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B2 - OVERHEAD LINES:PS 1 / CHALLENGES & NEW SOLUTIONS IN DESIGN AND CONSTRUCTION OF NEW OHL

Title:
Improvement of Bearing Capacity of Soil using Bamboo Nailing and Sand Piling for 400kV Transmission Line Tower Foundations in Tripura, India

R K TYAGI, L K KHAJKUMAR*, VIPIN J JOSEPH, SOUMITRA GOSWAMI
Power Grid Corporation of India ltd
India
tyagir@powergrid.in, lkkhajkumar@powergridindia.com, vipinjacob@powergrid.in, soumitra.goswami@powergrid.in

SUMMARY

In POWERGRID India, during construction of one 400kV line in Tripura state, problem of very low soil bearing capacity was encountered for a particular stretch. This required design of special foundations like concrete pile foundations or huge raft foundations. Considering time for completion of line construction as well as cost of foundations, other indigenous methods were explored. Usage of bamboo nailing and sand piling for improvement of Bearing Capacity of Soil is one such method which proved as a success story executed by Power Grid Corporation of India Ltd in Tripura, India for Transmission Line Tower Foundations. Foundations for soil with extremely low Bearing Capacity usually require special foundations like pile foundations. This would lead to extremely high cost and delay in project execution. In this part of the country, Bamboo availability is high and the usage of Bamboo nailing and Sand piling for improvement of bearing capacity has led to huge saving in cost of foundations and timely completion of the project. In this paper, the experience of POWERGRID on bamboo nailing and sand piling is discussed in details for improvement of soil bearing capacity and timely completion of the Project.

KEYWORDS

Bamboo Nailing, Sand piling, bearing capacity of soil, foundations

1. INTRODUCTION

All foundations primarily rest on underlying soil or rock, based on their nature and behaviour. Soil is a principal component of all structure - important limb of foundation. A foundation is the element of a structure which connects it to the ground, transferring loads from the structure to the ground. It is a root-tree phenomenon. No tree is healthy without sufficient roots. While designing of any structure it is important to determine the load carrying capacity of the soil underneath on which the foundation will be laid. This is applicable to all types of foundations starting from isolated footing to raft and pile foundations. The stability and life of any structure mainly depends upon the type of soil, their properties and behaviour under various constraints and influences during construction.

In order to develop any foundation design, following parameters of soil are taken into consideration:

- ✓ Safe Bearing capacity (SBC) of the soil
- ✓ Laboratory Test reports.
- ✓ Field Test reports.
- ✓ Boring data log sheets.
- ✓ Nature and texture of soil
- ✓ Observations like Water table, historical Data etc.

During construction of a 400kV Transmission line at Tripura, soil investigation was carried out in order to develop tower foundation design. Tripura is located in the north-eastern part of India. It is the third-smallest state in the country. The state is located between 22°56´ & 24°32´ north latitudes and 91°09´ & 92°20´ east longitudes. Its area is 10,491 km2 and is bordered by Bangladesh to the north, south, and west, and the Indian states of Assam and Mizoram to the east.

During soil testing, it was observed that Standard Penetration Test (SPT) values at 3 metre depth are almost "0" for most the tower locations. Exhibit-1 showing actual site condition at 1.5 depth of foundation may be seen.

Exhibit-1: Condition of Soil at 1.5m depth

During soil investigation, three different layers of soil were encountered.

a) The first layer consisted of Greyish brownish low plastic silty sandy clay up to depth 2.00 to 3.00 m below ground level.
b) The second layer consisted of deep ash to blackish ash colour very soft over saturated compressible clay virtually having very poor shearing resistance. Recorded N value(penetration resistance) was around 0 to 1. The formation has a tendency of lateral flow indicating liquid state of the formation.

c) The third layer consisted of fine-grained shale, megascopically appears like silty sand having good shearing resistance. Refusal N value was recorded. More than 24 bores (10.00 to 18.50m) are made.

