Slope Stability Assessment of Awba Earth Embankment Using Analytical Methods

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Abstract

Slope stability condition analysis is very important before, during and after construction especially in places like Nigeria where larger number of the dams fall under earthfill dam. Earlier studies revealed that Awba dam is having seepage problem, hence, there is need to carry out slope stability analysis so as to curb the dam failure. Samples were collected at Upstream Right Side (URS) Upstream Middle (UM) and Upstream Left Side (ULS) at 2.0, 55.0 and 105.0 m away from spillway respectively. Triaxial test was perfomed which gave shear strength parameters values Cohesion C (Kpa) and Phi Ø ((^{0}). Slope Stability analysis was run for each of the samples using SLOPE/W of GeoStudio (Version 7.23, 2007 Edition) software in accordance with the principle of limit equilibrium via SLOPE/W. The factor of safety (FOS) for samples at upstream left side varied from 1.285 to 1.554 for Ordinary method, 1.297 to 1.587 for Janbu method, 1.433 to 1.76 for Bishop method and 1.434 to 1.762 for Morgenstern-Price method. Also, factor of safety for samples at upstream middle varied from 1.414 to 1.590 for Ordinary method, 1.427 to 1.630 for Janbu method, 1.570 to 1.776 for Bishop Method and 1. 570 to 1.778 for Morgenstern price method.

Furthermore, factor of safety for samples at upstream right side varied from 1.423 to 1.534 for Ordinary method, 1.457 to 1.555 for Janbu method, 1.620 to 1.713 for Bishop method and 1.623 to 1.714 for Morgenstern price method. It was concluded that Awba dam is stable against overturning and sliding based on based on Morgenstern-Price method because it considered iteration of both moment and forces while other methods considered either.

Keywords: Awba dam, Analytical methods, Factor of Safety, Morgenstern-Price method, Slope Stability

1.0 Introduction

Slope stability analysis is performed to assess the safe and economic design of human-made or natural slopes like embankments, road cuts, open-pit mining, excavations, and landfills and the equilibrium conditions (Ammar and Mohammed 2013). Earthfill dam slope stability is determined by its ability to withstand damaging effect or total failure of inclined surface by sliding or collapsing. Dam fails as a result of slope instability of the Embankment materials which tends to make them under functioning or not in use for the purpose they were being constructed. It was stated in the research carried out by Oladejo and Ogunbode (2018), that, earthfill dams failure can occur as a result of structural instability conditions, seepage conditions and hydraulic conditions. Structural instability of an earthfill dams has being given attention to because it is ruinous when it happens. Tatewar and Pawade (2012**)** studied the stability analysis of Bhimid earthen dam by geo-studio software and they concluded that Computer based analysis is comparatively easy to compute and check stability analysis, Sinha (2008) emphasized that advanced method of slope stability analysis for economical design of earth embankment and discusses on the concept and theory involved in different methods of slope stability analysis of earth embankment. Also Abdoullah Namdar (2008) in his research noted that, achievement of slope load sustainability using mixed soil technique is considered acceptable method for slope construction technology.

This research is of a great important on Awba Earthfill dam as previous works shows that the dam is susceptible to seepage, hence, stability and effects of seepage on Awba dam need to be examined. The aim of the present work is to analyze and assess slope stability in awba dam by computing FOS for limit equilibrium based on **Ordinary, Bishop, Janbu and Morgenstern-Price** methods and then compare results with the standards.

Awba earthfill dam was located in University of Ibadan, Nigeria [1]. Figure 1 displays the Conceptual model of Awba earthfill Dam. The dam lies within Latitudes 07 26.85' º and Longitudes 03 52.85' and 03 54.12' E and 07 27.50' N. The dam embankment is 110 m long, 8.5 m high while the width of its crest is 12 m (Figure 3.2). Its surface area is about 81 km^2. The reservoir level is 5.5 m and the length of the pool is 700 m. Awba dam was designed to impound about 227 million litres of water.

2. Materials and Methods

Nine samples were collected with three each from each of the location Upstream Right Side (URS) Upstream Middle (UM) and Upstream Left Side (ULS) at 2.0, 55.0 and 105.0 m away from spillway respectively.. The disturbed soil samples were collected at depth of 1.2 m and 3 m interval at each location.

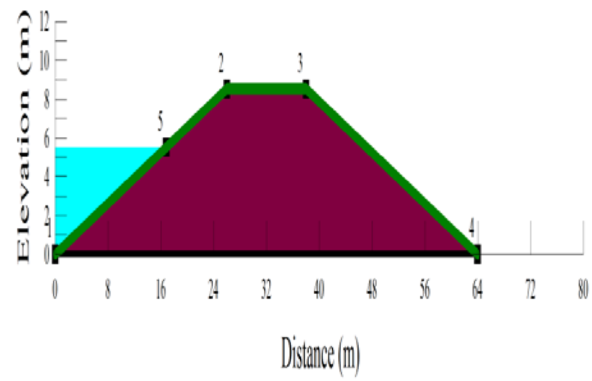

Figure 1: Conceptual model of Awba Earthfill Dam Embankment, University of Ibadan, Nigeria. Source: Oladejo and Ogunbode (2018).

Triaxial test was carried out as described by geotechnical test standards in accordance with ASTM: D4767. Slope stability analysis was performed using SLOPE/W of GeoStudio (Version 7.23, 2007 Edition) software. The four analytical methods used include: Morgenstern-Price, Bishop, Janbu and Ordinary to analyze the stability condition of Awba in accordance with the principle of limit equilibrium via SLOPE/W. These analytical methods were used to ascertain the slope stability condition of dam by computing the factor of safety and then compared with the acceptable standard.

3. Analysis of Slope Stability of Awba Earthfill Dam.

Slope stability analysis was carried out by using the seepage analysis results as the parent of the analysis. The input parameters like cohesion and phi for each of the soil samples were entered and SLOPE/W software was run for the slope stability analysis which yielded factors of safety for each of the methods used. a Factor of Safety (FoS) is used to describe the safety margin and is determined by dividing the summation of forces tending to resist failure by the summation of forces tending to produce failure

$$\text{FoS} = \sum \frac{\text{Resisting forces}}{\text{Driving forces}} \quad (1)$$

3.1 Stability analysis method of Slices

In some cases, the sliding soil mass may not be homogeneous, that is; some part of the soil mass could included with various composites of soil. Therefore it's not possible to apply the direct momentum equilibrium method for the stability analysis. In such cases, the method of slice is an effective method to solve the practical stability problems. Such methods include but not limited to Ordinary, Bishop, Janbu and Morgenstern-Price Methods.

