RIVER NILE BANKS STABILITY ANALYSIS MODEL
CASE STUDY (BENI-MAZAR REACH - EGYPT)

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ABSTRACT

A general layout of the Beni-Mazar area is located between km 735 and km 740 downstream the Old Aswan Dam. This area includes eroding banks, mainly on the west side of the river. A sample problem involves the stability analysis of the River Nile banks will be taken into consideration, considering the Beni-Mazar Reach, where a pilot project was implemented. The original concept of the pilot project was to stabilize specific reaches as examples which could be repeated at similar locations. The objective of Phase I involved protection of 400 m of eroding west bank. The objective of Phase II was to protect two eroding parts of the River Nile west side. Four boreholes were implemented; two boreholes towards Phase II – Part 1, and another two boreholes toward Phase II – Part 2 to a depth of 10 m. Representative samples of bed and bank material were obtained. The analysis of the samples taken showed that the bank is composed of layers of silty-clay (fill) of depth about 1 m, followed by 3 m of clayey silty sand, after which poorly graded sand exists till the end of the borehole penetrated depth.

The slope stability analysis was carried out using the STABLE 5M, computer Program for both the case of high and low water level. Safety factors have been computed for three case studies (Unprotected bank; Protected using the traditional method, but with a toe and smooth alignment and where landowners prepared a narrow terrace of 0.5 m thick above the placed stone; and same as Case 2, but landowners backfilled the area above the placed stone). 240 generated failure surfaces and the corresponding estimated factors of safety were calculated using the developed model. It is also clear that the stability factor of safety for River Nile banks protection carried according to the developed traditional method with narrow terrace is the preferable treatment. The application of the developed traditional method with narrow terrace increase the value of the Minimum Factor of safety for the unprotected River Nile banks by about 92.43%, while the application of traditional method with top filling increase the minimum factor of safety by about 61.67%.

1- INTRODUCTION

Environmental river bank failure and erosion has been a focus of recent concern for many major rivers of the world. River bank erosion is important geomorphologically in effecting changes in the rivers channel course and in development of the flood plain. River bank erosion is also important economically due to the loss of the farm lands and the undermining of structures adjacent to the river channel (El-Sersawy, 1995). It was deduced that a river bank erosion is a complex phenomenon (Pilarezyk, 1990), which includes interaction between river hydraulic environment, geotechnical environment and a structure.

Most routine analyses of slope stability concentrate on defining the conditions under which failure will occur. The factor of safety is the factor by which strength may be reduced to bring the slope to limiting equilibrium. The results of stability analyses should be viewed as a means for comparing the overall factors of safety obtained form specific designs with those previously determined for the existing banks – characteristics. Analysis of stability of alluvial stream banks (Springer, 1985) indicated the following:

a) the formation of tension cracks, and the filling of these tension cracks with water,
b) the values of the effective angle of internal friction, and the values of unit weight of the soils composing these banks,
c) the height of capillary rise, and the flood hydrograph, and
d) the time rate of tension crack formation.

The following processes can be identified as being of particular importance for a river bank erosion and failure (Simons, 1981):

a) Shear erosion of the bank material by water flow in the river,
b) Surface erosion of the bank slopes above the water level by rainfall and surface runoff, and
c) Seepage erosion of the bank soil by groundwater flow and seepage force.

Geological and Hydrological Parameters

The change in these parameters is influenced by the definite structural or fluid control:

Bank slope (β):
The slope of the banks is one the major structural parameters influencing its stability. The range of slope of the majority of banks is between $\beta = 15°$ (flat slope) and $\beta = 30°$ (steep slope) where β is the angle of slope.

Surcharge (q):
The design traffic which can use the banks is taken equivalent to 10 kN/m^2.

Bank height (H):

Reviewing many sites on the two sides of the River Nile banks, it was noticed that the bank height ranges from 5 to 15 m (Ebeid, 1999).

Ratio between Water height (hw) and Bank height (Hb):

For the River Nile, the following ratios were ranged between 0.4 and 0.8.