In an open cut excavation, we encountered some debris which are in 80% decomposed state. Refer Exhibit-2 showing decomposed soil. The sub-soil water level is very close to the ground level and some locations which are located at paddy field, the sub-soil water level recorded was 300 mm above the ground level. The soil where paddy is cultivated has a tendency of shrinkage and swelling, and as such there is a chance of development of innumerable cracks at ground surface during dry and lean season. The strength of the soil was so poor that it could not even support the excavator which continuously sank to the ground. Please refer Exhibit-3. After excavation of the foundation pit, soil heaving (lateral soil flow leading to lift of soil) was also observed. High water table also lead to inundation of foundation pits.

	
Exhibit-2: Decomposed soil with water logging	**Exhibit-3:** Site condition at depth 1.5m

In the present case, the bearing capacity of soil (SBC) varied between 0.5 Ton/M^2 to 2 Ton/M^2 at 3.0 metre depth in spite of having existing over burden pressure due to self weight of 3.00 Tonnes/M^2. No structure could be constructed with SBC of less than the existing overburden pressure to avoid lateral movement of foundation. In this type of soil, shallow foundation is not feasible. Alternatively, deep pile foundation was considered and found unfeasible due to considerable amount of time taken, huge cost involvement and high unsupported pile length of about 10-15 metre below ground level.

One of the vital design parameters for 400kV tower foundation is horizontal load. The horizontal load is excessively high although static load is less as compared to horizontal forces. Over turning forces is much higher than the dead load and other load of the structure. So, to balance the horizontal load applicable, it is required to have a minimum of 3 m depth of foundation. Due to frequent collapse of soil and high water level, it was very difficult to excavate the foundation pit up to 3m depth.
An attempt was made to study feasibility of ground improvement as per IS-13094. It was gathered that most of the places (now paddy fields) were originally low-lying area surrounded small hillocks. As stated above, during monsoon, rain off carries lots of vegetable and plants debris with rain cut soil and gradually transformed to a fertile soil (suitable for agriculture) after decomposition. In some places, semi decomposed debris was also noticed. After analysis, it is found that area is highly impervious in nature and little or nominal variation of water exist in all seasons. Existing overburden pressure was considered inadequate to drain out pore water from impervious clay soil.

The existing overburden pressure was resisted mainly by pore water pressure since soil has very poor shearing resistance. In case Pile foundation is to be used, pile length shall exceptionally be higher because, in a few locations, the soft stratum was extended up to 18.00 m below ground level.

The length of Pile (L) = (Unsupported length + equivalent cantilever length) X 1.50 = 34.50 m

Diameter of Pile, D = 0.05 X 34.5 = 1.72 m (1.5 m min)

As such, considering all aspects like safety, time duration, execution facility, economy, local resources availability etc, it was decided for ground improvement, using bamboo nailing and sand piling at a spacing of N < 10 D c/c. The quality of sand available is poor (Zone 4) and cost of gravel is almost 5 times higher than other North East States of India. In such a situation, alternate row of bamboo nailing was considered most suitable.

The novel technique of ground improvement was initially adopted at two locations. On dynamic plate load test, the bearing capacity was found to have improved substantially (to 8.5 T/m²). Exhibit-4 shows plate load test being conducted at site.

Exhibit-4: Plate load test in progress

Ground improvement is an ancient science of geotechnical engineering. In pre-history age also, ground improvement methods were adopted in various places depends upon soil condition. Soil bearing capacity has been improved by using ground improvement technique of Sand piling & Bamboo nailing. Compacted subgrade of thickness 300 – 500 mm granular cushion was also provided (1 sand: 2 gravel) above the Bamboo nailed and sand piled soil.

