Improvement on Geotechnical Failures at Erap Bridge Embankments

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Abstract

The bridges along highlands highway of Papua New Guinea were Erap Bridge is also found have been constructed from two distinct types known as steel gaiter concrete bridge and bailey bridge. These types of bridges commonly found throughout the country with piers on a long span or no piers on narrow channels, which may construct using different methods, but the procedure in which abutments establishment is slightly common where some features remain similar. Before the construction of the bridge abutment, soil manipulation within the maximum of 5 meters depending on the strength properties of soil structure is normally prioritized. Geotechnical analysis of the initial phase for progressive works is paramount as the entire structure depends on effective static performance during its service life. The selective and approved materials to be used is important for backfilling; however, it also reveals the use of right Geotechnical material is necessary for consistency of abutments for its durability and achieves maximum design period.

Keywords
Abutment: Bearing Capacity: Failure: Geotechnical: Structure.

1. Introduction
There are many defects associated with the failure of bridges, as observed by various sources or experts. The flaws or defects include scouring, lateral load pressure, earthquake, temperature, soil foundations, and off-course floods, and other natural causes, all of which contribute to the abutment failure. This dissertation article will emphasize the improvement of abutments and materials required to improve the construction of the substructure and, importantly, soil stability by maximizing its bearing capacity in Erap Bridge.

The loads and moments from abutments and the bridge are transferred and distributed across the span. When the foundation is weak due to the dissipation of water through pores beneath, it is most likely that settlement of abutments propagates when the weight of structure presses the pore holes, thereby displacing pore gaps and such may be continuous. In overtime, consequences are catastrophic. Research by (Authority, 2019) concluded that dead loads, superimposed loads, including moments transferred down to footings where the vibrations due to lateral forces and natural movements impacting the structure are absorbed. It is necessary to ensure applied footing pressure does not exceed allowable bearing capacity of soil beneath in which the footings established. The bearing capacity failure occurred when the shear strength of the earth exceeded. Thus, consequences are immediate excessive movement on overlying bridge and approach.

It is also useful to consider natural impacts on the abutment basements or superstructure, such as a change in temperature, floods, earthquakes, and landslides. The investigation will then conclude with the best method of improving the foundation structure of the proposed bridge. Furthermore, the study will elaborate on with recommendations as to how the foundations can treat with advanced engineering materials for the best of its design in years to come. Further still, the investigation of improvements on bridge abutments' geotechnical failures with the agreed cost-wise and within budget and time to yield the best possible outcome. The construction of a dam or bridge foundation before abutment construction is one of the most critical stages of bridge active's stability and its ultimate rigidity. The dam plays a significant role in upholding the superstructure without failing its design life as long as the initial construction is given the best attention right from the beginning until preparation for abutment construction. The solidarity or compaction and consolidation of substructure depend on the amount of effort spent, the composite of materials used, and precise cost budgeted, including advance construction methodology or materials for improvements without failure.

Research by (Hawkins and Rende, 2018), revealed that when live loads transferred down from the abutments, forces are distributed within the zone of influence and disseminates throughout foundation uniformly where the bearing capacity of transverse soil foundation is capable of withstanding or containing the loads transpired. The careful and practical approach is necessary and taken intensely to ensure the shear force does not supersede the soil's bearing capacity, which ultimately defends the earth from depression creaks, crumbling shrinkage, and other geotechnical failures.

As affirmed by (Mohamed K. ElBatanouny, Ph.D., S.E. *et al.*, 2020), that vital factor inducing the size of performance on bridge approaches necessarily depends on the foundation soil engineering properties of filled abutment and embankment. Practical surface inspection is necessary and essential for the benefit of its service by thoroughly analyzing soil and its constituents. Compared to gravels or sands, clays and slits exhibit long-term compression and settlement (consolidation). Figure 1 and 2 shows a side view of bridge abutments and possible rectification ideology on its substructure.

