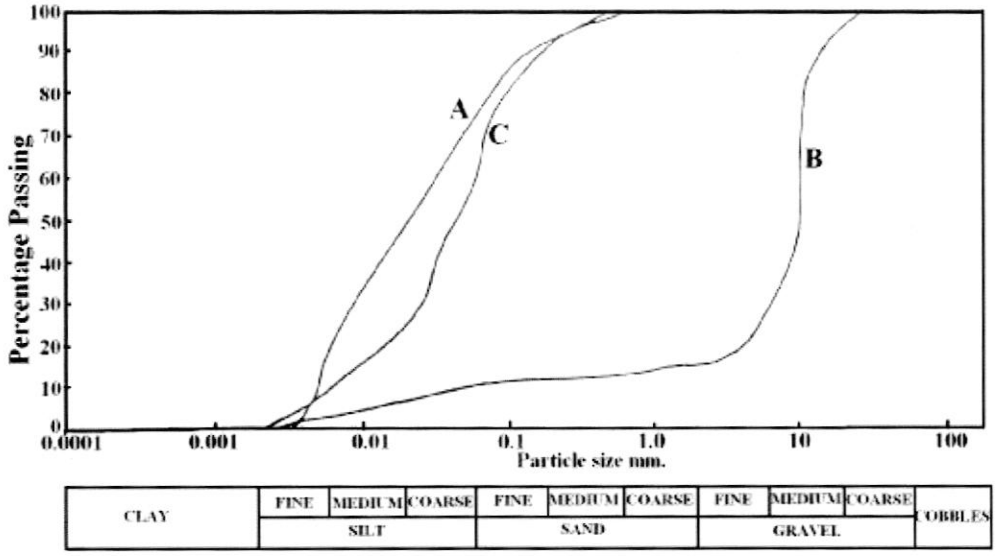

Figure 3 Cumulative grain size distribution of bank materials for the three areas A,B,C.

Fig.(4) and Fig.(5) shows the diurnal and daily amount of water level fluctuation of the lake. The daily fluctuation is about 3 m and the rate of water level drawdown is 12.4 cm/hr.

The results of the shear strength parameters are shown in fig.(6). $\acute{\emptyset} = 31°$ and the cohesion c equal to zero (0). These values influenced by the natural water content of soil. Okagbua and Abam,1986 found that an increase of water content by 10% decrease the $\acute{\emptyset}$ by 18% [8].

