Global Scientific JOURNALS

GSJ: Volume 7, Issue 9, September 2019, Online: ISSN 2310-9186
www.globalscientificjournal.com

A STUDY OF THE STABILITY OF SLOPES OF A RAILWAY LINE: ABUJA RAIL MASS TRANSIT PROJECT BETWEEN LOT1 (KUBWA) AND LOT3 (CENTRAL BUSINESS DISTRICT), AS A CASE STUDY

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KeyWords

Slope stability Analysis, Critical Failure Surface, Slope Failure, Factor of Safety, Cut Slope, Limit Equilibrium Method, Shear Strength Parameters c and ϕ, Stability Number Method

ABSTRACT

The limit equilibrium (LE) methods were used in this study to analyse the stability of existing cut slopes of the Abuja Rail Mass Transit project at the Central Business District, Abuja, Nigeria. This paper considered slopes at Lot 3 between kilometre 2 and kilometre 4. Representative soil samples were taken at each of kilometres 2, 3 and 4 for geotechnical investigation. The soils were classified and the shear parameters c and ϕ were obtained from direct shear box tests. The Stability Number Method was employed manually to perform the stability analysis for both cohesive and frictional soils. Results of the quantitative analyses were verified using a spread sheet solution that applies Fellenius and the Simplified Bishop Methods of slices. Results from all the methods adopted validate stability of the slopes in this study. The factors of safety obtained using the Stability Number Method were 2.20 for kilometre 2, 1.82 for kilometre 3 and 2.07 for kilometre 4. However, the spreadsheet results of factors of safety were 2.187, 1.821 and2.001 for the Fellenius Method and 2.250, 1.882 and 2.060 using the Simplified Bishop Method. This paper therefore presents the details of the geotechnical investigations and stability analyses carried out. General recommendations both preventive and remedial were made in order to prevent slope failures. These include the provision of adequate surface and subsurface drains, periodic inspection and maintenance to reduce rainwater infiltration and thereby prevent erosion of the slope forming materials.

1.0 Introduction

Slopes are found in Civil Engineering, principally in the design and construction of hydraulic structures and transportation infrastructures.

Slope stability is the resistance of inclined surface to failure by sliding or collapsing. It is performed to assess the safe design of human-made or natural slopes (examples: embankments, road cuts, open-pit mining, excavations, landfills etc.) and the equilibrium conditions. The main objectives of slope stability analysis are finding endangered areas, investigation of potential failure mechanisms, designing of optimal slopes with regard to safety, reliability and economics, designing possible remedial measures, e.g. barriers and stabilization [1].

Slope failure due to slope instability in highway and railway infrastructures is a natural disaster that can endanger human lives and properties. It can negatively affect the economic growth of any country due to inefficient movement of goods, raw materials and services across the country. Frequent failures can also affect investor decision. Extra expenditure is incurred in the repair of the failed slope.

Among other common forms of slope failures, which are slip failure, slide failure, creep failure, failure due sinking into soft soil caused by excessive settlement and failure by plastic squeezing of soil and heaving of ground surface when water content exceeds the plastic limit of the soil [2]. However the most common mode of failure is slipping of an embankment or cutting. Considerable research work has been carried out into the causes of such failure. Through the results of various research collated, it has been established that water is frequently the cause of earth slips. It occurs either by eroding of the soil layer or by an increase of the moisture content of the soil resulting in the decrease of shear strength.

Water increases the disturbing moment on the soil by increasing the weight of the soil. This causes failure when the ratio of the resisting moment developed due to the shear strength of the soil to the disturbing moment induced by the shear stress on the soil is less than the specified factor of safety for failure to never occur. The ratio of the resisting moment to the disturbing moment is the factor of safety of the slope. “The purpose of slope stability analysis is to provide a quantitative measure of the stability of a slope or part of a slope. Traditionally, it is expressed as the factor of safety against failure of that slope [3]."

Owing to the damages caused by unstable slopes, the planning, design and construction of slopes along a highway or railway requires thorough geotechnical studies on representative soil samples of the proposed and existing slopes in order to determine their sustainability, suitability and stability. This study will determine the stability of the existing Abuja railway slopes. It will be achieved through the geotechnical analysis of representative soil samples of the existing slopes.

Analyses will be done to determine the factor of safety of the existing slopes. The higher the factor of safety of the representative soil of each slope, the higher the chances that the slope will not fail.

2.0 Materials and Methods

2.1 Site Visit and Description of Study Area

Abuja Rail Mass Transit commonly known as Abuja Light Rail is a light rail transport system in Abuja in the Federal Capital Territory, FCT, Nigeria. It is the first of its kind in the country and in West Africa and second such system in sub-Saharan Africa (after Addis Ababa Light Rail). It is 27 kilometres long with 8 stations, connecting the Abuja city center to the Abuja International airport and also connecting to the Federal Abuja-Kaduna line [4]. It is characterized by both cut and fill slopes along the railway line.

The site was visited to collect necessary data and soil samples for detailed geotechnical laboratory investigations and to evaluate the physical condition of the existing slopes.

