Discussion on the Analysis, Prevention and Mitigation Measures of Slope Instability Problems: A case of Ethiopian Railways

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ABSTRACT

Ethiopia is striving to build modern railway infrastructures and services to meet its endeavor in building a globally competitive economy, which uses electricity and connects the country's development centers and links with ports of neighboring countries. However, the planned railway routes in Ethiopia pass through the hilly and mountainous terrains of the highlands of Ethiopia. The hilly terrains of the highlands of Ethiopia remain highly fragile environments in terms of slope stability whereby any external factors such as heavy rainfall and/or excavations could trigger landslides [2].

In Ethiopia large infrastructure works (including railways) already lie or will be in or in close proximity to the some of the most seismically active regions of the country such as Afar Triangle, the Main Ethiopian Rift (MER), and the Southern Most Rift (SMR) where well-documented damage-

causing earthquakes are common [6]. Interestingly, secondary effect of earthquakes is slope movement there can be many different types of earthquake-induced slope movement. In addition to seismic hazard, substantial amount of the newly planned railway routes in the country pass in the heart of expansive soils. Expansive soils are cause of slope failures due to swell and reduction in strength.

According to the previous case studies [2], Slope failures in Ethiopia are mainly controlled by the presence of soft and low permeability materials or shales. The brittle nature of the failure and the strain-softening are such that the peak strength measured in the laboratory cannot be used directly in limit equilibrium analyses. Moreover**,** wide coverage of overconsolidated soils with fissures was also identified during site investigations along the new railway routes [10]. In these types of soils, experience shows that conventional practice of testing only vertical samples can be misleading [7]. Since progressive failure can occur for soils with brittle stress–strain characteristics, peak strengths should not be used for these soils in limit equilibrium analyses; using peak strengths for brittle soils can lead to inaccurate and unconservative assessment of stability [7]. Both shallow and deep seated slope failures have been occurring in Ethiopia following prolonged and intensive rainfall. It was indicated that drainage is the principal measure used in the repair of landslides, with modification of slope geometry the second most used method [23].

The judicious choice of alignment can minimize the severity of the problem due to expansive soil, if good reconnaissance surveys are made [31]. For example, if the alignment can be adjusted problems may be mitigated by such approaches as minimizing cuts and areas of poor drainage.]. Or it can be subsequently recompacted with good moisture and density control to minimize the expansion potential. Risk mitigation is the final stage of the risk management process and provides the methodology of controlling the risk. At the end of the evaluation procedure, it is up to the client or policy makers to decide whether to accept the risk or not, or to decide that more detailed study is required [24] A GPS landslide monitoring system can be used to notify approaching trains if the ground movement is exceeding a threshold that rendered the track impassable.

KEYWORDS: Railway; Landslide; Earthquake; Expansive soil, and Drainage.

INTRODUCTION

Ethiopia is striving to build modern railway infrastructures and services to meet its endeavor in building a globally competitive economy, which uses electricity and connects the country's development centers and links with ports of neighboring countries. The grand project, which was launched in November 2010, aims to connect major cities and towns by railways, totaling 4,744 km in length at a cost of 173.6 billion Br. The first phase of the project, which is expected to be completed within the current growth & transformation plan (GTP), includes a 2,300 km-long railway line [1].

However, the planned railway routes in Ethiopia pass through the hilly and mountainous terrains of the highlands of Ethiopia. The hilly terrains of the highlands of Ethiopia remain highly fragile environments in terms of slope stability whereby any external factors such as heavy rainfall and/or excavations could trigger landslides [2]. In general, the visible movement of the slope-forming materials in the downward and outward directions, including their movement within the slope, is termed a *landslide* (although all movement does not involve slides); during which shear failure may occur along a specific surface or simultaneously along a combination of surfaces, called *slip surfaces* [3]. Landslides and related slope instability phenomena plague many parts of the world. Japan leads other nations in landslide severity with projected combined direct and indirect losses of $4 billion annually [4]. Landslide disasters are also common in developing countries and economical losses sometimes equal or exceed their gross national products [5].

Also in Ethiopia large infrastructure works already lie or will be in or in close proximity to the some of the most seismically active regions of the country such as Afar Triangle, the Main Ethiopian Rift (MER), and the Southern Most Rift (SMR) where well-documented damage-causing earthquakes are common [6]. Under the influence of cyclic loads, bonds between soil particles may be broken and pore pressures may increase. The soils most subject to loss of strength due to cyclic loads are loose soils and soils with particles that are weakly bonded into loose structures. Loose sands may liquefy under cyclic loading, lose virtually all strength, and flow like a liquid [7]. In addition, substantial amount of the newly planned railway routes in the country pass through in the heart of expansive soils. Clays, especially highly plastic and heavily overconsolidated clays, are subject to swell when in contact with water. Low confining pressures and long periods of access to water promote swell [7]. Expansive soils are cause of slope failures due to swell and reduction in strength.

Over the past decade, the geotechnical profession has moved in a direction of increased awareness of both its role and contribution to a safer society, and the need for targeted communication has emerged more strongly than earlier [8]. The prime objective of this paper is to discuss on the analysis, prevention and mitigation measures of slope instability problems along the new Ethiopian railways.