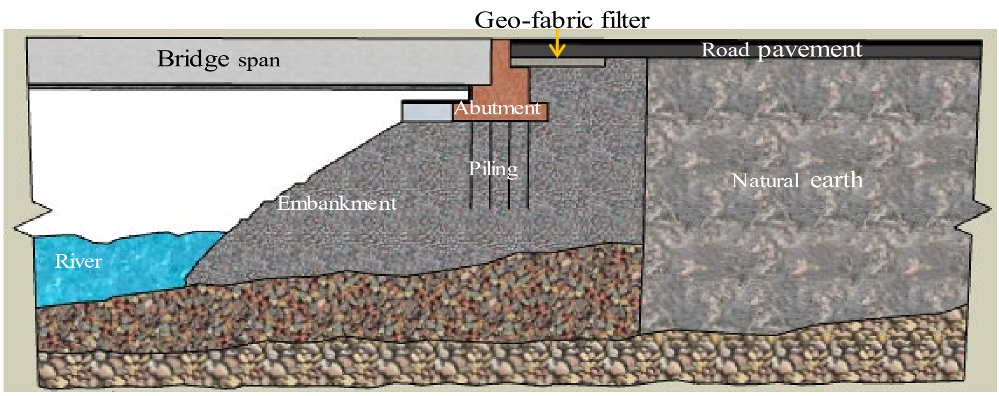

Figure 1. Drawing depicts the Erap bridge to be rectified per the image

The images above reassemble more likely Erap bridge as recently establishment structure. However, invading soil foundations as depicted server threat to the foundation where the continuous floods on the Markham planes may wash away Lae approach abutment due to its current progress of constant embankment displacement and depression. The persistent waves hitting the basement have gradually encroached the granular soil particles, causing a massive movement of both abutments and gabion protection walls. The bridge is susceptible to confronting server nightmare through actions of nature as the dams are already undermined and associated depression and collapse of protection walls. The sub-abutments (flexible abutments) (Institute, 2013) observed are subject to significant disaster on Lae approach abutment where encroaching efforts from floods drastically eroded the basement leaving gabion baskets defenseless and hanging. The soil bearing capacity no longer performs its active role in maintaining stability. The erosion underneath continues to affect the basement where maximum shear failure is imminent and already occurred.

The erosion alongside natural walls by steady pressure from water particles has subsided the basement walls, affecting the entire structure on the bridge. It's a natural phenomenon that seemed unstoppable when rectification measures delayed on this structural link. The earth particles dissolved very rapidly, where drastic forces from water release a massive blow towards the foundation, as observed per our physical visit to Erab bridge. The structure depicts a prototype drawing of the Erap bridge foundation and abutment, as shown in Figure 2. The magnitude of river extended as far as both bridge abutments where cause of failure is believed to be from the activities of nature including earthquake. No overlap of the basement remains unoccupied and thus, the structure is into the verge of extreme pressure and force which will most probably be subject to the natural failure.

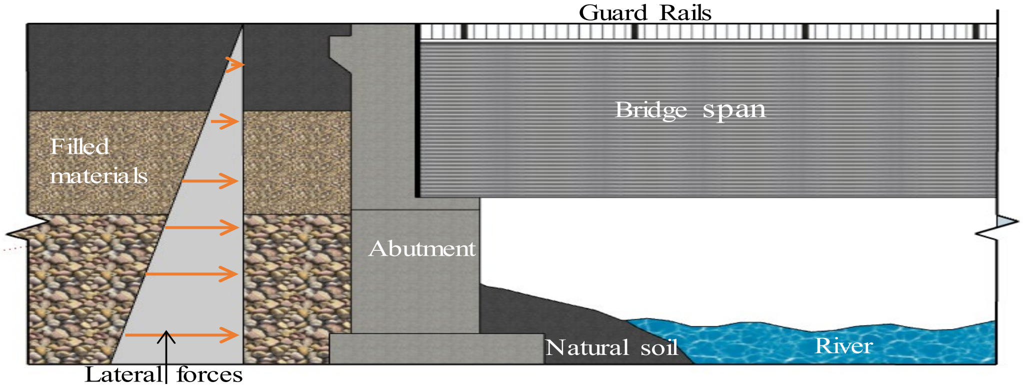

Figure 2. Forces acting on the structure establishment currently on Erap Bridge

Erap Bridge is a steel gaiter concrete bridge where four reinforced concrete piers are aligned vertically to support the weight of the load, including live charges. The bridge constructed on a downstream of Erap River, where the channel is narrow and suitable for quick access. However, due to continuously flooded during its service life, Erap River has drastically reclaimed upstream and downstream, leaving the bridge confined to its protection walls. The current natural cause will surely induce catastrophic damages to Lae approach embankment. The soil is found to be granular and loosing despite compaction measures taken during construction; the gravels hardly compacted due to its maximum porosity existence. No clay constituent thus demonstrates poor binding properties where the continuous stress exerted by flood has subsided both embankment bays and cause a substantial impact on the structure. According to (Nmdsg-, 2006), minimal deterioration effect and more cost-effective are characters of integral abutments (flexible or movable abutments), thus such is preferred often compared to non-integral abutments or stub/fixed abutments. The abutments experience longitudinal deflection from temperature changes as bridge gaiters embedded in integral concrete abutments.

Thus, void development is induced due to deflection abutment-backfill interface and settlement between the bridge and the approach slab (Monuments *et al.*, 2011). The dam behind abutments is more susceptible to erosion due to voids, which ultimately encourages approach slab settlement and the formation of a bump. Strategies for preventing cracks included (Barker *et al.*, 1990). Preloading may improve soil foundations; the elasticity of soil improves as backfills of suitable selective materials that left a limited number of fines are easily compacted, thus erosion-resistant; the improvement due to selective backfilling develops weak materials susceptible to erosion or settlement including reinforcement and compressible and collapsible materials in embankments; instead of driving piles, footings or another shallow used in abutment; provides efficient drainage and surface for the comfort ride of road users.

Affirmed by (Horvath, 2000), integrally reinforced approach slabs intended to mitigate bump development by minimizing differential settlement, permitting expansion, and preventing surface water from entering the dam. Thus, it is necessary that approach abutments soil strata to be expertly constructed to attain its solidity and minimize potential settlement due to lateral forces and vibrations to traveling vehicles, as shown in Figure 3.