2. KEY PARAMETERS ASSOCIATED WITH SOIL IMPROVEMENT TECHNIQUES

- ✓ Soil and Sand
- ✓ Bamboo
- ✓ Shallow Foundation/ Deep Foundation
- ✓ Bearing Capacity of Soil

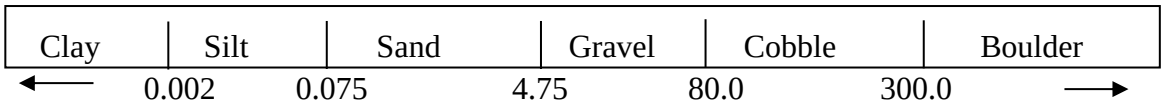
2.1 Soil and Sand

When we use the term *soil*, it has various meanings in different professional fields, depending upon the use where it has been specified. To an agriculturist, Soil is the part of the earth's surface which supports life or growth of plants and similarly for a geologist, soil is a mixture of inorganic with or no organic matters, minerals, gases and liquids which exists on the outer surface of the earth and the rest of the crust is grouped under rock irrespective of its hardness. In engineering term, soil is that part of the earth surface which is formed from weathering of rocks under various natural physical and chemical processes and also a natural aggregate of mineral grains, cohesive or cohesion less, organic or inorganic particles like silt, clay, sand, gravel sizes ranging from micron to big size boulder. In general civil engineering term, soil is the part of the earth which supports foundation of structure.[1]

A soil mass consists of three basic elements, solid particles, water and air. Basically, the void between the soil particles is filled partly with water and partly with air. In a dry soil state, the void spaces are filled with only air and in the perfectly saturated soil mass, void spaces are filled with only water. These three constituents of soil form a complex blended material without occupying separate spaces.

2.1.1 Classification of Soil

Soil is mainly classified in Indian Standard Unified classification system. In Engineering application, the soil is divided into two groups – (a) Fine grained soil – soil grains smaller than 0.075 mm (75 micron) and (b) Coarse grained soil – soil grains larger than 75 micron. The soil is again divided as under:



Particle sizes in millimetre

2.2 Bamboo

Material availability in a near vicinity of construction site and use of locally produced material saves a lot on construction cost. The North Eastern states represents 28% of the countries bamboo stock and Tripura has 2397 sq. Km of bamboo forests forming about 23% geographical area of the state. 21 species of bamboos are found in Tripura. Most common bamboos are;

- Muli (Melocanna baccifera)
- **Barak (Bambusa balcooa**)
- Bari (Bambusa polymorpha)
- Mritinga (Bambusa tulda)
- Paora (Bambusa teres)
- Rupai (Dendrocalamus longispathus)
- Dolu (Neohuzeaua dullooa)
- Makal (Bambusa pallida)
- Pecha (Dendrocalamus hamiltonii)
- Kanak kaich (Bambusa affinis)

- **Jai (Bambusa spp**.)

We have used **Barak (Bambusa balcooa**) and **Jai (Bambusa spp**.) in our works due to their good physical properties.

Timber has been used as a construction material for ages. To mitigate the problem of limited use and extinction of the timber species for rapid deforestation, time has arrived for the construction industry to explore for an alternative of timber with similar properties. Bamboo is identified as a forest resource which has proven to have the qualities that makes it an excellent material for construction industry.

There is a huge scope for bamboo as a construction material in the future because of some of its natural properties. Bamboo has high compressive strength. It also shows high tensile strength, high strength to weight ratio and high specific load bearing capacity. Bamboo has a high potential use as a low cost and locally available construction material. Structural design codes are published by many countries including India (IS 9096:2006) to use bamboo in structural construction work.

