Model for prediction of potential instability of riverbanks in the Niger Delta

Modèle de prédiction de l'instabilité potentielle des rives du delta du Niger

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ABSTRACT: The effect of hydraulic forces on the stability of river banks, particularly the impact of water level fluctuations, has been investigated in the Meander section of the Nun River in the Niger Delta Region of Nigeria. A model for predicting the potential instability was developed by modifying the infinite slope method of analysis to incorporate the effects of water level fluctuation on the geotechnical and hydrographical parameters of the case-study site. Justification for the model was partly based on the prevailing site condition which revealed that the soils underlying the riverbanks here are largely cohesionless. Furthermore, stability charts were generated using site-specific parameters with values in ranges typical of the Region. These stability charts can be used for the prediction of riverbank instability potential of the study area as well as elsewhere in the world with similar site conditions. An expression relating the Factor of Safety as the measure of stability and water level fluctuation for the study area was subsequently developed.

RÉSUMÉ: L'effet des forces hydrauliques sur la stabilité des berges, en particulier l'impact des fluctuations du niveau d'eau, a été étudié dans le méandre de la rivière Nun dans la région du Delta du Niger au Nigeria. Un modèle pour prédire l'instabilité potentielle a été développé en modifiant la méthode d'analyse de la pente infinie pour incorporer les effets de fluctuations du niveau de l'eau sur les paramètres géotechniques et hydrographiques de l'étude de cas sur site. Justification pour le modèle a été fondée en partie sur l'état du lieu qui a révélé que les sols sous-jacents aux berges des rivières ici sont en grande partie des. En outre, la stabilité des graphiques ont été générés en utilisant les paramètres spécifiques à un site avec des valeurs dans les gammes typiques de la région. Ces diagrammes de stabilité peut être utilisé pour la prévision de l'instabilité des berges de l'aire d'étude potentiels ainsi qu'ailleurs dans le monde avec des conditions du site. Une expression concernant le facteur de sécurité comme la mesure de la stabilité et les fluctuations du niveau d'eau pour la zone d'étude a été élaboré par la suite.

KEYWORDS: Measure of stability, instability potential; prediction Model; Riverbank; Infinite Slope; Niger Delta

1 INTRODUCTION.

Riverbanks refer to the sloping land alongside the body of a River. They are known to be prone to instability but the degree of occurrence varies from one location to another. The extent of instability depends on the severity of the forces induced by the causative mechanisms such as slope geometry, stress states, geotechnical parameters, hydraulic and hydrological conditions or human activities such as irrigation, hydro power construction, dredging, etc. In the Niger Delta as a whole and at the meander section of Nun River in particular, most oil and gas exploration and other related activities take place near-shore and onshore and most communities have their dwellings, farm lands and commercial activities along the coast line. When failures of Riverbanks occur the cost is usually economically enormous and the effect very grave. The Riverbanks are significantly impacted with associated consequences of loss of land, damage to agriculture, creation of flood plains, distress to adjacent structures and displacement of coastal communities and towns. The primary focus of this work is the development of appropriate predictive model and charts that could be used in identifying potentially unstable riverbanks in the study area as delineated below. In the process, geotechnical parameters that influence the stability of riverbanks as well as the effect of water level fluctuation are considered.

1 .1 *Study Area*

The case study area for this research work is the Nun River meander Belt Region located in the Niger Delta, Southern Nigeria. The Nun River is a distributary of the River Niger and is one of the major Rivers in the Niger Delta area. This work is limited to a section of the River specifically situated at Gbaran Ubie district, North of Yenagoa, Bayelsa State Nigeria.

The site consists of typical mangrove swamp vegetation with network of rivers and creeks. The subsoil comprises of various thicknesses of coastal plain sands and marine clay. Figure 1 shows the map of the Niger Delta region.