A. Ordinary Method

The Ordinary method (OM) satisfies the moment equilibrium for a circular slip surface, but neglects both the interslice normal and shear forces. Here, the equation does not require an iteration process. The FOS is based on moment equilibrium and computed by (Abramson et al, 2002):

$$Fm = \frac{\sum(C' * l + N' \tan \phi')}{\sum(W \sin \alpha)} \quad = \text{equation (1)} \quad (2)$$

$$N' = W \cos \alpha - u * l \quad (3)$$

Where:

u = pore pressure,

B. Bishop's methods

This method considers the interslice normal forces but neglects the interslice shear forces (Abramson et al. 2002). It further satisfies vertical force equilibrium to determine the effective base normal force (N'), which is given by:

$$N' = \frac{1}{M_\alpha}\left(W - \frac{C' l \sin \alpha}{\text{F}} - ul \cos \alpha\right) \quad (4)$$

Where,

$$M_\alpha = \cos \alpha \left(1 + \tan \alpha \, \frac{\tan \phi'}{\text{F}}\right) \quad (5)$$

C. Janbu's Method

Janbu's simplified method (JSM) is based on a composite SS (non-circular) and the FOS is determined by horizontal force equilibrium. As in BSM, the method considers interslice normal forces (E) but neglects the shear forces (T). The base normal force (N) is determined in the same way as in BSM and the FOS is computed by:

$$F_f = \frac{\sum(C' * l + (N' - ul) \tan \phi') \sec \alpha}{\sum(W \tan \alpha) + \sum \Delta E} \quad (6)$$

Where,

$\Sigma\Delta E = E2 - E1$ = net interslice normal forces (zero if there is no horizontal force).

D. Morgenstern-Price Method

The Morgenstern- Price method (M-PM) also satisfies both force and moment equilibriums and assumes the interslice force function. The interslice force inclination can vary with an arbitrary function (f(x)) as:

$$T = f(x).\lambda.E \quad (7)$$

Where,

f(x)= interslice force function that varies continuously along the slip surface,

λ = scale factor of the assumed function.

The relationships for the base normal force (N) and interslice forces (E, T) are the same as given in JGM. For a given force function, the interslice forces are computed by iteration procedure until, *Ff* is equals to *Fm* in Equations (2.18) and (2.19) as

$$F_f = \frac{\sum [\{C' * l + (N - ul)\tan\phi'\}\sec\alpha]}{\sum\{W - (T_2 - T_1)\}\tan\alpha + \sum(E_2 - E_1)} \quad (8)$$

$$Fm = \frac{\sum(C' * l + (N - ul)\tan\phi')}{\sum(W\sin\alpha)} \quad (9)$$

4. Results and Discussion

Shear strength parameters (Cohesion C (Kpa) and Phi Ø (^{0})) obtained from laboratory test and FOS from numerical slope stability analysis are presented below:

4.1 Triaxial test Results

The result of consolidated-undrained test (CU test) Braja (2010), on samples at ULS, UM and URS is showing in table 1 below:

4.2 Numerical Slope Stability Analysis

The slope stability analysis of Awba earthfill dam was carried out in accordance with the principle of limit equilibrium via SLOPE/W and the summary of the results are presented in Table 2, 3 and 4 for samples at upstream left side, upstream middle and upstream right side respectively.

Table 1: Results of Triaxial test

S/N	Samples	Cohesion C (Kpa)	Phi Ø (^{0})
1	Upstream Left Side 1	3.8	20
2	Upstream Left Side 2	5.0	20
3	Upstream Left Side 3	3.0	27
	Average	**3.9**	**22**
4	Upstream Middle 1	4.1	23
5	Upstream Middle 2	4.2	26
6	Upstream Middle 3	3.3	24
	Average	**3.9**	**24**
7	Upstream Right Side 1	3.9	24
8	Upstream Right Side 2	2.2	26
9	Upstream Right Side 3	4.3	24
	Average	**3.5**	**25**

From the results obtained, the resisting moment and activating moment for Ordinary, Bishop and Morgenstern-Price methods varies from 2514.5 to 1847.9 kN-m and 1721.3 kN-m to1162 kN-m ; 2847.7 kN-m to 2063.2 kN-m and from 1721.3 kN-m to1162 kN-m and 2851.5 to 2065.5 kN-m and 1721.3 kN-m to1162 kN-m respectively. Also, the resisting force and activating force for Janbu and Morgenstern-Price methods ranges from 238.6 to 171.03 kN and 159.38 to 104.96 kN and 242.93 to 173.55 kN and 148.87 to 97.448 kN respectively.

Both the Resisting moment and force are higher than the activating moment and force for the four methods, this shows that the Awba dam has ability to withstand overturning and forces along X-Y planes which can cause failure.

The factor of safety for samples at upstream left side varied from 1.285 to 1.554 for Ordinary method, 1.297 to 1.587 for Janbu method, 1.433 to 1.76 for Bishop method and 1.434 to 1.762 for Morgenstern-Price method. Also, factor of safety for samples at upstream middle varied from 1.414 to 1.590 for Ordinary method, 1.427 to 1.630 for Janbu method, 1.570 to 1.776 for Bishop method and 1. 570 to 1.778 for Morgenstern price method.

Furthermore, factor of safety for samples at upstream right side varied from 1.423 to 1.534 for Ordinary method, 1.457 to 1.555 for Janbu method, 1.620 to 1.713 for Bishop method and 1.623 to 1.714 for Morgenstern price method. Graphical views of the computed factor of safety are shown in figure 1 to 12.

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In addition, various factor of safety computed portray the stability condition of Awba dam.

Table 2: Factor of safety, moments and forces acting on sample upstream left side splices

Parameter	Ordinary	Janbu	Bishop	Morgenstern-Price
Upstream Left Side 1 (ULS 1)				
Factor of Safety	1.285	1.297	1.433	1.434
Total Volume	30.258 m³	30.258 m³	30.258 m³	30.258 m³
Total Weight	636.02 kN	636.02 kN	636.02 kN	636.02 kN
Total Resisting Moment	2211.9 kN-m	---	2467.2 kN-m	2467.7 kN-m
Total Activating Moment	1721.3 kN-m	---	1721.3 kN-m	1721.3 kN-m
Total Resisting Force	---	206.73 kN	---	209.64 kN
Total Activating Force	---	159.38 kN	---	145.87 kN
Upstream left side 2 (ULS 2)				
Factor of Safety	1.422	1.449	1.601	1.603
Total Volume	30.258 m³	30.258 m³	30.258 m³	30.258 m³
Total Weight	569.45 kN	569.45 kN	569.45 kN	569.45 kN
Total Resisting Moment	2192.1 kN-m	---	2467.3 kN-m	2469.7 kN-m
Total Activating Moment	1541.1 kN-m	---	1541.1 kN-m	1541.1 kN-m
Total Resisting Force	---	206.4 kN	---	209.78 kN
Total Activating Force	---	142.47 kN	---	130.51 kN
Upstream left side 3 (ULS 3)				
Factor of Safety	1.554	1.587	1.760	1.762
Total Volume	30.258 m³	30.258 m³	30.258 m³	30.258 m³
Total Weight	597.89 kN	597.89 kN	597.89 kN	597.89 kN
Total Resisting Moment	2514.5 kN-m	---	2847.7 kN-m	2851.5 kN-m
Total Activating Moment	1618.1 kN-m	---	1618.1 kN-m	1618.1 kN-m
Total Resisting Force	---	238.6 kN	---	242.93 kN
Total Activating Force	---	150.36 kN	---	137.34 kN
Average Factor of Safety	1.420	1.444	1.598	1.600

Table 3: Factor of safety, moments and forces acting on sample Upstream Middle splices