History and Development of Ethiopian Railways

The 784 km- long railway line linking up the city of Djibouti with Addis Ababa, the capital of Ethiopia, was built between 1897 and 1917. The operator was previously called Imperial Railway Company of Ethiopia. Then Franco-Ethiopian Railway Company from 1909 onwards before becoming in October 1981, Djibouti-Ethiopia Railway Company. Several operators tried to give service but were not effectively successful. Operation was stopped in 2007. Then Ethiopian Railways Corporation (ERC), government owned, established in 2007 [1]. Promptly, the Ethiopian Railways Corporation began construction of the double track electrified light rail transit project (Addis Ababa light rail) in December 2011. A 17 km line running from the city center (Figure 1) to industrial areas in the south of the city opened on 20 September 2015. The total length of the line is 31.6km, with 39 stations. Trains are expected to be able to reach maximum speeds of 70km/h [9]. The Ethiopian Railway Corporation has plans for several new lines including links to adjacent countries. Beside it has identified eight railway corridors for study, design and subsequent implementation, the total estimated length with buffer of which is some 5060km. The eight railway routes are shown in Table 1 and those contracted and future expansion lines are shown in Figure 2.

Figure 1: Addis Ababa light railway (Ethiopia)

Table 1: Identified eight railway corridors for study, design and subsequent implementation [1]

Route No.	Route Name	Estimated Length (km)
1	Addis Ababa-Mojo-Awash-Dire Dawa-Dewanle	656
2	Mojo-Shashemene-Arbaminch-konso-Moyale	905
3	Addis Ababa-Ljaji-Jimma-Guraferda-Dima	740
4	Ljaji-Nekemet-Assosa-Kumruk	460
5	Awash-Kombolcha-Mekele-Shire	757
6	Fenoteselam-Bahiradr-Wereta-Weldia-Semera-Elidar	734
7	Wereta-Azezo-Metema	244
8	Adama-Indeto-Garesa	248
	Total	4744

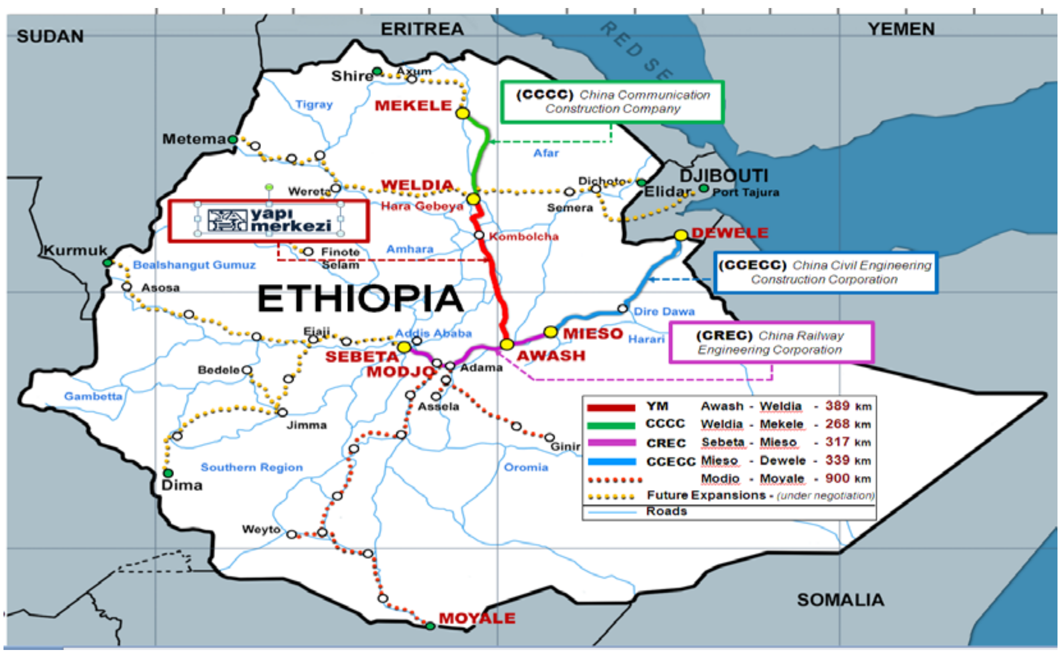

Figure 2: Contracted and future expansion lines of Ethiopian railways [10]

CAUSES OF SLOPE FAILURE

The fundamental requirement for stability of slopes is that *the shear strength of the soil must be greater than the shear stress required for equilibrium* [7]. The most fundamental cause of instability is that for some reason, the shear strength of the soil is *less than* the shear strength required for equilibrium. This condition can be reached in two ways: the first way is through a decrease in the shear strength of the Soil, and another way is through an increase in the shear stress required for equilibrium. Several different processes can lead to reduction in the shear strengths of soils [7]. The following processes are of particular importance with regard to slope stability: increased pore pressure, cracking, swelling, development of slickensides, decomposition of clayey rock fills, creep under sustained loads, leaching, strain softening, weathering and cyclic loading. Even if the strength of the soil does not change, slopes can fail if the loads on them change, resulting in increased shear stresses within the soil (e.g. Earthquake and surcharge load) [7]. When a slope fails, it is usually not possible to pinpoint a single cause that acted alone and resulted in instability. For example, water influences the stability of slopes in so many ways that it is frequently impossible to isolate one effect of water and identify it as the single cause of failure. Similarly, the behavior of clayey soils is complex, and it might not be possible to determine in some particular instance whether softening, progressive failure, or a combination of the two was responsible for failure of a slope [7].

