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Reinforced earth structures on soft alluvial deposits improved with prefabricated vertical drains and stabilizing berms

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ABSTRACT: This paper presents a case study on foundation treatment using prefabricated vertical drains and stabilizing berms supporting reinforced soil walls and abutments constructed over Calcutta alluvial plains – a stratigraphy consisting of very soft to firm clays with organics extending down to a depth of about 15 m below ground level. The behaviour of the structure during and post construction is reported in the paper, including instances where stability problems were reported during construction. Settlements of large magnitude were observed along with serviceability-associated problems in certain cases. The authors wish to share these experiences and discuss the remedial measures adopted and suggest various preventive and corrective actions that can be employed while constructing under similar conditions.

1 INTRODUCTION

Reinforced soil (RS) technology using discrete cruciform panels and high adherence steel strip reinforcement has been adopted for the construction of flyovers, overpasses, Rail over bridges and interchanges, being a part of the highway widening and strengthening project on NH-6 from Dankuni to Kolaghat (km 17.6 to km 72.0, Package : WB-I) and Kolaghat to Kharagpur (km 72.0 to km 130.0, Package: WB-II) in West Bengal on the Golden Quadrilateral corridor for National Highways Authority of India. Refer Fig. 1(a). There are a total of ten RS walls and pure abutments (total 42,000 sqm of face area). The static design of RS wall was done as per BS 8006, 1995 and the seismic design as per AFNOR NF P 94-220, July 1992.

The project involved construction of RS structures supporting high-density corridor traffic on soft alluvial deposits. This paper narrates the investigation, study, design, construction and post construction behavior and remedial aspects of the ground improvement program conceived, and adopted for the works. A combination of prefabricated vertical drainage system and stabilizing berm were used to accelerate dissipation of pore water pressure, and for improving sub-soil shear strength to cater to additional Reinforced soil structure wall heights without foundation failures and instability. Depending upon the height, loading and foundation characteristics of sub-soil, two to four stage construction was adopted, with hold periods. The gain in shear strength of subsoil due to consolidation under each stage of loading would allow construction of the next stage without chances of foundation failure.

In the Dankuni to Kolaghat (WB-I package) stretch, the RS walls itself act as direct surcharge for subsoil consolidation to occur with hold-periods till the next stage was built up. For the Kolaghat to Kharagpur (WB-II package) stretch, separate pre-loads surcharge were used to build out the first stage of consolidation before the first course of reinforced soil structure were constructed.

This project also involved the construction of pure load bearing abutment for the first time in India supporting bank seat loading from the end-floating span, in addition to live loads. The pure abutment design case have been used for abutment cross walls and return walls at most structure interfaces with the provision of jacking, should there be a necessity to lift the bank seat from its settled position.

An extensive instrumentation program has been adopted to record, monitor, analyse, interpret and correlate results with theoretical calculations. Settlement gauges (plates, spider magnets) and peizometers have been installed to regularly record the results as construction proceeds.

2 FOUNDATION SOIL INVESTIGATION

Soil investigation has been conducted for all the locations with 25-35 m deep boreholes, in-situ standard penetration test within boreholes, in-situ vane shear tests down to 15 m depth and laboratory tests on disturbed/undisturbed samples. The Sub-soil in most of the location consists of very soft-to-soft deposit of (gray, organic, yellowish or reddish brown) silty clay. In most of the cases the top 10 m soil is very soft with N-value varying from 1 to 4 (Undrained shear strength 20 to 30 kN/m^2). The soil generally consists of 40% of clay and 60% of silt. Typical soil profile is shown in Fig. 1(b). The ground water table fluctuates with season but reaches almost the ground surface during the rainy season.

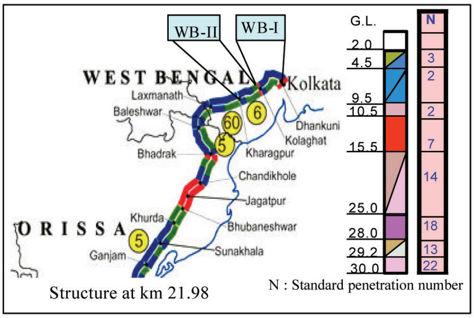

Figure 1. (a) Project site plan, (b) Typical bore log detail.

The investigation revealed that the supporting strata could not carry, with a suitable factor of safety, the height above 5.0 m retaining structures on the soft ground without ground treatment.

3 FOUNDATION IMPROVEMENT

The maximum height of RS wall varied from 6.0 m to 12.0 m for the structures. The foundation soil did not have adequate bearing capacity to support high structures. The wall was therefore, proposed to be built in stages. The gain in shear strength of subsoil due to consolidation under each stage of loading would allow construction of the next stage without any foundation failure. In order to accelerate the consolidation under each stage of loading the subsoil was proposed for treatment with prefabricated vertical drains (PVDs). The PVD was also proposed to be extended on all sides beyond RS wall width. The hydraulic and physical properties of PVD are shown in Table 1. The Reinforced soil structure walls are catered for total settlement of 600-1100 mm for maximum wall height of 10 m depending on the location.

The design of PVD is based on Rendulic and Barrons theory. 0.1 m wide (0.065 m effective diameter, D_w) PVDs are provided in square grids, with effective spacing (D_e) of 1.70 m. Design degree of consolidation is 90% and rate of consolidation 0.05 m^2/day. Based on above parameters, 'n' (refer Fig. 2) is calculated using (1):

Table 1. Hydraulic and physical properties of PVD.