Parameter	Ordinary	Janbu	Bishop	Morgenstern-Price
		Upstream Middle 1 (UM 1)		
Factor of Safety	1.462	1.483	1.632	1.632
Total Volume	30.258 m³	30.258 m³	30.258 m³	30.258 m³
Total Weight	566.73 kN	566.73 kN	566.73 kN	566.73 kN
Total Resisting Moment	2241.7 kN-m	---	2502.6 kN-m	2503.8 kN-m
Total Activating Moment	1533.8 kN-m	---	1533.8 kN-m	1533.8 kN-m
Total Resisting Force	---	209.08 kN	---	212.19 kN
Total Activating Force	---	141.01 kN	---	129.62 kN
		Upstream middle 2 (UM 2)		
Factor of Safety	1.59	1.63	1.776	1.778
Total Volume	30.258 m³	30.258 m³	30.258 m³	30.258 m³
Total Weight	429.36 kN	429.36 kN	429.36 kN	429.36 kN
Total Resisting Moment	1847.9 kN-m	---	2063.2 kN-m	2065.5 kN-m
Total Activating Moment	1162 kN-m	---	1162 kN-m	1162 kN-m
Total Resisting Force	---	171.03 kN	---	173.55 kN
Total Activating Force	---	104.96 kN	---	97.448 kN
		Upstream middle 3 (UM 3)		
Factor of Safety	1.414	1.427	1.57	1.57
Total Volume	34.97 m³	34.97 m³	34.97 m³	34.97 m³
Total Weight	610.57 kN	610.57 kN	610.57 kN	610.57 kN
Total Resisting Moment	2382.3 kN-m	---	2644.7 kN-m	2644.4 kN-m
Total Activating Moment	1684.6 kN-m	---	1684.6 kN-m	1684.6 kN-m
Total Resisting Force	---	212.79 kN	---	215.47 kN
Total Activating Force	---	149.16 kN	---	137.01 kN
Average Factor of Safety	1.489	1.513	1.659	1.660

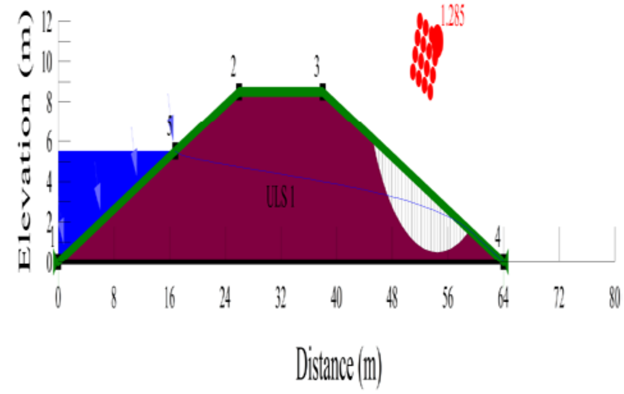
Table 4: Factor of safety, moments and forces acting on sample upstream right side splices

Parameter	Ordinary	Janbu	Bishop	Morgenstern-Price
		Upstream right side 1 (URS 1)		
Factor of Safety	1.491	1.515	1.67	1.671
Total Volume	30.258 m³	30.258 m³	30.258 m³	30.258 m³
Total Weight	583.97 kN	583.97 kN	583.97 kN	583.97 kN
Total Resisting Moment	2356.3 kN-m	---	2639.6 kN-m	2641.3 kN-m
Total Activating Moment	1580.5 kN-m	---	1580.5 kN-m	1580.5 kN-m
Total Resisting Force	---	220.75 kN	---	224.23 kN
Total Activating Force	---	145.76 kN	---	133.74 kN
		Upstream right side 2 (URS 2)		
Factor of Safety	1.423	1.457	1.62	1.623
Total Volume	30.258 m³	30.258 m³	30.258 m³	30.258 m³
Total Weight	609.99 kN	609.99 kN	609.99 kN	609.99 kN
Total Resisting Moment	2348.7 kN-m	---	2674.9 kN-m	2679.7 kN-m
Total Activating Moment	1650.9 kN-m	---	1650.9 kN-m	1650.9 kN-m
Total Resisting Force	---	224.32 kN	---	228.77 kN
Total Activating Force	---	153.93 kN	---	140.33 kN
		Upstream right side 3 (URS 3)		
Factor of Safety	1.534	1.555	1.713	1.714
Total Volume	30.258 m³	30.258 m³	30.258 m³	30.258 m³
Total Weight	583.06 kN	583.06 kN	583.06 kN	583.06 kN
Total Resisting Moment	2420.7 kN-m	---	2703.5 kN-m	2704.7 kN-m
Total Activating Moment	1578 kN-m	---	1578 kN-m	1578 kN-m
Total Resisting Force	---	226.02 kN	---	229.41 kN
Total Activating Force	---	145.31 kN	---	133.45 kN
Average Factor of Safety	1.483	1.509	1.668	1.669

However, out of the four methods that was used for the stability analysis, highest factors of safety was obtained in Morgenstern price method. This is attributed to the consideration of both force and moment equilibrium in the analysis while the three other methods considered either force or moment in the analysis (Table 2, 3 and 4). This is in line with what was reported by Khattab (2010).

Averagely, factor of safety values for samples at upstream left side, upstream middle and upstream right side are 1.420, 1.489 and 1.483; 1.444 1.513 and 1.509; 1.598, 1.659 and 1.668 and 1.600, 1.660 and 1.669 for Ordinary, Janbu, Bishop and Morgenstern price methods respectively (Table 2, 3 and 4). As reported by Zhou (2006), United State National Highway Institute (2006) suggested a safety factor of 1.50 for cut slopes in fine grained cohesive material which can easily lose shear strength. This indicate that Morgenstern price and Bishop methods shows a very good range of value for all the samples, hence, Awba dam is stable. Meanwhile, Janbu method's range of value was fair while Ordinary method range of values was unacceptable and indicate that Awba earthfill dam is not stable. Similarly, a range of an acceptable factor of safety between 1.5 - 1.75 was recorded by Liu and Evett (2005).

Graphical views of Awba dam with the computed critical factor of safety are shown in Figures 2 to 13 for samples at upstream left side, upstream middle and upstream right side respectively.



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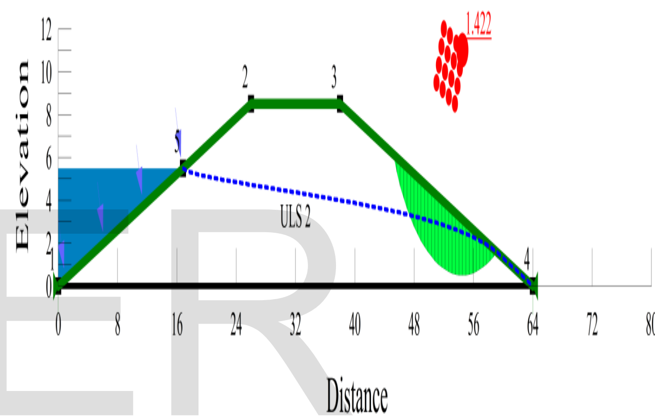

