# Causes of Damage of Rural Road in Coastal Areas of Bangladesh

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**ABSTRACT:** Developing countries spend a lot of budget each year for elevating, widening or repairing the existing coastal rural roads. These rural roads are constructed for a design life of 10 years. But these low volume roads loose serviceability within two or three years. To find out the reasons of less sustainability, different rural road sites in coastal region were visited by the authors and sandy soil (used for Improved Subgrade) and clayey soil (borrow pit soil used for side slope and shoulder) were collected from 28 sites. Grain size analysis, liquid limit and plastic limit of collected samples were determined. Fineness Modulus (FM) of sandy soils ranged from 0.00 to 0.50 and the most borrow pit soils are lean clay. Dynamic Cone Penetration (DCP) tests were conducted on pavement and shoulder. The test results were analyzed and compared with the Local Government Engineering Department (LGED) recommended DCP values for rural road by employing the AfCAP LVR-DCP software. It is found that the DCP values of base under pavement and shoulders were inadequate. Several reasons were identified which are responsible for less sustainability of rural roads. The reasons are use of unsuitable material, poor compaction, borrow pit location at toe, vehicle movement over soft shoulder, consolidation settlement due to soft soil under road embankment, inadequate design of palisading and slope protection, erosion of side slope by wave action. A new road widening methodology is proposed for making sustainable rural road in coastal areas of Bangladesh.

**KEYWORDS:** Unconfined compression test, Shear strength, Lime, Fly ash, Slag, Rural road, Compaction, DCP.

## 1. INTRODUCTION

The transportation by road is the only mode which can give maximum service to rural people of Bangladesh. Considering economic growth and social benefits, efficient road network is a very important issue. Transportation is vital for economic development of any region since every commodity whether it is food or clothing, industrial product or medicine, need transport to all stages from production to distribution. Especially in rural area, with the sustainable development of road can bring tremendous outcomes in the field of agriculture, industries, education and health care. As per Local Government Engineering Department (LGED) report of 2016-2017 (October 2017), they have constructed a total of 832 km Upazilla road at a cost of 127 million US dollar, 1872 km Union Road at a cost of 143 million US dollar, 2496 km Village Road at a cost of 308 million US dollar.

The design life of the rural road pavement is 10 years (Road Design Standards of LGED, 2005). But most of the rural roads damaged within 2-3 years as per road users' opinion. Every year huge amount of money is used to maintain or repair the rural roads. In Figure 1, the total maintenance cost of last ten years is shown.

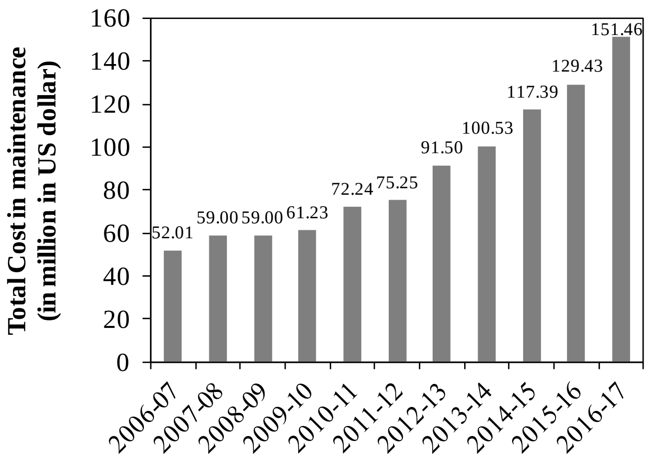



Figure 1 Yearly rural road maintenance cost (LGED, October 2017).

Road construction and maintenance works have activities that produce $CO_2$ directly or indirectly, such as, use of burned clay bricks (to make 1 ton burnt brick, 70 to 200 kg of $CO_2$ is released from brick kilns (Akinshipe & Kornelius, 2017)) in base and subbase. To reduce carbon footprint on earth, rural roads should be durable. Carrying of suitable materials has carbon footprint. Use of local material can also reduce carbon footprint on earth. That means the road which uses local materials and have long life can be termed as climate resilient road. Bangladesh is a riverine country. Every year huge amount of sedimentation takes place in coastal regions. In coastal districts of Bangladesh, suitable subgrade, sub-base and base materials are not available and the materials are imported from other districts.

Field investigations have been carried out to identify causes of road damages in coastal regions. In the coastal region of Bangladesh, there are 19 districts which cover 32% of this country and accommodate more than 35 million people (Huq & Rabbani, 2011). Three divisions out of the 8 divisions, namely; Dhaka, Khulna and Barisal of Bangladesh were covered in this study. Under those divisions, there are 12 districts (namely, Gopalgonj, Madaripur and Shariatpur of Dhaka division; Khulna, Bagerhat and Sathkhira of Khulna division; Barishal, Patuakhali, Barguna, Jhalokathi, Bhola and Pirojpur of Barisal division) and 83 upazilas under these districts. In this case study, randomly selected roads in rural areas were visited and the reasons of damage were identified based on visual observations and engineering judgement.

This paper focuses on the causes of rural road damage in coastal areas of Bangladesh.

## 2. FIELD INVESTIGATION

During site visits, authors observed that existing earthen roads are upgraded as shown in Figure 2. Earthen roads are widened using borrow pit soil from nearby land. 300 mm thick Improved Subgrade (ISG) is prepared using available local sand filling into box cut on top of the existing road. 150 mm thick sub-base is prepared using available local sand and brick chips mixed in 1:1 ratio. Then 150 mm thick base is prepared using brick chips only. 25 mm thick bituminous carpeting is done on base.

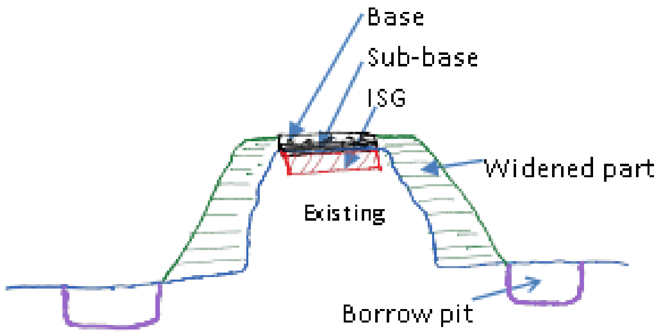



Figure 2 Typical rural road widening.