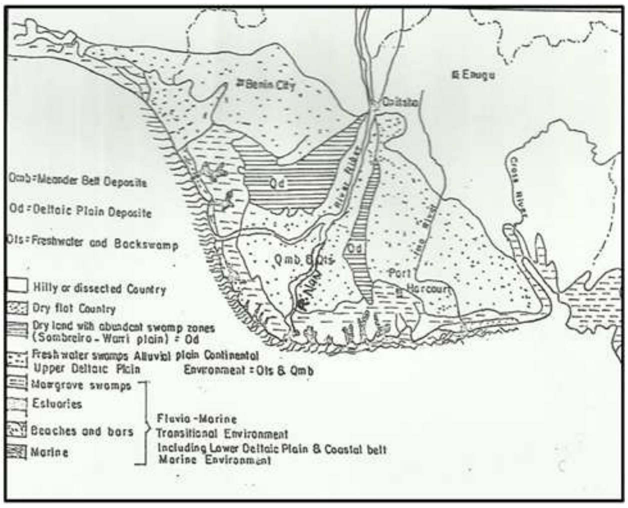

Figure 1: Map showing the Meander sections of the Niger Delta

2 THEORITICAL MODEL

The approach used in the study is the infinite slope method of analysis. This method was chosen due to the geometry and material properties of the Riverbank. Referring to Figure 2, the factor of safety (stability index) for the infinite slope is the ratio of the shear strength force to the shear force.

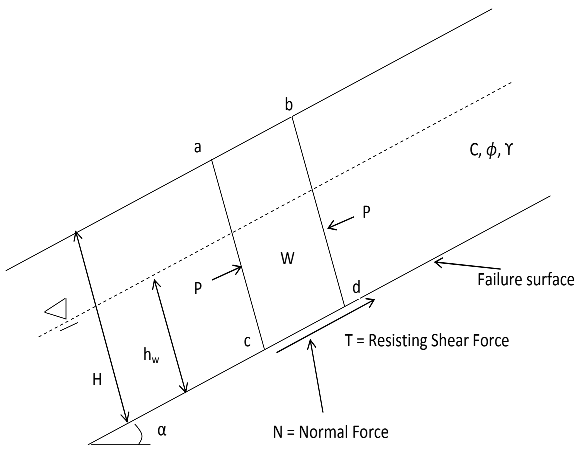

Figure 2: Geometry for infinite slope analyses

Using the notations given in the figure, the expression for the safety index can be obtained by considering the equilibrium of normal forces on the slope.
Hence, neglecting cohesion and the inter-slice forces gives the safety index as:

$$F = \frac{(\gamma H - h_w \gamma_w)\cos^2\alpha \tan \emptyset'}{\gamma H \sin\alpha \cos\alpha} \quad (1)$$

Where:
h_w = the water table height above slip surface
γ_w = Unit weight of water
Υ = Unit weight of soil
H = The slope height
α = Inclination angle
$\emptyset$ = Friction angle

The above expression for safety factor was modified to include effect of water level fluctuations by dividing the numerator and denominator by H and expanding it to give the following expression:

$$F = \frac{[\gamma - (\frac{h_w}{H} \cdot \gamma_w)]\ \cos^2\alpha \tan \emptyset'}{\gamma \sin\alpha \cos\alpha} \quad (2)$$

In this equation, the dimensionless ratio, h_w/H, represents different stages of groundwater fluctuation. The basic assumptions are that: (1) Groundwater flows parallel to the slope surface. (2) The River water level is coincident with the groundwater level. (3) The slip surface is parallel to the slope surface.

2.1 *Site Riverbank Model*

The maximum elevation at the crest of the slope is measured at +8.4m while the elevation at the toe of the Riverbank is measured as -4.23m. The slope angle measured 27° to the horizontal. The geometry of the Riverbank that includes the low and high River water level is given in Figure 3 while the graphical representation of the monthly variation of River water elevations is given in Figure 4.