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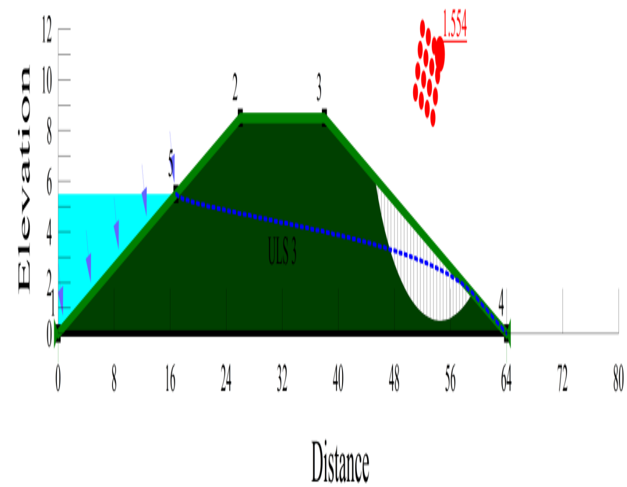
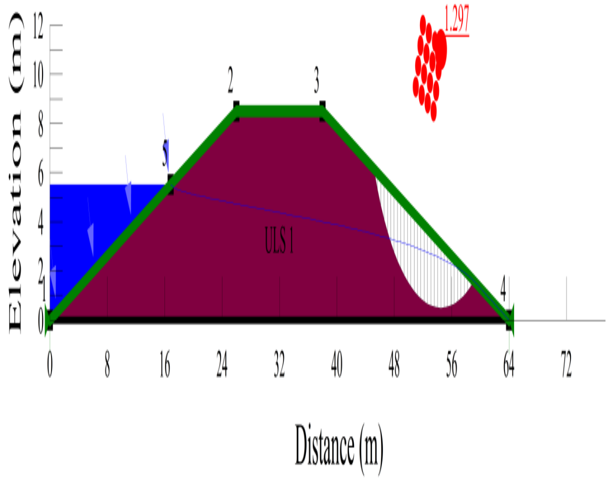


c

Figure 2(a,b,c): Factor of safety by Ordinary method for samples at upstream left side



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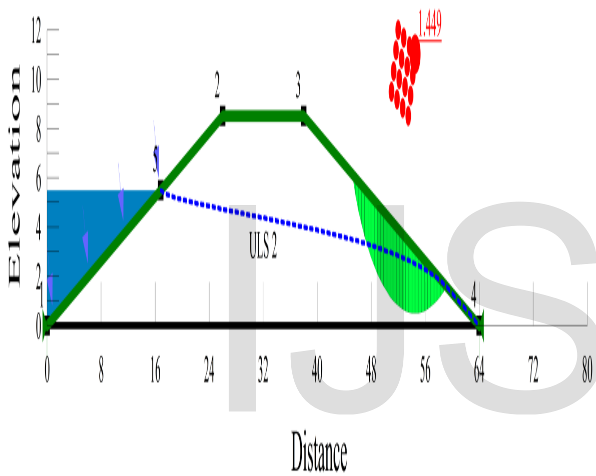

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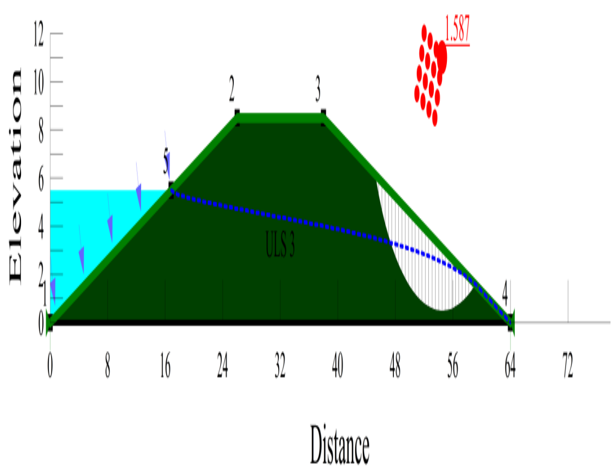
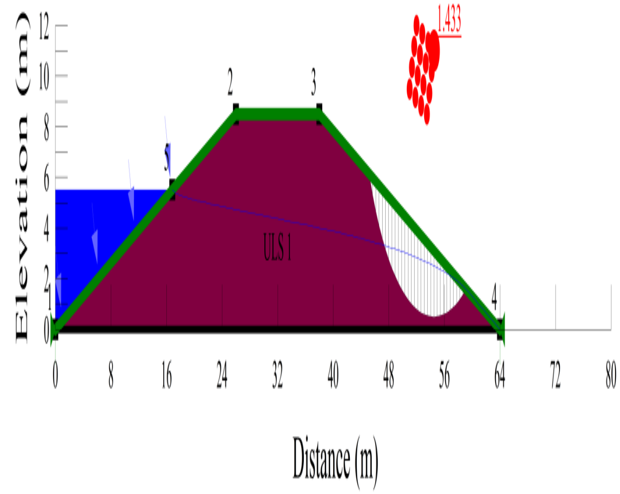


c

Figure 3(a,b,c): Factor of safety by Janbu method for samples at upstream left side



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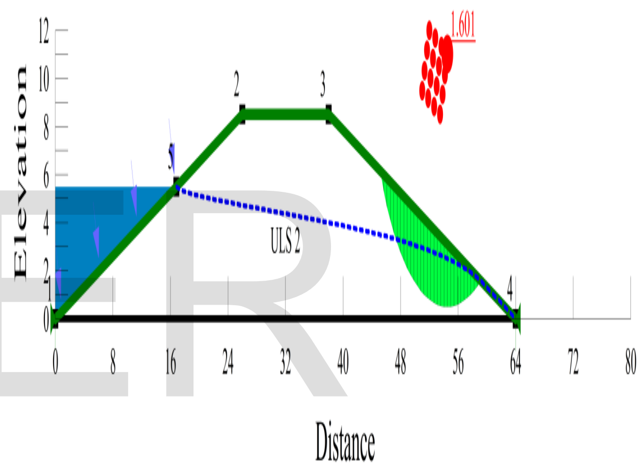

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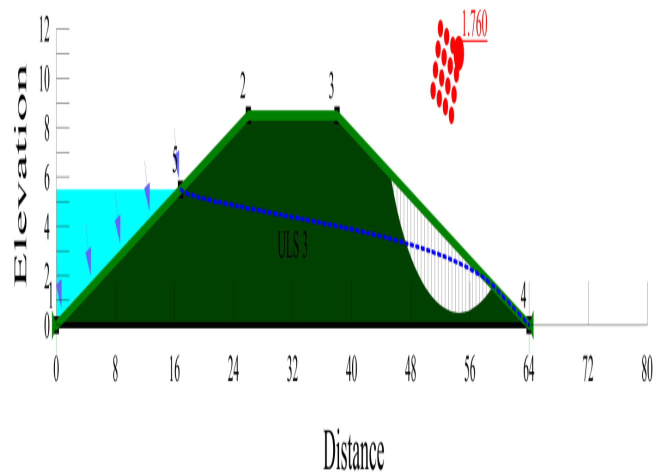


c

Figure 4(a,b,c): Factor of safety by Bishop method for samples at upstream left side