Major Causes of Slope Failures in Ethiopia

Rainfall-Triggered Landslides

The differences in elevation in Ethiopia; detailed topographic maps (Figure 3) reveal local elevations ranging from about 5000 m above sea level to 100 m below, as well as individual features with sheer drops of thousands of meters. In such a disturbed topography, slope failures become major hazards [11]. Despite multi-face challenges in landslide research in the country, several authors have reported on slope instability problems (Figure 4) in different parts of the country [2].

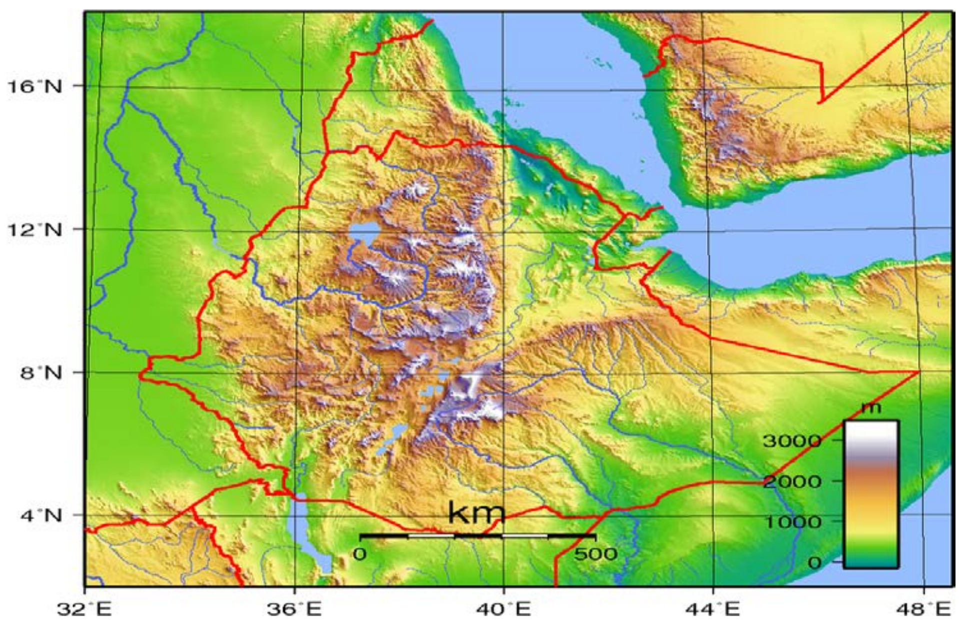

Figure 3: Topographic map of Ethiopia [12]

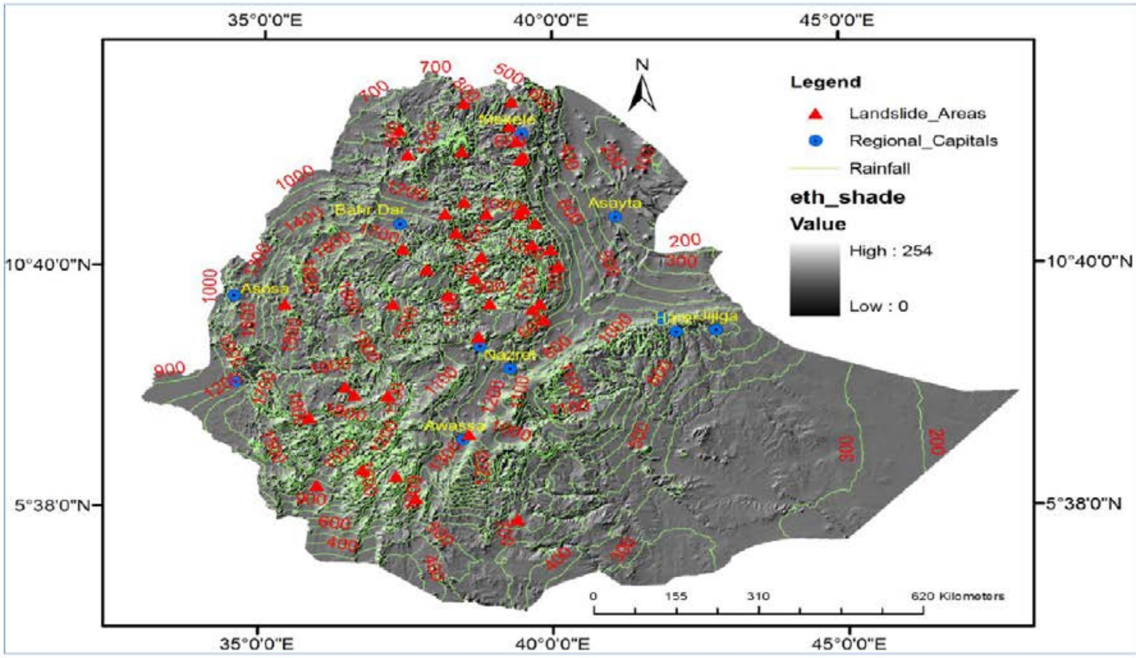

Figure 4: Location of landslide affected areas in the highlands of Ethiopia [2]

From the previous studies [2], the major types of landslides triggered by rainfalls in the highlands of Ethiopia include: debris/earth slides (Figure 5), debris/earth flows, and rockslides. Moreover, most of the reported rainfall-induced landslides have occurred during prolonged and heavy rain falls; dominantly at the end of the rainy seasons (mainly in the period mid August to mid September).