FIG. 1a: Project Site

FIG.1b: Project Site with Herringbone System of Drainage

2.2 Soil Sampling and Investigations

2.2.1 Soil Sampling

Disturbed and undisturbed soil samples, representatives of the case slopes, were collected from the slopes at different locations. Undisturbed methods of sampling provide samples with comparable condition to the site conditions. Disturbed soil samples do not retain the in-situ properties of the soil during the collection process [5].

2.2.2 Laboratory Investigations

Four test samples were investigated at Soilmen Engineering Services Ltd, Nigeria. The main purpose of the investigations was to determine the relevant material parameters required for slope stability evaluation. Representative soil samples were taken at each of kilometres 2, 3 and 4, for geotechnical investigation. The soils were classified and shear parameters obtained from direct shear box tests. The investigated shear strength parameters c and ϕ from the representative soil samples which are keys in the slope stability analysis were obtained.

Since the direct shear tests are mostly conducted for sandy or sandy lean clay or silt material and by classification the soil on slopes under study are silty clay materials. This necessitated the use of the drained direct shear test result to ascertain the stability of the slopes.

2.3 Stability Analysis Procedure

The process of evaluating slope stability involves the following procedure:

a. Explore and sample foundation and borrow sources.

b. Characterize the soil strength by determining the shear strength parameters.

c. Establish the 2-D idealization of the cross section, including the surface geometry and the subsurface

d. Select trial slip surfaces and compute factors of safety using the selected method.

e. Repeat step (d) above until the “critical” slip surface has been located. The critical slip surface is the one that has the lowest factor of safety and which, therefore, represents the most likely failure mechanism.

f. Compare the computed factor of safety with experience-based criteria. Return to any of the items above, and repeat the process through step f, until a satisfactory design has been achieved [6].

GSJ: Volume 7, Issue 9, September 2019
ISSN 2320-9186

2.4 Methods of Stability Analysis

Analysis of slopes has been carried out by limit equilibrium (LE) methods. The stability analyses were performed manually using the Taylor's Stability Number Method for cohesive and frictional soils. The result obtained by the above named methods was verified with a spread sheet solution for slope stability analysis using the Fellenius and Simplified Bishop Methods.

According to Aryal [7], LE methods are important mainly because of two reasons. First, the methods have proved to be reasonably reliable in assessing the stability of slopes. Second, the methods require a limited amount of input, but can quickly perform an extensive trial-and-error search for the critical shear surface (CSS). He further states that “LE methods are missing the fundamental physics of stress-strain relationship, and thus they are unable to compute a realistic stress distribution”. In spite of this limitation, the LE methods are still common practice because of their simplicity and the reasonably accurate FOS obtained.

2.4.1 Taylor's Stability Number Method

The stability number method is also based on the premise that resistance of a soil mass to sliding results from cohesion and internal friction of the soil along the failure surface. A parameter called the *stability number* is introduced, which groups factors affecting the stability of soil slopes. The stability number (N_s) is defined as follows [8].

$$N_s = \frac{c}{\mathrm{FYH}}$$

Where Y = unit weight of soil
H = height of cut
C = cohesion of soil
F = factor of safety for cohesion and friction

In 1948, D. W. Taylor proposed a simple method of determining the minimum factor of safety for a slope in a homogeneous soil. Using a total stress analysis and ignoring the possibility of tension cracks, he produced a series of curves which relate a stability number (N) to the slope angle β. For slope angles greater than 53°, the critical circle passes through the toe of the slope. For slope angles less than 53° the critical circle may pass in front of the toe [9]. Taylor's chart 1 is principally used forϕ=0 soils while Taylor's chart 2 is mainly used for ϕ>0 soils.

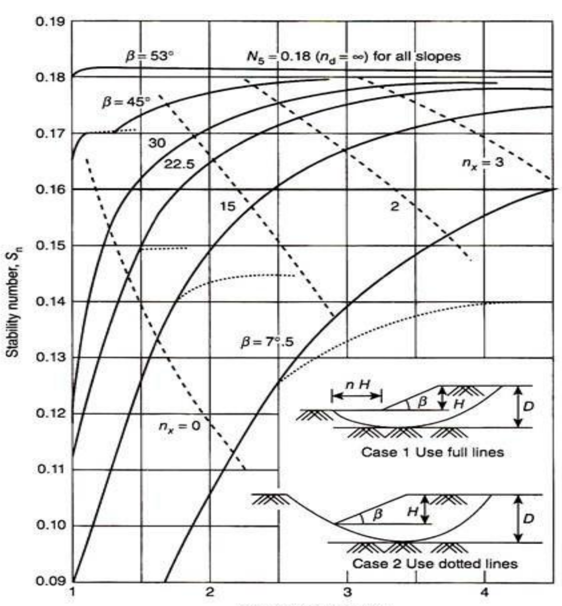

Figure 17.19 Taylor's stability chart (base failure).