Soil properties:

The soil forming the River Nile banks can be one of three types (Hamed, 1980):

i- Sand with some silt and clay:

γ (saturated) = 20.2 kN/m^3
γ (dry) = 16.0 kN/m^3
C = 5.0 kN/m^2
β = 20°

ii- Silty sand:

γ (saturated) = 20.2 kN/m^3
γ (dry) = 15.0 kN/m^3
C = 15.0 kN/m^2
β = 15°

iii- Silt with some clay and sand:

γ (saturated) = 19.0 kN/m^3
γ (dry) = 13.0 kN/m^3
C = 20.0 kN/m^2
β = 10°

Earthquake Force:

The earthquake factor used is about 0.10 (g) where g is the acceleration of gravity.

Seepage:

The level of water lake inside the bank is considered to be at the same level of the surface of the bank (due to irrigation water which can be infiltrated to the soil forming the bank).

Equivalent Height:

$$\text{H (equivalent)} = \text{Bank height (Hb)} + \frac{\text{Surcharge}}{\gamma_{\text{dry}}}$$

The bank erosion is affected by many hydraulic parameters. Table (1) can be used to represent these parameters as functions of the discharge Q (Winkely, 1992):

Table (1) General Hydraulic Geometry equations for the Nile River

Parameter	Equation
Width	$W = Q^{0.5}$
Depth	$D = Q^{0.4}$
Velocity	$V = Q^{0.2}$
Slope	$S = Q^{0.75}$
Manning Coefficient	$N = Q^{0.45}$

2- BENI-MAZAR DESCRIPTION

A sample problem involves the stability analysis of the River Nile banks will be taken into consideration, considering the Beni-Mazar Reach, where a pilot project was implemented. The original concept of the pilot project was to stabilize specific reaches as examples which could be repeated at similar locations. A general layout of the Beni-Mazar area is located between km 735 and km 740 downstream the Old Aswan Dam. This area includes eroding banks, mainly on the west side of the river as shown in Fig. (1).

a- BENI-MAZAR, PHASE “I”

This phase involved protection of 400 m of eroding west bank between km 735.550 and km 735.150. The design included a toe, with a smooth alignment and smooth transitions at the beginning and end of the revetment.

b- BENI-MAZAR, PHASE “II”

The objective of Phase II was to protect two eroding parts of the River Nile west side. The first part is of 1400 m length on a sharp bend, while the second part is about 1100 m in a moderate bend. The bank height is about 8 m. Typical Beni-Mazar reach cross-section is shown in Fig. (2).

