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PEATY GROUND IMPROVEMENT USING BAND DRAINS AND HEAVY TAMPING

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Abstract: Southern Transport Development Project in Sri Lanka has undertaken construction of an expressway that runs from Kottawa, near the capital Colombo, to Matara - a distance of about 120 km parallel to the western coast of Sri Lanka. Expressway embankment runs through soft ground underlain by peat, organic clays and soft clays whose natural water content normally ranges up to 800% and thickness up to about 8m.

Among many improvement methods, prefabricated vertical (band) drains and surcharge method for soft clays, and rock replacement, heavy tamping and vacuum consolidation for peaty deposits have been adopted. In the application of heavy tamping for enforcing settlement in peaty soils, excess pore pressure was handled using a stronger vertical drain in order to withstand pounding by the 15 tonne heavy tamper. Pore pressure generated during pounding dissipated quite fast making the application of tamping energy more productive. A saving of about 25-30% of the intended heavy tamping energy was realized due to the introduction of vertical drains. The paper presents soil data, site operational data and enforced settlement with and without vertical drains.

Keywords: Embankment, field performance, ground improvement, natural fibres, prefabricated vertical drain, settlement

INTRODUCTION

Southern Transport Development Project (STDP) in Sri Lanka consists of an expressway that runs from Kottawa, near the capital Colombo, to Matara a distance of about 120 km parallel to the western coast of Sri Lanka. It has provision for 4 lanes in a dual carriageway setting. Its lower half is under construction since 2003. The upper half was begun in 2006. The expressway embankment in the upper half runs through soft ground composed of peat, organic clays and soft clays whose natural water content normally ranges up to 800% and thickness up to about 8m in Package 1, where the first 32 km is covered.

It was envisaged that peat and soft clay of alluvial origin would pose considerable settlement when embankments are built for the expressway pavement. Embankment heights reaching 10m on soft ground posed not only large settlement but also instability problems during and after construction. The contract required that the pavement built on top of the embankment should not settle more than 150mm three years after handing over of the completed expressway. It was therefore necessary to determine the anticipated total and rate of settlement under the expressway loading conditions, which led to additional soil investigation for establishing the necessary geotechnical parameters of the underlying soft ground. Table 1 shows the salient parameters used in the design and monitoring of the constructed embankment.

Table 1. Salient soil properties

Type	Natural water content (%)	Unit weight (kN/m^3)	Undrained strength, Cu (kPa)	Compression index, Cc	Coefficient of consolidation, Cv (m^2/yr)
Soft clay	50 – 100	11 - 13	5 – 20	0.5 – 0.8	1 – 10
Peat	100 – 800	11 – 12	5 – 10	1 – 3.4	3 – 30
Weathered rock	20 - 30	18 - 23	50 – 100		
Compacted fill soil	15 - 20	18 - 22	50 – 75		

Settlement Computation

Ultimate primary settlement under varying heights of embankment constructed over varying thicknesses of peat / peaty clay can be estimated based on the consolidation properties of soil, thickness of soft ground and applied loading from the embankment fill. Expected secondary settlement for a 3 year period after primary can also be included based on coefficient of secondary compression of $C\alpha(1+e0)$, which ranges from 0.02 to 0.03 for soft inorganic clay and 0.04 to 0.06 to organic peaty clay (Mesri, 1973). More than 3m of peaty clay is likely to yield a secondary compression in excess of 150mm. In addition the embankment heights 3m or more will also yield primary consolidation settlement in excess of 1m. Therefore it is clear that both the primary and large portion of secondary compression must be removed by way of soft ground improvement, in order to limit the residual settlement to 150mm.

Much research has been carried out on the ‘creep’ or secondary settlement of peaty soils (Mesri, 1973). The extent of investigation assumes fully saturated peaty soils. Little has been done about the continuously evolving and entrapped gases in the peaty soil as part of the decomposition of organic material. If the secondary settlement is largely dependent on the gradual expulsion of organic gases then static surcharging may not eliminate long term creep settlement of peaty soil. Dynamic impact via heavy tamping (HT) was found to be more effective in reducing long term compression of such peaty soils (Lo et al, 1990, Karunaratne et al, 2000 and Lee et al 2003).