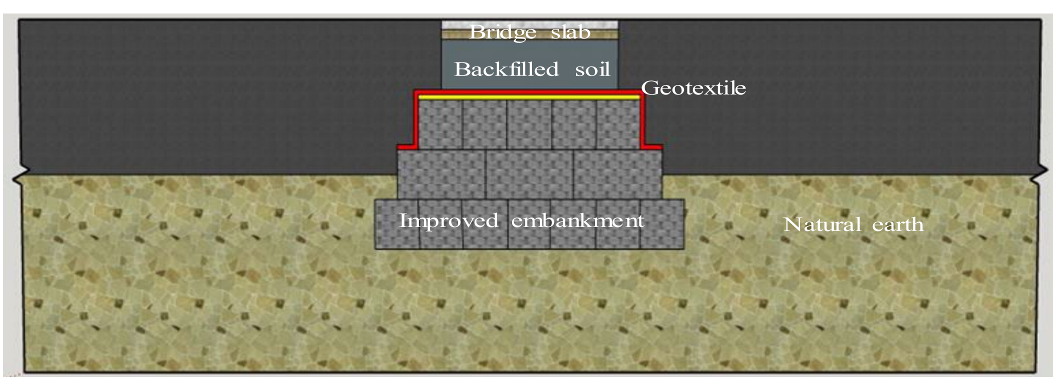

Figure 3. Possible rectification ideology necessary taken at Erap Bridge

The objective of the paper is to conduct an extensive investigation into analyzing the cause of the dam or geotechnical failure on Erap Bridge. The detailed study on the named bridge includes visual inspection, Geotech tests, and the best available information. As per the site visit, obvious causes spotted without much difficulty are subject to the scoring of bridge abutments and piers. Scoring is one of the leading reasons for failure which, when neglected, results in catastrophic collapses. Continuous floods drastically bang on the embankment walls, interacting with compacted soil every second causing land to be saturated and weak.

When water infiltrates through the allowable porosity, walls eroded microscopically at a constant rate every second. This happens for almost all year round. As such, the river banks crumbled and held loose, thus dissolved into the water, creating a underwater cave and hollow where the dam is vulnerable to crumble. Weight of existing huge lumps, including substructure or superstructure pressured on the barrier, where it no longer sustains its pressing stress. Thus, the result was tedious and server as observed on site. The exposed and vulnerable or weak abutment exposed without rigid support from the dam has seen to have been weak. Terrible consequences expected ahead when timely rectification processes not provided, as shown in Figure 5 possible corrective measures need to take, as demonstrated in Figure 4 and 5.

Figure 4. Hanging abutment without support (left), crumbled embankment from steady erosion (right)

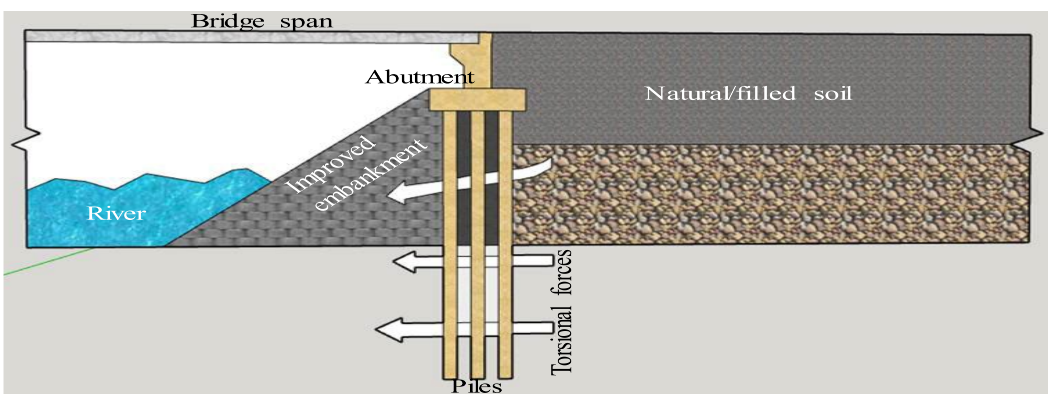

Figure 5. Provides a construction methodological approach to rectify the structure

2. Objective

The objective of the current study to improve scouring on from within the base or substructure, which leads to a drop-in approach bridge slabs by analyzing its source from the foundation to superstructure in Erap Bridge. The investigation includes rigidity and solidarity of the abutment through effective embankment performance. The transfer of lateral loads or abrasive forces excreted by moving trucks every day is distributed evenly for the best of perfect bridge performance. Tests have conducted both on-field and laboratory to substantiate findings to recommend for possible rectification approaches by appropriate state agencies or donor partners in line with proposed drawing, as shown in Figure 6.