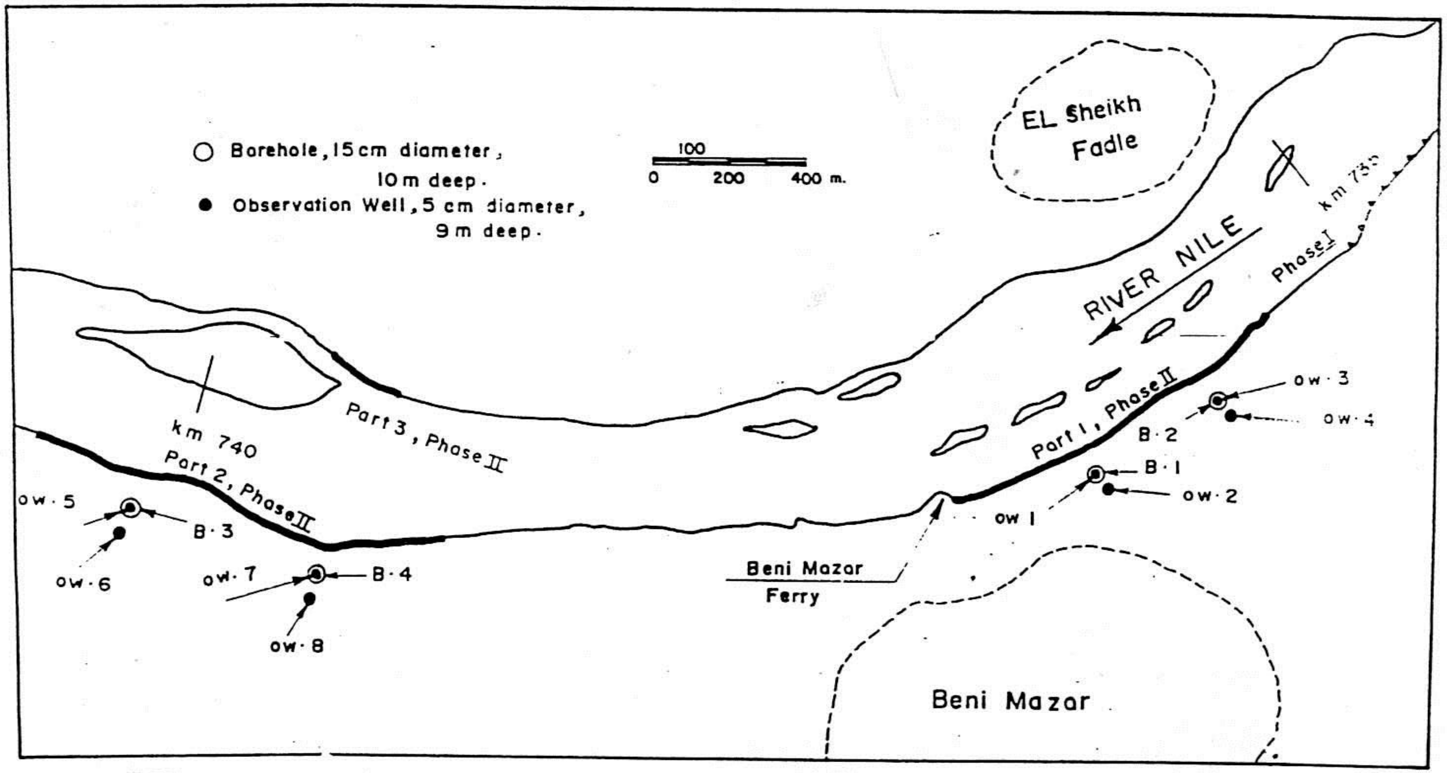


Fig. (1): Boreholes and observation wells at Beni-Mazar reach

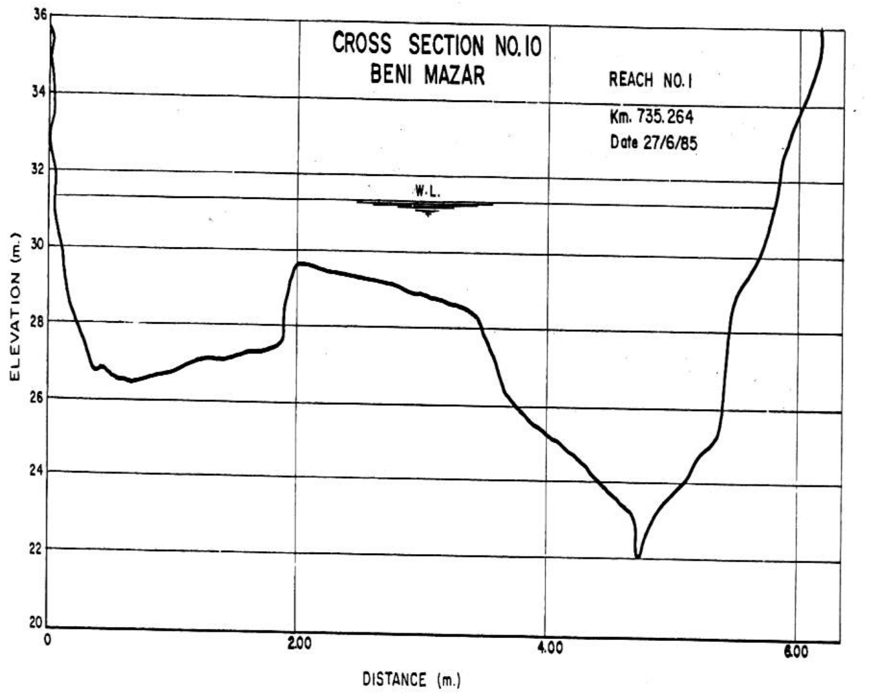


Fig. (2): Typical Cross-section Beni-Mazar Reach - Phase "I"

3- FIELD SURVEY

Four boreholes were implemented; two boreholes towards Phase II – Part 1, and another two boreholes toward Phase II – Part 2, to a depth of 10 m. Representative samples of bed and bank material were obtained. The analysis of the samples taken showed that the bank is composed of layers of silty-clay (fill) of depth about 1 m, followed by 3 m of clayey silty sand, after which poorly graded sand exists till the end of the borehole penetrated depth.