The physical appearance of bamboo is round, straight, smooth, strong and flexible. With the advancement of technology, bamboo can be treated with certain applications to withstand deterioration, therefore, leading to extensive multi-purpose usage; from improving soil conditions to building construction. [2][3]

Bamboo can prevent erosion and can revitalize devastated rain forest soil. Bamboo has inherent properties such as being regenerating, biodegradable, with high tensile strength (of 3656 kg/cm2), lightweight, very good weight to strength ratio and have reasonable life of 30 to 40 years. [4]

Some specific properties of Bamboo are:

- Specific gravity - 0.575 to 0.655
- Average weight - 0.625 kg/m
- Modulus of rupture - 610 to 1600 kg/cm2
- Modulus of Elasticity - 1.5 to 2.0 x105 kg/cm2
- Ultimate compressive stress- 794 to 864 kg/cm2
- Safe working stress in compression – 105 kg/cm2

2.3 Foundations

2.3.1 Shallow foundations: A foundation is considered as shallow if its width is equal to or more than depth.

2.3.2 Deep foundation: - Normally, a foundation is considered as deep foundation if its depth is more than width. For transmission line towers, deep foundations are normally classified as Pile foundations, Micro Pile foundations, Well foundations.

2.4 Bearing Capacity of Soil

Bearing capacity of soil is defined as the supporting power of a soil under different loading conditions. It depends primarily on the type of soil, density of soil and its shearing strength. Bearing capacity of soil also depends upon the depth of the found, deeper the depth better will be the bearing capacity.

3. ADOPTION OF SAND PILING AND BAMBOO NAILING - APPLICATION

After excavation of up to 3.5 m depth, bamboo was driven into the ground using hydraulic pressure. Sand piles are inserted with 150mm diameter bottom closed steel pipes. Spacing between Sand Piles are 1.6m and 2 bamboo nails were drilled in between one pair of sand piles and depth of penetration, up to depth of 4m. Exhibit-5 shows placement of Bamboo nailing and Sand piling. Compacted subgrade of sand and gravel in 1:2 ratio was provided above the bamboo nails and sand piles.

The method was adopted to drain out the excess pore water and to prevent soil slide vibration. The cushion shall act as catalyst for rapid consolidation besides absorbing good quantity of pore water and uniform stress distribution to foundation soil. Dynamic plate load tests reveal adequate improvement of strength of weak soils. Adequate consolidation was also expected during construction period. Exhibit-6 shows schematic diagram of Bamboo nailing and Sand piling.

