Kochi Chapter

Indian Geotechnical Conference
IGC 2022
15th – 17th December, 2022, Kochi

Rehabilitation of a Distressed Vertical Cut in Lateritic Soil

Unnikrishnan N[1]

[1] College of Engineering Trivandrum 695 024 India

Abstract. A vertical cut of 31 m height made in lateritic soil developed distress and failed in a region having heavy rainfall extending for over six months. The delayed failure happened almost after thirty years of creating the cut slope. Cracks developed in the remaining portions threatening the constructed buildings. Based on the field reconnaissance and geotechnical investigation, various options for rehabilitation were considered and the reconstruction of the slope with a steeper slope and soil reinforcement was chosen. The fascia of the reinforced soil slope was chosen so as to ensure the growth of vegetation and thus reduce the carbon footprint. The design and construction sequence of the system is discussed herein. Continuing rains and the resulting localized failures hampered the progress of the construction and interim stabilizing measures had to be adopted to prevent the smaller ongoing failures.

Keywords: Laterite, Delayed Failure, Rehabilitation, Reinforced Soil.

1 Introduction

Laterite is a common soil formation found in hot and wet tropical regions and is mostly confined to shallow depths. Laterite is rich in iron and aluminum and is formed by intense weathering of the underlying parent rock. The decomposition of parent rocks is mostly through the action of high precipitation and high temperatures. The percolating rainwater dissolves the primary rock minerals and easily decreases soluble elements such as sodium, potassium, calcium, magnesium, and silicon. This leads to residual concentration of more insoluble elements; viz. iron and aluminum. Laterites and lateritic soils consist mainly of the minerals such as kaolinite, goethite, hematite, and gibbsite which are formed in the course of the weathering process. Quartz is a stable mineral contained in laterite which is formed from the parent rock. The reddish brown colour of laterite is attributed to the presence of iron oxides, goethite, and hematite. Generally, the laterite cover extends to shallow depths only. The stiff natural structure of the laterites allows very steep or vertical cuts in certain formations. This has helped in creating near vertical slopes for rail and roadway cuts. The paper discusses the failure of one such vertical cut that happened at Kazhakkoottam in Thiruvananthapuram and the attempts made to repair and rehabilitate the same.

2 Delayed Failure in Laterite Cuts

Several failures have been reported in the geometrically modified slopes in laterite. The interesting feature noticed in all the laterite slope failures is that the failures have taken place after the satisfactory performance for several years. Due to the satisfactory performance for years before giving away, such failures have been named delayed failures (Hencher, 1984). A number of 'delayed' failures in saprolitic slopes in Hong Kong, which occurred a few days after heavy rainfall, were attributed to the gradual localized build-up of water pressures behind impermeable decomposed basic dykes (Hudson and Hencher, 1984: Franks et al., 1996). Junk Bay Road landslide in saprolite along Junk Bay Road in 1982 (Hencher and Martin, 1984; Hencher et al., 1984, Brand, 1984, Brand, 1985), The Fei Tsui Road landslide in 1996 after 20 years, Puen Shan Tsuen (Tuen Mun Road) landslides in 1983 after 7 years of construction. The cut slope at Tin Wan Hill Road in 1983 after 20 years (Irfan, 1998) is one example.

Several delayed failures have been reported in laterite cuts made for road and railway from Kerala. A series of major slides, in the lateritic cuts of the railway line, occurred in South Kerala during 1998-99 (Ayyar and Nair, 2000). These failures took place 25 years since the cuts were made and several seasonal rainfalls had occurred. The failure zones occurred in the vicinity of impounded water bodies and intensively irrigated areas with penetrating root systems.

3 Hydrology and Slope Failures

In tropical residual soils, most failures are caused by rainfall (Huat et al., 2005). During rainfall, water infiltration results in an increase in the pore water pressure leading to reduced shear strength. This is one of the reasons for the slope failure. The frequency and magnitude of rainfall events, combined with other parameters such as lithology, morphology, and overburden thickness influence the type and nature of slope failure.