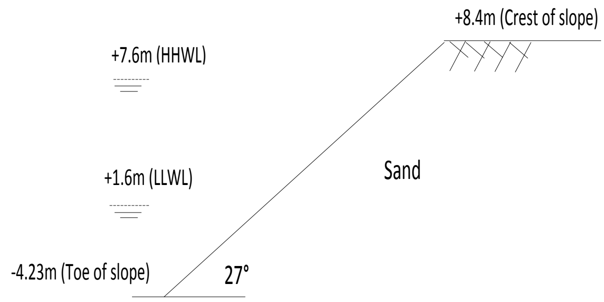

Figure 3: Geometry of the Riverbank

The Riverbank materials are cohesionless soils and for the purpose of the analysis, the critical geotechnical parameters that were obtained are densities and friction ratios. Summary of the geotechnical parameters are given in Table 1.

Table 1. Range of geotechnical parameters

Parameter		
Friction angle Ø (°)	16.0	26.0
Unit Weight □ (kN/m^3)	19.7	20.01

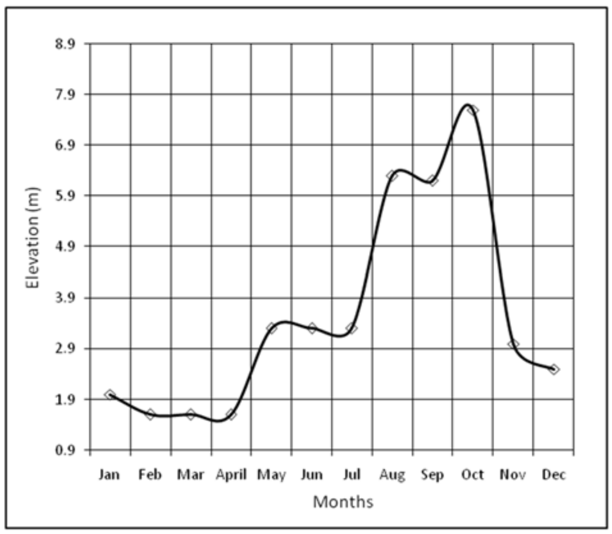

Figure 4: Monthly Variation of River water elevations

3 DISCUSSION OF RESULTS

3.1 Assessment *of Riverbank Stability*

For the study area, the influence of water level fluctuations on the Riverbank was performed by varying the water levels and keeping all other geotechnical and geometric parameters constant (α = 27°, Ø = 25°, □ = 19.7kN/m^3). With this, the relationship between FoS and water level fluctuation for the study area can be mathematically expressed as follows:

$$\mathrm{FoS} = -0.41\frac{h_w}{H} + 0.81 \ ;\mathrm{R}^2 = 0.99 \quad (3)$$

Figure 5 shows the relationship between the measure of safety represented by FoS and the water level fluctuation. An increase in water level creates a linear decrease in the measure of safety of the Riverbank.

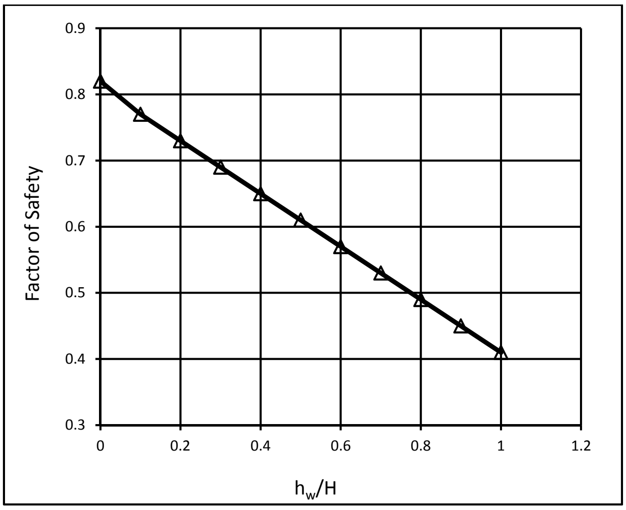

Figure 5: Variation of FoS against water level fluctuation

The prediction for potential instability gave factor of safety that is generally less than 1.0, signifying that the Riverbank is in an unstable condition. Relating to Figure 4, the most critical period is expected within the months of September and October when the river water level rises to full saturation of the riverbanks.