3.1 Underground Water Table Levels at Beni-Nazar Area

For the purpose of design, ground water levels were recorded from four dissertation wells, and the implemented four boreholes. It was concluded that the mean high ground water-table is (31.80) m, and the mean low ground water table is (30.20) m.

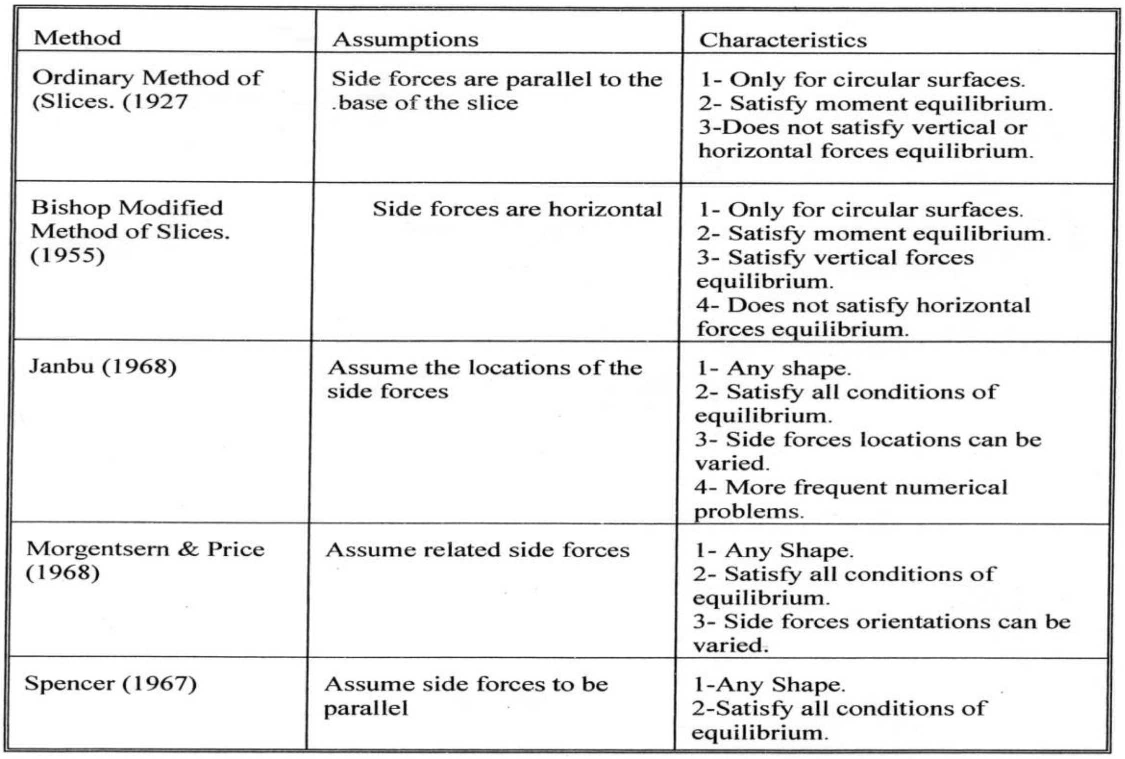
3.2 River Nile Water-Levels Hidrograph at Beni-Mazar Area

Water levels were recorded daily at El-Sheikh-Fadl staff gauge which is located on the River Nile east bank opposite to Part 1. It was completed that the High water level is (31.20) m, while the low water level is (29.20) m.