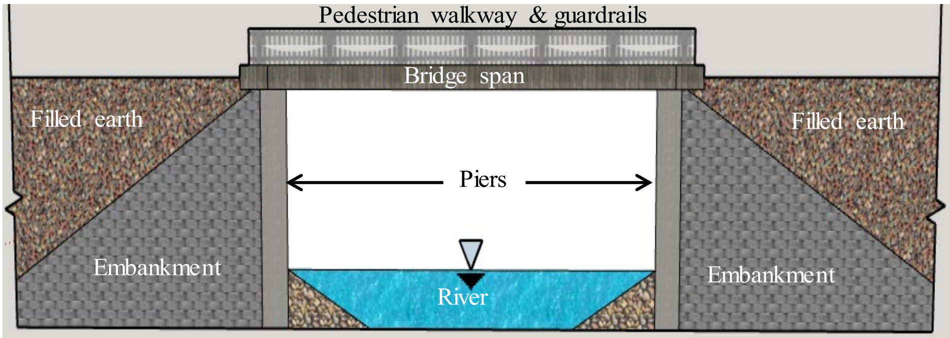

Figure 6. Drawing resembles piers to be inserted on each approach when rectified.

The study will encompass the origins of geotechnical failure and possible dissemination throughout the entire bridge component, which results in depression and shrinkage on approach slabs. Other essential factors to be considered shall include a thorough analysis of different layers of soil, which requires or does not require proper development through the addition of foreign approved materials to displace the excavated unsuitable earth for better foundation treatment

3. Methods and Materials

On proposed samples collection site, (Erap Bridge) for improvement on Geotechnical failures along Lae approach embankments, there were adequate quantities of bags collected for test samples. The samples were collected on either approach for practical test and recommended for a quality engineering approach to continual combat encroachment on both side basements. Erap River is untamed and flows vigorously through all angles when flooded. When it continues for a more extended period, the side dams are subject to erosion and crumble; thus, eventually affecting structure as exactly encountered as observed during our site visit. The interest of the study remained steady to understand the cause of bridge substructure failure. We have collected samples for tests, which include; Particle sizes distribution test, California Bearing Ration, Atterberge test, Liquid Limit, Plastic Limit, and Shrinkage limit test. Tests were then implemented forthwith per the above listed.

3.1 Dynamic Cone Penetration Test (DCPT)

The dynamic cone penetration test is the fastest and cost-effective method to determine the strength of compacted pavements/embankments of any structure's nature. The analysis customarily performed to compare and evaluate laboratory tests' conclusion to understand the nature of soil constituents and strength properties ('Bridge Procedures and Design Guide', 2018). Initial reading has recorded on the dynamic cone penetrometer scale. Compute the value of the penetration (in mm) for every blow by previous text recorded from the current. Compute the cumulative depth of penetration for every bump through the addition of last each depth of penetration as pictured in Figure 7-9, and associated graphs plotted as shown in Table 1 and Table 2.

Figure 7. Dynamic cone penetration test (DCPT) on Erap Bridge site

Table 1. List of data and associated CBR (%) /ABC (kPa) values from the DCPT field test

Goroka-Side Bridge Embankment (DCPT)

Depth (m)	Field Data (mm/Blow)	E' Value (100mm/Blows)	CBR (%)	Allowable Bearing Capacity (kPa)
0.0	0.0	00.00	00.0	000
0.1	3.0	33.00	06.8	100
0.2	5.0	20.00	12.1	150
0.3	5.0	20.00	12.1	150
0.4	3.0	33.00	06.8	100
0.5	5.0	20.00	12.1	150
0.6	7.0	14.30	18.2	170

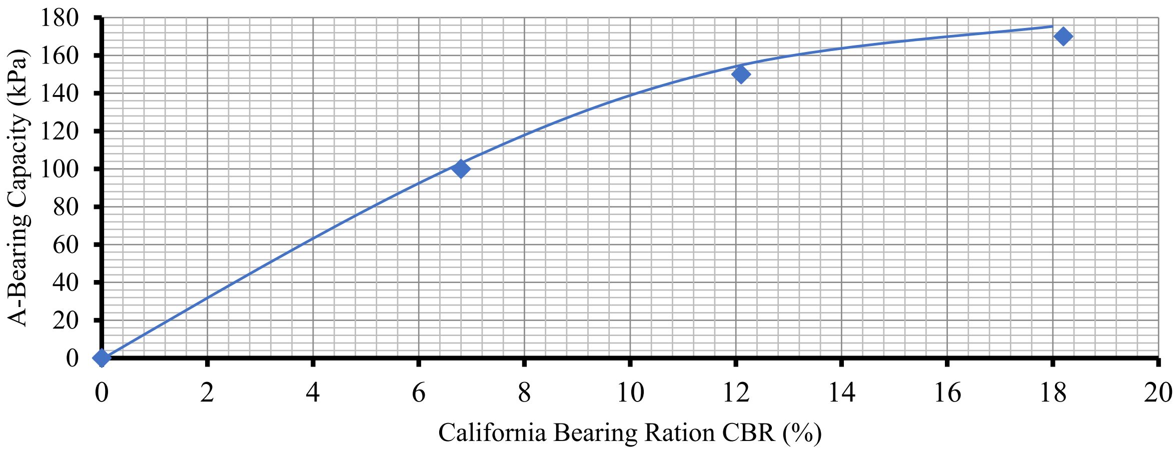

Figure 8. CBR (%) versus Allowable Bearing Capacity (kPa) from field test

Table 2. List of data and associated CBR (%)/ABC (%) values from DCPT filed test

Lae-Side Bridge Embankment (DCPT)				
Depth (m)	Field Data (mm/Blow)	E' Value (100mm/Blows)	CBR (%)	Allowable Bearing Capacity (kPa)
0.0	00	00.0	00.0	000
0.1	03	33.0	06.8	100
0.2	02	50.0	04.3	065
0.3	06	16.7	14.6	180
0.4	07	14.3	18.2	170
0.5	07	14.3	18.2	170
0.6	13	07.7	34.4	257