### 2.1 Soil sample

Borrow pit samples from randomly selected 28 spots in coastal districts are collected to classify the soil. Location of soil samples are mentioned in the legend of Figure 3 and Figure 4. If these soils can be used in ISG, sub-base and base with proper treatment using lime, fly ash and slag, sustainable environment-friendly rural road construction would be feasible. These soils are used to study the feasibility of their use as ISG, sub-base and base with treatment by mixing fly ash, slag and lime. Sand samples which are used in ISG and sub-base were also collected to see whether those meet the specification prepared by LGED. Grain size distributions of sandy soils are shown in Figure 3. Liquid Limit and Plasticity Index of borrow pit samples are shown in plasticity chart in Figure 4.

Among the 28 sand samples, 5 samples are poorly graded sand, 5 samples are sandy silt and other 18 samples were silty sand as per the Unified Soil Classification System (USCS) (Figure 4). The Fineness Modulus (FM) of 4 samples are more than 0.80, 2 samples between 0.50 and 0.80. Other samples have the FM ranged from 0.00 to 0.50. As per AASTHO, 14 samples are of group A-4, 7 samples of A-3 and of A-2-4 group 6 samples. Fines content of the sandy soil varied from 0 to 82%. Most of the sand samples did not meet the requirement of LGED specification. Due to unavailability of specified sand of FM greater than 0.80, contractors frequently use locally available very fine sand, silty sand and sandy silt in ISG and sub-base with poor compaction control. This is one of the reasons of unsustainable rural roads in Bangladesh.

Among 28 borrow pit samples, 6 samples were silt, 6 samples were fat clay and 18 samples were lean clay (as per USCS) (Figure 4). These soils are used in widened part and shoulder of embankment without compaction. Widened part is not integrated with existing embankment by benching and layer by layer compaction. As a result, shoulder and widened part of embankment is soft where vehicle runs frequently during passing over.

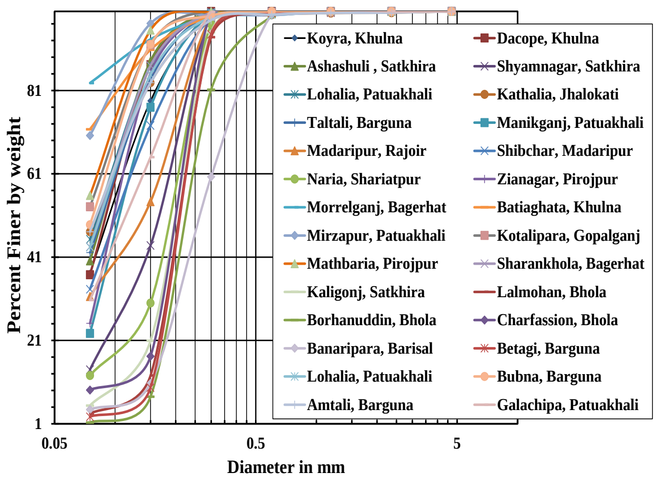



Figure 3 Grain size distribution of sands used for ISG and subbase in coastal districts of Bangladesh.

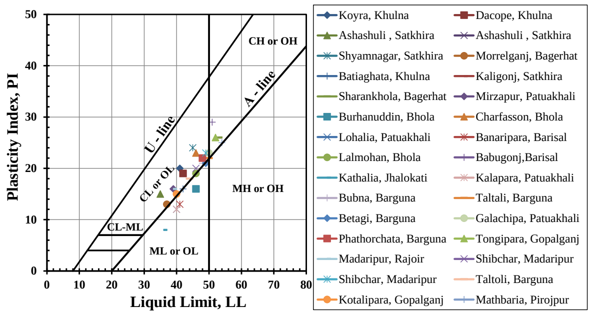



Figure 4 Position of borrow pit soil samples of coastal districts in the plasticity chart.

### 2.2 Sub-base and Base

Recommended size of the burned clay brick chips for subbase and base is 38mm down well graded brick chips (Road Design Standards of LGED, 2005). In many cases, it was found that 70% (by weight) of the total brick chips are larger than 38mm (see Figure 5). As per LGED specification, the ratio of the brick chips and sand should be 1:1 in subbase. In such a mixture, the brick chips become isolated and suspended in the fine sand matrix where property of sand dominates in stress-strain behaviour of the mixture. This ratio need to be revised based on experimental study using different mix ratios. In the field, more than 65% fine sand was found in sand-brick chips mixture. In the base, used brick chips are made from 2$^{nd}$ class clay bricks which are not properly burned in many cases. This type of brick chips are easily break-down during vehicle movement resulting rutting at wheel position of the road. These sub-base and base are responsible for rural roads with rutting, a lot of pot holes and damage.