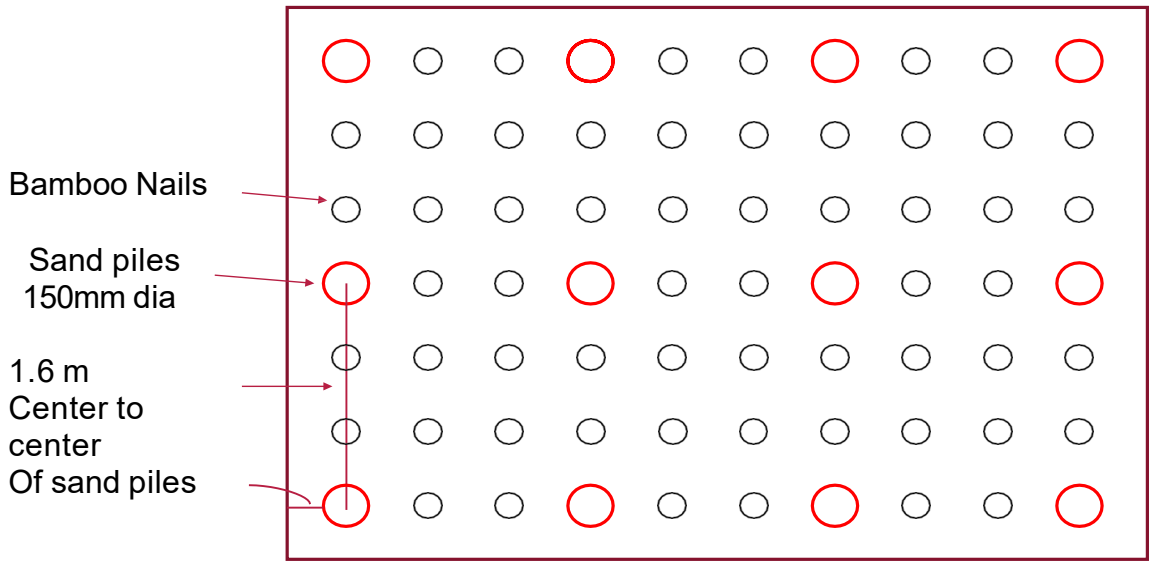


Exhibit-5: Placement chart of Sand piling and Bamboo Nailing

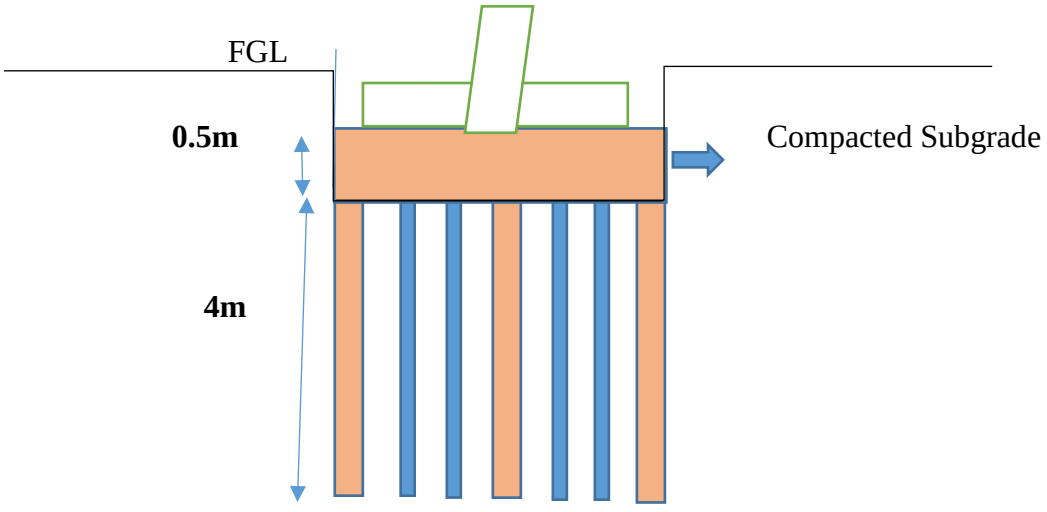


Exhibit-6: Schematic Diagram of Bamboo nailing and Sand piling

3.1 Sand piling:

Sand piling is a soil strength improvement technique which are in use from decades for improving the soil properties when deemed necessary. Sand piles improve neighboring soil while driving the casing pipe for pouring sand to it and compacting the same. In this way the void ratio of the neighboring soil will improve resulting in improvement in bearing capacity. Apart from the above, sand piles allow the radial drainage along with vertical drainage which reduces the void ratio and settlement. The main advantage of the sand piles is that it is readily available and cost implication is low. The sand pile driving procedure is easy which requires a casing pipe, hooper, bottom plug and driving assembly. During execution at site, extra care may be given whether the casing pipe which is used for sand piles are of proper Diameter (150mm diameter or as per design) and clean inside. After driving of each pile, it is to be ensured that the casing pipe is cleaned from inside before proceeding to the next pile.

3.2 Bamboo nail:

Bamboo nailing is a soil strength improvement method which serve as a soil reinforcement for weak soil. While nailing the bamboo in the soil, it consolidates the neighboring soil layers and increase the load carrying capacity. Also, being a reinforced media of soil, it can carry the load which is disbursed from any structure built above it and ultimately distribute the load to the soil by skin friction and end bearing. Exhibit-7 shows driving of bamboo with excavator i.e. bamboo nailing.

Bamboo is readily available and cost implication is low and hence, it can be adopted as per requirement. The bamboo nailing procedure is easy which involves a stem of bamboo of adequate length as per design and driving assembly (in this case Excavator was used). It has to be ensured that adequate length and Nos. of bamboo are used as per design/recommendation.