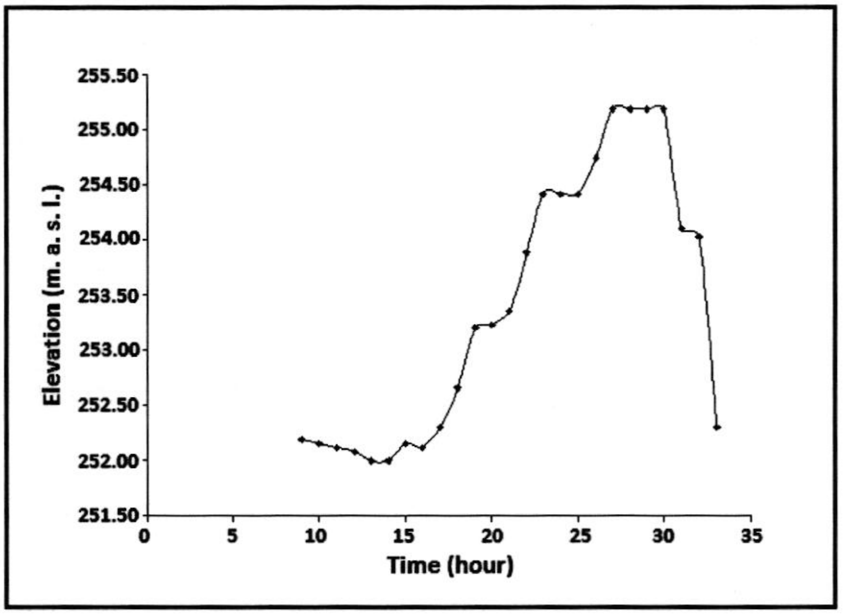

Figure 4 Diurnal water level fluctuation of regulating lake

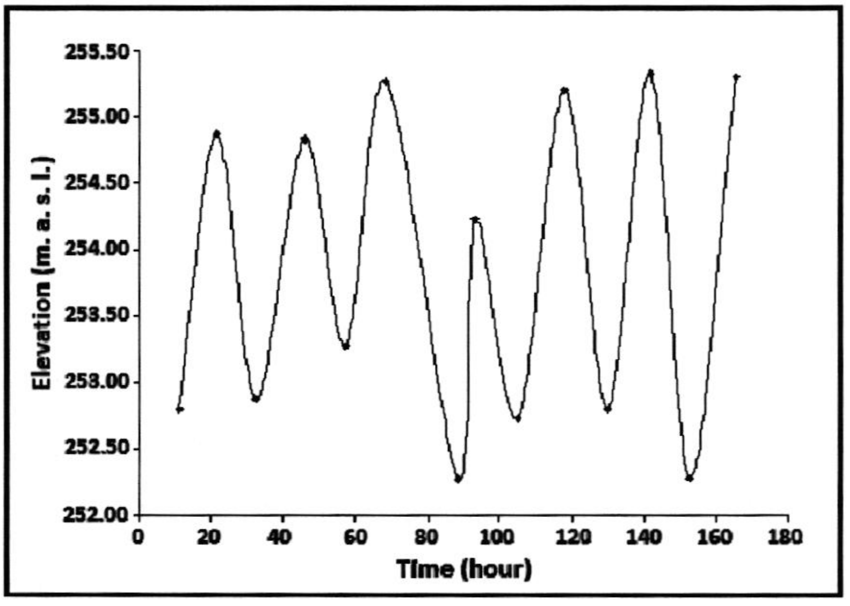

Figure 5. Daily water levels fluctuation of regulating lake for a period (1-8)Mach 1995

Stability analysis

Stability analysis depends mainly on the present geometry of slope, original geometry, position of water table and the shear strength parameters. The stability analyses performed in to two water table conditions, high and low. A slip circular failure model assumed for analysis, conventional method of slices used in the analysis. This method is simple, rapid and easy to apply [12].

Table (2) shows factors of safety for four trials failure surfaces. From the table it is clear that the most stable condition occurred when water level was minimum water level i.e. maximum lowering of water level. While the factor of safety is too low when the water level in the lake is maximum, which indicates that, the shear strength of banks materials reduced while the shear stress increased. The difference between the factors of safety at low water level condition was ranging "between" 46% to 61% (Table 2). It is clear that, the condition 3 and 4 in table (2) is more adequate, while condition 1 and 2 gives low values for the factor of safety. This may indicate that the failure model used in the analysis is inadequate.

Table (2) Factor of safety against sliding for the critical trial failure surface under maximum and minimum water depths for areas A .

Trial surface failure	Minimum water depth	Maximum water depth	Difference %
1	0.61	0.27	55
2	0.75	0.3	60
3	1.08	0.42	61
4	1.09	0.58	46