Figure 5: Earthslide affecting an asphalt road in Ethiopia [2]

According to the most recent study in Ethiopia [2], both shallow and deep seated slope instabilities have been occurred mainly due to soft and low permeability materials (shales).

Effect of Earthquake

East Africa is a developing market and constructing new infrastructure is one of the keys to the successful growth and prosperity for the region. However, the region is split by the active East African Rift Valley, which has a history of generating large earthquakes [13]. Historical records of the last six centuries and more recent instrumental observations reveal that Ethiopia and the northern sector of the Horn of Africa have been almost continuously jolted by earth tremors and, less frequently, by outbursts of volcanic activity [11]**.** Interestingly, however, a substantial amount of large infrastructure works already lie or will be in or in close proximity to the some of the most seismically active regions of the country such as Afar Triangle, the Main Ethiopian Rift (MER), and the Southern Most Rift (SMR) where well-documented damage-causing earthquakes are common [6].

For example**,** The Debre Berhan - Ankober road was blocked by an earthquake generated landslide during the spring of 1841; and (2) in December 1842, more important slope failures spread over many kilometers, destroyed the town of Ankober, destroyed or heavily damaged some villages, ruined the crops and caused a number of casualties (which cannot be estimated) [11]. The seismic activity, which was moderate, but by secondary effects, in this case landslides and rock falls. The triggering of such slope failures was favored by the heavy rains that had saturated the thin layer of clayish soil precariously laid upon very steep slopes [11]. Also, the 1961 Karakore earthquake M=6.1 destroyed the town of Majete. Which yielded: cracks, fissures and subsidence of up to 1m deep developed on the Addis Ababa –Asmara highway: many culverts and retaining walls along the road had been rebuilt. Rockslides and landslides were observed on steep escarpment slopes and 15-20km long fissures, in places 6-7m deep. Large boulders from rockslides, some estimated to weight 12-15 tones, blocked the road. Rubble from landslides covered the pavement in many places [11]. Figure 6 clearly indicates the effect of Karakore earthquake along the country’s main highway.

Figure 6: The1961 Karakore Earthquake in Ethiopia [11]

Also a cumulative distribution of damage causing earthquakes in Ethiopia [6] is shown in Figure 7. The damage related to earthquake will increase following the rapid construction of infrastructures in the country.

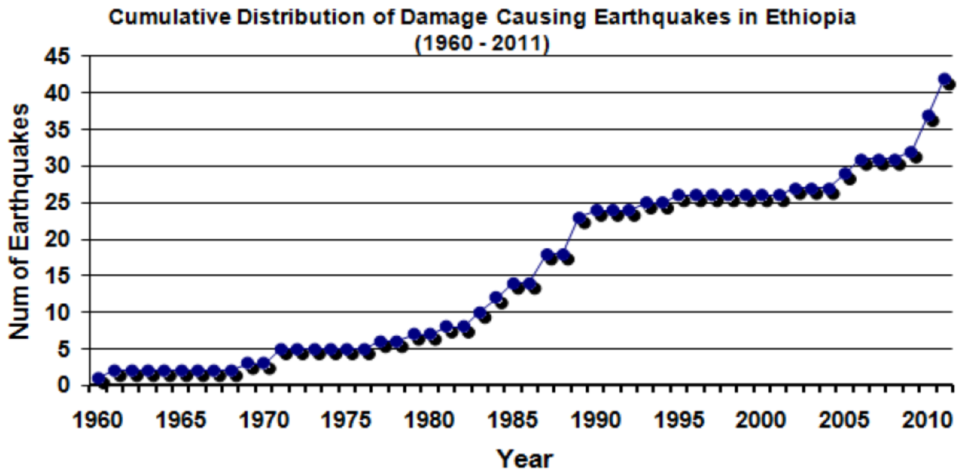

Figure 7: Cumulative distribution of damage causing earthquake in Ethiopia [6]

Figure 8 depicts the seismicity of the Horn Africa region by mapping the earthquakes that have occurred in the region from 1900 to 2010. The size of the red dots represents the magnitude of earthquakes – ranging from 3.5 to 7.2. The yellow stars are the major towns in Ethiopia – revealing that the seismic areas are often inhabited areas [14].