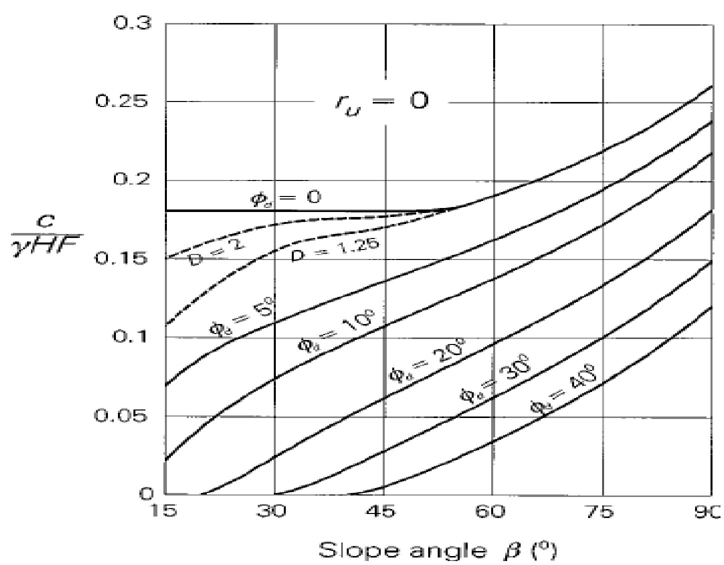

FIG.2a: Taylor's Stability Chart for c>0, ϕ=0 soils [10]

FIG.2b: Taylor's Stability Chart forc>0, ϕ> 0 soils [11].

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ISSN 2320-9186

2.4.3 The Simplified Bishop Method

The Simplified Bishop Method was developed by Bishop (1955). This procedure is based on the assumption that the interslice forces are horizontal, as shown in below.

A circular slip surface is also assumed in the Simplified Bishop Method. Forces are summed in the vertical direction. The resulting equilibrium equation is combined with the Mohr-Coulomb equation and the definition of the factor of safety to determine the forces on the base of the slice. Finally, moments are summed about the center of the circular slip surface to obtain the following expression for the factor of safety [6]:

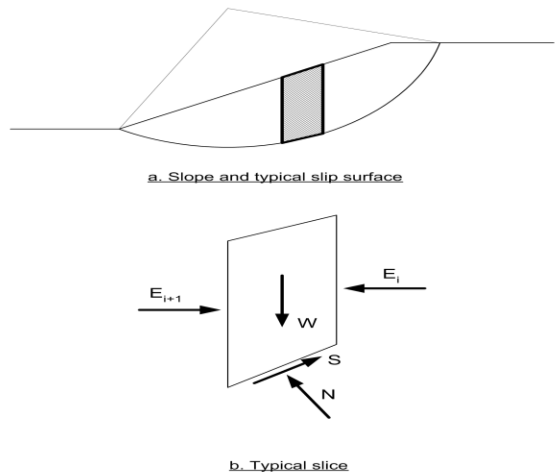

FIG 3: Simplified Bishop Method of slices [6]

$$F = \frac{\Sigma[c'\Delta x + (P\cos\beta - u\sqrt{x}\sec\pi)\tan\phi]/m\alpha]}{\Sigma W\sin\alpha - \Sigma Mp/R}$$

Where Δx is the width of the slice, and mα is defined by the following equation,

$$m_\alpha = \cos\alpha + \frac{\sin\alpha\tan\phi'}{F}$$

Where
c' and ϕ' = shear strength parameters for the center of the base of the slice
W = weight of the slice
A = inclination of the bottom of the slice
u = pore water pressure at the center of the base of the slice
Δx = length of the bottom of the sliceα = inclination of the bottom of the slice
P = resultant water force acting perpendicular to the top of the slice
B = inclination of the top of the slice
MP = moment about the center of the circle produced by the water force acting on the top of the slice
R = radius of the circle.

Because the value of the term m_α depends on the factor of safety, the factor of safety appears on both sides of Equation. Equation cannot be manipulated such that an explicit expression is obtained for the factor of safety. Thus, an iterative, trial and error procedure is used to solve for the factor of safety [6].

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ISSN 2320-9186

2.4.3 Fellenius method

In this method, the forces on the sides of the slice are neglected. The normal force on the base of the slice is calculated by summing forces in a direction perpendicular to the bottom of the slice. Once the normal force is calculated, moments are summed about the center of the circle to compute the factor of safety. For a slice and the forces shown in Figure below, the factor of safety is computed from the equation [6].

$$F = \frac{\Sigma [\, c' \Delta l + (W\cos\alpha - u \Delta l \cos 2\alpha) \tan\phi]}{\Sigma W \sin\alpha}$$