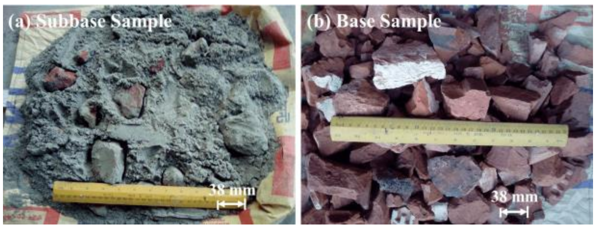



Figure 5 (a) Sub-base and (b) Base samples collected from Kaliganj, Satkhira

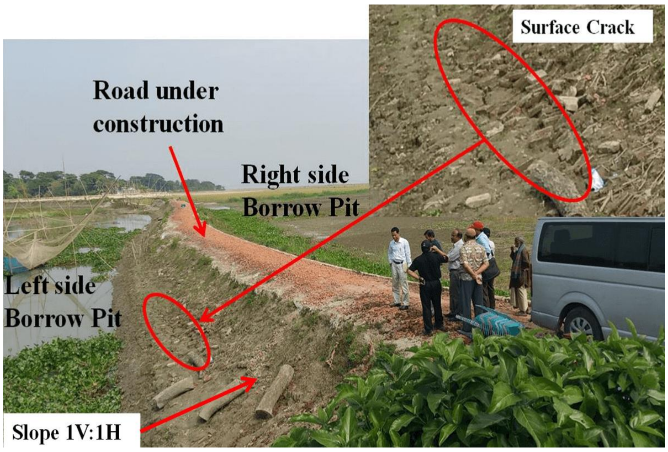
### 2.3 Moisture Content

One site was visited while the subbase construction was ongoing. There, brick chips and fine sand are mixed at a ratio of 1:1 to use as sub-base. After mixing, the samples were watered by the labours. The labours did not have any moisture meter to measure the immediate moisture content of the sample while rolling. They do not have any training or knowledge about optimum moisture content. They just water until the sample gets wet (see Figure 6(a)). Thereafter, the rolling is done (Figure 6(b)). It is possible to get better CBR value by maintaining the moisture content and proper compaction. So, better performance of road can be achieved by supplying the portable moisture meter and giving training to the workers, how to measure the moisture content and do better compaction.

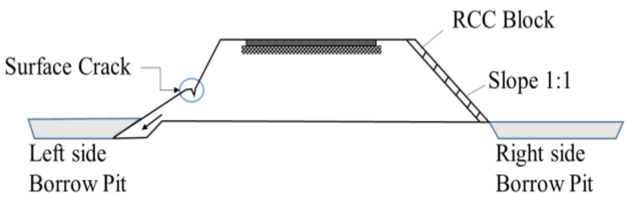

Figure 6 (a) Mixed brick chips and sand (1:1) in Sub-base and watering before rolling and (b) after rolling.

### 2.4 Side Slope

In most of the sites, side slopes of roads were found steeper (1V:1H) than the design value. Side slope of embankment mentioned in the Road Design Standards of LGED (2005) is 1V:1.5H for clayey soil, 1:2 clayey sand and 1:3 for sand or silty sand. Figure 7(a) shows a road at Bilaspur, Kaziarchar, Shariatpur. As the slope is steeper and the height of the road is more than 3.66 m, a surface crack was observed on the slope. To make it clear a real figure and schematic diagram is shown in Figure 7(b). Due to the steeper side slope and poor compaction, the crack also appeared on the shoulder of the road at Uttarpara, Uzirpara, Barisal (see Figure 8). Here, the Reinforced Cement Concrete posts were tilted. To make the steeper slope soil improvement need to be done or some protection system need to be followed. In some instances, farmers cut the embankment at toe making vertical cliff. This is another reason of steep slope of road embankment.




(a)




(b)

Figure 7 Failure line is observed in a road of Bilashpur, Kaziarchar, Shariatpur: (a) Photograph, (b) schematic diagram.


Figure 8 Steep side slope of rural roads in the study area (Location: Uttarpara, Uzirpar, Barishal).

### 2.5 Borrow pit location

Borrow pit locations were found at very near to the road in most of the cases. Borrow pit location should be at least 3 m or 1.5 times of road height (which one is bigger) away from toe line (Road Design Standards of LGED, 2005). But in Figure 9, it is observed that the location of the borrow pit is at the toe of embankment. This is another reason of surface crack shown in Figure 9. This kind of mistake is very common in the rural areas.

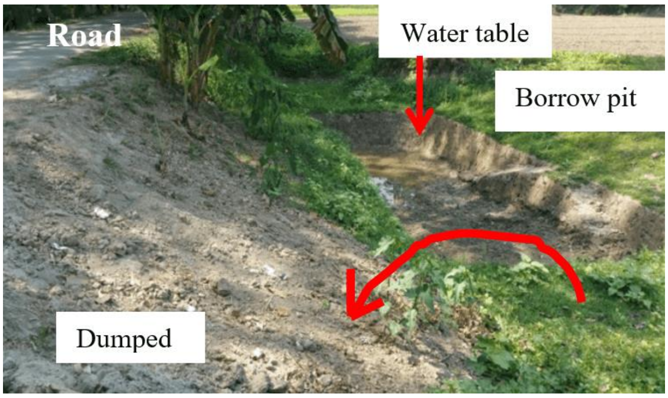



Figure 9 Borrow pit was at the toe of the road. (Location: Babubazar, Barishal).

### 2.6 Road along bank or river/khal

Some rural roads run along the bank of river or khal (Figure 10). This kind of road needs slope protection works for sustainable road construction. Sometimes, slope protection work is done using CC block revetment as shown in Figure 12. This is a typical design which is followed everywhere without any slope stability analysis. That is why sometimes slope failures are observed as shown in Figure 10(b) and Figure 12. Limited fund of rural road construction is a reason of not doing any proper slope protection design. If the slope protection is designed properly, construction cost of project will be more that the estimated budget.

### 2.7 Fish Farming along road

Crab, lobster and other fish farming in the coastal area are very common in Bangladesh. Nowadays, the farmers in the Bangladesh are converting their paddy lands to shallow water ponds (local name: Gher) to get more profit by doing fish farming. So, in the both side of the road the water exists throughout the year. Due to shallow water, wind generated waves erode side slopes (see Figure 13). Sometime, both sides of the road collapsed. Soil is not available for widening and elevating road. Dewatering of fish farm is done for road construction and the muds of the fish farms are used for road widening without. Figure 14 shows damaged slope repairing using mud of dewatered fish farm. The soil is too wet to compact.


Figure 10 Road along (a) khal and (b) river.