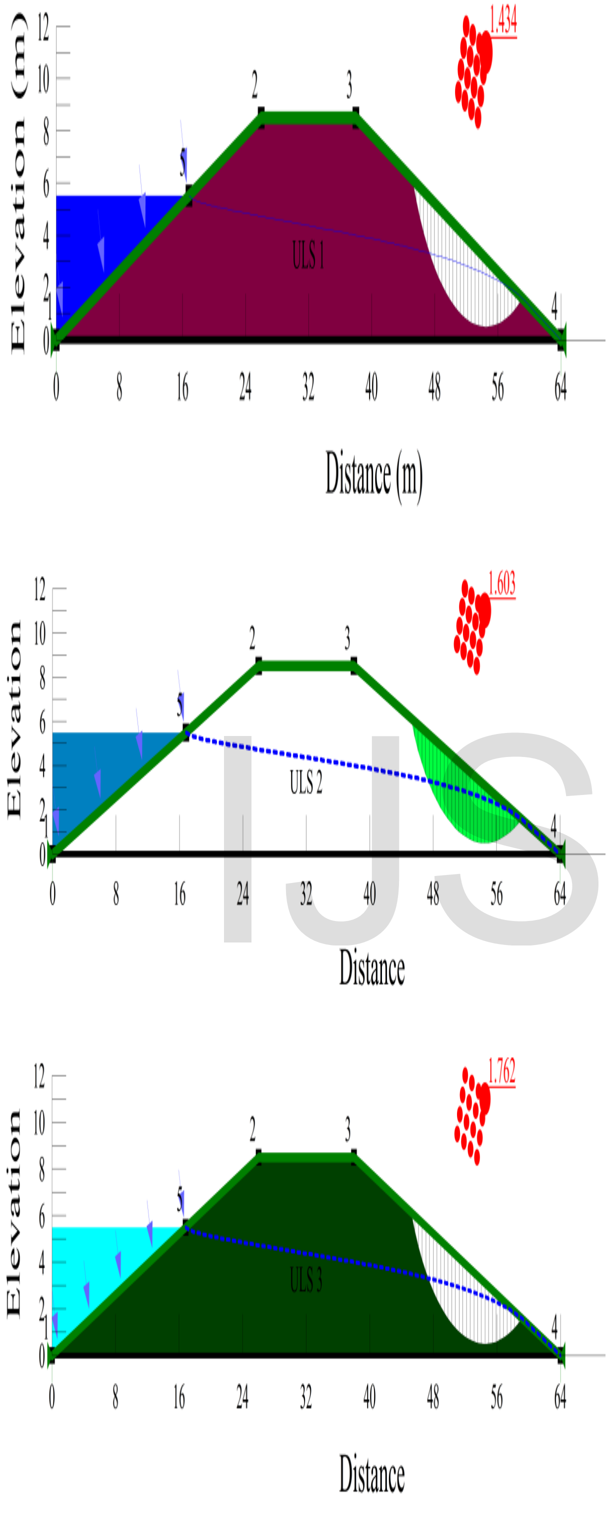


Figure 5(a,b,c): Factor of safety by Morgenstern price method for samples at upstream left side

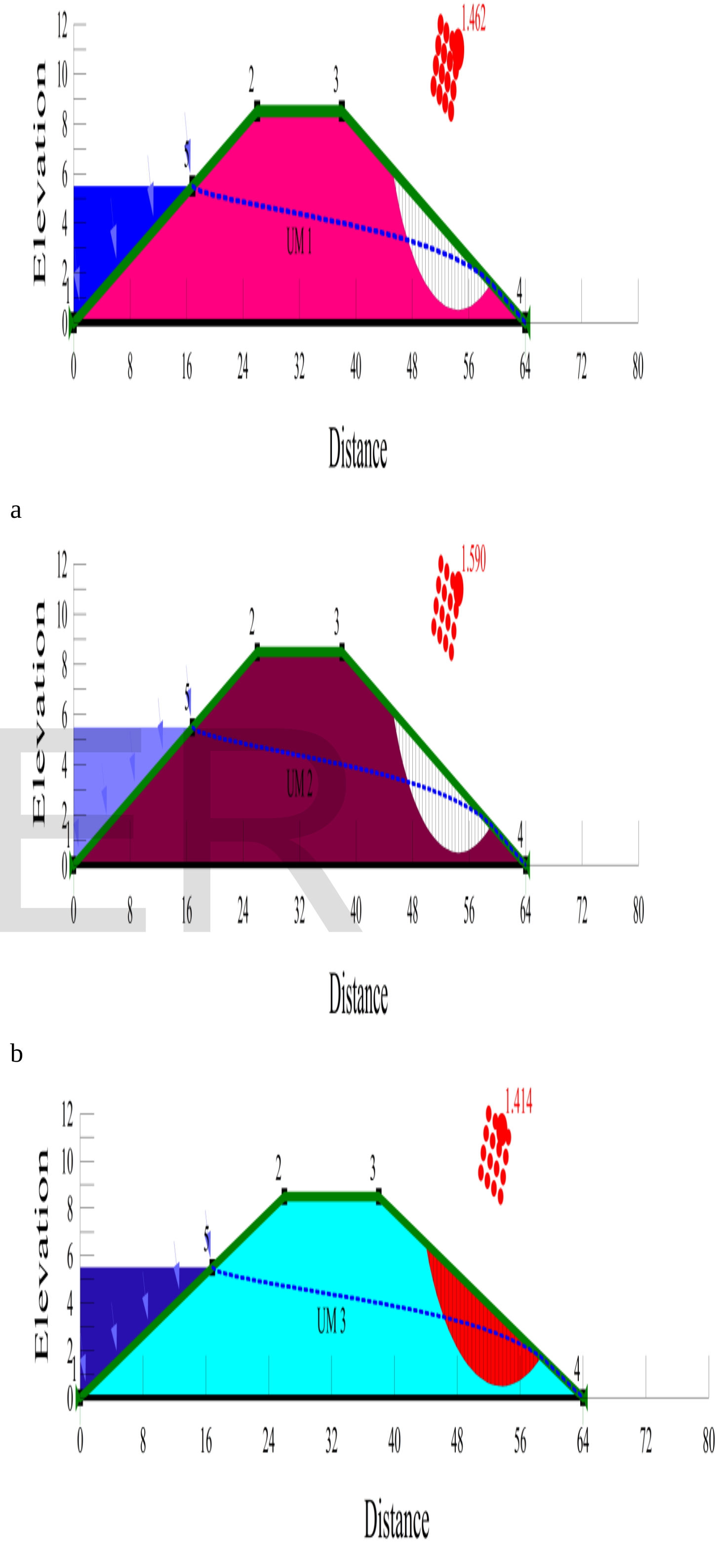
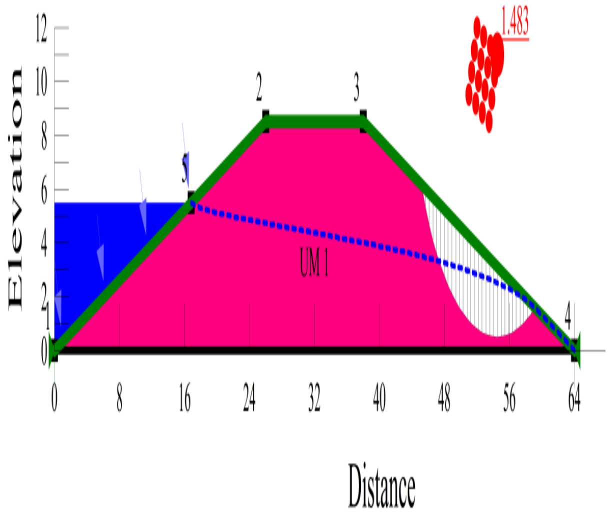


Figure 6(a,b,c): Factor of safety by Ordinary methodfor samples at upstream middle