Where

c' and ϕ' = shear strength parameters for the center of the base of the slice

W = weight of the slice

α = inclination of the bottom of the slice

u = pore water pressure at the center of the base of the slice

Δl = length of the bottom of the slice

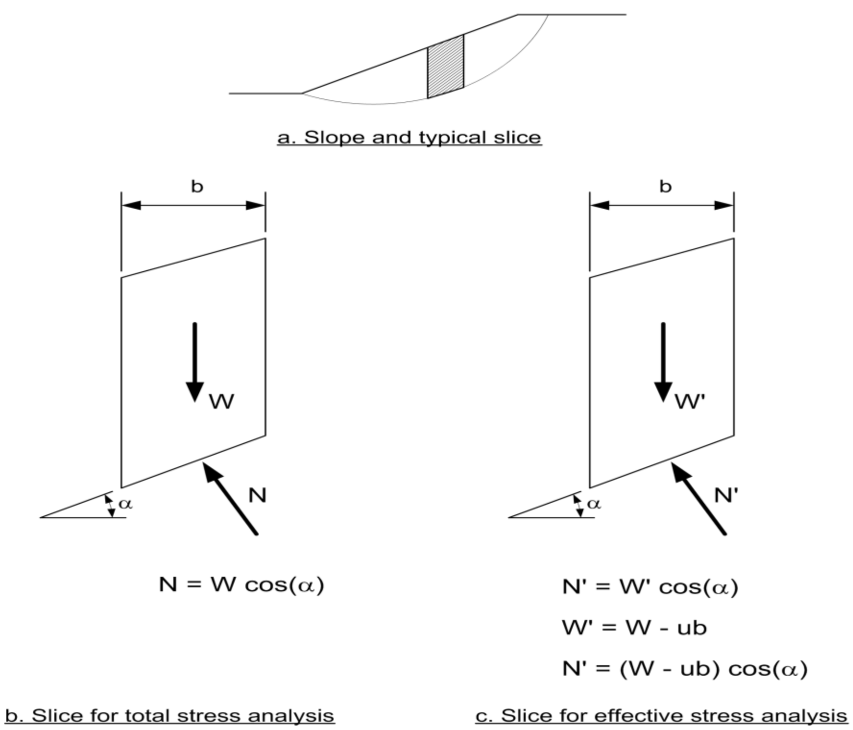

FIG 4: Fellenius Method [6]

3.0 Stability Analysis of Case Study

Table 1: **Summary of Laboratory Test Results**

Test	Location (Km)	c (KN/m^2)	ϕ (degree)	γb (Kg/m^3)
Direct Shear Box	2	15.1	35.9	1815
Direct Shear Box	3	11.0	35.6	1838
Direct Shear Box	4	12.8	34.4	1868

γ= total unit weight of soil KN/m^2; c= effective cohesion KN/m^2; ϕ= effective angle of internal friction in degree; β= angle of slope; H= height of slope; FOS= factor of safety; $\gamma_{b=}$ bulk density of soil in Kg/m^3.

Table 2: Safety Factor Design Significance [8]

Safety Factor	Significance
Less than 1.0	Unsafe
1.0 to 1.2	Questionable safety
1.3 to 1.4	Satisfactory for cuts, fills; questionable for dams
1.5 to 1.75	Safe for dams

3.2 Analysis of Slope Using the Limit equilibrium Methods of Slope Analysis.

3.2.1 Slope on KM 2

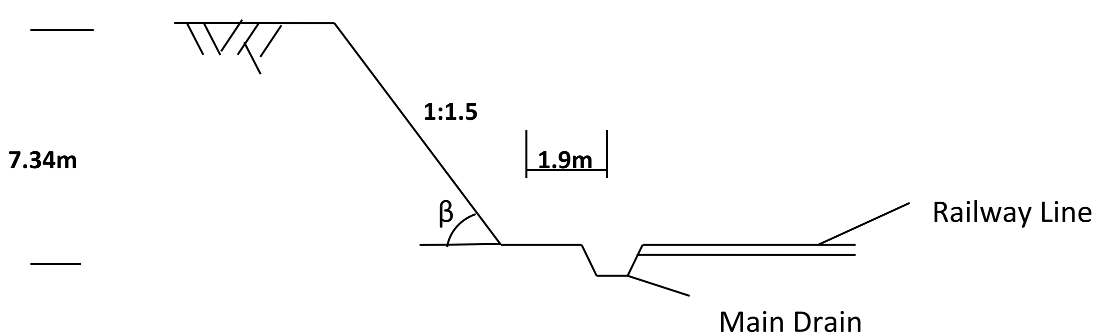

FIG.5: Cross Section of Slope at Kilometre 2

Using the Stability Number Method [12]:

Slope Height, H=7.34m

Slope =1:1.5

Slope angle $\beta = \tan^{-1}(1/1.5) = 34^o$

$c=15.1\ KN/m^2$, $\phi = 35.9^o$

$\gamma = 1815 \times 9.81/1000 = 17.81KN/m^2$

Assume FOS =1.5

FOS $=F_s=F_c$

$\phi_{developed} = \phi/FS = 35.9^o / 1.5 = 23.93$

Thus $[\phi_d, \beta] = [23.93, 34^o]$

From Taylor's chart (FIG. 2b), Stability Number, $N_s = 0.02$

$N_s = C/\gamma HFS$ or $H = C/N_s\gamma FS$

$H = 15.1/ (0.02\times17.81\times1.5)$

$H = 28.26m$

Thus the assumed slope height, 28.6m, is greater than the actual slope height, 7.34m, implying that the actual FOS is higher than 1.5 assumed; hence, a higher value of FOS must be tried[12].