Exhibit-7: Bamboo nailing

During the driving of bamboo, it is to be ensured that bamboo which will be used as a pile is matured enough and of adequate length. Sufficient depth of pile may be achieved by using proper procedure. Exhibit-8 shows excavated pit after sand piling and Bamboo nailing.

Exhibit-8: Excavated pit after Sand piling and Bamboo Nailing

As stated earlier, the life of bamboo under water condition is about 100 years for mature bamboo. The surface is highly polished and 100% impervious. Pore water can easily drain out along the surface of bamboo.

Compacted subgrade of sand-gravel cushion helps to drain out pore water rapidly during construction. Further, the compacted subgrade absorbs pore water and during compaction, gravel penetrates inside the soft clay soil and behaves like mud concrete. The formation transforms to GC (gravelly clay) with higher shear strength. Compaction is the critical factor here and it is suggested to do compaction by 5 to 7 Ton earth compactor. Exhibit-9 showing compacted Sand-Gravel cushion.

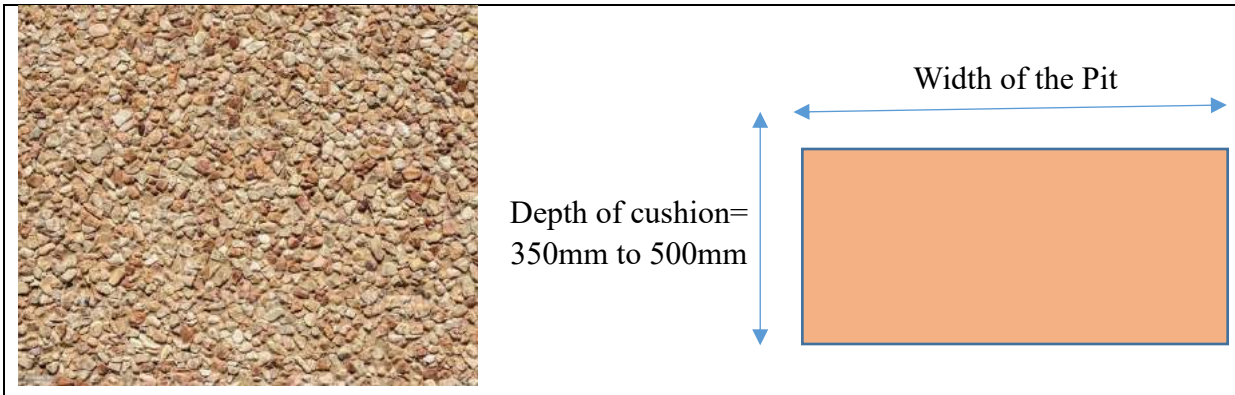


Exhibit-9: Compacted Sand-Gravel Cushion

After bamboo nailing, Sand piling and 350-500mm cushion, PCC work is to be carried out. Further, normal foundation works i.e. RCC work as per the design to be executed. In the present case, all 24 numbers of foundations are designed with Safe Bearing Capacity of 3.5Ton/M^2 and considering angle of Repose equal to Zero degree.

Following are the quantities required for Foundation pit having dimensions: 11.5m x 11.5m x 3 m

Bamboo Nailing	- depth 4m avg, 3072 RM
Sand piling	- depth 4m avg, 1024 RM
Sand-Gravel Cushion	- 11.5m x 11.5m x 0.50m
PCC(1:3:6)	- 11.2m x 11.2m x 0.05m
RCC(1: 1.5:3)	- 11.2m x 11.2m (tapered)

4. OTHER CHALLENGES AND SOLUTIONS

Decomposed soil has the characteristics of Shrink and Expand depending on weather condition which causes a collapse of excavated pit several times, resulting into a delay in execution. This problem was resolved with using proper steel shoring & shuttering for the excavated pit. Waterlogged areas which are obstructing the progress of the work with sinking in the ground of the excavator and other machineries has been resolved by using Heavy Duty Ground Stabilising Mat that allows machineries for movement over them without any sinking in the ground. Dewatering pump was used for removal of seepage water from the excavated pit. Mud pump/Fluid pump was deployed for removal of mud from the excavated pit.