Suction existing in the tropical soils due to deep-seated water table may enhance the stability of the slope during a dry spell. The soil suction will tend to increase the shear strength and may impart additional stability to a cut. With the infiltration of rainfall, such suctions are reduced or even removed and can lead to the development of positive pressures. As a result, there is a decrease in the soil shear strength and in the overall mass stability of the slope. Several researchers have studied the effect of infiltration in the slope stability analysis of the residual soils (Affendi and Ali, 1994, Suhaimi, 1997, Ali and Rahardjo, 2004). However, these analyses are based on simplifying assumptions of a constant rate of infiltration and the homogeneous nature of the soil.

Erosional soil pipes are a common feature in lateritic cuts. The pipes, generally behaving as subsoil drains operating under head and blockage, either by collapse or by construction activity, may result in rapid pore water pressure buildup in the slope. Such pipes cause loss of cementation in lateritic soils. The presence of pipes on slopes means that the real groundwater flow pattern may well be different from those postulated using Darcy's law.

Pipes and other surface erosion features in jointed lateritic soils are often controlled by relict joints. Severe internal erosion was observed in a number of lateritic soil slopes in Hong Kong following the removal of the protective older colluvium or residual soil cover during slope formation. The pipes can also form along joints in less weathered rock. The pipes have been implicated in a number of slope failures in Hong Kong (Hencher et al., 1984; Nash and Chang, 1987). Such pipes may be formed as a result of slope movements which caused the opening up of weathered joints. In a modified slope, the brittle separation of blocks along the weathered joints may accelerate the formation of such joints. A detailed review of the various processes involved in erosion-related slope failure and the remedial practices have been given by Kazmi et al. (2017).

4 Stability of Cuts and Natural Slopes

The cutting for road or railway in laterite is usually steep (sometimes even near vertical) and this is an advantage in the land acquisition cost. The stability of laterite slopes differs from that of other soils due to two reasons. The horizontal stresses existing in the top in laterite and the resisting shear strength are significantly higher and there is a steep decrease of both as the depth increases. This characteristic determines the failure surface. Secondly, the strength of laterite increases with time and therefore there is a difference between short-term failure and long-term failure in laterites. It is generally felt that once the initial stability is assured, the factor of safety against failure in the long run increases in laterites. However, the phenomenon of delayed failure is due to different factors.

Short-term failure happens due to stress relief at the bottom when the original lateral restraining stress of the adjoining soil is removed due to a cut. On account of this de-stressing, the tensile strength of the dispersive kaolinite or bauxite present at the bottom will be insufficient to prevent fracture. This may also be aggravated by the erosion caused by any slight groundwater seepage. This may progress and leave the top unsupported till the overhang breaks and shears off. With the passage of time, the tensile strength of the laterite at the top increases, and the safety should ideally increase, which may not happen due to the continuing degradation resulting from erosion.

In contrast to the end of construction instability, the problem of long-term stability has to be considered in view of the experiences of such failures in laterite. The loss of cohesion with time or deterioration of laterite can be considered to be the main cause of such failures. Heavy seepage of water during monsoon through cracked laterite may reduce the cohesion of the softer laterite at the bottom. Further to this, the length of the flow of groundwater is substantially reduced due to the slope geometry modification, while the head-causing flow is largely the same. This affects the flow regime and increases the seepage velocity. The erosive force of the increased seepage velocity gradually removes the cementing agents within the soil and leads to delayed failure (Mahesh Sankar, 2007, Mahesh Sankar and Unnikrishnan 2007, Mahesh Sankar et al. 2008).

5 Failure of the Vertical Cut Slope

Several vertical cuts were made in a major industrial area in the Southern part of the Indian peninsula as a part of landscaping and construction facilitation. The terrain is steeply sloping. An elevation difference of about 55 m exists between the lowest part and the highest part of the industrial park. Several tall buildings occupy the area including certain buildings of national importance. The subsoil typically comprises of lateritic formations with hardened crust at the top. The area receives heavy rainfall during the monsoon season which extends for almost six months every year.

