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A study on the Slope Instability Problems and Mitigation Measures for the Road Failure from Gebre Guracha to Lumame Road Segment

Habtamu Washe Mite [1], Prof. Emer T. Quezon [2], Tadesse Abebe[1]

[1] Department of Geotechnical Engineering, Faculty of Civil and Environmental Engineering, Institute of Technology, Jimma University, Jimma, Ethiopia

[2] Faculty of Civil and Environmental Engineering, Institute of Technology, Jimma University, Jimma, Ethiopia

ABSTRACT

Slope instability (landslide) cause damage civil engineering structures, such as buildings, dams, roads, railway, and other related structures. Road development is one of the major investments in Ethiopia. Roads damaged by slope instability. The research was conducted by identifying the slope instability problems and its effects on road segments in the central part of Ethiopia, specifically along Gebre Guracha - Lumame road segments. It was, identified the causes and effects of the slope instability problems on the road alignment conditions, which included investigation of the engineering properties of existing condition of the soils.

In this study, water content, sieve analysis test, specific gravity, Atterberg limits, density and unit weight, static direct shear test and compaction test were done by using ASTM laboratory test procedure for determination of the geotechnical parameters that used in slope stability analysis. Geotechnical parameters that determined from the laboratory experiments, LL 58-63%, PL 28-35%, PI 24-34%, Gs 2.80-2.84, and also unit weight and shear strength parameters of the study site was determined. According to USC classification scheme most of the soil of the study area was highly plastic inorganic clay and inorganic silt.

The main causes of the landslide of in the study site were pore water pressure, dynamic load due traffic and erosion of toe. Unit weight and shear strength parameters were used in slope stability analysis for the determination of the critical factor of safety and radius by using geostudio2012/slope/w software. The critical factor of safety, Bishop-1.17, Jambu-1.11, and Morgstem-price-1.17, ordinary-1.12 and spencer-1.17 and radius for all analysis methods were 32.889m. From results of the investigation the remedial solutions failed slope are the combinations of the Control works such as providing drain pipeline in the slope, surface drainage (provide ditch at the top of the crown to collect surface drainage out of the slide area), sub surface drain (by providing the horizontal and incline drain pipe) and restraint works by designed of cantilever retaining wall.

Keywords: *Slope Instability problems, slope instability parameters, factor of safety, remedial measure*

1. INTRODUCTION

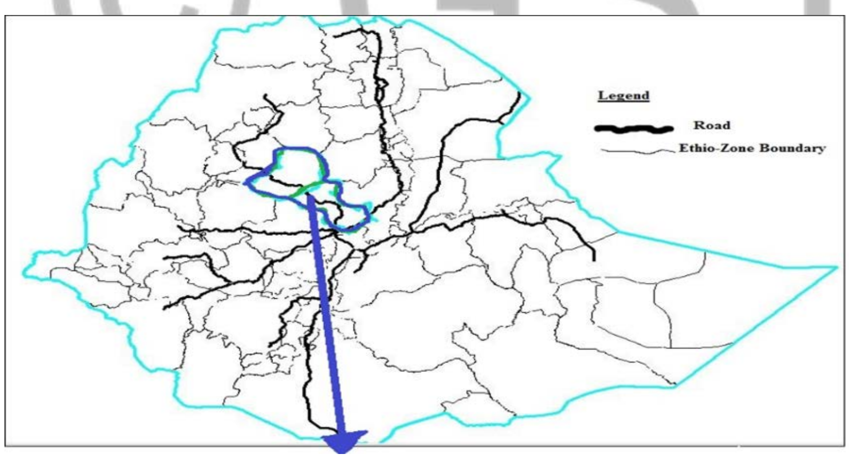
Slope instability problems damage civil engineering structures such as buildings, dams, irrigation canals, roads, railway, etc. in the world [1]. Slope instability problem is one of the geological and geotechnical problems which are a complex natural phenomenon that constitutes a serious natural hazard in many countries. Landslides belong to a group of processes referred to as mass wasting. The term mass wasting includes a wide variety of slope movements such as falls, slides, spread, flows and creep [2].

The Abay Gorge, along Gebre Guracha–Lumame road segment, is one of the common areas in the country where most slope instabilities are frequently observed. It is very common to see slope failure events that hinder traffic movements during the rainy season. Substantial columnar jointed basalt, groundwater, uncontrolled surface runoff, joints of rocks, and the presence of marl and shale within hard rocks are the main causes of slope instability. During the past years, landslides and rock fall had damaged the road sections, bridges, and farmlands [5].

The study area is a part of economically important of main Addis Ababa -Debre Markos Bahar Dar-Gondar-Metema-Sudan root and Gondar-Tigray road that connects north-central and northwestern part of the country with the capital of Addis Ababa and port of Sudan. This research was focused on slope instability problem identification and solving, investigation of slope stability analysis parameter and the remedial measure of the problem, protection from natural hazards, and continuing respect for the environment of the road segments.