Field Trial

A field trial was conducted in Package 1 of STDP for treating peaty soils using heavy tamping as part of the familiarization of the project personnel. The site consisted of 2 to 3m of peaty clay in an area of 60m by 40m of the proposed expressway. A steel pounder of 15 tonnes was built with 25mm thick mild steel plates, 2m by 2m in plan area. An automatic lifting and release mechanism was installed that operated via a hydraulic hose. Figure 1 shows the 80 tonne crane, the pounder with the automatic lifting and release mechanism. The pounder was dropped freely through a height varying up to 10 m.

Figure 1. 80 Tonne crane lifting 15 tonne steel pounder to be released hydraulically

A platform was prepared on the natural swampy ground using hill cut lateritic soil to maintain the pounding surface 1m above the prevailing water level. Inclusions of boulders less than 300mm size in the platform posed no immediate danger to the operation. A pre-determined number of drops of low height (5m) were then made at each tamping position, known also as a ‘print’ or a ‘crater’ when a depression is made after tamping. A spacing of 6m was used on a square grid as the pounder positions in Phase 1. For Phases 2 to 5 other grid locations and larger drop heights were used as shown in Table 2.

At each print location the depth and the plan area of crater formed were measured when the pounder top was below the platform level. Hill-cut lateritic soil was added in to the crater and tamping resumed until the predetermined number of drops was completed.

Table 2. Details of tamping energy application

Phase	Height of drop, H (m)	No of blows N	Energy level = (W* x H x N) (t.m)	Total number of prints in the given area	Total energy (t.m)	Volume of fill added to craters (m^3)
1	5	10	750	74	55,500	2103.59
2	5	10	750	58	43,500	
3	5	10	750	58	43,500	
4	5	10	750	32	24,000	
	8	20	2400	20	48,000	
5	8	20	2400	28	67,200	1404.7
	8	25	3000	26	78,000	
6	5	5	375	78	29,250	
				Total	**388,950**	**3508.29**

*W = 15 tonne

When the total applied energy of 388,950 t.m. is divided by the treated area (60m x 40m), the average energy intensity of 162 t.m/m^2 is obtained. Volume of fill added to the craters was meticulously measured. This volume of loose soil added was converted to compacted volume by using a compression factor of 20%. When this volume was divided by the treated gross area the enforced settlement was 1.169m. The platform level had risen about 0.11m over the initial level of platform due to accumulation of added soil. The net enforced settlement amounted to 1.059m.

FIELD OBSERVATIONS

During Phase 1 (details in Table 2), since the ground was very soft, the applied energy intensity was maintained at low level. Energy per phase was gradually increased either by raising the pounder higher and/or increasing the number of drops at a given point. The prints were uniformly distributed in each phase so as not to overstress the ground. Where concentration was inadvertently occurred, the saturated soft peat started oozing out at the tamping surface. Upon excavation with a back hoe the pit began filling with black colour water oozed out from adjacent peat, which had obviously been under high pore water pressure, as shown in Figure 2. Water was found to be acidic, pH = 4.5 and the water content had decreased from over 500% to 406% within the peat under high pore water pressure.

Figure 2. Water oozed out (and collected in a 1m long pit) when high pore pressure was created in peat with heavy tamping.

Ground Vibration

The ground vibration was monitored during tamping. The peak particle velocity at a distance of 50m was about 5 mm/sec, at 25m it was between 10 and 15 mm/sec. Much of the surface energy passes as surface waves, whereas the compression waves generated by the tamper densify the soil vertically downwards. Since the expressway runs far away from habitation, ground vibration posed no special difficulty for heavy tamping.

Ground Investigation after Treatment

Five Standard Penetration Tests (SPT) were conducted immediately after application of tamping intensity of 162 tm/m^2. SPT results are shown on the right hand side of Figure 3 compared with the SPT tests carried out before heavy tamping. SPT N value of peat before tamping was 0 even at 3m depth from the ground surface. It can be seen that the tamped residual soil and the crater centred columns have SPT N values in the region of 5 to 15, corresponding to Cu = 25 to 90 kPa, (Bowels, 1996) and perhaps as high as 25 (Cu = 175kPa). Peat displayed SPT N values in the range of 2 to 4 (12 to 20 kPa). Location Ch 17+400G is a spot where peat appeared to ooze to the surface in between the neighbouring print locations.