4- METHODOLOGY

For two-dimensional stability analysis, there are several methods based on the assumptions suitable for each method. Due to the complications of determining the lowest factor of safety, a stability software program (STABL 5M) was developed (PURDUE Univ., U.S.A). The operation of the two-dimensional limit equilibrium slope stability program PCSTABL 5M, developed to handle general slope stability problems by the simplified Jumbo, simplified Bishop, and Spencer method of slices as shown in Table (2). The calculation of the factor of safety against instability of a slope is performed by the method of slices. The particular method, applicable to circular shaped failure surfaces, the simplified Jumbo method, applicable to failure surfaces of general shape, and the Spencer method, applicable to any type of surface. The output for this software includes different slip surfaces and their corresponding factor of safety. STABL5M is used to determine the factor of safety corresponding to the type of bank protection. A value of 1.5 is accepted for any permanent protection according to the Egyptian Soil Mechanics Code (1995).

Table (2) Two-Dimensional Stability Analysis Methods



Method	Assumptions	Characteristics
Ordinary Method of (Slices. (1927	Side forces are parallel to the .base of the slice	1- Only for circular surfaces. 2- Satisfy moment equilibrium. 3-Does not satisfy vertical or horizontal forces equilibrium.
Bishop Modified Method of Slices. (1955)	Side forces are horizontal	1- Only for circular surfaces. 2- Satisfy moment equilibrium. 3- Satisfy vertical forces equilibrium. 4- Does not satisfy horizontal forces equilibrium.
Janbu (1968)	Assume the locations of the side forces	1- Any shape. 2- Satisfy all conditions of equilibrium. 3- Side forces locations can be varied. 4- More frequent numerical problems.
Morgentsern & Price (1968)	Assume related side forces	1- Any Shape. 2- Satisfy all conditions of equilibrium. 3- Side forces orientations can be varied.
Spencer (1967)	Assume side forces to be parallel	1-Any Shape. 2-Satisfy all conditions of equilibrium.

The slope stability analysis was carried out using the STABLE 5M, computer Program for the following two cases:

Case 1: High water level in river, hence high ground water table.
Case 2: Low water level in river, hence low ground water table.

Study Cases

Safety factors have been computed for three case studies:

Case 1: Unprotected bank.
Case 2: Protected using the traditional method, but with a toe and smooth alignment and where landowners prepared a narrow terrace of 0.5 m thick above the placed stone.
Case 3: As Case 2, but landowners backfilled the area above the placed stone.

The different combinations of data regarding the different parameters were used to define 24 cases input data for the River Nile Beni-Mazar pilot reach. 8 runs for cases of unprotected bank, 8 runs for the cases of developed protection traditional method with narrow terraces 0.5 m thick above the placed stone, and 8 runs for the cases of developed protection traditional method and top filling above the placed stone revetment carried out till the bank top.

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5- RESULTS AND DISCUSSION

5.1 Model Output

240 generated failure surfaces and the corresponding estimated factors of safety are shown in Tables (3, 4, 5, 6, 7, 8).

Table (3) Estimated Factor of Safety for Unprotected bank corresponding to different failure surfaces – Cases of Low Water Level and different soil logs

Run	Factor of safety corresponding to failure surface specified by n coordinate points					
	6	7	8	9	10	Minimum F.S.
MIB 1L	0.870 0.889	0.859	0.839 0.859 0.883	0.804 0.858	0.872	0.804
MIB 2L	0.873 0.891	0.861	0.840 0.860 0.878	0.804 0.860	0.874	0.804
MIB 3L	0.829 0.837	0.805	0.800 0.824 0.851	0.784 0.814 0.850	0.844	0.784
MIB 4L	0.838 0.841	0.801	0.781 0.801 0.820 0.833	0.780 0.833	0.807	0.780

Table (4) Estimated Factor of Safety for Unprotected bank corresponding to different failure surfaces – Cases of High Water and different soil logs

Run	Factor of safety corresponding to failure surface specified by n coordinate points					
	6	7	8	9	10	Minimum F.S.
MIB 1H	0.793 0.805	0.768	0.771 0.803 0.824	0.785 0.794 0.8176	0.842	0.768
MIB 2H	0.794 0.807	0.770	0.773 0.804 0.825	0.768 0.794 0.819	0.844	0.770
MIB 3H	0.738 0.764	0.712 0.801	0.724 0.764 0.776	0.737 0.770 0.777	0.844	0.712
MIB 4H	0.752 0.779	0.718	0.716 0.750 0.762 0.787	0.740 0.764 0.771		0.718