Try FOS = 2.0

FOS $= F_s = F_c$; $\phi_d = 35.9/2.0 = 17.95$

With ϕ_d=17.95 and $\beta = 34^o$, from Taylor's stability chart (FIG. 2b) Stability Number, N_s= 0.045

$H= 15.1/ (0.045\times17.81\times2.0)$

$H = 9.42m$

Because the assumed slope height 9.42m and the actual slope height 7.34m are still not the same, a higher value of FOS must be tried.

Try FOS=2.2

Hence $[\phi_d, \beta] = [16.34, 34^o]$

With ϕ_d=16.34 and $\beta = 34^o$, Stability Number, Ns=0.053

$H= 15.1/ (0.053\times17.81\times2.2)$

H =7.27m; approximately, H= 7.30m.

Thus the computed height 7.30m is approximately close to the actual height of 7.34m.

Therefore the FOS is 2.2.

The slope is safe (see table 2, for safety factor design significance).

3.2.2 Slope at KM 3

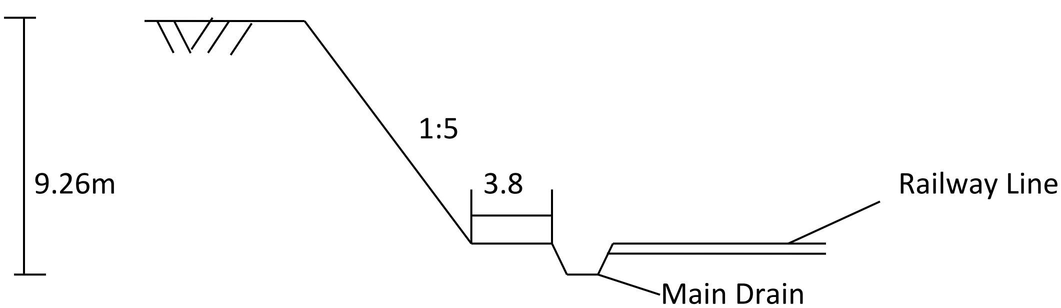

FIG 6: Cross Section of Slope at kilometre 3

Slope height H=9.26m

Slope =1:1.5; $\beta=34^o$

γ= 1838×9.81/1000=18.03KN/m^2

c=11.0 KN/m^2, ϕ= 35.6^o

Try FOS =1.8

$\phi_{developed}$ = ϕ_d= ϕ/FOS = 35.6^o / 1.8 =23.93

Thus [ϕ_d, β] = [19.77, 34^o]

From Taylor's chart (FIG. 2b), Stability Number, N_s = 0.035

N_s = C/γHFS or H = C/$N_s\gamma$FS

H = 11.0/ (0.035×18.03×1.8) = 9.68m

Thus the assumed slope height, 9.68m, is greater than the actual slope height, 9.26m, implying that the actual FOS is higher than 1.8 assumed; hence, a higher value of FOS must be tried [12].

Try FOS=1.85

Thus [ϕ_d, β] = [19.24, 34^o]; from FIG 2b, Stability Number, N_s= 0.038

H= 11.0/ (0.038×18.03×1.85)= 8.68m

Thus the assumed slope height, 8.68m, is less than the actual slope height, 9.26m, implying that the actual FOS is lower than 1.85 assumed; hence, a lower value of FOS must be tried.

Hence, try FOS=1.75

Thus [ϕ_d, β] = [20.34, 34^o]

Stability Number, N_s=0.034

H= 11/ (0.034×18.03×1.75)

H =10.25m

Try FOS=1.82

Thus [ϕ_d, β] = [19.56, 34^o]; Stability Number, N_s=0.035

H= 11/ (0.035×18.03×1.82) =9.58m

The computed H =9.58 is close to the actual slope height of 9.26m; therefore, the factor of safety against failure is 1.82.

The slope is safe (see table 2, for safety factor design significance).

3.2.3 Analysis of slope on KM 4

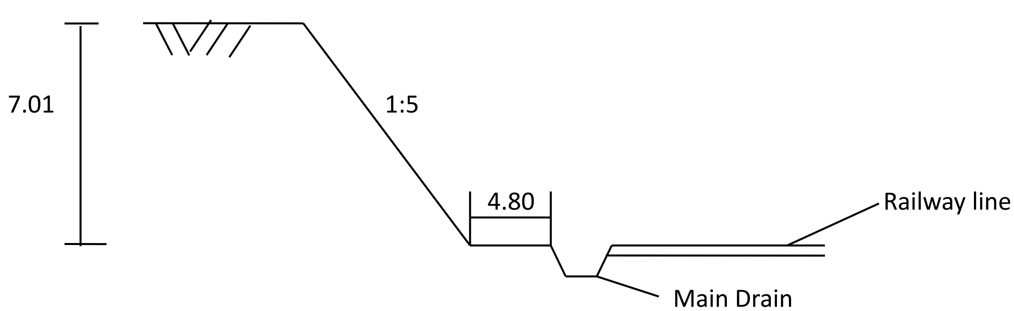

FIG. 7: Cross section of Slope at kilometre 4

Using the Stability Number Method [12]:

Slope height H=7.01m

Slope =1:1.5, β=34^o

γ = 1868×9.81/1000 = 18.33KN/m^2

c=12.8 KN/m^2, ϕ= 34.4^o

Try FOS =2.2

$\phi_{developed}$= ϕ/FS = 34.4^o / 2.2 =15.64

[ϕ_d, β] = [15.64, 34^o]

From Taylor's chart (FIG. 2b), Stability Number, N_s = 0.053

Ns = C/γHFS or H = C/N_sγFS

H = 12.8/ (0.053×18.33×2.2)

H = 5.99m

Thus the assumed slope height, 5.99m, is less than the actual slope height, 7.01m, implying that the actual FOS is lower than 2.2 assumed; hence, a lower value of FOS must be tried.

Try FOS = 2.1

[ϕ_d, β] = [16.38, 34^o]

Stability Number, N_s= 0.052

H= 12.8/ (0.052×18.33×2.1)

H = 6.39m

Because the assumed slope height and the actual slope height are still not the same value, another value of FOS must be tried.

Try FOS=2.07

Thus [ϕ_d, β] = [16.62, 34^o]

Stability Number, N_s=0.048

H= 12.8/ (0.048×18.33×2.07)

H =7.03m

Try FOS=1.95

Thus [ϕ_d, β] = [17.64, 34^o]

Stability Number, N_s=0.045

H= 12.8/ (0.045×18.33×1.95)

H = 7.96m

The computed H = 7.03m is close to the actual slope height of 7.01m; hence, the FOS against failure is 2.07.

The slope is safe (see table 2, for safety factor design significance).

3.0 Spread Sheet Solution

3.1 Table 3: Spread Sheet Solution of Slope at KM 2

Spread Sheet Solution for Slope Stability Analysis
Using Fellenius and Simplified Bishop Methods **long term case** **KM2**
***Height of slope(m)* 7.34** **α=34**

										γ_w=	Fellenius Method			Simplified Bishop Method					
								φ	α	10				F.S. =	2.187	F.S. =	2.256	F.S. =	2.261
Slice	Area	Width	H1	H2	γ	W	c	(deg.)	(deg.)	Hw	cXl	N tanφ	Wsinα	m_a	Numer.	m_a	Numer.	m_a	Numer.
1	tri					0.0													
	rec					0.0													
	tri	1.55	0.00	0.92	18.2	**12.9**	15.1	35.9	5.8	0.00	23.45	9.27	1.30	1.028	31.75	1.027	31.78	1.027	31.78
2	tri					0.0													
	rec					0.0													
	tri	1.55	0.92	1.84	18.2	**38.6**	15.1	35.9	9.5	0.00	23.66	27.56	6.38	1.041	49.26	1.039	49.34	1.039	49.34
3	tri					0.0													
	rec					0.0													
	tri	1.55	1.84	2.39	18.2	**59.2**	15.1	35.9	12.6	0.00	23.91	41.81	12.89	1.048	63.14	1.046	63.27	1.046	63.28
4	tri					0.0													
	rec					0.0													
	tri	1.55	2.39	3.30	18.2	**79.8**	15.1	35.9	15.0	0.00	24.15	55.79	20.59	1.052	77.10	1.049	77.30	1.049	77.31
5	tri					0.0													
	rec					0.0													
	tri	1.55	3.30	4.04	18.2	**102.9**	15.1	35.9	21.1	0.00	25.01	69.52	37.02	1.052	92.99	1.048	93.32	1.048	93.34
6	tri					0.0													
	rec					0.0													
	tri	1.55	4.04	4.40	18.2	**118.4**	15.1	35.9	27.9	0.00	26.40	75.74	55.35	1.039	104.96	1.034	105.44	1.034	105.47
7	tri					0.0													
	rec					0.0													
	tri	1.55	4.40	4.40	18.2	**123.5**	15.1	35.9	34.0	0.00	28.14	74.12	69.07	1.014	111.17	1.008	111.80	1.008	111.84
8	tri					0.0													
	rec					0.0													
	tri	1.55	4.40	2.94	18.2	**102.9**	15.1	35.9	39.1	0.00	30.07	57.82	64.91	0.985	99.35	0.978	100.00	0.978	100.04
9	tri					0.0													
	rec					0.0													
	tri	1.55	2.94	1.84	18.2	**66.9**	15.1	35.9	45.2	0.00	33.13	34.11	47.49	0.939	76.40	0.932	76.99	0.932	77.03
10	tri					0.0													
	rec					0.0													
	tri	1.55	1.84	0.00	18	**25.7**	15.1	35.9	49.0	0.00	35.54	12.23	19.41	0.906	46.30	0.899	46.70	0.898	46.72
											(1)	**(2)**	**(3)**		**(4)**		**(4)**		**(4)**
					Sum	**730.8**					273.45	457.97	334.42		752.43		755.93		756.15
											F.S. = (1)+(2)]/(3)			**F.S. = (4)/(3)**		**F.S. = (4)/(3)**		**F.S. = (4)/(3)**	
											F.S. =	2.187		F.S.=	2.250	F.S.=	2.260	F.S.=	2.261