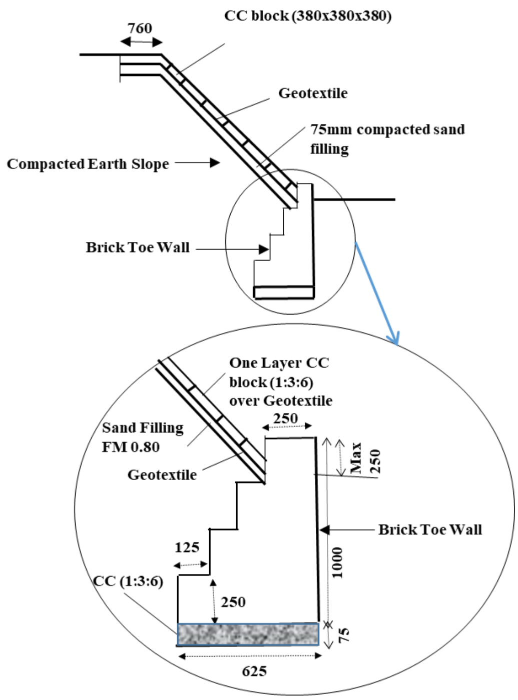



Figure 11 Schematic diagram of designed slope protection.

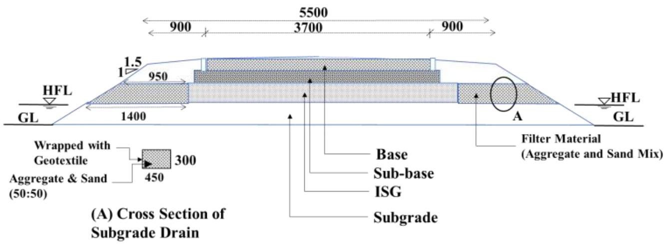

Figure 12 Embankment slope failed.


Figure 13 Side slope of rural road washed away by wave action.

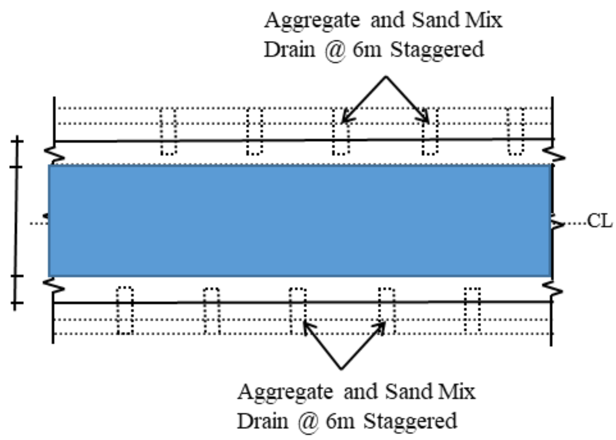

Figure 14 Mud is dumped for repairing side slopes and shoulder (source: LGED website).

## 2.8 Subsurface Drainage Path

Authors observed a subsurface drainage path is installed in some recently completed rural roads. In the both sides of subgrade layer aggregate and sand wrapped with geo-textile are installed. The cross section of this modified road is shown in Figure 15 (a). This wrapped aggregate and sand mixture would work as a drain line through subgrade of the road. Here, the water inlet and outlet are placed in a zigzag pattern that is illustrated in Figure 15(b). Subgrade drain is 450 mm wide and 300 mm thick (Figure 15(a)). The center to center distance of subgrade drain is 6 m. However, in the rainy season it was found that the soils above the subgrade drains were washed away (the dashed oval marked portions in Figure 16). In Figure 16 (a) two photographs are exhibited where this type of erosion observed.




(a)




(b)

Figure 15 Modified design of road; (a) typical cross section of road with subgrade drain and (b) plan of subgrade drain.


Figure 16 Effect of sub-surface drain.

## 2.9 Approach road

Approach road on the two side of bridge need extra attention in construction methodology and design. Removal of mud from the base of approach road and proper compaction of fill is necessary. More importantly, alternative design is needed to avoid differential settlement between abutment and approach road. In Figure 17, some photographs are added to show the settlement of approach road. Geotextile and CC blocks were used for slope protection at approach embankment. Consolidation settlement of underlying soft soil, lack of compaction of approach embankment and inadequate wing wall are the major reasons of approach road damages. Sand compaction pile or PVD with preloading may be adopted to improve soft soil.


Figure 17 Damages of an approach road of a bridge.

### 2.10 Rain Cut Erosion

Lean clay or silt from nearby borrow pits are dumped at shoulder and side slopes. As the water table is high in the coastal region, so the collected borrow pit soils are highly moist and difficult to compact. In most of the cases, side slopes and shoulders are washed away during torrential rain in the next monsoon after construction (Figure 18) or the rain water makes her own path by eroding the shoulder.


Figure 18 Rain cut erosion in shoulder without vegetation

### 2.11 Vegetation and Trees on Side Slope

Vegetation is eco-friendly and has a very beneficial effect on the side slope protection. In many cases, it helps to make a sustainable slope. But, due to lack of maintenance and inadequate sunlight, it does not grow properly to protect the slope (Figure 19). Sometimes, deep seated slope circle failure occur which cannot be protected by vegetation only. At the side slopes, trees are planted to protect slopes. Sometimes, trees are uprooted (Figure 19) during storm and shoulder and road are damaged. This uprooted trees should be removed immediately and road should be repaired.

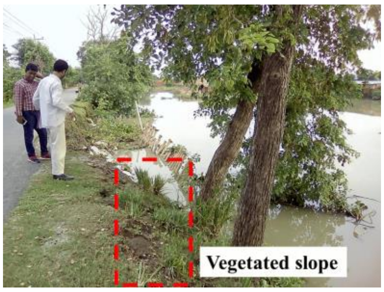
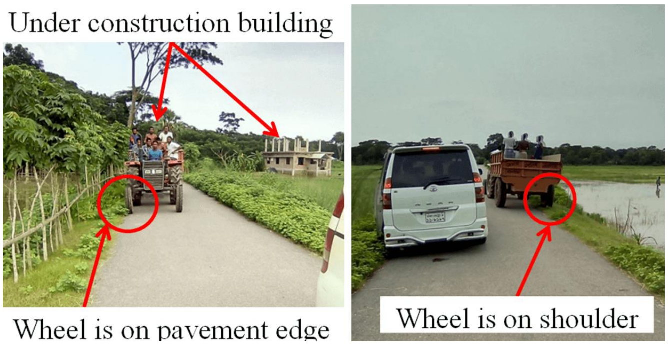



Figure 19 Slope failed in a vegetated slope.