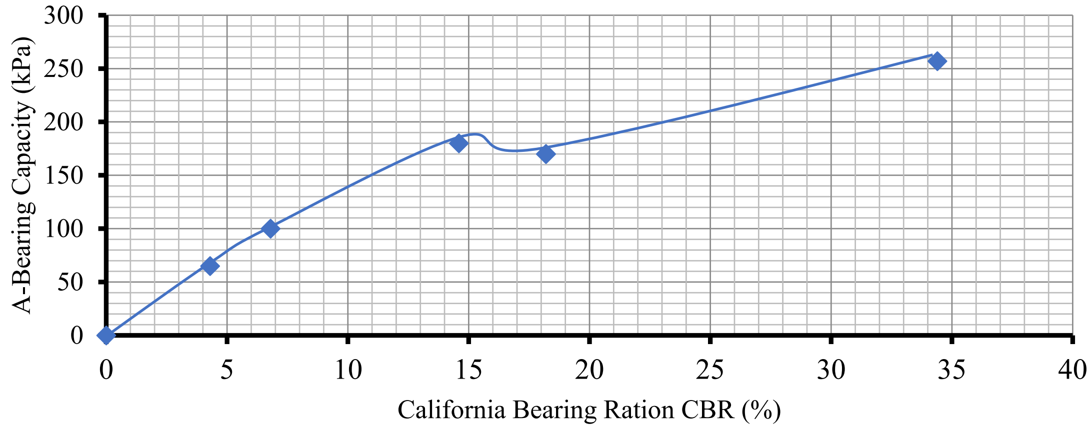

Figure 9. CBR (%) versus allowable bearing capacity (kPa) from field test

Thus, the site's possible result derived and evaluated suggests that both sides of the dams have adequate compaction but penetrated through allowable bearing capacity, which means no clay particles for sufficient cohesiveness and binding or consolidation. The CBR values again fall between 6.8% to 34.4% on Lae side while 6.8% to 18.2% on Goroka side, which means less strength attained and less consolidated as depicted in Figure 5. This further resembles that materials were weak and porous with the nil existence of clay for active binding and cohesiveness. This is correlated and concluded in the same approach as with the lab test.

3.2 Particle Size Distribution Test (PSD)

The particle size distribution test customarily conducted to determine a particular site's material properties. It further determines and resembles the size of soil present in a specific location. PSD tests conducted through a range of procedures and maximum allowable time required effectively completed to attain the expected quality results. In Lae, the preparation and the steps for the particle size distribution (PSD) test analysis in depth of Erap bridge embankments as follow: The samples collected were air-dried on an open rectangular steel tray for four days on either path; two separate plastics were also collected on both sides for moisture content through oven-dried; samples then sieved through different sizes of sieve bowls from 75 mm to 32 micro millimeters; sieved particles up to 9.5 mm even distributed through 250 grams each for both sides and oven-dried for effective dewatering from a soil sample. Results are then calculated and noted in lab sheets for further testing to calculate moister content (Figure 10).

Figure 10. Oven dry samples (left), air dry samples (right)

3.3 California Bearing Ration

The California bearing ratio (CBR) is a test carried out to determine the strength of the soils layer and to conclude whether or not the earth has enough power to withstand pressing shear load from the structure. This also associates to determine if the bearing capacity of the soil is greater than the maximum force applied, which may not cause shear failure.

There were two distinct tests conducted on the preparation for geotechnical improvement on Erap bridge embankments. One has done on-site while next effectively performed in the civil engineering laboratory. The current work focus, which is to improve geotechnical failure on Erap Bridge and recommend possible conclusion, all tests were allowed equal focus and attention. Procedures undergone includes but not limited to; The two specimens, each of approximately 7.5 kg, have been compacted generally with 53 blows in a mold. Initially, the weight of an empty shell is taken from the balance in grams (g) and recorded. Water has been added to the first sample and compacts it in 3 layers by giving 53 blows per layer. The collar is removed after compaction and leveled the layer. The moister content determined by taking samples. Weight of mold noted plus compacted specimen. The pattern plus specimen is placed in the socking tank for four days as seen in Figure 10 as ready to be submerged into the tank after gauge reading (Figure 11).

Figure 11. Before shocking (Gauge reading)

The next approach samples conduct by repeating the same technique. Before socking in the tank, the swell reading noted. After four days, again, take the swell text and find the shrinkage difference in percentage. Next, allow water to dehydrate from mold, thereby removing from the tank. The specimen was removed after four days of socking, placed under the CBR penetration machine, and applied the load from 1Newton every interval of between 0.5 mm, 1mm, 2 mm, 3 mm, etc.