Table (5) Estimated Factor of Safety for protected banks applying Developed Traditional method with narrow terrace corresponding to different failure surfaces – Cases of Low Water and different soil logs

Run	Factor of safety corresponding to failure surface specified by n coordinate points					
	5	6	10	11	12	Minimum F.S.
M2B 1L		1.670	1.565 1.668 1.690 1.718 1.734	1.633 1.635 1.727 1.740		1.633
M2B 2L	1.471		1.537 1.588 1.599	1.588 1.625 1.637 1.644	1.581 1.584	1.471
M2B 3L	1.442		1.572 1.578	1.509 1.575 1.605 1.611 1.632	1.560 1.562	1.442
M2B 4L	1.574 1.604		1.559 1.575	1.571 1.598 1.612 1.628	1.557 1.561	1.557

Table (6) Estimated Factor of Safety for protected banks applying developed Traditional method with narrow terrace corresponding to different failure surfaces – Cases of Low Water and different soil logs

Run	Factor of safety corresponding to failure surface specified by n coordinate points						
	5	6	10	11	12	13	Minimum F.S.
M2 B1H		1.630	1.660	1.598 1.612 1.643	1.578 1.589 1.624 1.652	1.650	1.630
M2 B2H	1.471 1.537		1.521 1.527 1.581 1.619	1.537 1.573	1.526 1.531		1.471
M2 B3H	1.442 1.509		1.509 1.567 1.596	1.492 1.523 1.564	1.509 1.515		1.442
M2 B3H	1.442 1.509		1.509 1.567 1.596	1.492 1.523 1.564	1.509 1.515		1.442
M2 B4H	1.574		1.501 1.546 1.596	1.514 1.518 1.540 1.582	1.501 1.504		1.501

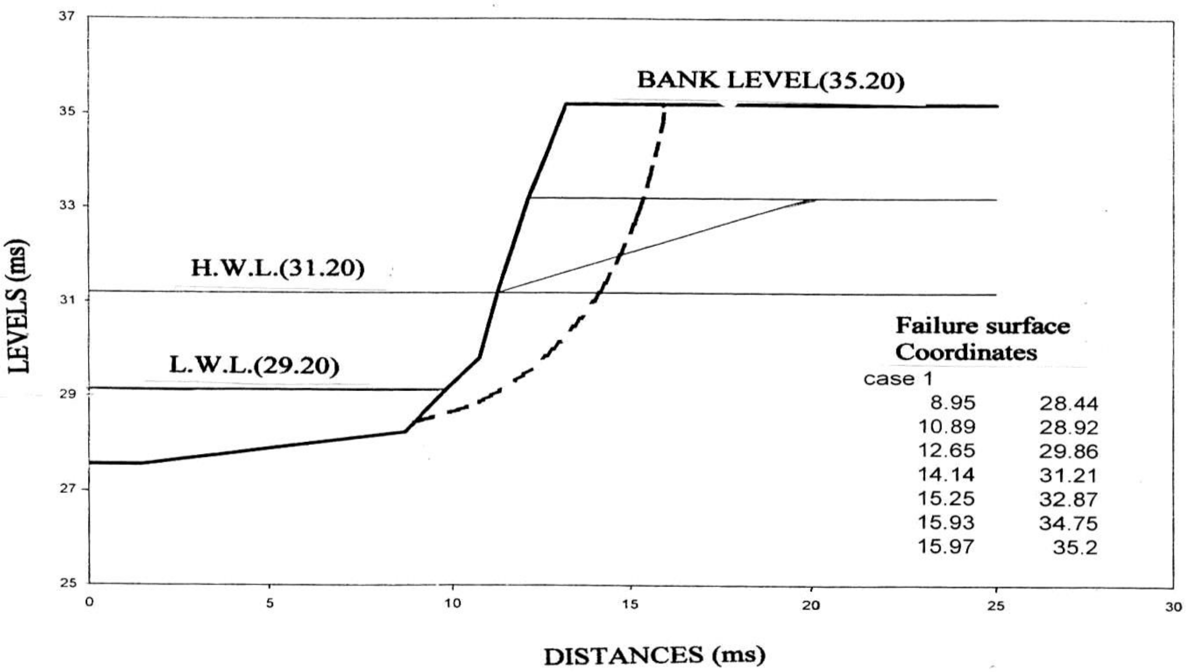
Table (7) Estimated Factor of Safety for protected banks applying developed Traditional Method and Top-filling carried out till Top of bank – Cases of Low Water Level and different soil logs