1.1 Background of the Study Area

The study area or road segment is located Gebre Guracha to Lumame road segments which are found in the Amhara Regional state and Oromia regional state in the central part of Ethiopia. The Gebre Guracha to Lumame Road segment is 105 km long. The first 50km of the road is located in the Oromia region while the last 55km of the road is located in Amhara region. It lies within the Abay basin. The land use pattern along the road alignment can be defined as mostly cultivated land with the small portion covered by bushes, shrubs, eucalyptus trees, etc. Bushes cover the limited part of the study area, which is used for grazing. Most people are dependent on the farming and cattle breeding which is the main livelihood for them. The terrain (topography)of the road alignment can generally be described as escarpment/mountainous over the large portion of the road with some sections characterized by rolling and flat physiographic features.



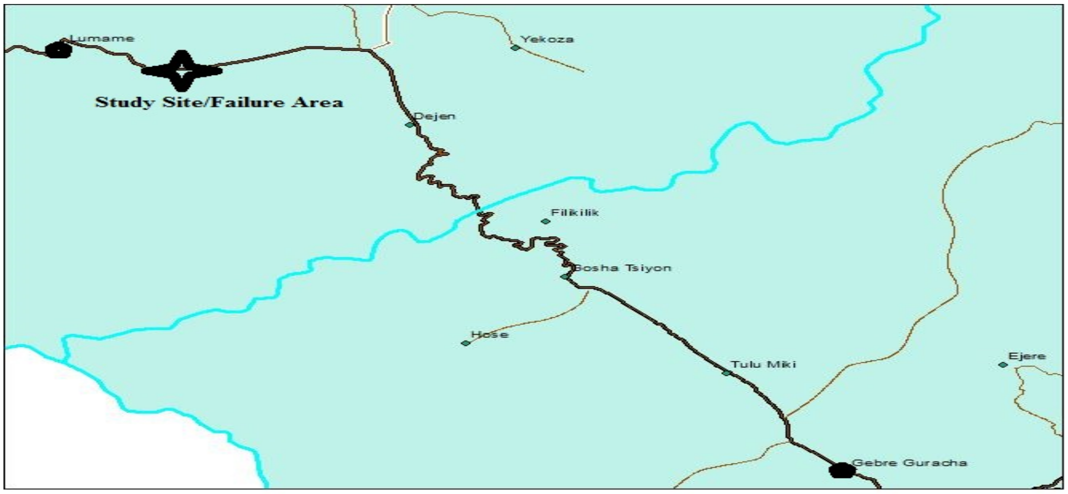


Figure 1.1: Map of study area

2. RESEARCH METHODOLOGY

2.1 Research design

The research was conducted by using both descriptive and analytical methods. The research was performed the following activities.

review of literature documents such as testing manuals, soil mechanics & related books, articles, new papers and wrote review related litratures

Site visualization and collecting soil samples was done from field

Conducting experiments and tests of soil in lab

Analyzing the result of tests and experiment

Interpreted the analysis of results and conclusion & recommendationwas taken

Figure 2.1: The research strategies frame

Generally, the data has been analyzed and interpreted using both descriptive (i.e., case reports and case series, conducting experiments, field visualization, cross-sectional study) and analytical methods of approach.

3. TEST RESULTS AND DISCUSSION

3.1 Laboratory test results of the study site

Table 3.1: Natural Moisture Content and Specific Gravity (Gs) of the Study Site

Name of a test pit	Depth of sample	Natural moisture content (w %)	Specific gravity (Gs)
TP1	3m	50.73	2.81
TP2	3m	52.44	2.84

TP3	3m	51.43	2.80

In fine-grained soils, Gs are more variable due to the presence of clay minerals and may range from 2.80-2.84. The study site is silt- clay soil.

Table 3.2: Atterberg Limits Test Results of The Study Site

Name of Test Pit	Sample Depth (m)	Liquid Limit (LL %)	Plastic Limit (PL %)	Plasticity Index (PI %)	Natural Moisture Content (w %)	Liquid Index (LI) $= \frac{W - PL}{PI}$	Consistency Index (CI) $= \frac{LL-W}{PI}$
TP1	3m	58	34	24	50.73	0.70	0.30
TP2	3m	63	35	28	52.44	0.62	0.38
TP3	3m	62	28	34	51.43	0.69	0.31

Liquid Limit ranges from 58% – 63%, Plastic Limit ranges from 28%-35% and Plastic Index from 24% – 34%.