Figure 20 Uplifted tree damaged the road.

### 2.12 Overloading

When a road network is developed in rural area, economic activity increases. Some people build multi-storied buildings beside road. So, loaded trucks enter into rural roads for which the road is not designed. During passing other vehicle, wheels of truck go on soft shoulder causing initiation of damage at pavement edge and shoulder (Figure 21). Because of frequent movement of loaded truck the small damage becomes bigger.

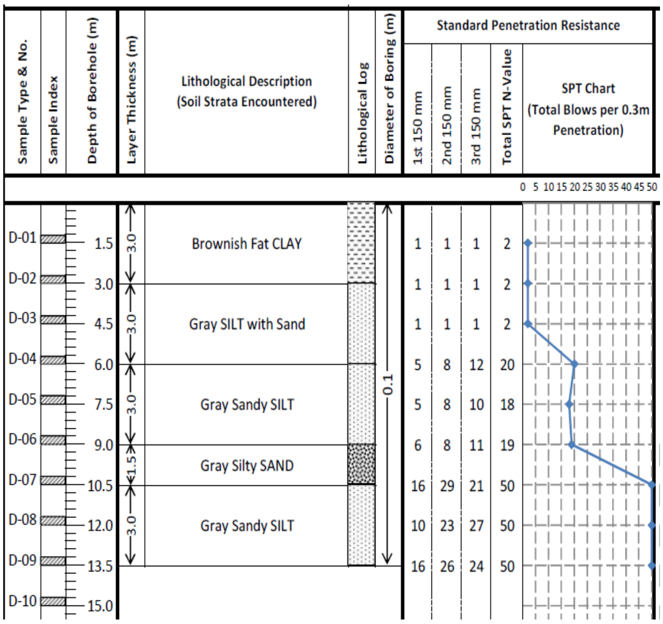



(a) (b)

Figure 21 Truck is on (a) the edge of pavement and (b) shoulder.

### 2.13 Road Settlement

Nearly 85 percent of Bangladesh is underlain by deltaic and alluvial deposits of Ganges, Branhmaputra, and Meghna river systems (Alam et al, 1990). In the previous studies of the coastal region of Bangladesh, it was found that the sub-surface soil is soft (Kabir et al, 2000; Nath et al, 2017). At least 4-8 m soft clay exists at top layer of subsoil in coastal districts. Figure 22 shows a bore log of plot for Civil Surgeon office, Gopalganj. In another research report on “Ground Improvement on Khulna Soft Soil” revealed that more than 15 m soft clay layer exist at top of subsoil in Khulna region (AsCAP final report, 2017). The soft soils consist of silt or clay. Besides, in that region, in some places, an organic clay layer of 3-5m thickness was found. This organic layer was formed from the decomposition of mangrove vegetation of the largest mangrove forest of Bangladesh (Kabir et al, 2000). As the soils of the coastal area are soft and sometimes those are organic, settlement of the newly constructed road or widened or elevated road continues more than 10 years. This settlement is not uniform along longitudinal direction of road.



| Sample Type & No. | Depth of Borehole (m) | Layer Thickness (m) | Lithological Description (Soil Strata Encountered) | 1st 150 mm | 2nd 150 mm | 3rd 150 mm | Total SPT N-Value |
|---|---|---|---|---|---|---|---|
| D-01 | 1.5 | 3.0 | Brownish Fat CLAY | 1 | 1 | 1 | 2 |
| D-02 | 3.0 | | | 1 | 1 | 1 | 2 |
| D-03 | 4.5 | 3.0 | Gray SILT with Sand | 1 | 1 | 1 | 2 |
| D-04 | 6.0 | | | 5 | 8 | 12 | 20 |
| D-05 | 7.5 | 3.0 | Gray Sandy SILT | 5 | 8 | 10 | 18 |
| D-06 | 9.0 | | | 6 | 8 | 11 | 19 |
| D-07 | 10.5 | 1.5 | Gray Silty SAND | 16 | 29 | 21 | 50 |
| D-08 | 12.0 | 3.0 | Gray Sandy SILT | 10 | 23 | 27 | 50 |
| D-09 | 13.5 | | | 16 | 26 | 24 | 50 |
| D-10 | 15.0 | | | | | | |



Figure 22 A subsoil bore log at Civil Surgeon Office, Gopalganj, Dhaka

When roads are constructed on this subsoil, consolidation and squeeze out of soft clay cause subsidence, cracking and rutting of constructed road. Subsoil investigation should be mandatory for road project in coastal areas. Special attention should be given in the planning and design phase of road projects. Geotechnical Engineers should be involved in the design phase. Figure 23 shows the settlement of road on soft soil. In the both sides of the road fish farm is full of water.

Figure 23 A portion of road settled.

## 2.14 Palisading

Palisading is done to stabilize the slope of the road along the pond, khal and river. In most of the cases palisading does not work properly. Figure 24 shows the design of palisading followed by LGED. Firstly the precast piles of 3 m length are driven into the existing soft soil at a c/c distance of 0.90 m. Thereafter the RCC precast plates are hooked using nuts and bolts. After one or two years of construction the nuts and bolts become corroded and slipped from hooked piles (see Figure 25(a)). Besides, in between two vertical RCC plates small gap exist through which the soil washed away day by day and erode the slope (Figure 25(b)). Later this design is modified by LGED. They used cast in place plates instead of precast plates. However, this system is not stable in many soil conditions of coastal districts. The posts are inserted within the soft soil layer. Failure of palisading is observed in Kajiarchor, Shariatpur (Figure 26). Existing typical design and construction methodology of palisading need to be revised. Palisading design need to be modified with proper stability analysis by Geotechnical Expert.