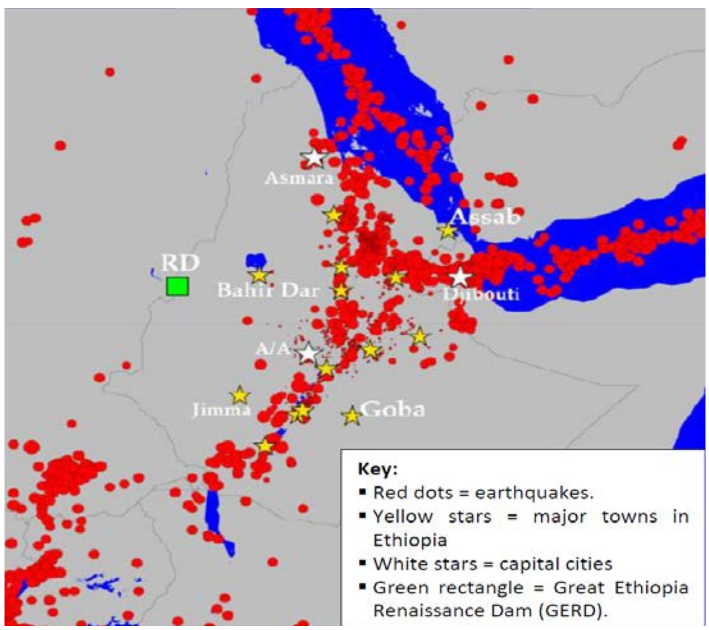

Figure 8: Recorded earthquake in the East African region from 1900 to 2010 [14]

Effect of Expansive Soil

Expansive soils (Figure 9) cover a large portion of Ethiopia [15]. According to information obtained from literature about 10% of the country's land is covered by Vertisols [16] or by their commonly known name 'Black cotton soils' alone. The dominant clay minerals of these soils are indicated to be the smectite groups and are nontronite & montmorillonite clays [16]. Others have reported the occurrences of clay soils of mixed mineral composition with significant smectite contents in various parts of the country [16]. At places where expansive soils are abundant, they are well known by their adverse property which poses difficulties of different types in fields mainly engineering and agriculture [16]. For example, Ethiopian Roads Authority (ERA) was forced to decrease the maximum speed limits below the original design speeds at many localities for instance on the main road connecting Addis Ababa and Jimma town [17]. Costly and repeated maintenance requirements were also frequently demanded as a result of such problems. Problems of clogging of road side ditches and culverts are common difficulties that demanded the allocation of high budgets for the clearing and maintenance of such drainage structures every year [16]**.** Moreover, a gully formation is associated with the poor permeability and erosion susceptibility nature of these soils. This poses negative and serious economical as well as environmental problems. Scouring drainage structures seriously affects the overall performance of road infrastructures in many localities [16]. Expansive soils are cause of slope failures due to swell and reduction in strength.

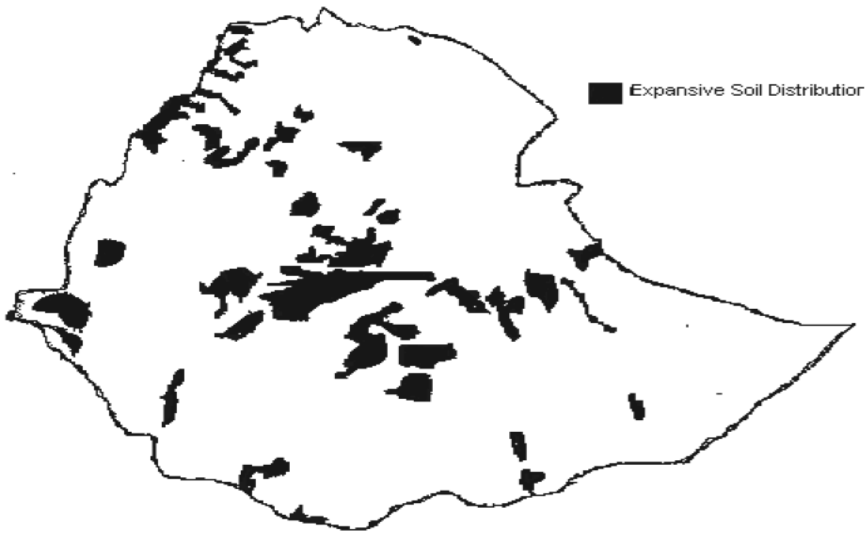

Figure 9: Distribution of expansive soils in Ethiopia [15].

Figure 10: Problems due to expansive soils occurred on the Ethiopian roads [16]

DISCUSSION AND RECOMMENDATION BASED ON THE PREVAILING PROBLEMS AND PITFALLS

Misuse of SPT

In Ethiopia, embankments and cuts have been designed based on the correlations made on SPT results. This is because its simplicity and cost effectiveness. The use of the SPT as part of insitu testing for ground Investigations of fine soils have become common practice in Ethiopia. However, recent research [18] has revealed that there is little if any relationship between SPT N values and the undrained shear strength or the coefficient of volume compressibility for fine soils within the geographical area of South Lanarkshire. Consequently the continued use of historical empirical correlations is questioned [19]. The findings confirm the guidance given in Eurocode 7 that the use of the SPT should be restricted to a “qualitative evaluation of the soil profile” [19].