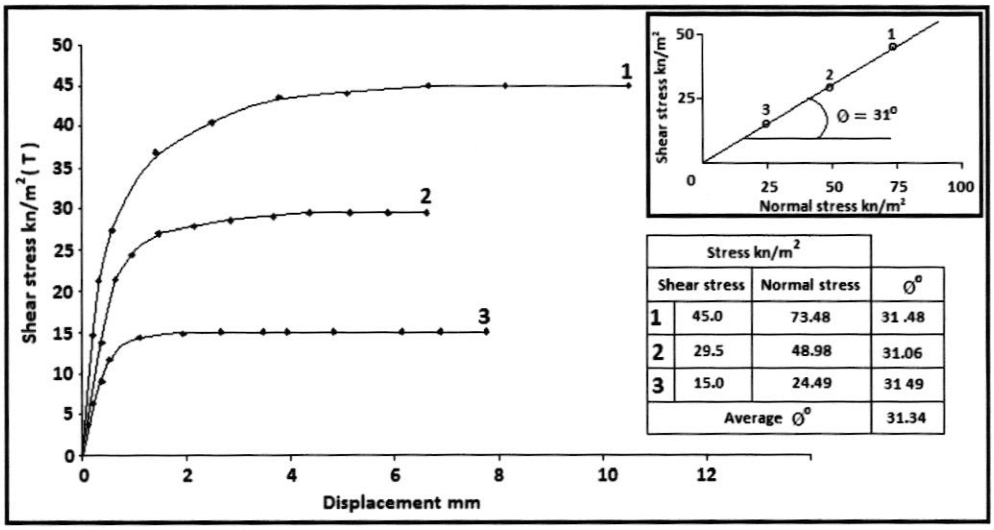

Figure 6 Shear strength parameters of silty loam soil of study area.

Discussion

When the bank is covered by water, (from 6 am to 12 pm the period of high water level of the regulating lake), the bank becomes saturated as a result of water percolation. A pressure balance forms between water in the lake and the height of saturated bank. This balance helps in keeping the bank stable. Two conditions cause bank failure, depending on the fluctuation of water level in the lake. The first condition is the quick drawdown of the water level causes a sudden removal of the hydrostatic pressure of the water in the lake where the soil can not drain quickly. In this case a pressure imbalance will be formed which may bring the lake banks to slough if the bank materials have insufficient shear strength resist failure, (fig.7). In other ward, when the capability of the bank materials to drain water, (i.e. the permeability of the bank material) is less than the drawdown velocity of water level in the lake, the probability of bank failure increases, [1]. This coincides with the present work in which the hydraulic conductivity of bank material in areas A and C was 0.32 and o.57cm/hr respectively, table (1). These rates are less than the average drawdown velocity of the water leveling the lake, 12.4cm/hr, and fig. (4). It is clear from the figure (4) that the gradient of the rising limb of the water level was 0.29 while the falling limb was 0.9. This inhomogeneous fluctuation of the water level between the rising and recession water velocity may lead to instability of bank material.

In second condition, as shown in table (2) high water level gives law factor of safety, owing to the load increment on the bank due to the water percolating into the soil. This in turn increases the shear stress and decreases in shear strength of the soil as a result of soil softening through water percolation.

Most of the failed material breaks up on impact with cracks run parallel to the bank face. Those processes include area A and C that form mainly of silty loam soil. Soil blocks fall directly into flowing water during water level recession and, do not come to rest on the bank base "bank toe". The disintegrated parts fluctuation of water level degrades and erodes the cementing material of pebbles resulting in collapsing bank material and initiating new bank face. In both cases failure occurred along the four kilometers length of banks. It is worth mentioning that during rainfall and flooding condition, the time needed for soil bank retreat will reduced. However, in this study the effect of rainfall have not take into consideration.