Table 3.3: Test results, density and unit weight of the study site soil

Name of a test pit	Depth of sample	Bulk density (ρt),(Kg/m^3)	Bulk Unit weight, γ_t, (KN/m^3)	Dry density ρd,(Kg/m^3)	Dry unit weight (γ_d)(KN/m^3)
TP1	3m	2026.27	19.88	1596.46	15.66
TP2	3m	2068.29	20.30	1615.85	15.85
TP3	3m	2030.37	19.92	1571.90	15.42

Table 3.4: Optimum moisture content the maximum dry density and Free Swell Test of the study site

Name of a test	Depth of	OMC %	MDD(g/cm^3)	Free Swell (%)	Water used for testing
TP-1	3	35	1.39	50	Tap water
TP-2	3	31	1.41	35	Tap water
TP-3	3	34	1.37	40	Tap water

From the test result, one can see that the free swell of the soil under investigation ranges from 35% to 50%. Those soils were having a free swell less than 50% are considered as the medium in a degree of expansion

Table 3.5 (Static) Direct Shear Tests

Name of a test pit	Depth of sample	Cohesion (C)	A frictional angle of soil (Φ)
TP-1	3m	47.7	14.55

TP-2	3m	47.0	13.37
TP-3	3m	48.9	9.82

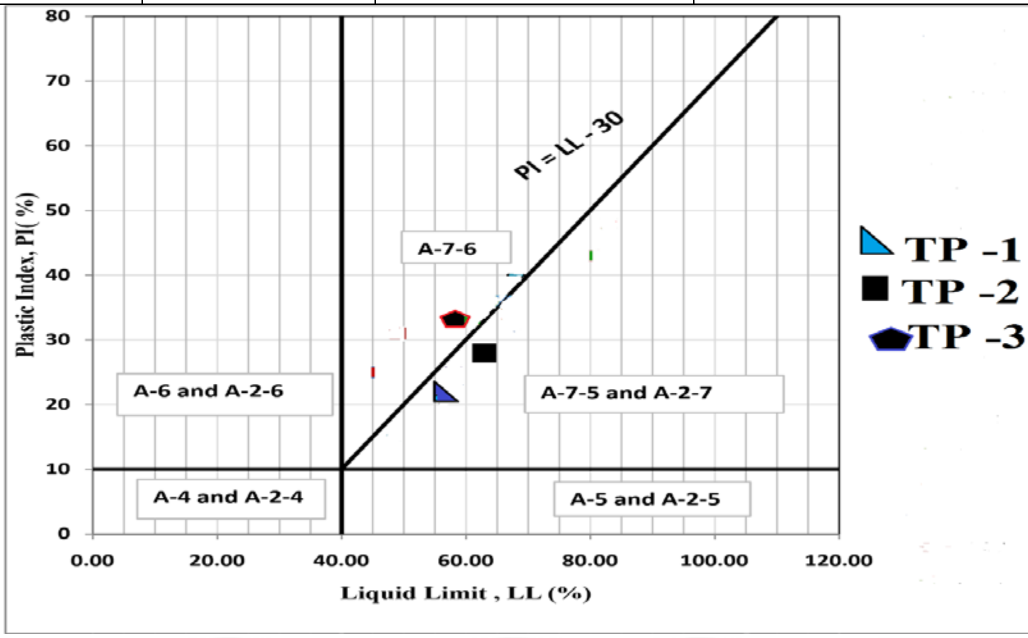


Figure 3.1: Plasticity chart of soil in the study area according to AASHTO classification system