Figure 1 shows the location of the failure. The main road that provides access to all facilities passes close to this vertical cut. During a rainy season, the portion of a vertical cut of almost 31m in height and length of 100m caved in. A three-dimensional scoop-like earth mass movement was noticed. Curved racks were developed in the road indicating the plastic separation of another potentially failing soil mass. A tall building was located at a close distance on the other boundary (elevated) of the road. The building was reportedly on isolated column footings. On the lower side of the vertical cut, the surface soil appeared to be marshy due to the heavy seepage. A narrow stream was seen originating in this region. Elevated land is noticed on the left bank of the stream. The vertical cut is on the right bank. Such cuts were largely unprotected and remained stable for a few decades. However, laterite formations are known for delayed failure due to the change in drainage pattern resulting from the modification of geometry. Failure of vertical cut that is being dealt with herein is a typical case of delayed failure in lateritic cuts.

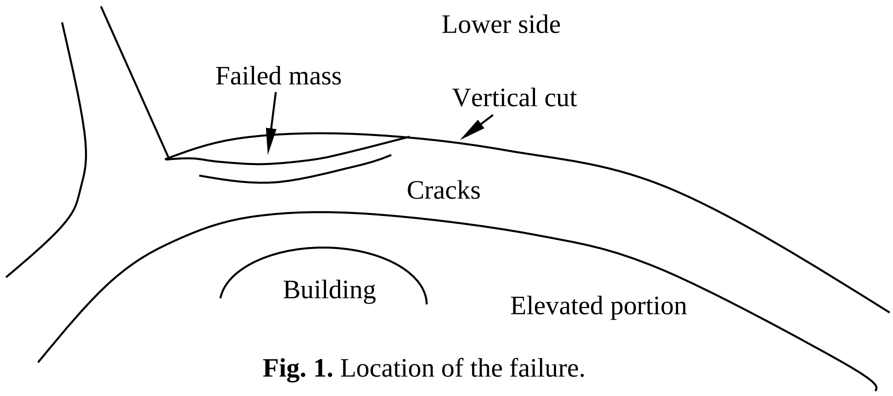

Fig. 1. Location of the failure.

6 Subsoil Conditions

A geotechnical investigation was performed. Three boreholes were taken at the site. One borehole (BH1) was taken on the road in the elevated portion, beyond the cracks. Two boreholes (BH2 and BH3) were taken at the lower elevation at the foot of the vertical cut, just in front of the failed soil mass. Contrary to the indication provided by the slushy nature of the surface soil at the foot of the vertical cut, the subsoil conditions indicated the presence of weathered rock within shallow depths. In borehole BH2, penetration resistance values (N values) above 100 were obtained from 1.5m depth onwards. A similar condition was met in the borehole BH3 also. In the borehole BH1, soft rock/medium hard rock / hard rock were obtained within the depth of 32.3m depth and extended up to 37.3m. In borehole BH2, the soft rock stratum started at 5.3m and extended up to 11.3m depth. Hard rock was encountered below this layer up to 14m depth. In borehole BH3, the soft rock stratum started at 2.9m and extended up to 12.9m depth. Hard rock was obtained from this depth onwards up to s explored. The thickness of the soft rock stratum varied among the boreholes. Poor to very poor Rock Quality Designation (RQD) values were obtained in the rock stratum (IS:11315-P11-1985). Compressive strength varying between 180 kg/cm2 to 299 kg/cm2 was obtained in the rock cores. It may be noted that rock cores of adequate size could not be obtained from some of the boreholes.

It was suggested to remove the soft surface soil at the lower elevations completely to expose the stratum having penetration resistance value above 100. The provision of a suitable geosynthetic or geocell layer on the surface was advised to be considered to account for any possible relative movement of weak joints in the weathered rock material. However, this was not required for the short term stability of the rehabilitated slope.