Figure 12. Ready for CBR penetration test (left), after penetration (33 mm depth)

Now multiply the load by proofing ring factor (0.0547345) and plot the reading to generate the CBR graph. Drawing the graph between the penetration (mm) and penetrating pressure (N) and find the value of CBR at costs (2.5 mm and 5 mm)**.**
Drawing the graph between the percentage CBR and dry density, and find CBR at the required degree of compaction.

3.4 Atterberg Test

Atterberg test is the combination of plastic limit, liquid limit, and shrinkage limit. This test performed to determine whether or not the soil as maximum moister content and visible portion of clay particles content. Moister content often determined in four stages, namely; solid, semi-solid, plastic, and liquid. The possible test we could go to was the shrinkage limit test. The analysis depicted zero moister content, which does not allow the trial to proceed further to the plastic and liquid limit. Thus, we stopped in shrinkage limit. Test procedure performed in the following manner (Monuments *et al.*, 2011).

The mass of particles retained from 32 micro millimeter dish mixed with water. Then, the mixture tilted several times and packed into a shrinkage rectangular-shaped steel bowl. Shrinkage determines that further water loss will not reduce the volume of soil patched due to adequate water content. Collect results and noted, which shows much reduction in shape or size, thus considered non-plastic, as shown in Figure 13-14.


Figure 13. Tilting samples (left), packing in steel bowl (right)

On Goroka side embankment or dam, the materials were concluded to be non-plastic as detected from visual inspection and felt through hands. This is because the gravel demonstrated pure river-sands with nil binders that may allow for perfect cohesiveness, thereby high moister content due to maximum porosity (Barker *et al.*, 1990). Thus, it was not glued together even after adequate compaction. The river particle continuous interaction has resulted in erosion and the abutment as seen hanging and vulnerable to catastrophic disaster if reliable agencies do not rectify in time. Thus, we disregarded the test because it has small binders found that will have no use even if proceeding to other criteria, thus limiting our analysis to shrinkage.

On Lae side dam, we have done a practical test to re-evaluate the plasticity of the samples. Thus, the full procedural test of atterberg has conducted to analyze all levels of analyses. The results were again as unsatisfactory and failing due to limited binders. The samples also concluded as non-plastic material; thus, the maximum porosity has been analyzed this time through the test (Bureau, 1999). The procedures executed in the following manner but this time for the liquid limit test; The same procedures as in the first instance, the Casagrande cup was packed with moister soil samples to half its spherical. Cut through the center by "V" shaped groove using as in standard procedure. Then the cup dropped from the height of 10 mm at a rate of 2 drops per second. The separated half of the soil on the cup meets each other in less than ten counts. The ground was considered less binder and crumbling, thus meets its end in less count, as shown in Figure 14.


Figure 14. Depicts casagrade cup full of soil for liquid limit test

4. Results & Discussions

Of the test conducted, results are designated in summary (Lae side). The finalized values of moisture content test to determine CBR rations and graph (Figure 15 and Figure 16).

Table 3. Final values from proceeding test to evaluate CBR graph

Dry Density (t/m^3)	2.01	2.04	2.11	02.08
Moisture Content (%)	3.25	6.36	9.28	12.43

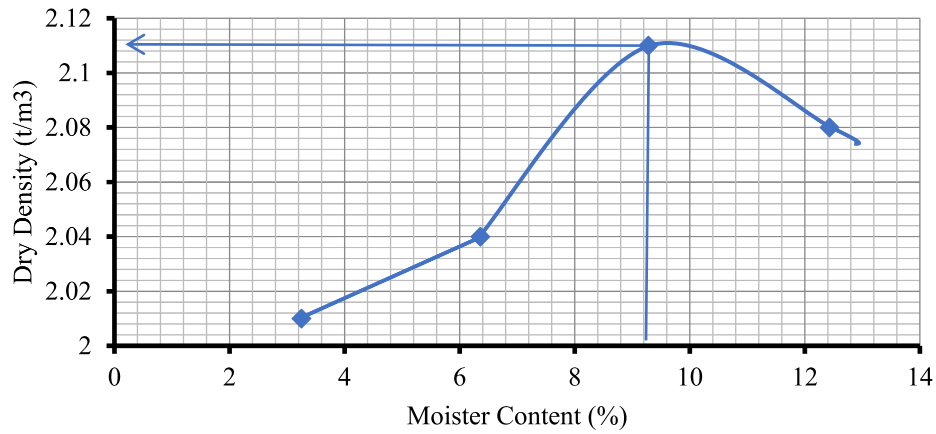

Figure 15. Moisture content against dry density from lab test as presented in Table 3

At 9.28 % moisture, the dry density at maximum is 2.11 t/m^3. The material is non-plastic or nil clay particles for cohesiveness and paltry binder constituent. As such, the filled materials turned to be losing or maximum porosity and crumbling when a flood hits embankment wall. Require an effective combination of selective equipment to reflect better-consolidated embankment (Institute, 2013).