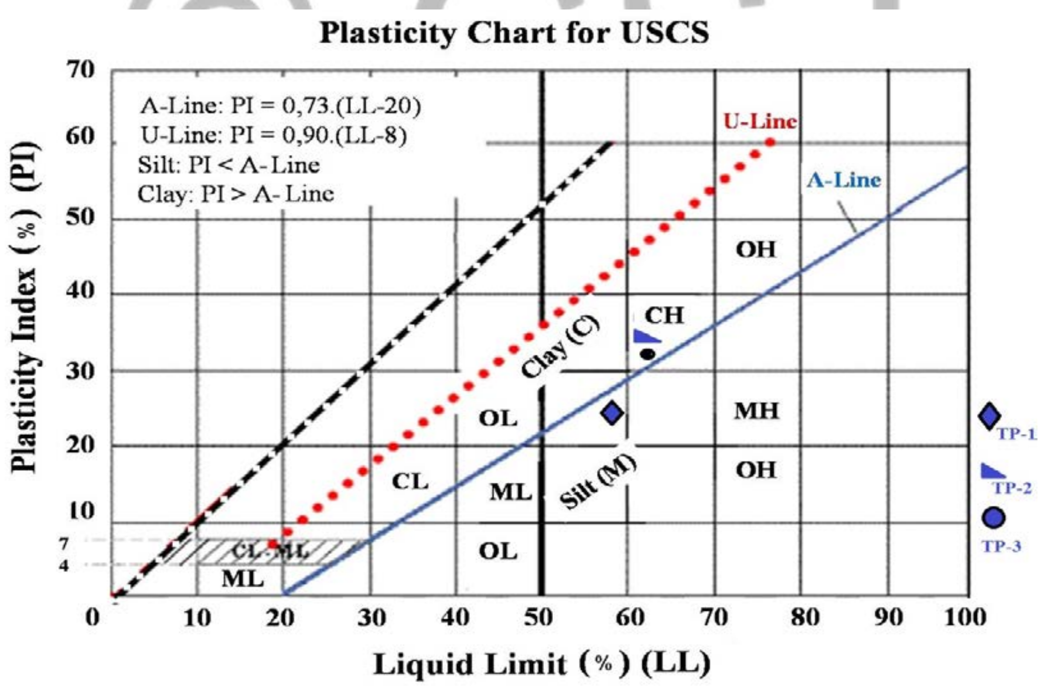


Figure 3.2: The Unified Soil Classification System (USCS)'s Plasticity Chart

With these test results, soil classification using the Unified Soil Classification System (USCS), TP-1 and TP-2 were the type of CH i.e. clay with high plasticity soil and TP-3 was MH i.e. silt soil with high plasticity

3.2 Field Investigation

Fieldwork is relevant and necessary for any geological and geotechnical problems (landslide) study. It is essential to observe the clear indications and field manifestations about slope instability and to collect data on various causative factors responsible for inducing instability to the slope. The site visit was the most important part of the preliminary work because it was the earliest visit to the landslide site and provides the opportunity to obtain photographs and descriptions of the conditions before they are changed. Even if the landslide occurred months or years earlier, it was still the first opportunity to assess the situation and should be used to collect as much information as possible.

3.2.1 Description of sample location and slope failure (Slide) characterization

During the investigated of the slide by digging the three test pits; the depth of test pit is 3m. In this study undisturbed and disturbed soil samples was token from the slide plane and slide material and tested for classification, strength determination and hence for the characterization of the slide mass. From the tests, one can determine the strength parameters and index properties for the slide plane and index properties for slide mass, which eventually is used to characterize the slide mass and sliding plane.

Table 3. 1: Dimension of failure slope

Description	Dimensions
Total length (L) of slide (3)	60m
Length of displaced mass (1)	58m
Width of rapture surface (2)	80m
Width/length/ of displaced mass (4)	78m
Length of rapture (5)	52m