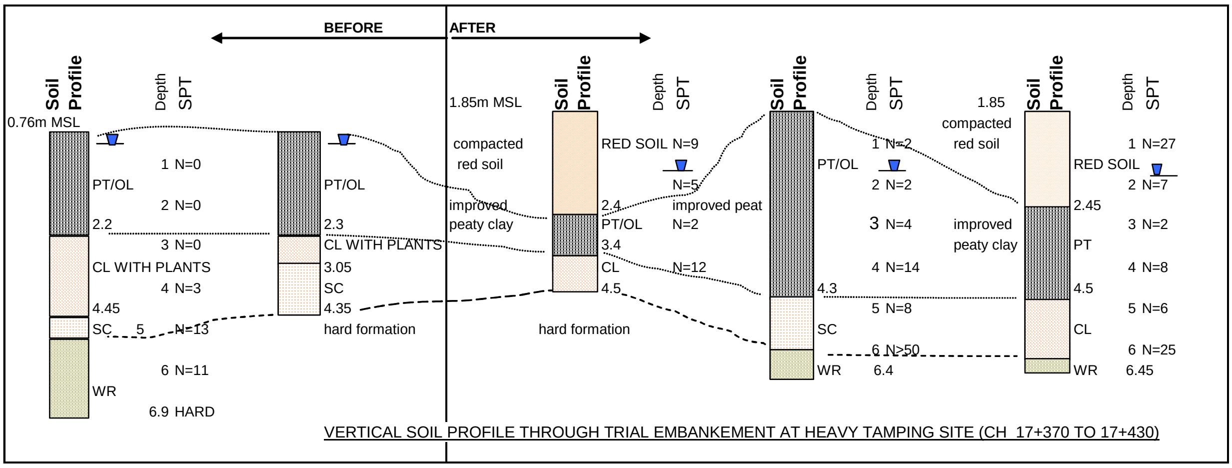

Figure 3. Soil profile and SPT before and after heavy tamping operation

Soil Sampling

Large diameter peat samples before and after ground treatment were tested for consolidation properties. Improvement was evident in salient soil properties. Most important and readily assessable property was the natural water content that changed from over 500% (before treatment) to 406% immediately after treatment, down to 180% after removal of proof load an 50% during excavation for structures.

INSTRUMENTATION AND PROOF LOADING

Instruments consisting of 3 settlement plates placed on the improved ground, 7 piezometers inserted in soft clay or peaty clay, and a set of displacement stakes on either side of the proof load were placed at the centre of Ch 17+400. One of the seven piezometers was placed outside the trial area in the original ground to monitor the pore pressure in the clay.

Proof Load

A 3m high fill imposing a total pressure of 54 to 58 kPa was placed on the treated ground in August 2006 as a proof load, in 10 days instead of 40 days as prescribed in the Construction Specification. Proof load was removed in early May 2007 when the settlement rate fell below 5 mm a month. Figure 4 shows the settlement of the centre of the proof load with time. Asaoka Plot proved that the residual settlement is very small, as the settlement curve just touched the 45º line through the origin. Rapid placement and sustenance of the proof load for more than 10 months confirm the stability of the improved soft ground after heavy tamping. Factor of safety against slope failure was found to be 2.47 while the slip circle passed through the pounded soil in crater-columns

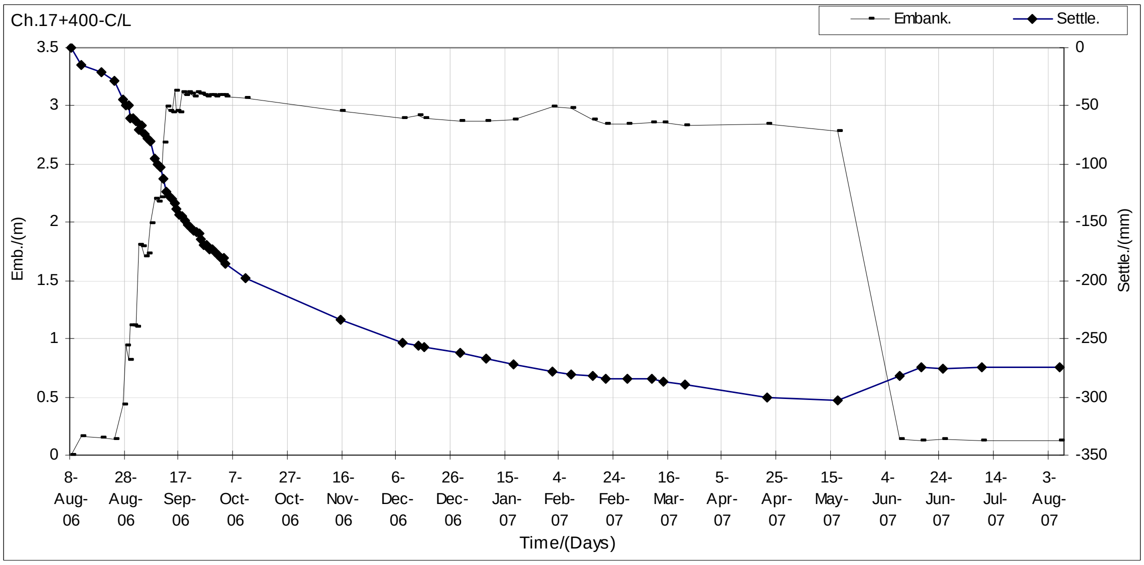

Figure 4. Centreline settlement of the proof load during placement, maintenance and after removal