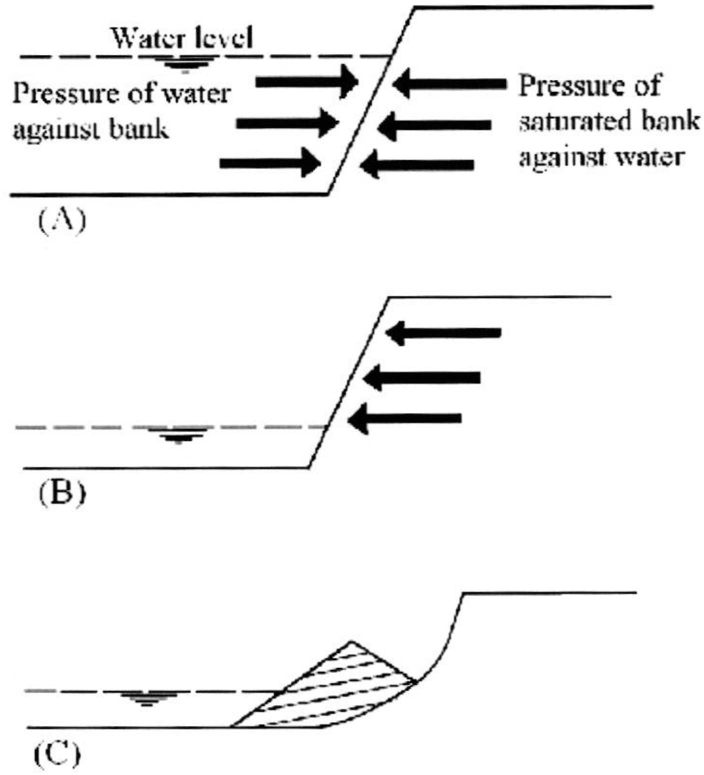

Figure 7 Bank failure due to the water drawdown against the saturated bank being lowered faster than the bank can drain, (rapid drawdown). (A) Pressure balance of stream water and saturated bank. (B) If water surface elevation drops rapidly and the bank cannot drain quickly, a pressure imbalance will develop. (C) Bank may fail because of pressure imbalance.

Conclusion

The bank failure due to the variation of the balance system between the hydrostatic pressure in the lake and pore water pressure in the saturated bank are owing to the following:

1- The average permeability of the silty loam material is 0.44cm/hr; this is less than the draw down velocity of water level 12.4cm/hr.

2- The gradient of rising limb of lake water level is less than the recession limb.

3- The high water level increases the load on the bank, which in turn increase the shear stress. At the same time, the water causes a softening of soil material, which reduces its shear strength.

4- The degradation and erosion of cementing material of the gravel terrace causing collapses of the bank.

5- The average amount of bank retreat for the three areas studied is 0.144 m/month. Thus, the retreat may takes a decades to cover the whole area of 4 kilometer long by 0.4 kilometer width, if the lake continues subjected to a regular daily fluctuation in water elevation. This may affect on the life storage of the lake, which increase its dead storage reflecting on the operation mechanism of the regulating lake.

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انحسار ضفاف البحيرة التنظيمية في سد الموصل

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الملخص

قامت لدراسة الحالية باستعراض ومناقشة حالة محلية لأنهيار ضفاف البحيرة التنظيمية لسد الموصل في العراق. امتدت الضفاف المعرضة للأنهيار الى مسافة 4 كيلومتر طول و0.4 كيلومتر كأقصى عرض. يعتمد تذبذب مستوى الماء في البحيرة بشكل رئيسي على إطلاق ألماء من سد الموصل الرئيسي وعلى متطلب التدفق اليومي في نهر دجلة. وهكذا فان ضفاف البحيرة قد انحسرت بشكل كبير منذ تشغيل السد عام 1985 إن حالاتَ الفشل دَرتبطُ عموما بشقوقِ الشد الموجودة على الضفاف. فضلا عن السحب السريع اليومي للماء من البحيرة مما يؤدي إلى حالات من عدم التوازن بين الضغط الهايدروستاتيكي للبحيرة و ضغط الماء المسامي للضفاف المشبعة بالماء. إن عدم التوازن هذا يؤدي إلى مقاومة قص غير كافية ضد الانهيار، إضافة إلى ذلك فان رطوبة مواد الضفة تسبب زيادة في الوزن ونقصان في القوىمما يؤدي الى انخفاض و تآكل المادة اللاحمة لمواد المصاطب المكونة من صخور الكونكلومريت .

لقد أعطت عمليات تحليل الأستقرارية اعلى عامل أمان عند منسوب ماء منخفض ويقل عامل الأمان كلما ارتفع منسوب الماء في البحيرة.