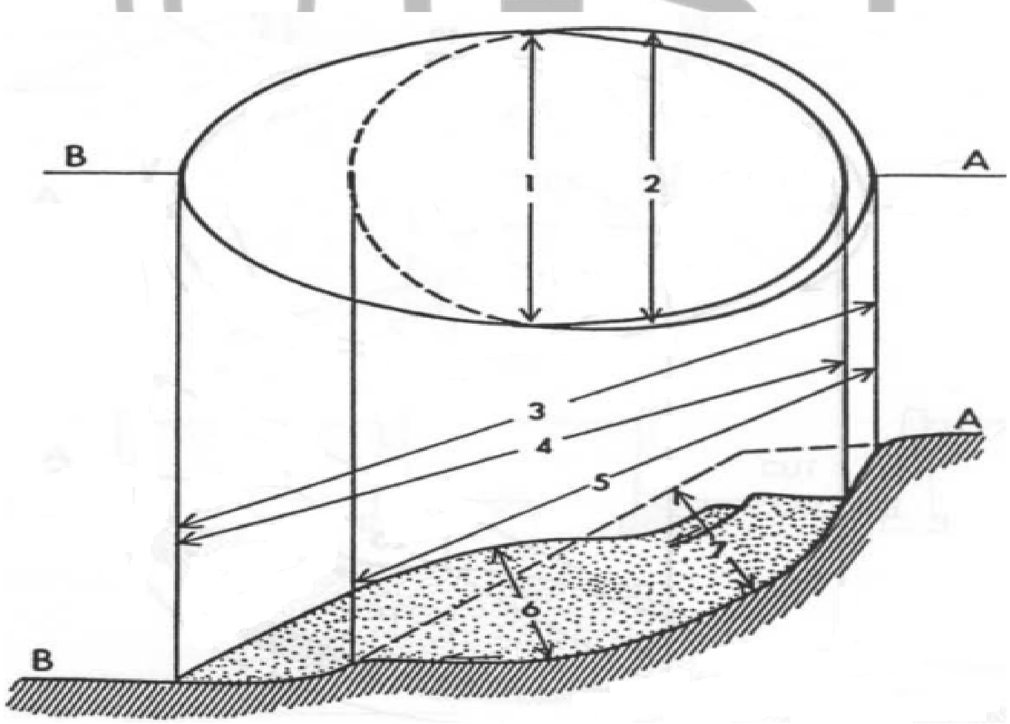


Figure 3.3: Sketching dimension of failure slope in the study area

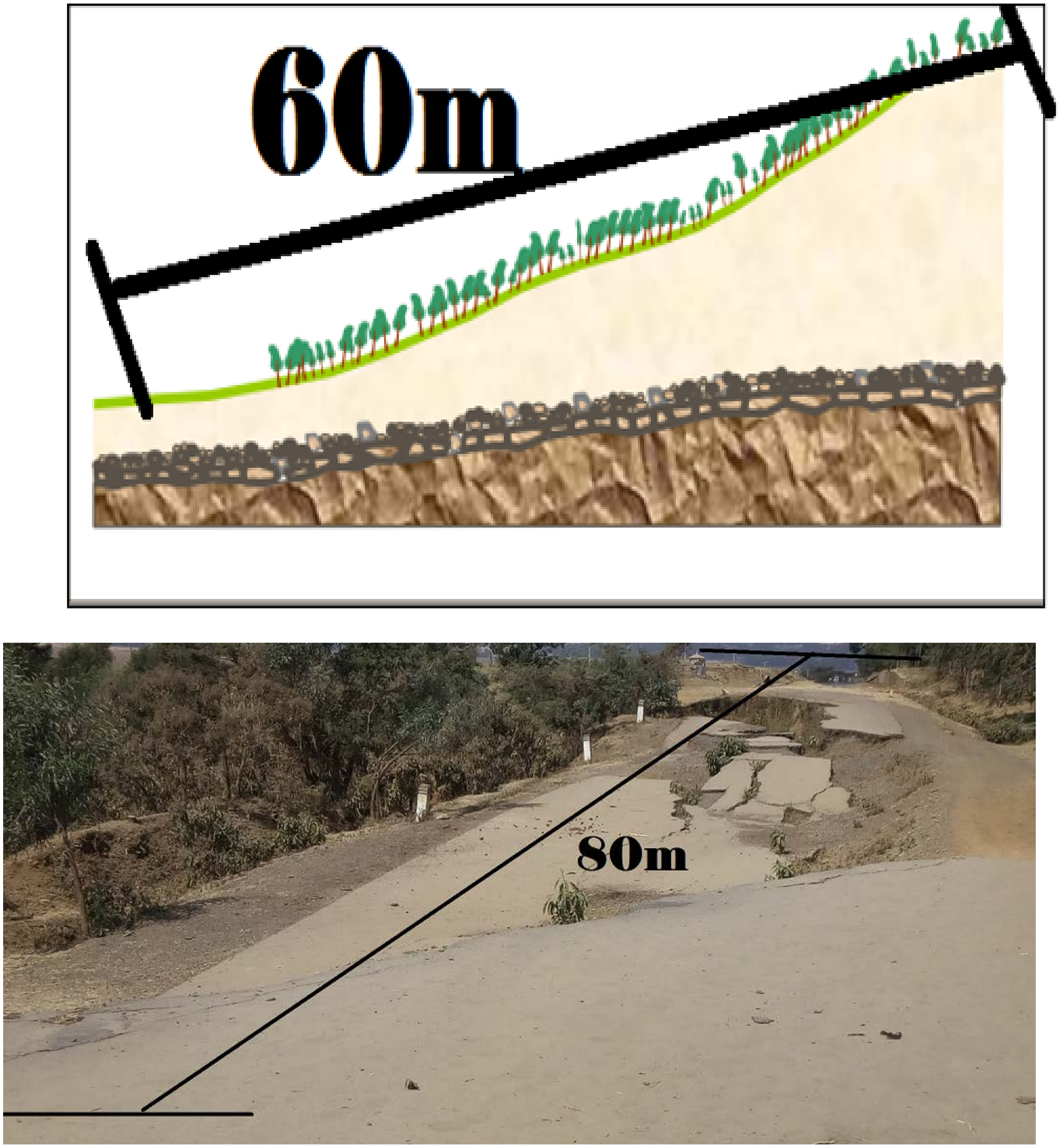


Figure 3.4: slope failure/slide characterize

3.2.2 Investigation of groundwater table profile and slope geometry of the study site

The most important requirement is to put a line of borings through the center of the landslide to determine the geological conditions, measure the depth of slippage, measure groundwater levels near the slip surface, and collect samples for laboratory testing of classification and strength. In this study three test pits took, these are in a toe of a slide, in center of slate, and in a crown of the slide.

Slope geometry of study site: It was determined by ArcGIS software. The slope of the slide is 60 ^{o}, so the sloping geometry of the study site is the gentle slope.