Treated Ground Performance

The pore pressure, as displayed in seven piezometers, in the treated peat/peaty clay is shown in Figure 5. At the end of 3m high proof load placement, on 31 August 2006, the stand pipe piezometers overflowed due to high excess pore pressure arising from compression of the peat/peaty organic clay in the foundation. Afterwards the pore pressure dropped gradually for about 6 months before nearly stabilizing at 2000mm to 2500mm above the outside ground water level. Removal of proof load plummeted all pore pressures to water table level. Then the piezometers re-established at a slightly higher level (Figure 5) in early July 2007. Settlement profile in Figure 4 also shows the elastic rebound of the ground after proof load removal.

Heavy tamping causes permeability of peat and clay to decrease due to densification of soils. Water trapped in the clay displays high pore pressure. Since there are no pervious paths in the clay or peaty clay, more than 0.5m thick, high pore pressure remains for a long time.

APPLICATION TO MAIN WORKS

Heavy tamping was subsequently used in the main works to improve peat / peaty clay where removal and replacement with rock was not contemplated. Vertical band drains were used to dissipate excess pore pressure generated in such material. Plastic vertical band drains of tensile strength less than 2 kN were too weak to sustain heavy tamping. Hence a stronger band drain (FD) with a tensile strength 8 kN and manufactured from natural fibres was installed prior to tamping. As the tamping progressed, the excess pore pressure in the neighbourhood of the tamping location began to dissipate via vertical drains, around the tamping location near the crawler crane as shown in Figure 6, and also in the neighbourhood of the tamping locations as shown in Figure 7.

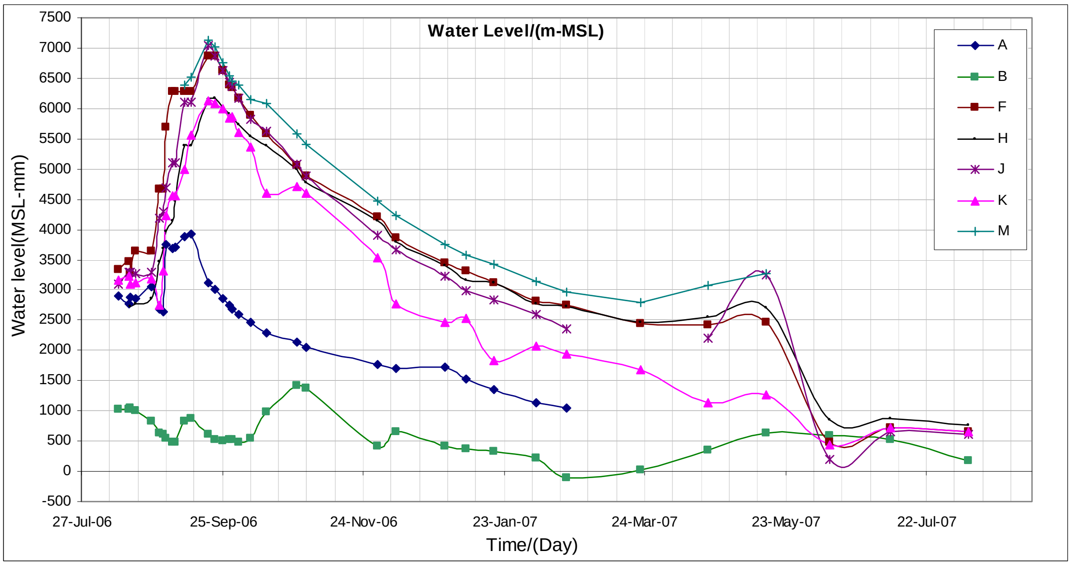

Figure 5. Pore pressure variation and consolidation of underlying organic clay from August 2006 to August 2007 with proof loading

Figure 8 shows how the enforced settlement, phase-wise and cumulatively, developed with heavy tamping phases. Four phases of tamping on a 6m square grid delivered 20.8, 50, 50 and 80 tm/sq m of energy intensity. The crater depth first began to increase with a decreasing trend, indicative of the gradual stiffening of the soft ground with treatment. At the end of Phase 3, applied total energy was 120.8 t.m/m^2 and cumulative settlement was 1.046m.