7 Rehabilitation Proposal

Urgent rectification of the distress was necessary considering the importance of the main road which was closed. The presence of tall buildings close to the progressing landslide is also a major concern. Considerable land width is available under the hold on the lower side. This allows space for the construction of a reinforced soil slope. It is preferable to use a fascia system that promotes the growth of vegetation. In the proposal herein, a system of galvanized double twisted steel wire meshes together with non-woven coir geotextile (IS 16014: 2018, and MoRT&H 3100) was suggested. Figure 2 shows the fascia system adopted. The minimum quantity of galvanization shall be 260 g/m2 and polymer shall be 0.4mm as per IS 16014: 2018, Table No. 8 and Table No. 5. Specification of coir geotextile was suggested to be confirmed with MORT&H 700, Clause No. 707. This system is expected to provide the initial stiffness needed and will encourage the growth of vegetation. High-strength polyester flexible geogrid comprising composite geosynthetics strips was suggested as the reinforcement. A suitable drainage system using a drainage composite was also suggested. A high-performance-Flexible Growth Medium (HP-FGM) as per IRC 56 was included in the fascia for facilitating quick growth of the vegetation. 100% recycled natural fibers, and or naturally derived cross-linked biopolymers and water absorbents. The HP-FGM shall be free from plastic netting which upon application should form an intimate bond with the soil surface to create a continuous, porous, absorbent, and flexible erosion-resistant blanket that allows for rapid germination and accelerated plant growth.

DT Mesh

Erosion control
Blanket

Welded Mesh

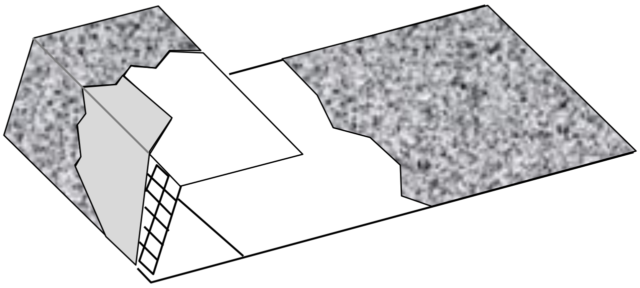

Fig. 2. Fascia system.

All materials used in such a reinforced soil slope will thus be re-useable in the event of a requirement. Multi-tiered construction is considered from the stability point of view, maintenance and aesthetics. A schematic diagram is shown in Figure 3. Un-failed portions of the similar vertical cuts shall be supported through soil nailing.

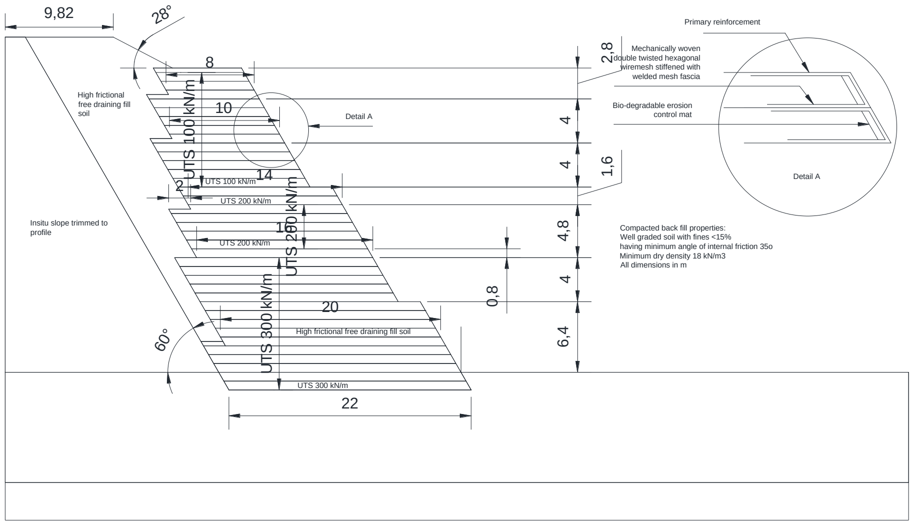

Fig. 3. Schematic diagram of the proposed reinforced soil slope.