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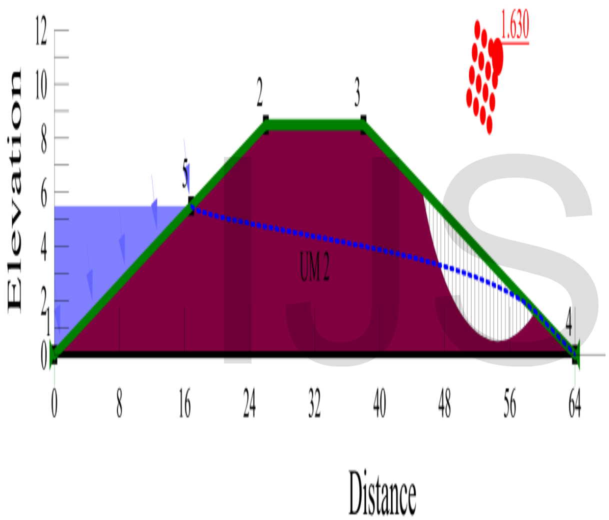

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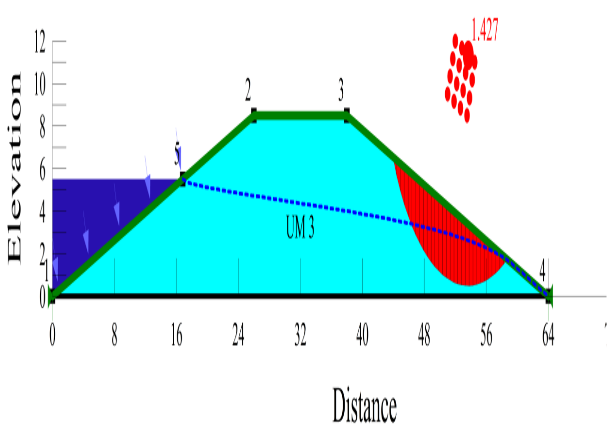

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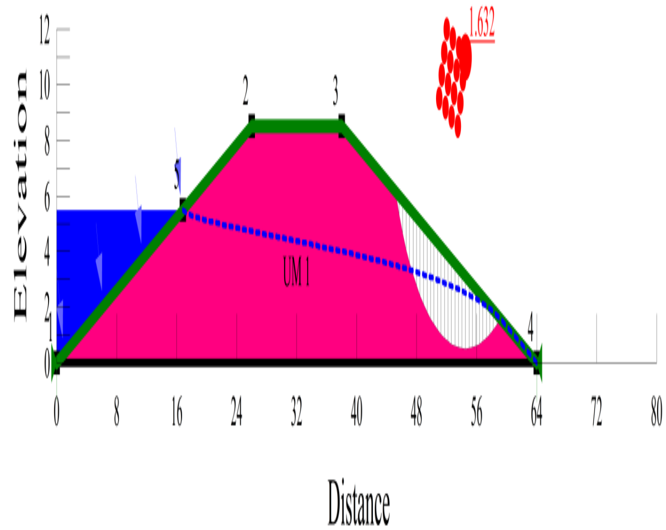
Figure 7(a,b,c): Factor of safety by Janbu method for samples at upstream middle



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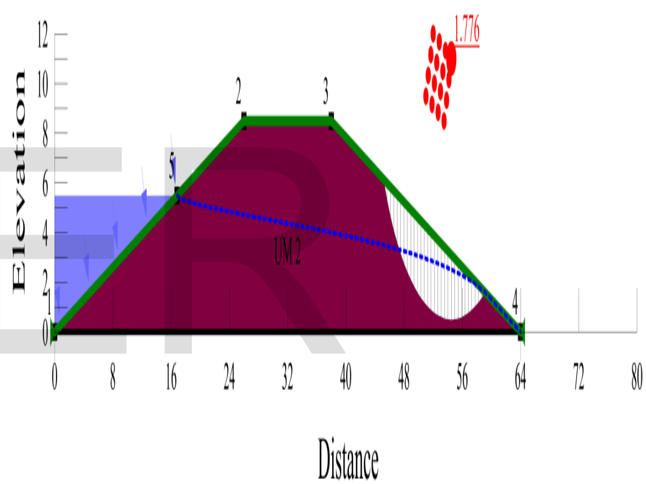

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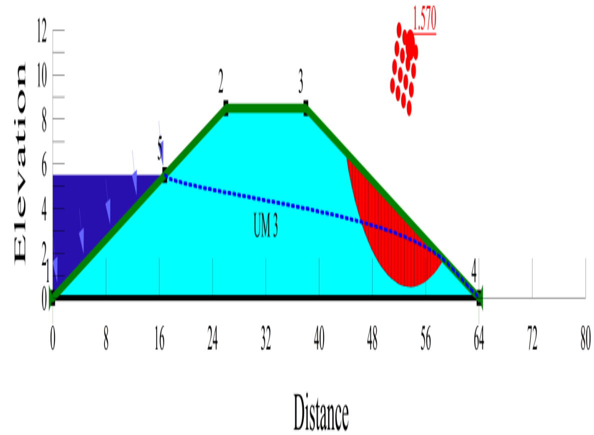
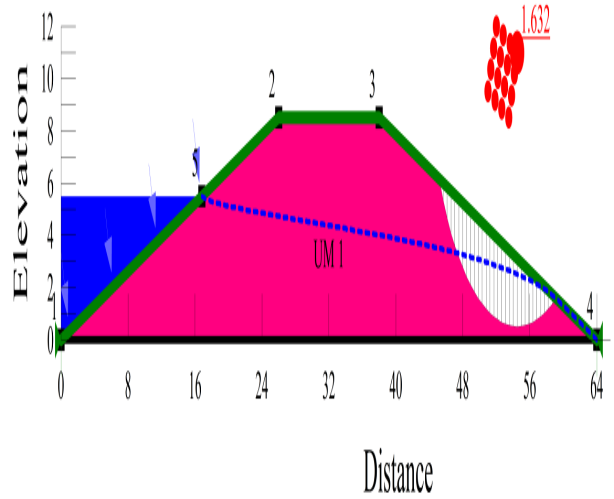


c

Figure 8(a,b,c): Factor of safety by Bishop method for samples at upstream middle



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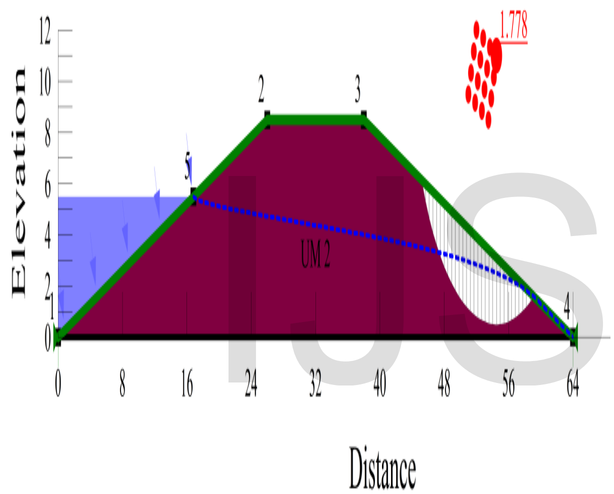