Shear strength parameters to be used in the limit equilibrium analysis

According to the previous case studies [2], Slope failures in Ethiopia are mainly controlled by the presence of soft and low permeability materials or shales. For brittle materials, the strain-softening behavior needs to be taken into account in the stability analyses [20]. The brittle nature of the failure and the strain-softening are such that the peak strength measured in the laboratory cannot be used directly in limit equilibrium analyses. In addition to that**,** wide coverage of overconsolidated soils with fissures was also identified during site investigations along the new railway routes [10]. In these types of soils, experience shows that conventional practice of testing only vertical samples can be misleading [7]. Since progressive failure can occur for soils with brittle stress–strain characteristics, peak strengths should not be used for these soils in limit equilibrium analyses; using peak strengths for brittle soils can lead to inaccurate and unconservative assessment of stability [7]. Particularly fissured clays, shows that *fully softened strengths* are appropriate for these materials in cases where slickensides have not developed, and *residual strengths* are appropriate in conditions where slickensides have developed [7]. One needs to establish a reduction in the peak shear strength required to account for the strain-softening in limit equilibrium analyses [8]**.** One can either apply a reduction factor on the peak undrained shear strength from triaxial compression, direct simple shear and triaxial extension tests, or one can apply different factors on each test type, e.g. 15% on the triaxial compression strength, 10% on the direct simple shear strength and 5% on the triaxial extension strength [8]**.** Alternatively, empirical correlations [21] established based on liquid limit, clay-size fraction, and effective normal stress to capture the variability and stress-dependent nature of drained residual and fully softened strength envelopes can be used directly in slope stability analyses for preexisting and first-time landslides, respectively, and can be compared to assess the importance of identifying the presence or development of a shear surface [21].

Drainage

Both shallow and deep seated slope failures have been occurring in Ethiopia following prolonged and intensive rainfall. Since rise in groundwater tables and more adverse seepage, frequently during periods of heavy rainfall, are the most frequent reasons for increased pore pressures and associated decrease in effective stresses within slopes. All types of soils are affected [7]. The length of time long periods of higher-than-average rainfall cause deep-seated, slow moving slides, with shear surfaces that can extend tens of feet below the ground surface. One or two days of very intense rainfall, in contrast, tend to cause shallow slides involving only a few feet of soil, which move with high velocity once they are in motion [7].

A short list of landslide remedial measures has been prepared and arranged in four practical groups, namely: modification of slope geometry, drainage, retaining structures and internal slope reinforcement [22]. It was indicated that drainage is the principal measure used in the repair of landslides, with modification of slope geometry the second most used method [23]. These are also generally the least costly of the four major categories, which is obviously why they are the most used [24]. The experience shows that while one remedial measure may be dominant, most landslide repairs involve the use of a combination of two or more of the major categories. Modification of slope geometry is a most efficient method particularly in deep seated landslides. However, the success of corrective slope regarding (fill or cut) is determined not merely by size or shape of the alteration, but also by position on the slope [24]. Drainage is often a crucial remedial measure due to the important role played by pore-water pressure in reducing shear strength. Because of its high stabilization efficiency in relation to cost, drainage of surface water and groundwater is the most widely used, and generally the most successful stabilization method [24]. As a long-term solution, however, it suffers greatly because the drains must be maintained if they are to continue to function [25]. The following Figure shows the problems related to impaired drainage structures on the railway embankment [26].

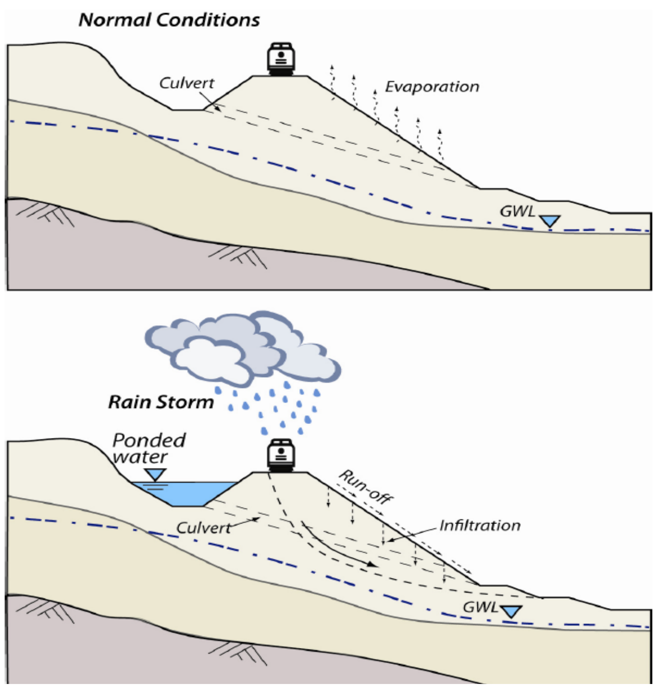

Figure 11: Hazards associated with overland/ through flow and earth (Embankment) landslide scenario induced by a rain-storm event [26]

In the case of deep landslides, often the most effective way of lowering groundwater is to drive drainage tunnels into the intact material beneath the landslide. From this position, a series of upward - directed drainage holes can be drilled through the roof of the tunnel to drain the sole of the landslide. Alternatively, the tunnels can connect up a series of vertical wells sunk down from the ground surface. Another approach is to use a combination of vertical drainage wells linked to a system of sub-horizontal borehole drains [24].