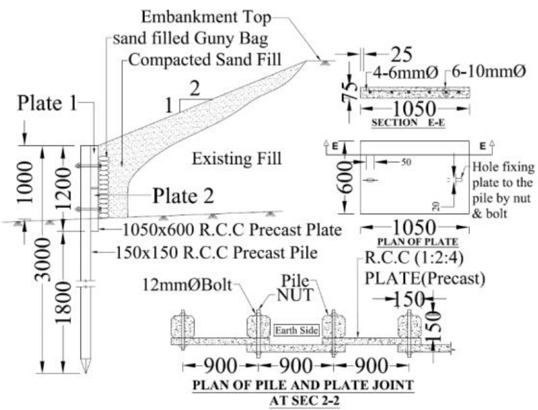



Figure 24 A typical design of palisading implemented by LGED.

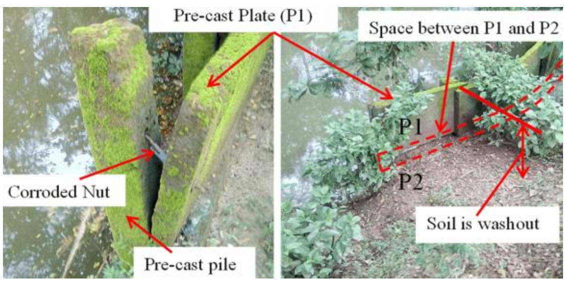



Figure 25 (a) Nut corroded and (b) Soil washed out in between the plates.

Figure 26 Palisading failed.

## 2.15 Rutting and water Logging

When roads are constructed, crown and 3% lateral slope is maintained (Road Design Standards of LGED, 2005). After one year of construction, rutting and subsidence of pavement create water logging on the road pavement. This water logging damages the bituminous carpeting and subsequently base layer. Two photographs of Khulna region are exhibited in Figure 27 (a) and (b). Figure 27 (a) is the photo of rural road constructed in 2015 and the water logging is started in 2016 though the pavement is not damaged yet whereas Figure 27 (b) represents the photograph of another road (more than one year) where due to water logging as well as vehicle movement the pavement and base were damaged.


(a) (b)

Figure 27 Water logging on the new pavement road. (a) Initial settlement and (b) settlement and wide spread pot holes.

## 3. DCP test on pavement and shoulder

The recommended CBR value verses DCP penetration per blow for rural road construction was collected from LGED as shown in Figure 28. To compare the LGED recommended DCP values with field DCP values, total 34 DCP (Dynamic Cone Penetration) tests were conducted in rainy season on some village roads in Khulna district, Bangladesh. Test locations are listed in Table 1. Results of DCP tests done on road pavement are shown in Figure 29 (a) and (b) whereas results of DCP tests done on shoulders are shown in Figure 30 (a) and (b). In Figure 29 and Figure 30, the black lines are the LGED recommended maximum DCP penetration per blow (denoted as DN in mm/blow) for various layers of pavement. Where DN exceeded black line indicates not meeting the requirement set by LGED.

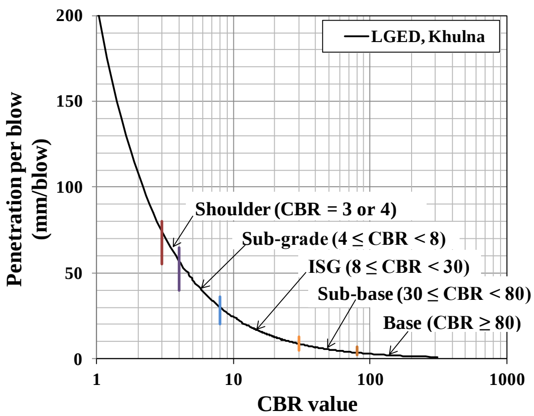
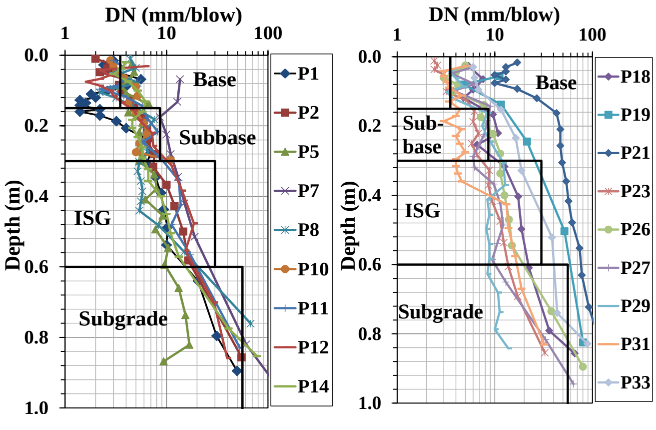



Figure 28 CBR verses DCP penetration rate (mm/blow) recommended by LGED for rural road.




(a) (b)

Figure 29 DCP test results conducted on the village road.

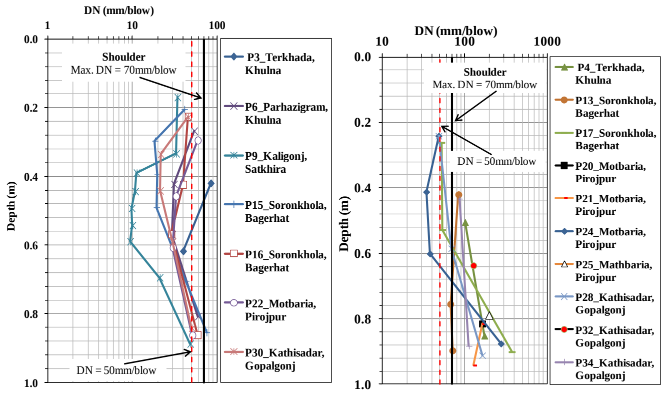



Figure 30 DCP tests conducted on the shoulder of the rural road.

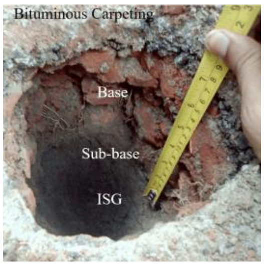



Figure 31 Verification of pavement layer thicknesses by making hole on road pavement.