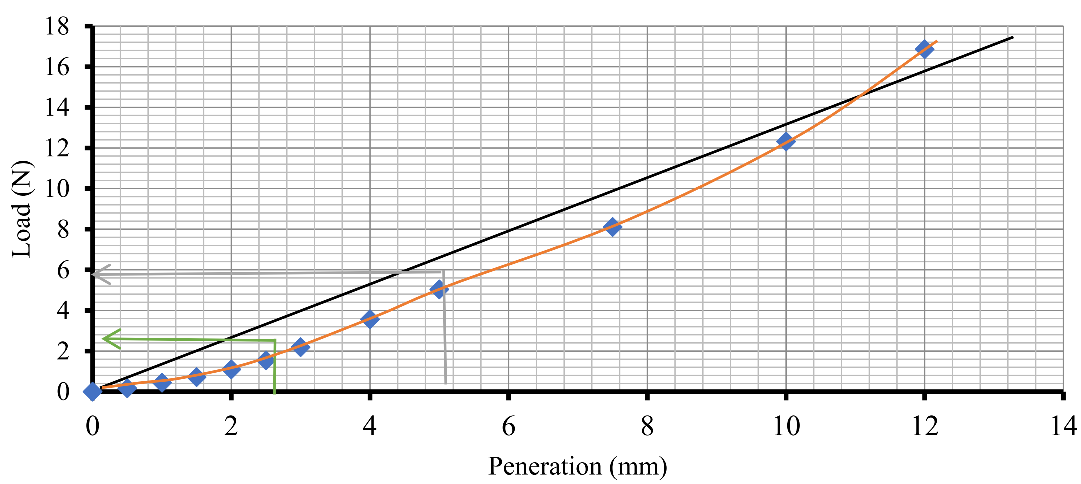

Figure 16. CBR graph, load (N) versus penetration (mm)

Now Formula: At $P_{2.5}$ = —— & P_5 = ——

$Where\ N = Load\ (N)\ from\ the\ Graph$

$At\ 2.5\ mm = (3.8/13.2)x10 = 28.78\%$

$At\ 5\ mm = (6.59/19.80)x100 = 33.36\%$

This means that shear strength does not vigorously counteract the load when applied. Because the materials were weak and porous with nil/fewer clay particles to reinforce the soil, weight quickly penetrated. Optimum and suitable materials will typically withstand the applied shear force, and thus results will be above 50 % demonstrating solidity and rigidity of soil (Nmdsg-, 2006). In Goroka side, the finalized values of moisture content test to determine CBR ration and graph as indicated in Table 4 and Figure 17.

Table 4. Final values from the proceeding test to evaluate CBR graph

Dry Density (t/m^3)	2.04	02.07	02.12	02.08
Moisture Content (%)	9.21	11.26	12.26	12.85

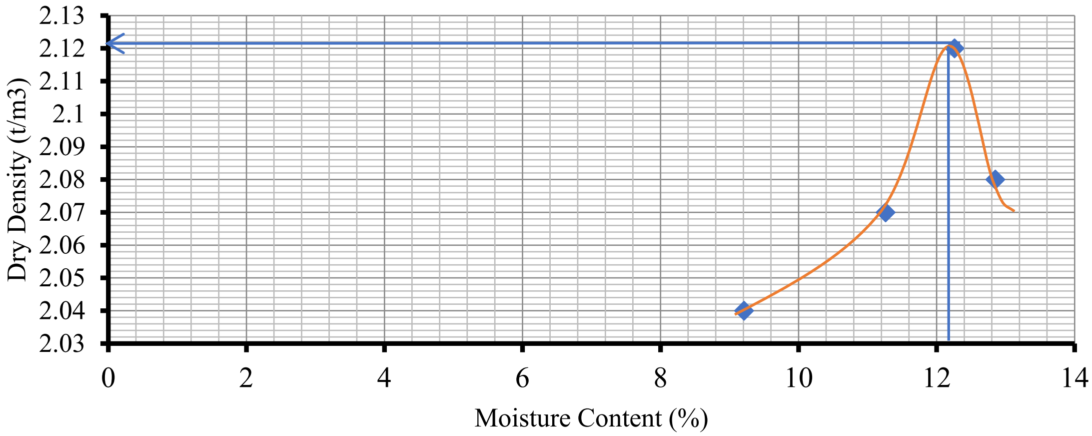

Figure 17. Moisture content (%) against dry density (t/m^3) from lab result test

Again, the same results have presented. In good cohesive soil, the graph will depict a semicircular diagram. However, the acute Figure resembles that there is much less or zero existence of binders, thus increase in porosity and naturally crumbling hence presence in moisture at its highest (Mohamed K. ElBatanouny, Ph.D., S.E. *et al.*, 2020). At 12.26 % moisture, the dry density at maximum is 2.12 t/m^3. They highly recommended that the mixture of clay soil with effective combinations of selective materials reflect better-consolidated embankments (Figure 18).