Earthquake

The theory of plate tectonics in the 1960s has helped immeasurably in the understanding of earthquakes. It is evident that the locations of the great majority of earthquakes correspond to the boundaries between plates [27]. Most of the tectonic processes active in the East African Rift System are related to rifting and associated magmatic intrusions. Figure 12 shows an example of the phase changes and associated deformation caused by a dike intrusion in October 2008, in Ethiopia generated from data collected by the Advanced Land Observing Satellite (ALOS) on September 19, 2008, and December 15, 2008. The 'fringes' in the resulting interferogram (each color cycle from blue to blue) represent approximately 12 cm of deformation in the radar's line of sight [28].

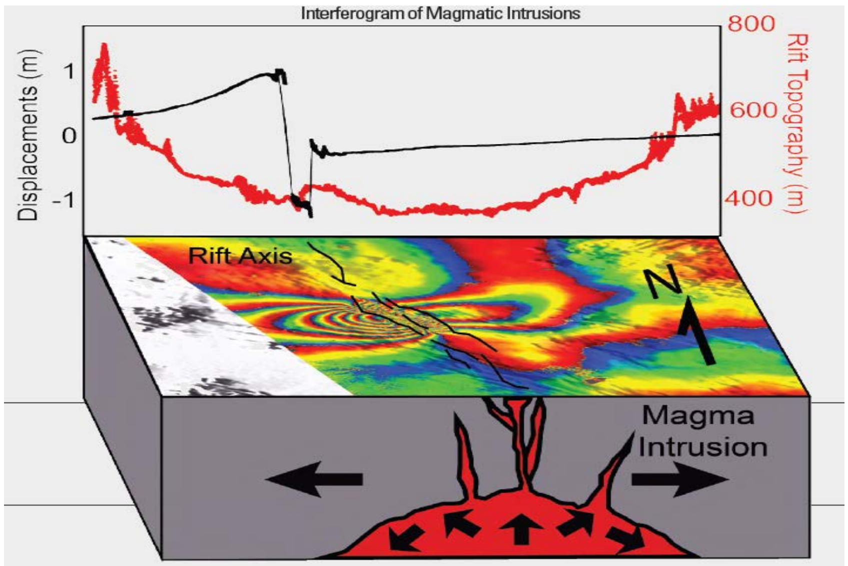

Figure 12: Dike intrusion in October 2008 in Ethiopia [28]

This occurs when the relative movement of two plates is away from each other. The upwelling of hot magma that cools and solidifies as the tectonic plates move away from each other forms spreading ridges. Earthquakes on spreading ridges are limited to the ridge crest, where new crust is being formed. These earthquakes tend to be relatively small and occur at shallow depths [29].

One of the pitfalls made by practicing engineers in Ethiopia is using less efficient building code standard. The current Ethiopian building code standard (EBCS-8/95) considers a return-period of 100 years which is not conservative enough for buildings as well as large infrastructures [6]. The use of return-period of 475 years was recommended [6] as strong candidate for consideration. Further, for large infrastructure projects such as dams, bridges, power-plants, railway structures, the tendency to use existing practice of 100 year return-period should also be disallowed immediately and the proposed use of 475 years of return-period should also be extended to these specialized codes [6].

Secondary effect of earthquakes is slope movement there can be many different types of earthquake-induced slope movement. For rock slopes the earthquake-induced slope movement is often divided into falls and slides [27]. Falls are distinguished by the relatively free-falling nature of the rock or rocks, where the earthquake-induced ground shaking causes the rocks to detach themselves from a cliff, steep slope, cave, arch, or tunnel [30]. Slides are different from falls in that there is shear displacement along a distinct failure (or slip) surface. For soil slopes, there can also be earthquake-induced falls and slides addition, the slope can be subjected to a flow slide or lateral spreading. For the seismic evaluation of slope stability, the analysis can be grouped into two general categories, as follows [27]:

- *Inertia slope stability analysis:* The inertia slope stability analysis is preferred for those materials that retain their shear strength during the earthquake. There are many different types of inertia slope stability analyses, and two of the most commonly used are the pseudostatic approach and the Newmark method (1965).
- *Weakening slope stability analysis:* The weakening slope stability analysis is preferred for those materials that will experience a significant reduction in shear strength during the earthquake. The residual shear strength is used in slopes whose soils liquefy by seismic loading.

Expansive soils

The judicious choice of alignment can minimize the severity of the problem due to expansive soils, if good reconnaissance surveys are made [31]. For example, if the alignment can be adjusted problems may be mitigated by such approaches as minimizing cuts and areas of poor drainage. In-place expansive soils can be ripped and scarified to destroy the natural structure of the materials and can be subsequently recompacted with good moisture and density control to minimize the expansion potential. This method is well known and widely practiced. In some instances sand has been added to the soil prior to recompaction to decrease swell potential. Lime is the most effective and widely used chemical additive for expansive soils [31]. It has been demonstrated to be effective when thoroughly mixed with pulverized clay materials in percentages ranging from about 3 to 6%. The depth of treatment is generally limited to about 8 to 12 in. (20 to 30 cm) in a single lift. Deep plowing techniques have been used to extend this depth to 2 ft (0.6 m) or more. The methodology for the use of lime is well established and numerous excellent results have been achieved [31]. In China expansive soils were mixed with lime and fly ash, and then wrapped with flexible, reinforced material such as geotextiles or woven bags. The composite was then compacted [32]. Thereafter, the non-expansive soil was filled in and compacted on the slope surface, and a drainage channel system was built on the top, surface and toe of the slope to prevent erosion and infiltration of rain water. Finally, plants with shallow roots were planted on the slope surface to intercept precipitation. This Chinese practice can be adopted effectively in Ethiopia.