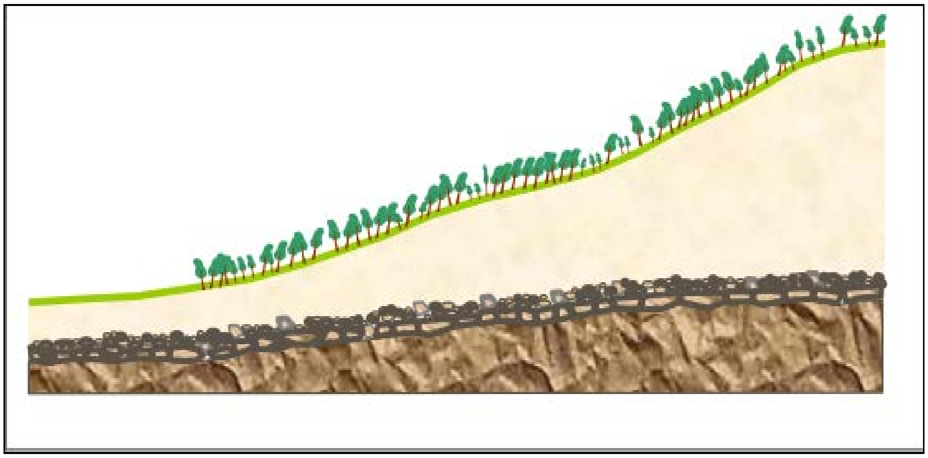


Figure 3.5: Slope geometry of the study site

Ground Water Table Profile: Water plays a very important role in slope stability. Groundwater condition can affect slope stability in the following ways:reduce the shear strength of the soil**,** change the bulk density of soil**,** generate pore water pressure**,** cause erosion**,** and change the mineral constituents of soil through chemical alteration and solution

In test pit one the ground water was 3m from the surface of the natural ground level. By using the TP-1 and two domestic well around the study area, the ground water teble profile was estimated.

Well – 1: This well is public use domestic well. It is found around the slide toe . the distance between the well and the slide toe is 20m. the depth of the well is 5m from the natural groun level and the depth of ground water table from natural ground level varies from 3m to 4m. At rainseason the depth of ground water level 3m from ground level.

Figure 3. 6: Photo of well-1

Well -2: This domestic well is Ato Melese Lakew’s well. It is found around the crown of slide. the distance between the well and the slide toe is 30m. the depth of the well is 7m from the natural groun level and the depth of ground water table from natural ground level varies from 4m to 5m. At rainyseason the ground water level 4m from ground water level.

Figure 3. 1 : Photo of well-2

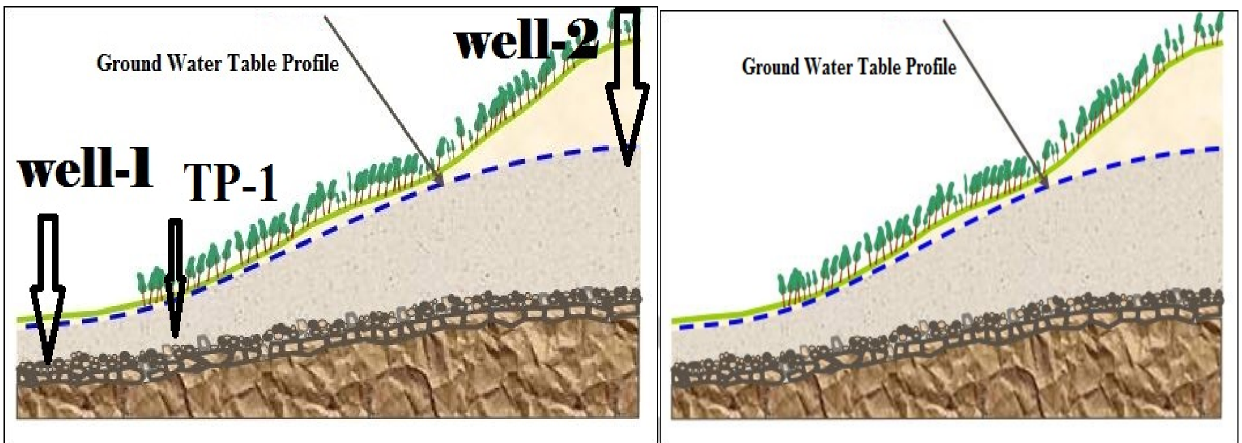


Figure 3. 8: Groundwater table profile of the study site

In addition to these, it was attempted to identify the damages caused by the landslide on infrastructure.

Figure 3. 2: Some Photos of the Site

3.2.3 Causes of Landslides in the study site

The main causes of the landslide of in the study site were; pore water pressure, slope of the ground, dynamic load due traffic and erosion of toe.

3.2.4 Geotechnical parameters for Slope stability analysis that gotten from laboratory test and field activities

The geotechnical parameters that got from lab and field observation were unit weight, cohesion and frictional angle of the study area soil.