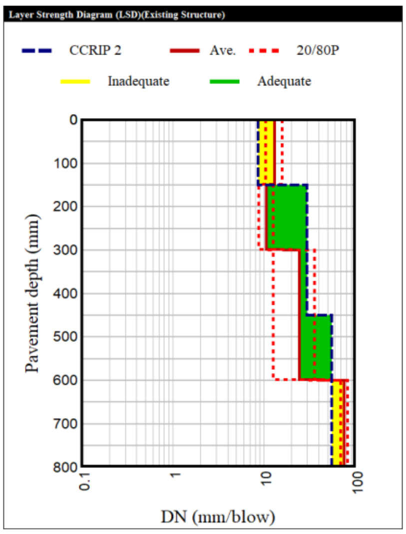



Figure 32 Analysed DCP test result (P7_Modhupur, Khulna): Layer strength diagram.

Table 1 Condition of Road and Shoulder by using AfCAP-DCP software.

| No. | Point_Point_Location* | Road Pavement | | | | Shoulder |
|---|---|---|---|---|---|---|
| | | Base | Sub-base | ISG | Sub-grade | |
| 1 | P1_P3_Terkhada, Khulna | A | A | A | A | I |
| 2 | P2_P4_Terkhada, Khulna | I | A | A | A | I |
| 5 | P5_P6_Parhazigram, Khulna | I | A | A | A | A |
| 7 | P7_Modhupur, Khulna | I | A | A | A | -- |
| 8 | P8_P9_Kaligonj, Satkhira | I | A | A | A | A |
| 10 | P10_Kaligonj, Satkhira | I | A | A | A | -- |
| 11 | P11_ Kaligonj, Satkhira | I | A | A | A | -- |
| 12 | P12_P13_Soronkhola, Bagerhat | I | A | A | A | I |
| 14 | P14_P15_Soronkhola, Bagerhat | I | A | A | A | A |
| 16 | P16_Soronkhola, Bagerhat | | | -- | | A |
| 18 | P18_P17_Soronkhola, Bagerhat | I | I | A | A | I |
| 19 | P19_P20_Motbaria, Pirojpur | I | I | I | I | I |
| 21 | P21_P22_Motbaria, Pirojpur | I | I | A | A | A |
| 23 | P23_P24_Motbaria, Pirojpur | I | A | A | A | I |
| 26 | P26_P25_Mathbaria, Pirojpur | I | I | A | I | I |
| 27 | P27_P28_Kathisadar, Gopalgonj | I | A | A | A | I |
| 29 | P29_P30_Kathisadar, Gopalgonj | I | I | A | A | A |
| 31 | P31_P32_Kathisadar, Gopalgonj | I | A | A | A | I |
| 33 | P33_P34_Kathisadar, Gopalgonj | I | I | I | A | I |

A digital moisture meter was used to measure moisture content of the subbase and ISG after making a small hole on road pavement. Later it was filled with concrete. Moisture contents of roads were between 14 and 18 percent for subbase and ISG. In the shoulder the moisture content was more than 50 percent. Moisture meter was capable to measure up to 50 percent moisture content. The DCP test data were analysed by using the AfCAP LVR-DCP software (A software developed by Africa Community Access Program). The analysed typical result of a DCP test which is done on road pavement is shown in Figure 32. Layer thicknesses were verified by making small hole on road pavement. In Figure 32, adequacy of each layer is checked by comparing with maximum recommended DN (mm/blow) values shown in Figure 28. Adequate layers are represented by green colour and inadequate layers by yellow colour. Thus, all DCP tests data were analysed and adequacy of layers is listed in Table 1. In most of the cases, bases were found inadequate. 10 points out of 16 points on shoulder were inadequate. Some subbases were found inadequate and few ISG (Improved Subgrade) were found inadequate.

Rutting on road pavement may be attributed to inadequate base layer. Initiation of damage at the edge of pavement may be attributed to inadequate shoulder. Shoulder and widened part of road acts as confinement to existing road. Soft shoulder is not capable of giving confinement to pavement layers. That is why authors think that shoulder should be hard type with herring bone brick under which there should be a sub-base layer. Dumping of mud at shoulder and side slope must be avoided to make sustainable rural road.

## 4. Recommendations for Climate Resilient Rural Road

Following sub-sections explain the recommended materials and method of climate resilient rural road.

### 4.1 Soft Foundation Soil Improvement

Soft foundation soil need to be improved before construction of road to avoid excessive settlement. Several economical methods are available for soft soil or organic soil to accelerate settlement in short time and strengthening before accomplishing the full road construction work. Nath et al (2017) conducted research work by using the organic soil of Khulna, Bangladesh. They proposed to improve the organic soil by employing industrial by-product fly ash. Their outline was that the C type fly ash has the economical and beneficial engineering effect on organic soil than F type fly ash. However, in Bangladesh the rice husk ash waste is common in the rural area; each year huge amount of rice husk ash generates (Farooque et al, 2009). Rather than dumping, this waste can be utilized for soil improvement by mixing with lime (Ali et al, 1992; Muntohar, 2002; Choobbasti et al., 2010). The soft soil can be improved by doing vertical drain such as Sand Compaction Pile (SCP) (Nazir & Azzam, 2010) or Prefabricated Vertical Drains (PVD) (Chu et al, 2006). In bridge approach road construction, SCP or PVD or other low-cost technology (Elbadry & Eid, 2016) should be followed to reduce the settlement of the approach road.

In case of road widening, major portion of soil under embankment is already consolidated over the years. So, SCP or PVD are not required during road widening. Soft soil under the widened part of embankment may be replaced with treated soil as explained in following section.