RISK MANAGEMENT

Risk mitigation is the final stage of the risk management process and provides the methodology of controlling the risk. At the end of the evaluation procedure, it is up to the client or policy makers to decide whether to accept the risk or not, or to decide that more detailed study is required [24]. Typical options would include [33]:

♦ *Accept the risk* - this would usually require the risk to be considered to be within the acceptable or tolerable range.

♦ *Avoid the risk* - this would require abandonment of the project, seeking an alternative site or form of development such that the revised risk would be acceptable or tolerable.

♦ *Reduce the likelihood* - this would require stabilization measures to control the initiating circumstances, such as reprofiling the surface geometry, groundwater drainage, anchors, stabilizing structures or protective structures etc.

♦ *Reduce the consequences* - this would require provision of defensive stabilization measures, amelioration of the behavior of the hazard or relocation of the development to a more favorable location to achieve an acceptable or tolerable risk.

♦ *Monitoring and warning systems* - in some situations monitoring (such as by regular site visits, or by survey), and the establishment of warning systems may be used to manage the risk on an interim or permanent basis. Monitoring and warning systems may be regarded as another means of reducing the consequences.

♦ *Transfer the risk* - by requiring another authority to accept the risk or to compensate for the risk such as by insurance.

The procedure developed [34] to manage the railroad risk associated with landslides. Factors considered included the magnitude and frequency of landslide activity and the rate of ground movement compared to the frequency of track maintenance. In areas where the land slide is moving at a gradual rate, the frequency of the railway maintenance should be sufficient to periodically realign the track such that the track speed could be maintained without compromising the safety of rail operations, despite periods requiring more frequent track maintenance. The primary successful landslide mitigation measure of the other landslide locations was the placement of an erosion-protection toe-berm of rip-rap into and along the river bank [8]. A GPS landslide monitoring system can be also used to notify approaching trains if the ground movement is exceeding a threshold that rendered the track impassable. When the implications of avoiding or stabilizing landslides are significant, this can be a viable risk reduction strategy. However, this approach did not reduce the likelihood of a prolonged service interruption, with the ensuing costs [8].

CONCLUSION

This paper discussed the likely causes of slope failures, prevention and mitigation measures to be employed for the new Ethiopian railway projects. According to the previous case studies [2], Slope failures in Ethiopia are mainly controlled by the presence of soft and low permeability materials or shales. For brittle materials, the strain-softening behavior needs to be taken into account in the stability analyses. The brittle nature of the failure and the strain-softening are such that the peak strength measured in the laboratory cannot be used directly in limit equilibrium analyses. In addition to that**,** wide coverage of overconsolidated soils with fissures was also identified during site investigations along the new railway route [10]. In these types of soils, experience shows that conventional practice of testing only vertical samples can be misleading. Particularly fissured clays, shows that *fully softened strengths* are appropriate for these materials in cases where slickensides have not developed, and *residual strengths* are appropriate in conditions where slickensides have developed.

Both shallow and deep seated slope failures have been occurring in Ethiopia following prolonged and intensive rainfall. Since rise in groundwater tables and more adverse seepage, frequently during periods of heavy rainfall, are the most frequent reasons for increased pore pressures and associated decrease in effective stresses within slopes. It was indicated that drainage is the principal measure used in the repair of landslides, with modification of slope geometry the second most used method [23]. These are also generally the least costly of the four major categories, which is obviously why they are the most used [24]. In the case of deep landslides, often the most effective way of lowering groundwater is to drive drainage tunnels into the intact material beneath the landslide.

One of the pitfalls made by practicing engineers in Ethiopia is using less efficient building code standard. The current Ethiopian building code standard (EBCS-8/95) considers a return-period of 100 years which is not conservative enough for buildings as well as large infrastructures. The inertia slope stability analysis is preferred for those materials that retain their shear strength during the earthquake. The weakening slope stability analysis is preferred for those materials that will experience a significant reduction in shear strength during the earthquake. The residual shear strength is used in slopes whose soils liquefy by seismic loading.

The judicious choice of alignment can minimize the severity of the problem due to expansive soil, if good reconnaissance surveys are made [31]. In-place expansive soils can be ripped and scarified to destroy the natural structure of the materials and can be subsequently recompacted with good moisture and density control to minimize the expansion potential. This method is well known and widely practiced. In some instances sand has been added to the soil prior to recompaction to decrease swell potential. Lime is the most effective and widely used chemical additive for expansive soils [31].

Risk mitigation is the final stage of the risk management process and provides the methodology of controlling the risk. At the end of the evaluation procedure, it is up to the client or policy makers to decide whether to accept the risk or not, or to decide that more detailed study is required [24]. A GPS landslide monitoring system can be also used to notify approaching trains if the ground movement is exceeding a threshold that rendered the track impassable. When the implications of avoiding or stabilizing landslides are significant, this can be a viable risk reduction strategy. However, this approach did not reduce the likelihood of a prolonged service interruption, with the ensuing costs [8].

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