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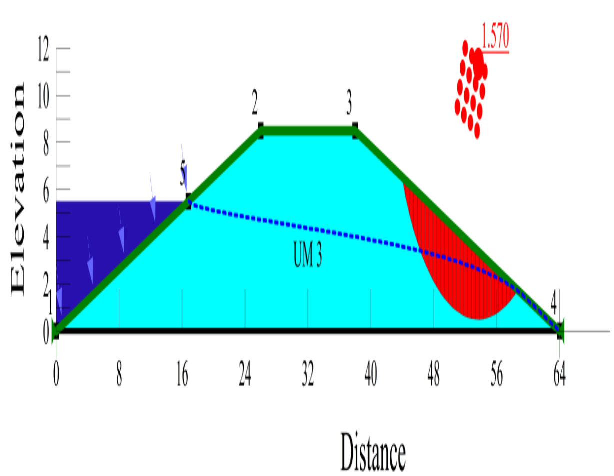
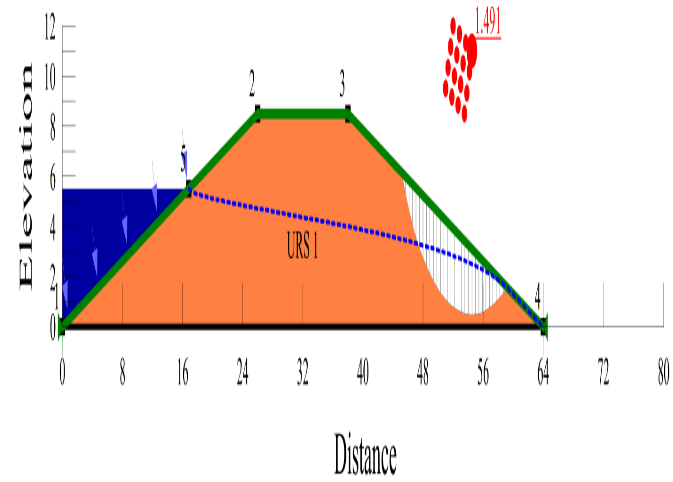
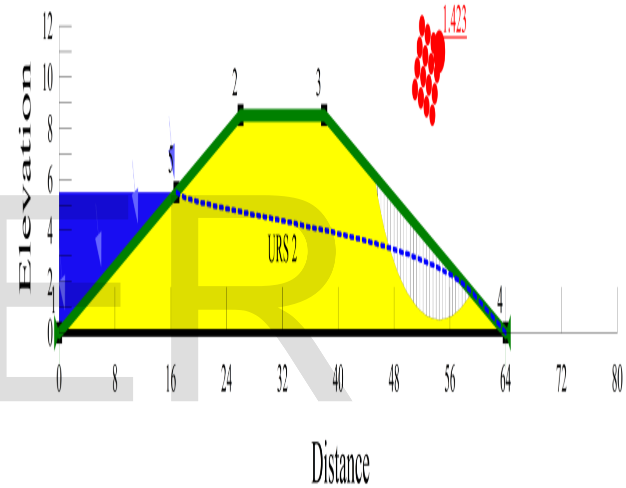


c

Figure 9(a,b,c): Factor of safety by Morgenstern price method for samples at upstream middle



a



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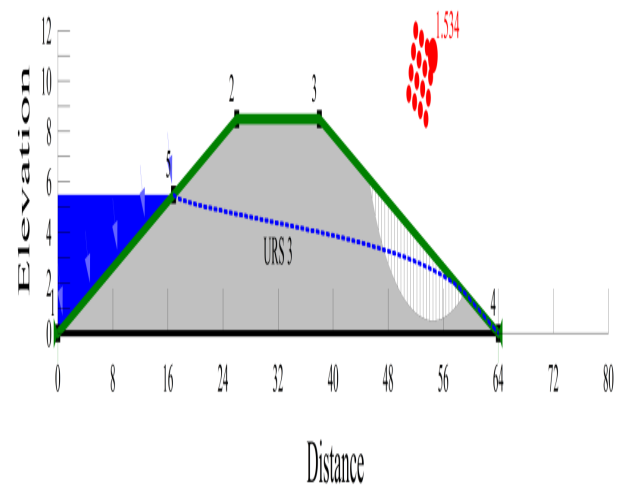
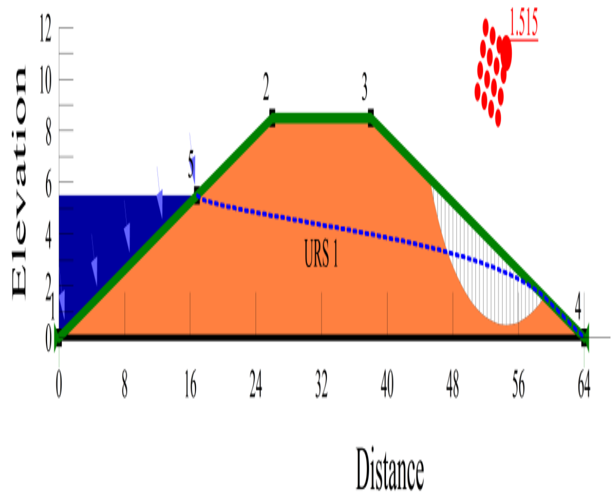


c

Figure 10(a,b,c): Factor of safety Ordinary method for samples at upstream right side



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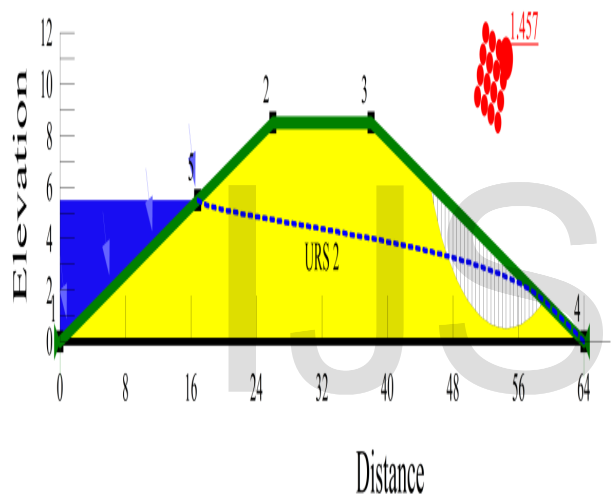