### 4.2 Embankment and Pavement Construction

In rural areas, existing earthen roads are upgraded to paved roads. Here, road widening and elevating is required. Mud or wet soil is usually dumped for road widening and elevating. Authors conducted a research on treating clay and sand for the purpose of using those as Improved Subgrade (ISG), sub-base and base (Final Report of Test Protocol, CCRIP, LGED, 2017). Table 3 shows the CBR values of treated soil with cost comparison. As the compaction is difficult at the widened part of the embankment, half of the energy required for Standard Proctor Compaction is used in laboratory on the treated soil to simulate field condition at laboratory. Required CBR values were achieved even at low compaction energy. Required material costs are compared between traditional and recommended pavement layers. It is found that material cost is less in recommended pavement layers. However, recommended pavement layers will need an additional rigid plain concrete layer of 100 mm thickness which will add additional cost compared to 25 mm thick bituminous carpeting.

Major problems identified in rural road construction are improper methodology of construction and unavailability of suitable material. Recommended method of road widening and elevating is shown in Figure 33. Benching at existing side slopes, layer by layer compaction and keeping required distance between borrow pit and toe should be done for making sustainable rural roads. Compaction of soil at widened part of embankment is difficult due to two reasons. One reason is high moisture content in borrow pit soil and another reason is roller cannot move in muddy land. 4% lime treated clay can be used for filling widened part of embankment (Abdi, 2011; Osinubi, 2006). Addition of lime reduces the water content due to hydration and reaction with clay and it will increase the workability, such as easy compaction. Compaction must be done using diesel operated plate compactor. After accomplishing the road construction work, a 150 mm thick clay cladding may be used on lime treated clay slope for growing vegetation. Besides, by treating the soil it is possible construct the rural road at steep slope (1H:1V) which will be also reduce the cost. Lime treatment may increase the budget of the project but considering the steep slope and life-cycle cost it is more economical. The borrow-pit location should 3m or 1.5 x height (whichever is greater).

Table 2 Traditional pavement layers and their material cost.

| Road layer | Materials | CBR Required | Cost in USD per $m^3$ (material cost only) |
|---|---|---|---|
| | | | Without treatment |
| Improved Sub-grade (ISG) | Fine Sand | 8 | 5.56 |
| Sub-base | Fine Sand and Brick Aggregate Mixture | 30 | 30.54 |
| Base | Brick Aggregate | 80 | 49.56 |
| | | Total = | 85.66 |

Table 3 Recommended pavement layers and their cost.

| Road layer | Binding Material Added | Original Material | CBR Achieved* | CBR Required | Cost in USD per $m^3$ (material cost only) |
|---|---|---|---|---|---|
| | | | | | With treatment |
| Improved Sub-grade (ISG) | 1% Slag | Silty Sand or Sandy Silt | 9 | 8 | 5.48 |
| Sub-base | 10% Slag | Silty Sand or Sandy Silt | 56 | 30 | 26.91 |
| Base | 1% Lime + 10% Slag | Silty Sand or Sandy Silt | 114 | 80 | 29.51 |
| | | | | Total = | 61.91 |

* Compaction energy applied was half of that required for Standard Proctor Compaction Test

For Improved Subgrade (ISG), sand of FM $\geq$ 0.80 is prescribed in Road Design Standards of LGED (2005). This sand is not available locally. FM of locally available sand is less than 0.50. Contractors cannot afford to buy sand of FM $\geq$ 0.80 from 100 km away. Moreover, cost of sand of FM $\geq$ 0.80 is not profitable for contractors considering current price schedule of Local Government Engineering Department (LGED). Locally available fine sand, silty sand or sandy silt can be treated by 1% slag to get the target soaked CBR value of 8. This alternative solution is cost effective. It is climate resilient too; because the slag is a by-product of steel refinery which needs recycling to protect environment. If the road need elevating and lime treated compacted clay is used for elevating the road, ISG can be omitted. That means sub-base shall be constructed on treated and compacted clay directly.

Above the 300 mm ISG, 150 mm sub-base is prepared using brick aggregate and fine sand mixture with 1:1 ratio (Road Design Standards of LGED, 2005). In this ratio, brick aggregates remain suspended in a sand matrix where fine sand behaviour dominates when it is loaded. Sand of FM<0.40 is used by contractors instead of FM $\geq$ 0.80. As a substitute of sand-aggregate mixture, locally available silty sand or sandy silt only (without brick chips) can be treated by 10% slag to get more than target CBR value 30.

The 150 mm thick base is prepared on sub-base using brick aggregates by roller compaction. During compaction, some aggregates break down to lower sizes. During operation of road, if heavy vehicles move, brick aggregate particles of base break and rutting occur on pavement. Therefore, brick aggregate is not a suitable material for base at all. In addition, brick manufacturing produces greenhouse gas $CO_2$. Crushed stone is very expensive imported material in coastal districts. 1% lime and 10% slag treated silty sand or sandy silt can be climate resilient base material which satisfies the target soaked CBR value 80.

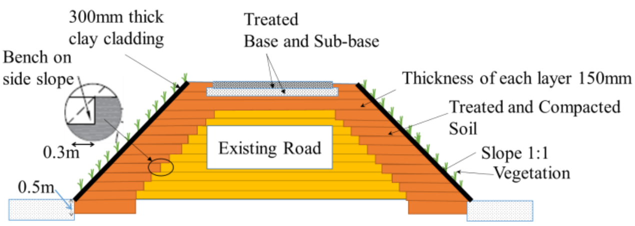



Figure 33 Proposed method of rural road widening.

## 3. CONCLUSION

Based on the test results and field observations, following reasons of road damage were identified.

i. Use of unsuitable soil for improved subgrade, subbase, base and slope.
ii. Lack of training and concern about relation of moisture content and compaction.
iii. The side slope is steeper than the designed slope.
iv. Borrow pit location is along the toe.
v. No extra protection or proper protection for the road embankment along the river or khal.
vi. Erosion of side slopes due to wave action from the shallow fish pond (Gher).
vii. Settlement of the approach road due to underlying soft soil, uncompacted approach embankment and inadequate wing wall.
viii. Rain cut erosion of soft lean clay or silt on the shoulder and slope.
ix. Uprooting trees from the slope of the road.
x. Overloaded vehicle movement on the pavement and on the shoulder.
xi. Soft subsoil under road embankment.
xii. Rutting and water logging on the road.
xiii. Lack of vegetation on side slopes.

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