3.2 Table 4: Spread Sheet Solution of Slope at KM 3

Spread Sheet Solution for Slope Stability Analysis
Using Fellenius and Simplified Bishop Methods **long term case** **KM3**
Height of slope(m) **9.26** **α=34**

										γw=	Fellenius Method			Simplified Bishop Method					
								φ	α	10				F.S. =	1.821	F.S. =	1.888	F.S. =	1.894
Slice	Area	Width	H1	H2	γ	W	c	(deg.)	(deg.)	Hw	cXl	N tanφ	Wsinα	m_a	Numer.	m_a	Numer.	m_a	Numer.
1	tri					0.0													
	rec					0.0													
	tri	1.95	0.00	1.16	18.4	**20.7**	11.0	35.6	5.8	0.00	21.55	14.77	2.09	1.035	35.08	1.033	35.13	1.033	35.13
2	tri					0.0													
	rec					0.0													
	tri	1.95	1.16	2.32	18.4	**62.2**	11.0	35.6	9.5	0.00	21.74	43.93	10.29	1.051	62.77	1.049	62.90	1.049	62.92
3	tri					0.0													
	rec					0.0													
	tri	1.95	2.32	3.01	18.4	**95.4**	11.0	35.6	12.6	0.00	21.97	66.65	20.78	1.062	84.53	1.059	84.77	1.058	84.79
4	tri					0.0													
	rec					0.0													
	tri	1.95	3.01	4.17	18.4	**128.6**	11.0	35.6	15.0	0.00	22.20	88.93	33.19	1.068	106.30	1.064	106.66	1.064	106.70
5	tri					0.0													
	rec					0.0													
	tri	1.95	4.17	5.09	18.4	**165.9**	11.0	35.6	21.1	0.00	22.98	110.82	59.67	1.075	130.49	1.069	131.11	1.069	131.16
6	tri					0.0													
	rec					0.0													
	tri	1.95	5.09	5.56	18.4	**190.8**	11.0	35.6	27.9	0.00	24.26	120.73	89.21	1.068	147.99	1.061	148.91	1.061	148.99
7	tri					0.0													
	rec					0.0													
	tri	1.95	5.56	5.56	18.4	**199.1**	11.0	35.6	34.0	0.00	25.87	118.16	111.32	1.049	156.32	1.041	157.50	1.040	157.60
8	tri					0.0													
	rec					0.0													
	tri	1.95	5.56	3.70	18.4	**165.9**	11.0	35.6	39.1	0.00	27.63	92.17	104.63	1.024	136.92	1.015	138.12	1.014	138.22
9	tri					0.0													
	rec					0.0													
	tri	1.95	3.70	2.32	18.4	**107.8**	11.0	35.6	45.2	0.00	30.44	54.38	76.54	0.984	100.30	0.974	101.33	0.973	101.42
10	tri					0.0													
	rec					0.0													
	tri	1.95	2.32	0.00	18	**41.5**	11.0	35.6	49.0	0.00	32.66	19.50	31.28	0.953	53.65	0.943	54.25	0.942	54.30
											(1)	**(2)**	**(3)**		**(4)**		**(4)**		**(4)**
					Sum	**1177.9**					251.31	730.03	539.00		1014.35		1020.67		1021.23
											F.S. = (1)+(2)]/(3)			**F.S. = (4)/(3)**		**F.S. = (4)/(3)**		**F.S. = (4)/(3)**	
											F.S. = 1.821			F.S.=	1.882	F.S.=	1.894	F.S.=	1.895

3.3 Table 5: Spread Sheet Solution of Slope at KM 4

Spread Sheet Solution for Slope Stability Analysis
Using Fellenius and Simplified Bishop Methods — long term case — KM4
***Height of slope(m)* 7.01** — α=34