Table 3. 2: Geotechnical parameters of the study area

Parameters	Value
Unit weight	20 kN/m^3
Cohesion	47.87 kpa
Frictional angle of soil	12.6^o
Length of slide	60m
Slope angle of the study site	60^o
Ground water depth	At toe 3m and at crown 5m

3.2.5 Critical Factor of safety by using GeoStudio 2012/slope/w

In this study, it was shown that limit equilibrium methods are reliable and can be used with confidence to investigate the stability of slopes. The critical factor of safety and radius are determined by geo-slope software Geostudio-2012/slope/w. The results are shown in the table 3.8

Table 3.8: The critical factor of safety and radius of the study area

Analysis method	Critical factor of safety	Critical radius(m)
Morgenstem-price	1.17	32.889
Spencer	1.17	32.889
Bishop	1.17	32.889
Jambu	1.11	32.889
Ordinary	1.12	32.889

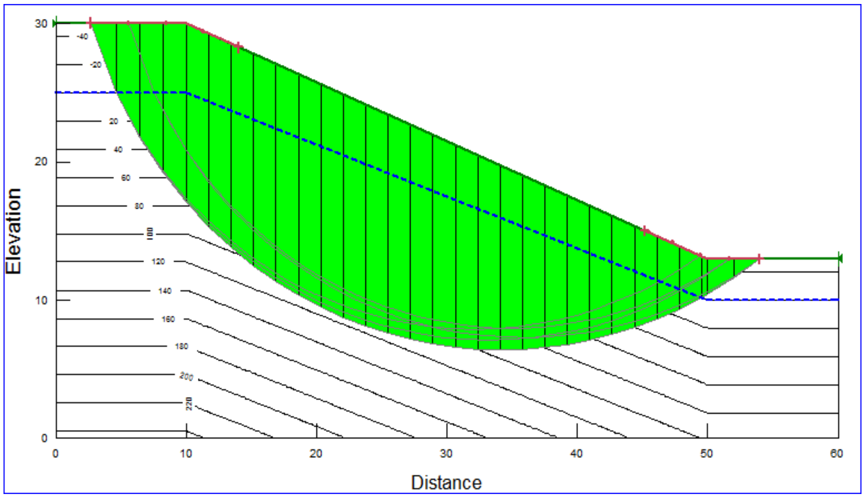


Figure 3. 30: slope stability analysis geostudio 2012 software output

3.2.6 Prevention of Landslides in the study area

In general, landslides can be minimized by making complete roadway soil surveys in questionable areas, making adequate provisions to handle surface and subsurface water, by reducing the activating forces, and by increasing the resisting forces, or in limited cases by avoidance of the area or relocation of the route. At that time relocation can be accomplished, or if the alignment must be maintained, providing drainage or construction of restraining or retaining structures at the toe can be accomplished. Once a landslide is identified on a natural, cut or fill slope, the remedial measures must provide a reduction in the driving forces, an increase in the resisting forces, or combination of both. Two major countermeasures for landslide preventions are control works and restraint measures. Generally, the selection of appropriate remedial measures depends on engineering feasibility, economic viability, and environmental acceptability [1].

Control works are the methods to avoid or reduce the triggering factors, i.e., up rise of groundwater level, proper surface drainage, and proper subsurface water by using draining pipes. And **Restraint measures**- stabilize the landslide by a construction of structures to counteract the driving force of the landslide. Remedial measure may be sufficient to minimize the effect of rainfall triggered landslide, most remedial works usually involve a combination of two or more methods. Generally, the selection of appropriate remedial measures depends on engineering feasibility, economic viability, and environmental acceptability [1].

In this study, the list of remedial measures proposed and designed for respective slide locations are outlined below.

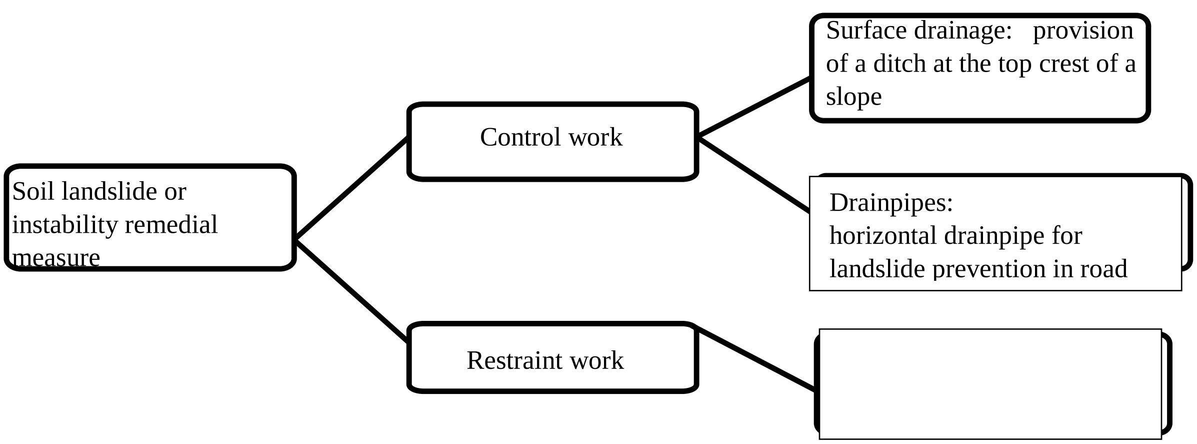


Figure 3.11: soil slope instability or landslide countermeasures

However, the specific proposed remedial measures at each rainfall-induced landslide locations depend on the investigation and analysis of the respective slides. From the investigation of the landslide or instability, the reasons for the failure of the slope were as a result of: in proper surface drainage; the presence of extended period of wet (rainfall) season per year which makes slopes wet; the relict bedding planes which could be considered as weak planes in residual soil formations; dynamic loads due to movement of traffic and steeps of slope.