8 Numerical simulation and Stability Analysis

The slope was analysed with the maximum permitted spacing as per various standards. Figure 3 gives the dimensions chosen for the analysis. Two-dimensional non-linear finite element analysis was conducted for the proposed dimensional scheme. The material properties given in Tables 1 and 2 were taken. Figure 4 shows the finite element mesh. The excavation and stage-wise construction sequence were simulated.

Table 1. Soil in the in-situ existing slope (soil investigation data not available)

Description	Values		
Location	In-situ slope	Foundation soil	Structural fill
Material type	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb
γ_{unsat}	18 kN/m^3	17 kN/m^3	18 kN/m^3
γ_{sat}	20 kN/m^3	20 kN/m^3	20 kN/m^3
e_{init}	0.5	0.7	0.5
E	60000kPa	60000kPa	30000kPa
ν	0.3	0.3	0.3
c	300 kPa	20 kPa	5 kPa
ϕ	40^o	38^o	35^o
kx=ky	0.008 m/day	0.008 m/day	0.02 m/day

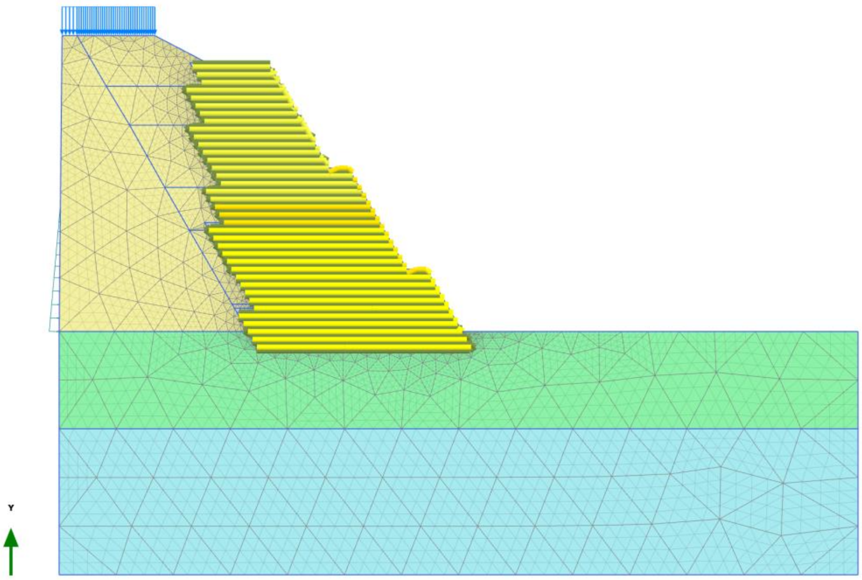

Fig. 4. Finite element mesh.

Table 2. Primary geosynthetic reinforcement

Properties	Mean Values (Minimum)	Tolerance (Maximum)	Test Method
Tensile Strength (MD)	100, 200 and 300 kN/m	±10 kN/m	IS 16635 / EN ISO 10319
Elongation at maximum load (MD)	10%	±3%	IS 16635 / EN ISO 10319

9 Closure

Delayed failure that happened in a vertical cut in laterite has been presented. The vertical cut remained stable for more than three decades and then gave away. Quick after-failure slides kept happening in continuity indicating considerable erosion of the original strength. Quick repair and rehabilitation were necessary to be adopted. Considering the geographical features and the need for fast completion, a steep-sloped reinforced soil wall was chosen as the solution. A green fascia comprising of a stiff double twisted hexagonal polymer coated galvanized wire supported by welded mesh and biomedium was adopted. The construction was hampered by rains even during summer. The after-slides prompted temporary intervention in the form of nailing and shotcreting the fascia. The construction is progressing well.