For the purpose of devising a workable solution for the Riverbank instability condition, an adjustment to the inclination angle was made. Using the same geotechnical condition and height of slope but reducing the inclination angle to 13° will yield a factor of safety that is greater than 1.0. This implies that the higher the slope angle for a cohessionless Riverbank, the more prone it is to failure.

3.2 *Development of Stability Charts*

To develop the stability charts (presented in Figure 6 through Figure 8) that can be applied for Riverbank safety prediction, geotechnical parameters (friction ratio, ø and the unit weight of the soil, γ), geometric parameters (inclination angle α, and the height of the Riverbank) and the hydrographic property which include the water level hw were combined together. Different values of water levels hw/H that were considered include: 0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0. The value of h_w/H = 0 represent the case when the riverbank is in a completely dry condition. h_w/H = 1.0 connotes the case of saturation. The other values represent different stages of water level in the Riverbank. The various values parameters considered in the development of the stability charts represent typical ranges of both geotechnical, geometric and hydrographic property that can be expected in the study location and in the Niger Delta region as well as elsewhere in the world with similar conditions. From the charts it can be found that Factor of safety reduces in a linear trend with decrease in friction ratio as hw/H increases.

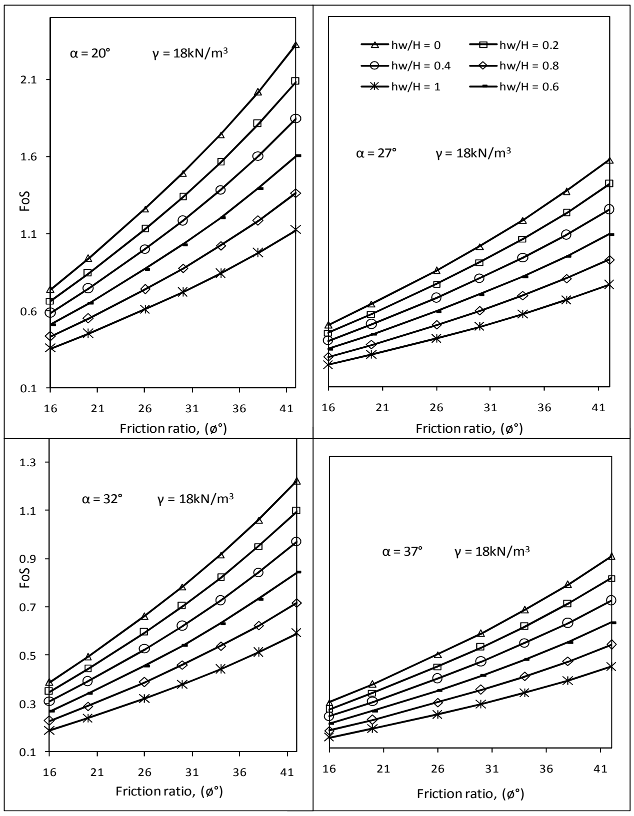

Figure 6: Stability chart for unit weight of 18kN/m^3 and for various friction angle and inclination angle