Run	Factor of safety corresponding to failure surface specified by n coordinate points						
	6	7	8	9	11	12	Minimum F.S.
M3 B1L	1.352 1.544	1.533 1.549 1.565		1.451	1.522 1.541 1.552	1.565	1.352
M3 B2L	1.381 1.473 1.553	1.549 1.573			1.525 1.544 1.553	1.568 1.574	1.381
M3 B3L	1.344 1.448 1.525 1.542	1.527 1.541 1.552			1.499 1.518 1.533		1.344
M3 B4L	1.493 1.565				1.520 1.529 1.542 1.566 1.584	1.551 1.559 1.574	1.493

Table (8) Estimated Factor of Safety for protected banks applying developed Traditional Method and Top-filling carried out till Top of bank – Cases of High Water Level and different soil logs

Run	Factor of safety corresponding to failure surface specified by n coordinate points					
	6	7	8	9	10	Minimum F.S.
M3 B1H	1.352 1.451	1.457 1.499	1.477	1.439 1.459	1.476 1.482 1.500	1.352
M3 B2H	1.381 1.473	1.474 1.505	1.485	1.471	1.442 1.478 1.485 1.502	1.381
M3 B3H	1.344 1.448	1.451 1.48	1.472 1.485	1.420 1.455	1.462 1.464	1.344
M3 B4H						1.440

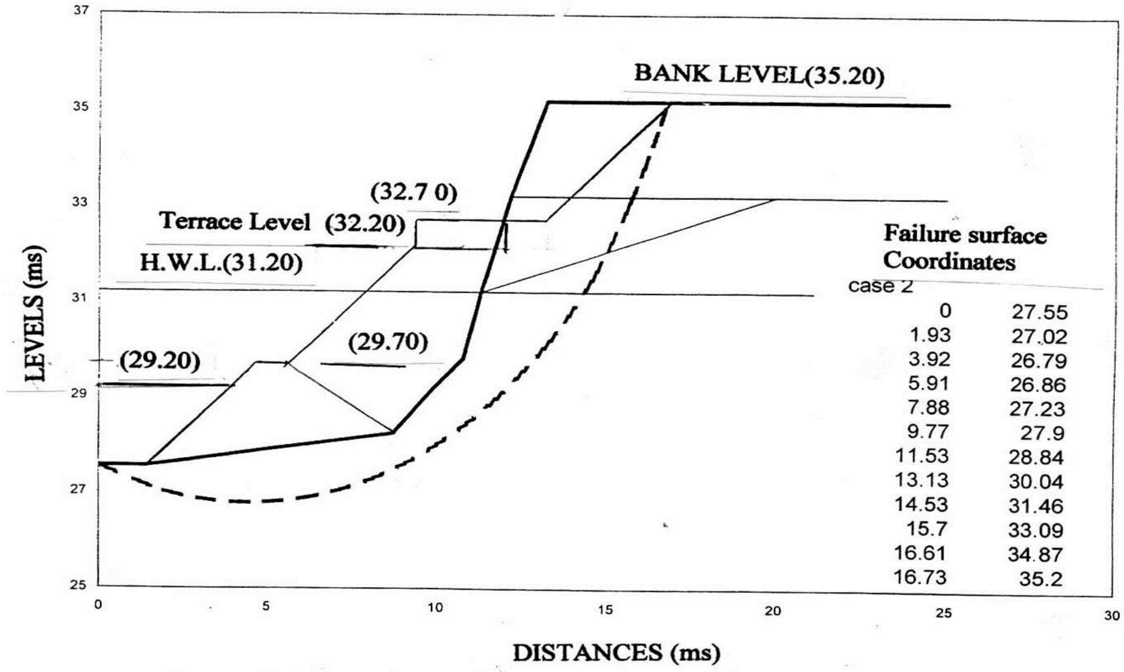
Figures (3, 4, 5) illustrate the coordinates of the surface failure for the cases of: 1) unprotected river bank, 2) protected applying the traditional method with narrow terrace, 3) protected according to the traditional method with top-filling up till the top of the bank.