The applied energy of 120.8 t.m/m^2 was much less than 162 t.m/m^2 needed for enforcing 1.1 m in the field trial area in the field trial area at Ch 17+400 without band drains. This clearly shows that part of the applied energy in the trial area was wasted in compressing the 'incompressible' water.

Figure 6. Prefabricated vertical (band) drains (FD) (100mm wide) at 1m centres near the crawler crane oozing water under pressure in the tamped peaty soil

Figure 9 utilizes tamping energy intensities and the corresponding enforced settlement in the main works and trial areas, with and without band drains. It can be clearly seen that the energy levels without band drains are much higher for the same type of peaty soils and thicknesses experienced in this project. Therefore provision of a strong band drain to withstand heavy tamping impact while allowing excess pore pressure to dissipate freely is useful in reducing the required tamping energy level.

Figure 7. Vertical drains nearby tamping location (within 5m radius) conducting water

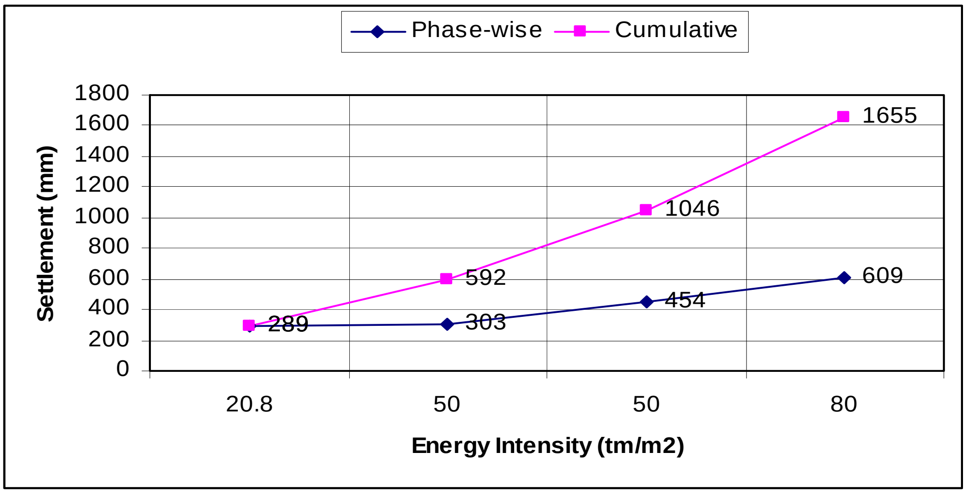

Figure 8. Enforced settlement against applied energy intensity in Phases 1 to 4 (Total energy = 202.8tm/m^2)

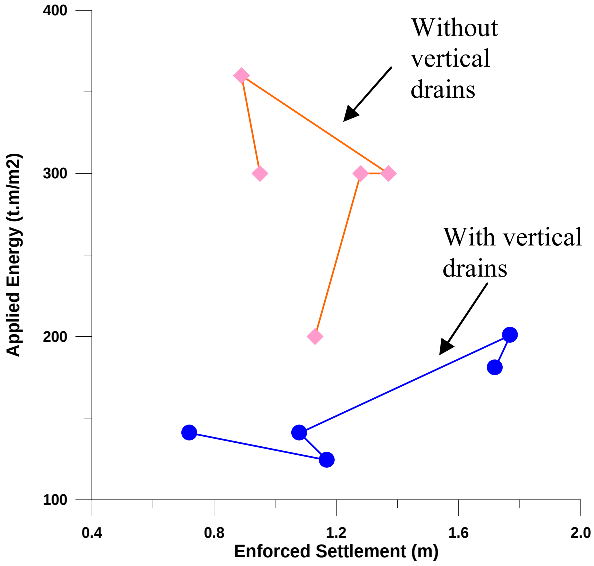

Figure 9. Applied energy intensity against enforce settlement in different locations of the main works showing the reduced energy levels when excess pore pressure in peat soil is allowed to dissipate

Figure 10 shows an oblique view of a vertical excavation made for a hydraulic structure through the improved peaty ground with heavy tamping. Rubble packed foundation is laid on the excavation on the right hand side of the picture. The left hand side of the higher ground shows 2m to 2.2m diameter craters of heavy tamping filled with lateritic soil. A ring of grey peaty soil can be seen at the periphery of each crater. The excavation is vertical to a depth of 2.5m in the surrounding ground with water table nearly at the surface of the original ground at the grass patch in the background. Such excavations are open unsupported in improved peaty soils for 1-3 months, illustrating the extent of improvement with heavy tamping.