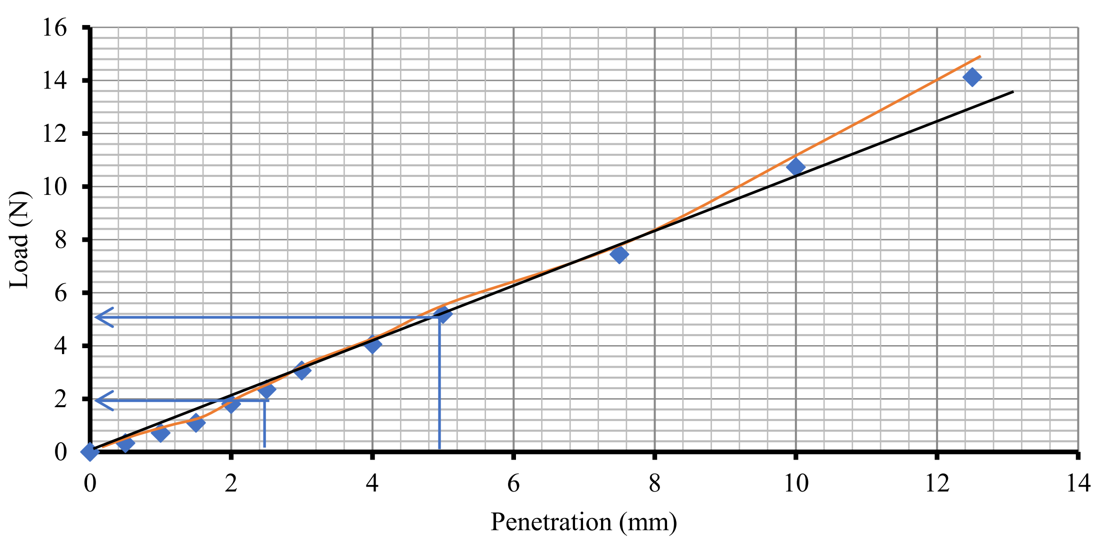

Figure 18. CBR graph of load (N) against penetration (mm)

Now Formula: At $P_{2.5}$ = —— & P_5 = ——

$Where\ N = Load\ (N)\ from\ the\ Graph$

$At\ 2.5\ mm = (2.59/13.2)\ x100 = 19.62\%$

$At\ 5\ mm = (5.59/19.80)\ x100 = 28.80\%$

Again, it shows that the shear strength does not vigorously counteract on load when applied and is much weak and more porous sand gravel than Lae side (Authority, 2019). Because materials were of zero clay existence as depicted by the test for optimum soil stability, the load is easily penetrable compared to Lae. The combination of clay will typically produce enough consolidation and suitable materials that usually withstand applied shear force or shear strength and, thus, less than bearing capacity. The results will be above 50 %, demonstrating solidity and rigidity of the soil. However, this does not ensure due to weak material with reduced binding due to non-cohesiveness obviously from no clay constituents.

5. Discussion

As noted from the results and visual inspection, there is still major improvement required at earliest time possible to avoid catastrophic disaster imminent ahead. Thus, to minimize further deterioration and embankment failure which will definitely affect abutment and entire bridge, following discussions are necessary.

Proper compaction and selective backfill materials in mixture of clays and river gravels are required for effective consolidation and compaction. It was observed that the Erap river when floods, drastically subsides embankments base, thus erode and interact with loose or porous particles which results to crumble. Thus required to tame from upstream. Necessary to use geo-grids for possible compaction and rigid gripping. The lateral transverse stress will be distributed evenly and minimizes side erosion. Proposed for concrete reinforced walls on each sides to protect embankment walls. Tones of stone boulders are needed for backfills. Proper and adequate river training works required for both upstream and downstream about 50m from embankments (Horvath, 2000). Necessary to allow plants or tress to grow within the vicinity of bridge embankments. This is because when their roots and leaves decay, it dissolves into the ground and infiltrates through and mix with gravels and thus becomes clay which will enhance and facilitate proper compaction and ultimately becomes binders which develops through years. Such will consolidate embankments and thus, becomes rigid and consolidated. Reliable agencies to pay regular visit is necessary Funding's should be allocated for similar bridge throughout highlands highway to improve embankments

6. Conclusion

Generally, as per our visit to the site for sample collection, we have discovered that the side embankments have gradually eroded to a point where the entire bridge will fail or collapse and crumble. All necessary tests implemented to derive reliable conclusions from avoiding mere engineering recommendations and judgments (Hawkins and Rende, 2018). The laboratory tests equally performed in a paradigm order. However, Liquid Limit and Plastic limit test have not been able to proceed through as the other trial did not guarantee further deliberation; thus, materials were non-plastic. Therefore, the materials were concluded less plasticity or zero clay presence for active binding and consolidation. This is because; the test results revealed that the following notions were correct and valid.

The soil is generally porous with 95 % river gravel and stones. No clay composition for sufficient cohesiveness and proper consolidation. The porosity of existing embankment is relatively higher. No fine constituents as in clays were mixed or combined with river gravels for perfect compaction or improved cohesiveness and consolidation to ensure the survival of foundation. More compactions have been attempting during construction but equally failed with time due to no selective materials like clays combined for proper binding and perfect consolidation. If the respective authorities do not attempt to Erap Bridge quickly, the structure may crumble and disband from the public use.

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