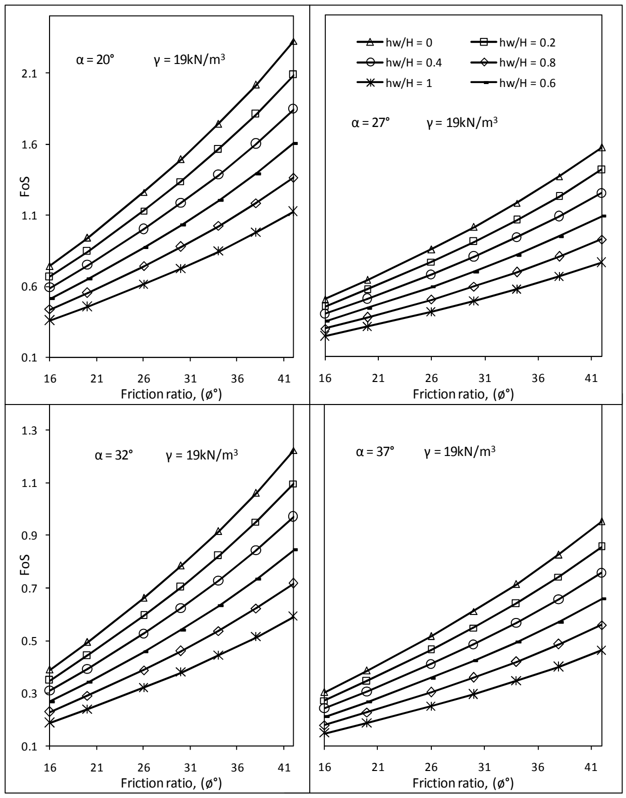

Figure 7: Stability chart for unit weight of 19kN/m^3 and for various friction angle and inclination angle

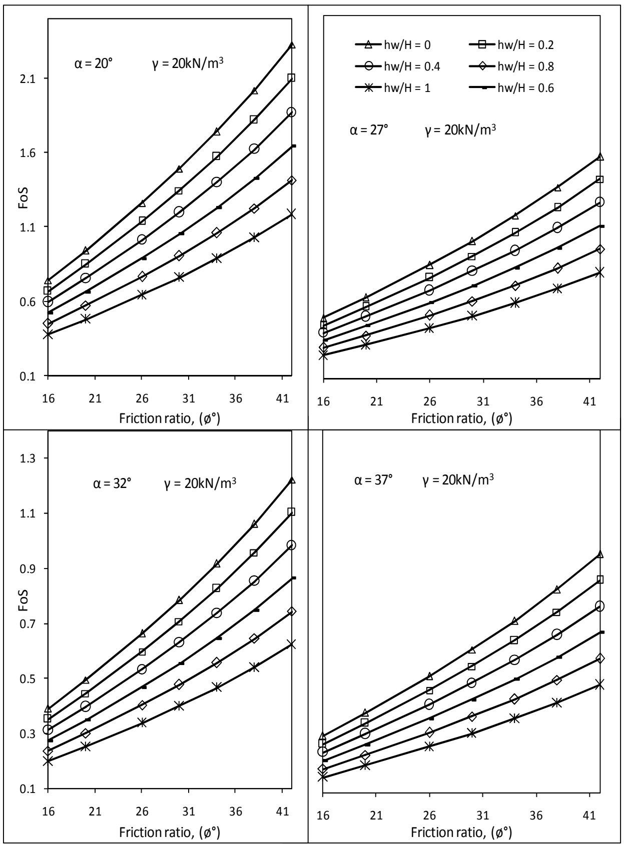

Figure 8: Stability chart for unit weight of 20kN/m^3 and for various friction angle and inclination angle

4 CONCLUSION

This study highlights the influence of water level fluctuations and other geotechnical parameters on the instability potentials of Riverbanks. The measure of stability of the riverbanks was verified in terms factor of safety. Data used for the analysis and the development of the stability charts are both site specific and typical ranges of values that may occur in other locations in Niger Delta Region and elsewhere with similar settings. The findings of the study will greatly complement previous research efforts on Riverbanks in the Niger Delta Region particularly for areas with cohessionless soil formation. From the results of the study, the following conclusions are made.

- The higher the values of friction ratios of the Riverbanks, the less prone they are to instability.
- Factor of safety reduces as the water level in the Riverbank increases.
- The higher the inclination angle for a cohesionless Riverbank, the more prone it is to failure.
- The charts can be applicable in predicting the instability potentials of Riverbank at other areas within and outside the Niger Delta region where similar geotechnical and hydrographical setting exist.

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