From results of the investigation, the proposed remedial solutions for the remediation of the failed slope are the combinations of: **Control works:** Providing drain pipeline in the slope; Surface drainage: provide furrow ditch at the top of the crown to collect surface drainage out of the slide area; Subsurface drain: providing the horizontal and incline drain pipe in the slide area. **And Restraint works:** selected to be reinforced cantilever retaining wall, due to the following reasons: The failure is due to the undermining of the toe of the slope coupled with the increase of shear stresses due to rainfall, and a rigid structure can accommodate such failures; The free height of the retaining wall to be provided will be short as much failed soil mass shall be removed by flattening of the slope or reducing the overall slope angle; Construction material selected fill, can be produced on-site at reasonable distances and good workmanship can be achieved.

The use of clay backfills is not recommended because of problems associated with swelling, shrinkage, and consolidation of clay. Backfills composed of uniform silts should not be used, as these materials are very difficult to compact. For backfills composed of fine soils, adequate drainage should be provided to prevent the build-up of water pressure. Free-draining granular materials usually do not warrant the same amount of attention in this respect but may still require protection by properly designed filters.

4. Conclusion

The conditions to ensure a possible control of a slide detailed knowledge on geological, hydrogeological and geotechnical conditions and parameters for understanding of the behaviour of the landslide mass and efficient modelling of its behaviour in its natural state and after control works. Landslides in road segment, particularly along the Gebre Guracha – Lumame road has been a common problem, especially during the rainy seasons. Rising ground water in the rainy season, the ground water table rise from 1m in rainy season. The rising water table is due to infiltration of surface runoff, so controlling of the infiltration process using different remedial techniques to minimize the subsurface problem. Dynamic load due to vehicles, i.e. the external forces due to large vehicles apply additional forces on slope; this can be resisted by stabilizing the soil or supporting the slope the retaining wall.

Geotechnical parameters that determined from the laboratory experiments in range LL 58-63%, PL 28-35%, PI 24-34%, Gs 2.80-2.84, and also unit weight and shear strength parameters of the study site was determined. Unit weight and shear strength parameters were used in slope stability analysis for the determination of the critical factor of safety and radius by using geostudio2012/slope/w software. The critical factor of safety, Bishop-1.17, Jambu-1.11, Morgstem-price-1.17, ordinary-1.12 and spencer-1.17 and radius for all analysis methods were 32.889m.

Hence, detailed investigation of the type of landslides and the materials involved in the slope instability and identification of the causes of the slope instability are necessary for the developmental works in the area. A detailed slope stability analysis gave the opportunity to analyze slopes individually, and to understand the causes for independent slope sections. This will also be helpful to find a better remedial measure, because different slope sections may have different mode of failure, and may involve different engineering materials. The soil tests do not show that the slope is safe. The road failure leads by rainfall and runoff (bank), erosion of the slope toe.

The back-analysis shear strength parameters at slope slide locations were obtained from laboratory test and field identification for the use of limit equilibrium 2D analysis. The results of back analysis shear strength values (unit weight, cohesion and angle of internal friction) at the slide locations are 20kN/m3, 47.87kPa and 12.60 respectively.

5. Recommendation

The selection of appropriate mitigation measures should be based on an assessment of risk, uncertainty, possible consequences, constructability, environmental impacts and costs. In this research, the remedial measure was described, to apply this remedial measure in the slide area use all criteria's that mention in this paper. In this study the ground water investigation was done by using one bore hole and the two domestics well were used that found around surrounding of the sliding area, so it should be detail investigated the slide area to get the accurate ground water table depth.

Two-dimensional limit equilibrium analyses were used to calculate the factor of safety of the failed slopes at respective slide locations. Accordingly, the shear strength values obtained under this study were conservative. However, for design of remedial measures, especially restraints work, the shear strength values obtained from the use of 3D finite element analysis methods which consider the three-dimensional end or side effects should be used.

To protect the level of stability of a landslide or mitigated area from not being decreased over time, it would be prudent to place conditions on properties in the landslide area to prevent changes that could potentially cause landslide reactivation, partial reactivation or further instability. The area of concern would extend a reasonable distance uphill and downslope of the landslide area, which could be determined by stability analyses.

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