										γ_w=	Fellenius Method			Simplified Bishop Method					
								φ	α	10				F.S. =	2.001	F.S. =	2.066	F.S. =	2.070
Slice	Area	Width	H1	H2	γ	W	c	(deg.)	(deg.)	Hw	cXl	N tanφ	Wsinα	m_a	Numer.	m_a	Numer.	m_a	Numer.
1	tri					0.0													
	rec					0.0													
	tri	1.48	0.00	0.88	18.7	**12.1**	12.8	34.4	5.8	0.00	18.99	8.23	1.22	1.029	26.38	1.028	26.41	1.028	26.41
2	tri					0.0													
	rec					0.0													
	tri	1.48	0.88	1.75	18.7	**36.2**	12.8	34.4	9.5	0.00	19.15	24.47	5.99	1.043	41.90	1.041	41.98	1.041	41.98
3	tri					0.0													
	rec					0.0													
	tri	1.48	1.75	2.28	18.7	**55.6**	12.8	34.4	12.6	0.00	19.35	37.13	12.10	1.051	54.19	1.048	54.31	1.048	54.32
4	tri					0.0													
	rec					0.0													
	tri	1.48	2.28	3.15	18.7	**74.9**	12.8	34.4	15.0	0.00	19.55	49.54	19.33	1.054	66.54	1.052	66.72	1.051	66.73
5	tri					0.0													
	rec					0.0													
	tri	1.48	3.15	3.86	18.7	**96.6**	12.8	34.4	21.1	0.00	20.24	61.73	34.75	1.056	80.53	1.052	80.82	1.052	80.84
6	tri					0.0													
	rec					0.0													
	tri	1.48	3.86	4.21	18.7	**111.1**	12.8	34.4	27.9	0.00	21.37	67.25	51.96	1.044	90.97	1.039	91.41	1.039	91.45
7	tri					0.0													
	rec					0.0													
	tri	1.48	4.21	4.21	18.7	**115.9**	12.8	34.4	34.0	0.00	22.79	65.82	64.84	1.020	96.31	1.014	96.89	1.014	96.93
8	tri					0.0													
	rec					0.0													
	tri	1.48	4.21	2.80	18.7	**96.6**	12.8	34.4	39.1	0.00	24.34	51.34	60.94	0.992	85.74	0.985	86.34	0.985	86.38
9	tri					0.0													
	rec					0.0													
	tri	1.48	2.80	1.75	18.7	**62.8**	12.8	34.4	45.2	0.00	26.82	30.29	44.58	0.947	65.33	0.940	65.87	0.939	65.90
10	tri					0.0													
	rec					0.0													
	tri	1.48	1.75	0.00	19	**24.2**	12.8	34.4	49.0	0.00	28.77	10.86	18.22	0.915	38.73	0.907	39.08	0.906	39.10
											(1)	**(2)**	**(3)**		**(4)**		**(4)**		**(4)**
					Sum	**686.0**					221.38	406.66	313.93		646.64		649.83		650.05
											F.S. = (1)+(2)]/(3)			**F.S. = (4)/(3)**		**F.S. = (4)/(3)**		**F.S. = (4)/(3)**	
											F.S. =	2.001		F.S.=	2.060	F.S.=	2.070	F.S.=	2.071

Table 5: Summary of Stability Analysis Result

Slope Location	Spread Sheet Solution for Stability Analysis		Hand Calculation Method	Stability of Slope
	Bishop Simplified Method	**Fellenius Method**	**Stability No. Method**	**Safe/Unsafe**
KM2	2.250	2.187	2.20	Safe slope
KM3	1.882	1.821	1.82	Safe slope
KM 4	2.060	2.001	2.07	Safe slope

3.4 Discussion of Results

Analyses carried out using the various named methods verified that the slopes under consideration are all stable with factors of safety against failure not lower than 1.5. Generally, the Bishop method gives slightly higher factors of safety than those calculated from the Fellenius Method [8].From the spread sheet solutions, the factors of safety obtained using the Simplified Bishop Method were slightly higher than that obtained using the Fellenius Method.

For a stable slope, the slope angle β (angle of inclination) should not exceed the angle of internal friction ϕ; the geometric properties of the slopes satisfy this condition as shown in Table 1[8].

The results of the study showed that the factor of safety of the slope does it increase or decrease with increase in values of cohesion c of the soil.

4.0 Conclusion and Recommendation

The limit equilibrium (LE) methods were used in this study to analyse the stability of existing cut slopes of the Abuja Rail Mass Transit project at the Central Business District, Abuja, Nigeria. The analyses were carried out using the Stability Number Method and verified using a spread sheet solution that applies the Fellenius and Simplified Bishop Methods of slices. Analyses carried out using the various named methods confirm that the slopes under consideration are all stable with factors of safety against failure not lower than 1.5.

However, Conditions of a slope can be easily deteriorated within a certain period of time; to ensure continuous stability of slopes, the following safety measures are recommended:

1. Surface drains and sub-surface drains should be provided to drain water from the surface of the slopes and to maintain the ground water at a safe level.
2. Slopes may be protected by a rigid surface using sprayed concretes or by stone pitching to reduce rainwater infiltration and to prevent slope surface erosion.
3. The surface of slopes can also be protected by planting of vegetation, either grasses or trees. The type used is very much dependant on the angle of inclination of the slope (β). For slopes less than 35^{o}, hydro seeding and pit planting of tress are recommended [13].
4. A cantilevered retaining wall may be designed and constructed at the toe of the slope on a deep pile foundation, to resist the active pressure of soil and the hydrostatic pressure that will develop behind the slope. A filter material should be provided behind the retaining wall for easy flow of water and wipe holes should also be provided on the walls to act as spillway. This removes excess ground water into the main drain at the toe.
5. Counter weights should be provided at the toe to provide passive pressure, resisting force, to prevent movement.
6. The shear strength in a cutting diminishes with time and so does the factor of safety [9]; thus periodic inspection and maintenance should be carried out. This will help detect early movement of the slopes.

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