Improved Peat with Heavy Tamping

The water content of peat was measured after heavy tamping in the main works, when the embankment construction or excavation for box culverts is already begun. Water content has decreased from the range of 584% to 746% for the original peaty soil, to as small as 100%. Smaller the natural water content, smaller is the compression index C_c or higher the pre-consolidation pressure. Hence it can be seen that the resulting compression upon loading shall be small, due to improvement with heavy tamping.

Peat consists of partially or fully decomposed organic matter buried in shallow depths of marshy areas. In alluvial environments fine clay, silt and sand may occur in the interstices of peat fibre or granules. Peat also releases organic gas bubbles (methane, ethane, sulphur and nitrogen oxides etc) during its continuing decomposition. An effective method of compressing such gas bubbles is to provide dynamic impact as in heavy tamping. Sudden reduction of gas bubble volume due to dynamic impact under Boyle's law, solubility of gas under pressure (Henry's Law) and rapid flow of water in peat capable of carrying away the gas bubbles with peaty water contribute to rapid compaction of peaty soils during heavy tamping. Provision of vertical drains that can withstand heavy tamping is beneficial if the permeability of peat drops many folds upon dynamic compression, which was observed in the field trial. It should be clear that static loads are less effective in eliminating all gas bubbles. Hence static surcharges used for preloading will not completely remove residual settlement in peaty soils.

Heavy tamping has the additional benefit of imparting a dynamic load on a column of soil as large a size as the pounder foot-print at the surface, reducing in size with depth. Depth of column formation may be as much as 5 to 6m with 150 t.m energy per blow. Such columns force the peat to compress vertically as well as laterally reinforcing the original peat deposit and pre-stressing the peat laterally, thereby developing a lateral pressure in excess of K_0 condition, more akin to K_P condition. Upon loading a heavy tamped deposit the settlement is greatly reduced due both to the compressed columns transferring the load to the lower levels of the deposit like piles; and the stiffening of the compressed peat vertically and laterally in a K_0 to K_P environment.

Figure 10. A vertical excavation for a hydraulic structure in improved peaty soil with heavy tamping. Crater outlines of peaty soil are visible on the horizontal ground on the bank of excavation

Applied Energy vs. Enforced Settlement

Lo et al (1990) on heavy tamping in peaty and cohesive soils have shown that a saturation energy level exists for a given enforced settlement. These energy levels are based on the type of soils, energy per blow and stiffness of soil among other parameters. However in majority of the cases band drains were not used in peaty clay. A certain number of days have been allowed to dissipate pore pressure between different phases of tamping in certain projects involving heavy tamping. Had the pore pressure been eliminated during heavy tamping using band drains, then a smaller intensity of tamping energy could have been used. A reduction of about 25% has been observed in the main works of the current project with a strong vertical drain.

CONCLUSIONS

The main conclusions from the heavy tamping trial and application in the main works in this project in order to ensure that the residual settlement of embankments built on peaty ground is limited to 150mm at the end of three years are:

- Water content has decreased from about 600% -750% to below 100% in the treated peat.
- With proper assessment of peaty clay thickness and probable settlement under a given embankment fill, required tamping energy level may be determined, where strong band drains are installed prior to heavy tamping.
- Construction of the embankment after heavy tamping will enable deeper levels of peaty clay and soft clay to be consolidated with the band drain environment already existing. A suitable surcharge may be used with band drains for enforcing additional consolidation settlement desired in deep rooted clays.
- Though saturated clay is difficult to compress, generally peat is more pervious, unsaturated, and has organic gases and therefore more compressible. Peat can absorb the applied energy and can be compressed to the anticipated settlement, including a certain percentage of secondary compression, under the fill load.
- No prefabricated vertical (band) drains were used in the reported field trial. A strong vertical band drain capable of withstanding heavy tamping would have facilitated tamping with reduced effort, eliminated high pore pressure in peat, and saved applied energy of 25%.
- A strong prefabricated vertical (band) drain made of natural fibres was used in the main works subsequently.

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