5. COSTING AND COMPARISON

Within short duration of 2 months, 22 numbers of 400kV tower foundation having following quantities have been executed:

Particulars of Item	Unit	Quantities
Excavation of Soil up to 3.5meter depth	Cubic meter	27707
Concreting (M20 having ratio 1:1.5:3)	Cubic meter	3993
PCC works having concrete ration 1:3:6	Cubic meter	444
Consumption of Reinforcement Steel	Metric Ton	426
Sand piling(150mm ⌀)	Running Meter	12144
Bamboo Nailing	Running Meter	43776
Sand Gravel cushion	Cubic meter	4381

The approximate cost of execution for above quantities was Rs. 14 Crore. Average cost per location works out to Rs. 63.6 lakhs.

The alternate option was to construct concrete pile foundations. Eight numbers of piles of 450 mm dia would be required per tower leg for pile foundation. i.e. Total 32 piles are required for one 400kV tower. The average cost of Pile foundation having Pile length of 14.6meter, 450mm pile diameter and 32 nos. pile per tower is Rs. 100 Lakhs. The total cost for 22 nos. of tower location will be Rs. 2200 lakhs.

From, the above it can be seen that there is approximately 36% cost saving in adopting special foundation with Bamboo nailing and Sand piling in addition to considerable saving in time.

6. CONCLUSION

The use of Bamboo Nailing and sand piling to improve the bearing capacity of soil was implemented by Power Grid Corporation of India Ltd for 400 kV D/C Transmission Line for 24 tower locations. This type of Soil Bearing Capacity improvement was implemented by the Corporation for the first time in the country for transmission line towers. Economy in terms of single tower foundation (for which, otherwise concrete piles should have been implemented) and economy for the whole project have been achieved by using this method. The bearing capacity of the soil improved upto 8.5

Tonne/sqm after the soil treatment. This has led to considerable savings in cost, as otherwise, concrete piles were suggested for foundations of very low bearing capacity. This would not have only increased the cost per foundation, but also would have led to delay in execution of the project apart from other commercial penalties.

7. FUTURE ROADMAP

The future roadmap of bamboo aligns with Government of India articulated "Green India Mission" and the "Sustainable Development Goals" of development agenda helping to strengthen resilience and reduce the Global Carbon footprints.

- ✓ Bamboo can include, strengthen, and diversify the incomes of small holder farmers and tribals as significant actors in the nation's drive towards industrial growth.
- ✓ India has the "second largest" bamboo resources worldwide; efficient & economical use of bamboo can add significant value to any kind of application design and its execution. Bamboo is easily available almost in all part of India.
- ✓ Concrete piles and other soil improvement techniques are time consuming and expensive as compared to bamboo nailing. For remote construction sites the availability of coarse aggregate is limited it had to be arranged from nearby places (Assam & Meghalaya in this case) including skilled manpower & machineries. It became a challenge specially in the time of Covid 19 pandemic. This ground improvement technique implemented with readily available materials like Bamboo & River Sand.
- ✓ Time factor: Time of construction of concrete pile in case of transmission line takes almost 6 months whereas improvement of soil using Bamboo nailing and sand piling along with granular cushion and construction of foundation over it takes about 20-25 days only.
- ✓ With a more research and/or with the help of the expert agency (as some treatment on bamboo is required to increase the life span), this method can be included in all future Transmission line project so that wherever soft soil encounters, this treatment can be used effectively with low cost which will increase the quality and sustainability of the transmission line with time bound completion of the projects.

Shallow foundation with sand gravel cushion & sand piling cum bamboo nailing will enable simple & quick execution of work thereby involving lesser time and expenditure considering the stringent deadlines for completion of projects. Sand & Bamboo are natural and easily available eco-friendly raw materials. The impact on environment due to manufacturing of construction materials such as cement, reinforcement steel cannot be denied. Use of sustainable material for construction

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