References

1. Affendi, A., Ali, F.H.: Field measurement of soil suction. Proceedings 13th International Conference on Soil Mechanic and Foundation Engineering. Pp. 1013-1016. New Delhi. (1994)
2. Ali, F.H., H. Rahardjo: Unsaturated residual soil. Chapter 4 In, Huat et al. (eds) TROPICAL RESIDUAL SOILS ENGINEERING, pp. 57-72. Leiden. Balkema, (2004)
3. Ayyar T.S.R, Nair T.K.G.: long Term Stability of Cuts in Lateritic Terrain. Indian Geotechnical Conference, Mumbai.(2000).
4. Brand, E.W.: Landslides in Hong Kong. In: S.E. Asian Geotech. Conf. Proceedings. Vol. 2. Kuala Lumpur. (1985).
5. Brand, E.W.: Landslide in Southeast Asia. In: Proceedings of 4th International Conference on Landslide Proceedings. State of the Art Report. Toronto, 1: 17- 59. 1984
6. Franks, C.A.M., Pun W.K., Yeo, K.C.: Landslip investigation of a failed cut slope with complex geology". In: 7th International Symposium on Landslides Proceedings. Pp 733-738. Trondheim. (1996).
7. Hencher, S.R. Martin, R.P.: The failure of a cut slope on the Tuen Mun Road in Hong Kong. In: Int. Conf. Case Histories in Geotechnical. Engg. Proceedings. St. Louis, Missouri. (1984)
8. Hencher. S.R. Massey. J.B. Brand. E.W.: Application of back analysis to Hong Kong landslides. In: 4th International Symposium on Landslides Proceedings. pp 631-638. Toronto. (1984).
9. Hudson, R.R. Hencher, S.R.: The delayed failure of a large cutting in Hong Kong. In: International Conference on Case Histories in Geotechnical Engineering Proceedings. pp 679-82. St Louis, MO (1984).
10. Huat, B.B.K., Ali, F.H., Low, T.H.: Water infiltration characteristics of unsaturated soil slope and its effect on suction and stability. *Geotech Geol Eng* **24**, pp 1293–1306 (2006).
11. Irfan, T.: Structurally controlled landslides in saprolitic soils in Hong Kong. Geotechnical and Geological Engineering 16, 215–238 (1998).
12. IRC 56: Recommended practice for treatment of embankment and roadside slopes for erosion control. Indian Road Congress, New Delhi (2011)
13. IS 11315-Part 11: Method for the quantitative descriptions of discontinuities in rock masses - Core recovery and rock quality, Bureau of Indian Standards, New Delhi (1985).
14. IS 16014: Mechanically woven, double-twisted, hexagonal wire mesh gabions, revet mattresses, rock fall netting and other products for civil engineering purposes (galvanized steel wire or galvanized steel wire with polymer coating) — specification, Bureau of Indian Standards, New Delhi (2018).
15. Kazmi, D., Qasim, S. Harahap, I. Baharom, S. Mehmood, M. Irfan, F. Imran, M.: Slope Remediation Techniques and Overview of Landslide Risk Management. Civil Engineering Journal. 3. 18 (2017).
16. Mahesh Sankar, C.P.: Investigating Delayed Slope Failures in Lateritic Cuts. Graduate Thesis, Kerala University. (2007)

17. Mahesh Shankar, C. P. Unnikrishnan, N.: Investigating Delayed Slope Failures in Lateritic Cuts. In. 8th National Conference on Technological Trends, Trivandrum. (2007).
18. Mahesh Shankar, C. P., Unnikrishnan, N. and A.S. Johnson: Investigating Delayed Slope Failures in Lateritic Cuts, In: Indian Geotechnical Conference Proceedings. pp 166-170. Bangalore. (2008).
19. Nash, J.M., Chang, D.C.H.: A proposed erosion model for cut slopes in Hong Kong. In Proceedings of the Eighth Asian Regional Conference on Soil Mechanics and Foundation Engineering. pp. 477-82. Kyoto. (1987).
20. Specifications for Road and Bridge Works: Ministry of Road Transport and Highways MoRTH, 2013.
21. Suhaimi, A.T.: Comparative study of infiltration in residual soils. In 4th Regional Conference in Geotechnical Engineering, Geotropika 97 Proceedings. pp. 343–354. Malaysia. (1997)