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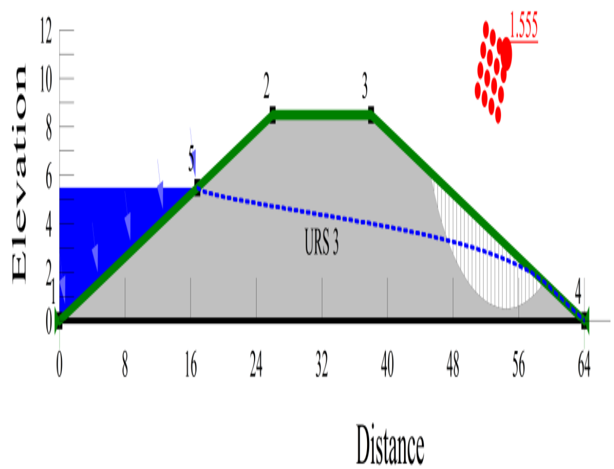
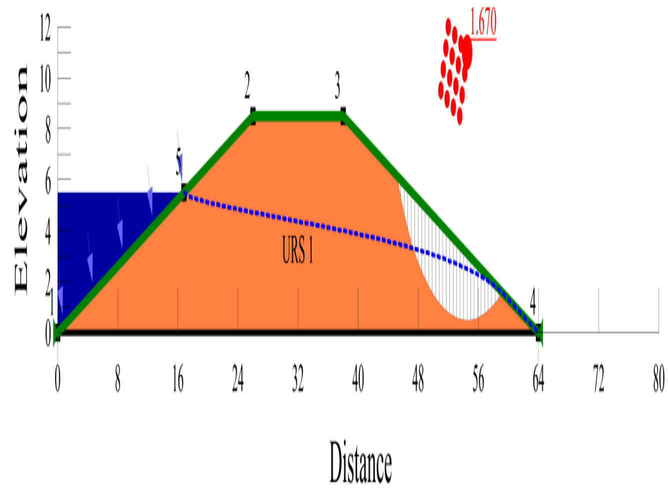
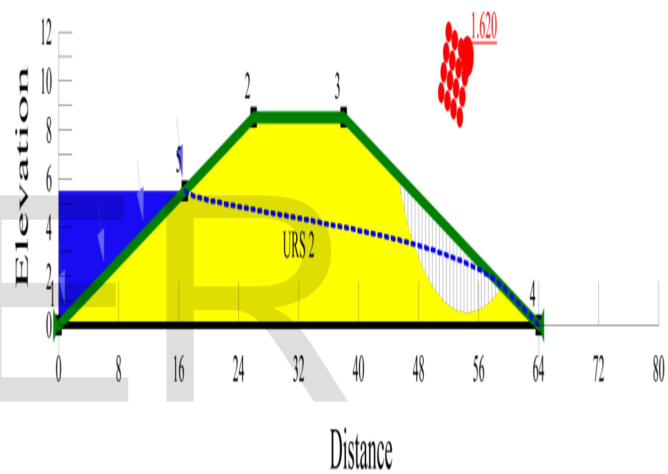


c

Figure 11(a,b,c): Factor of safety Janbu method for samples at upstream right side



a



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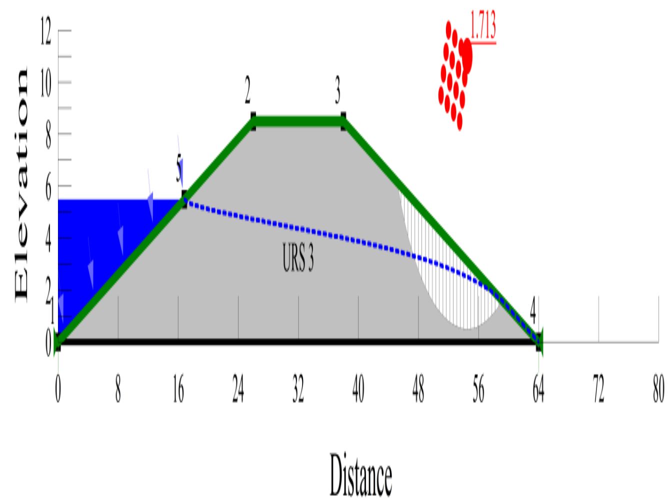
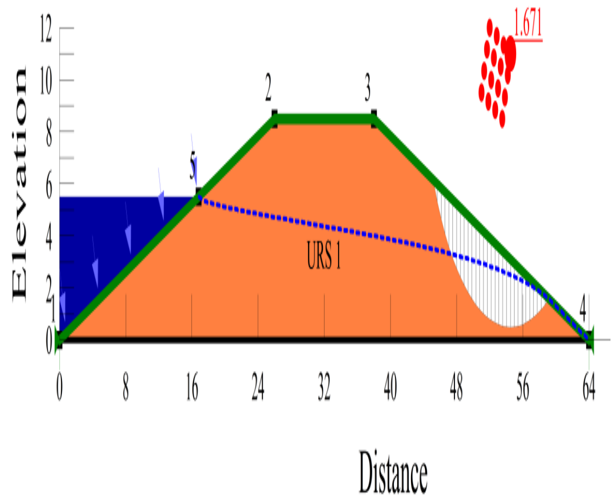
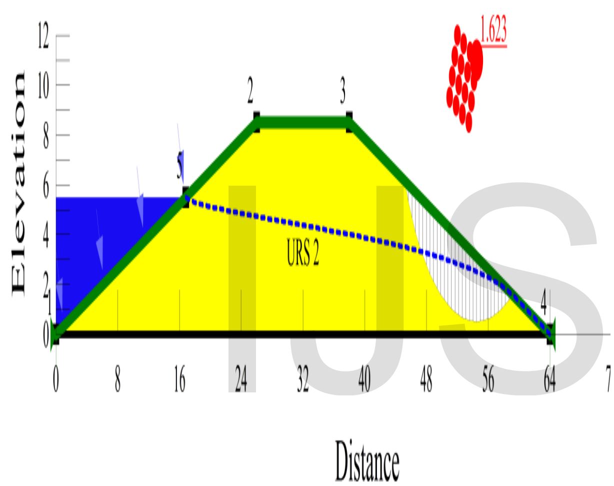


c

Figure 12(a,b,c): Factor of safety by Bishop method for samples at upstream right side



a



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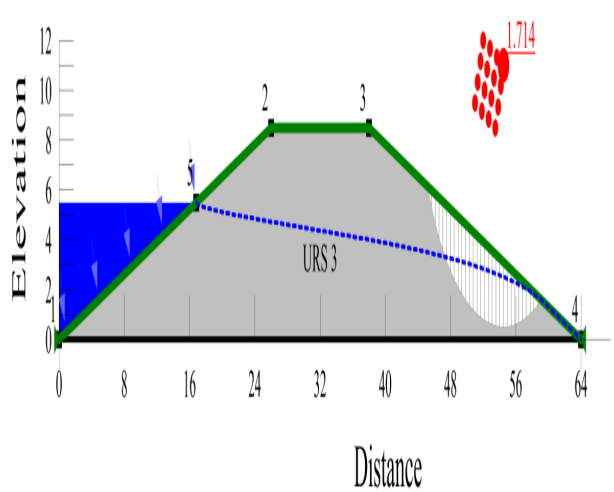

c

Figure 13(a,b,c): Factor of safety by Morgenstern price method for samples at upstream right side

5. Conclusions

Slope stability analysis of Awba dam via four analytical methods which include Ordinary, Janbu, Bishop and Morgenstern-Price gives factor of safety value which was compared with the standard for an earthfill dam. From the analysis, the following conclusions were drawn:

i. factor of safety for ordinary was not within the acceptable range, hence, the dam is not stable.

ii. Upstream Middle, Left and Right sides factor of safety for Janbu shows fairly acceptable range but this does not make the dam stable since only the force was considered for the analysis.

iii. the value of factor of safety for Bishop methods was within the acceptable range and this suggest that the Awba dam is safe against overturning moment

iv. Morgenstern-Price method factor safety is within the acceptable limit. Hence, the factor of safety obtained indicate that Awba dam is safe and stable against overturning and sliding as iteration of computed factor of safety considered both moment and forces acting on the dam.

It was concluded that Awba dam is stable against overturning and sliding based on based on Morgenstern-Price method because it considered iteration of both moment and forces while other methods considered either.

6. Recommendations

Based on the findings made from this study, the following recommendations were made:

i. Slope stability analysis should be carried out from time to time in order to avert failure as a result of instability of dam slope.
ii. Research on the effect of confirmed seepage within Awba dam on slope stability should be carried out
iii. Slope stability analysis results of dam should consider Morgenstern-Price method as its results are more reliable.

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