case 1

8.95	28.44
10.89	28.92
12.65	29.86
14.14	31.21
15.25	32.87
15.93	34.75
15.97	35.2

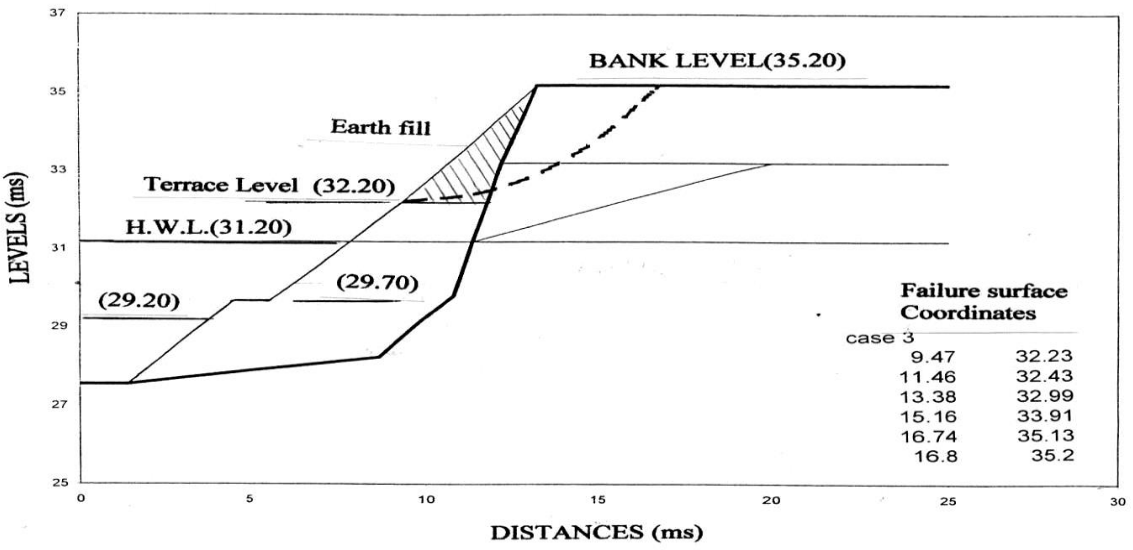
Fig. (3): Surface failure for the case of unprotected River Nile Banks



case 2

0	27.55
1.93	27.02
3.92	26.79
5.91	26.86
7.88	27.23
9.77	27.9
11.53	28.84
13.13	30.04
14.53	31.46
15.7	33.09
16.61	34.87
16.73	35.2

Fig. (4): Surface failure for the case of Applying Traditional Method with Narrow terrace



case 3

9.47	32.23
11.46	32.43
13.38	32.99
15.16	33.91
16.74	35.13
16.8	35.2

Fig. (5): Surface failure for the case of applying traditional method and top-filling till the bank-top

5.2 Slope Stability Results

Based on the model output, the table above summarizes the means of the minimum factor of safety for the different cases.

From Table (9), it is clear that the maximum mean minimum factor of safety is 1.526 for the case of river Nile bank protection applying the developed traditional method with narrow terrace.

Table (9) Mean Minimum Factor of Safety

Case	Mean Minimum Factor of Safety	
	High Water Table	Low Water Table
Unprotected	0.742	0.793
Developed Traditional Method & Terrace	1.511	1.526
Developed Traditional with top filling	1.379	1.393

6- CONCLUSIONS

With respect to hydraulically, geotechnical stability analysis, it was concluded that the stability factor of safety for River Nile banks protection according to the developed traditional method with narrow terrace is preferable. The application of the developed traditional method with narrow terrace increases the value of the minimum factor of safety for the unprotected River Nile banks by about 92.43%, while the application of traditional method with top filling increases the minimum factor of safety by about 61.67% by 30.76% more than the application of traditional method with top filling increase.

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