Hydraulic Properties				
Hydraulic gradient, i		0.1		
Water flow capacity in plane l/(s.m) as per EN ISO 12958		Mean Value 0.08	Tolerance Value –0.015	
Physical Properties				
Thickness, (mm)	5	Length (m)	200	
Weight, (g/m^2)	700	Area (m^2)	20	
Width, (m)	0.1			

$$\frac{D_e}{D_w} = \frac{1.70}{0.065} = 26 \tag{1}$$

The time factor (T_r) is derived from Fig. 2 and then time required for 90% consolidation is calculated using (2):

$$t = \frac{T_r D_e^2}{C_{vt}} \tag{2}$$

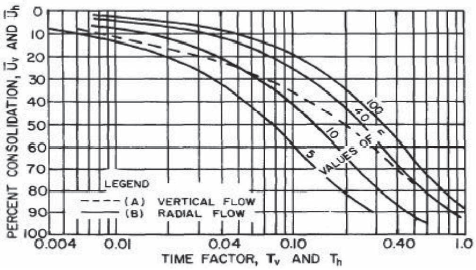

Figure 2. Time factor (T_r) versus degree of consolidation plot for various 'n' value.

3.1 *Typical proposed foundation improvement programme*

Typical ground treatment proposed for 10 m high walls for various structures depending on type of foundation soil is as follows:

3.1.1 *Foundation treatment: Type-1*

For reinforced soil walls upto a height of 5 m, no ground treatment was proposed. Walls exceeding 5 m height, the ground was proposed to be treated with prefabricated vertical drains (PVDs) @ 1.5 m c/c × 12 m deep (refer Fig. 3). The PVDs were extended 3-4 m on all sides beyond the structure width.

Two or three-stage construction was proposed for wall exceeding height of 5 m. The details of stage construction were as follows:

1. Stage I: RS wall upto 5 m high, were built first. Thereafter, 40-60 days pause period was provided

for allowing consolidation of the subsoil till the increase in pore pressure reduces to zero.
2. Stage II: In next stage another 2 m-compacted soil was filled up, increasing the wall height to 7 m. Thereafter, another 40-60 days pause period was provided for allowing 90% consolidation of the subsoil.
3. Stage III: RS wall upto 12 m high was built after the pause period, including granular sub-base (GSB), wherever applicable. Thereafter, another pause period of 45 days was provided.
4. Then the pavement structure was built.

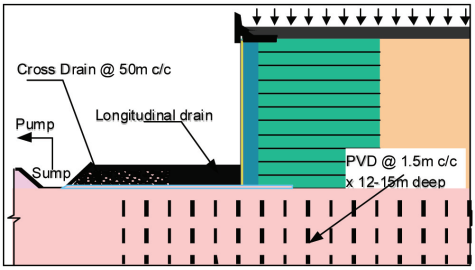

Figure 3. Drainage arrangement detail and proposed treatment above 5.0 m height wall for Structure at km 17.6, 21.98, 23.831, 24.6 and 26.1.

3.1.2 *Foundation treatment : Type-2*

In some location stabilizing berm was proposed for improving the stability of the structure. The details of construction were as follows:

1. For walls upto a height of 4-5 m, no ground treatment was provided
2. The walls exceeding 5 m heights, a stabilizing berm 5 m wide by 2 m deep, RS wall was provided (refer Fig. 4).

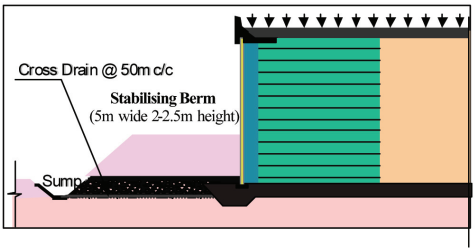

Figure 4. Drainage arrangement detail and stabilizing berm above 4.0 m height wall for Structure at km 17.4 and 18.094.

In all the structure in WB-I project, the Reinforced soil structure itself acted as direct surcharge for subsoil consolidation to occur with hold-periods till the next stage was built up. For the WB-II package, separate pre-loads surcharge were used to build out the first stage of consolidation before the first course of RS walls were constructed. Drainage details are shown in Figs 3 and 4.

4 INSTRUMENTATION

Settlement plates and pizometers have been installed at regular interval to monitor the settlement and dissipation of pore water pressure with the progress of construction. Regular and well planned monitoring of all the structures is being carried out at every alternate day. Settlement monitoring was essential to validate the design of tier wall, especially in requirements of stage II and stage III constructions. Design of top two-tier panel was done only after having a fair idea of actual settlement at site. Typical settlement data and piezometer reading of structure at Kolaghat interchange (WB-II) is recorded in the format as shown in Fig. 5 below.

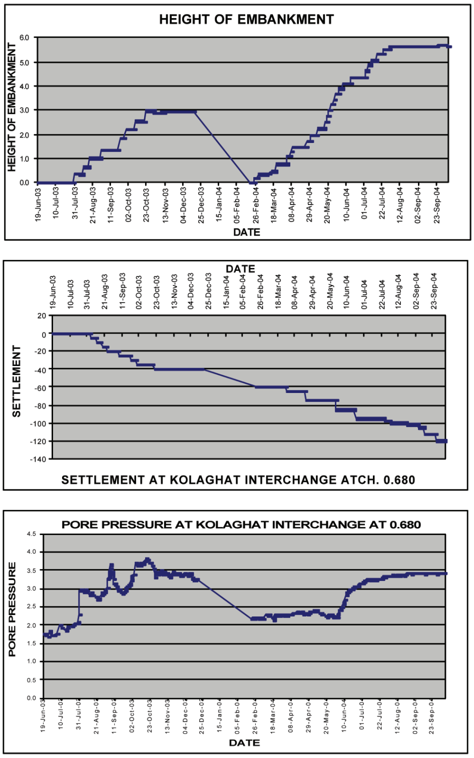

Figure 5. Settlement and pore water pressure data at various stage of construction for structure at Kolaghat.

5 CONSTRUCTION EXPERIENCE

The experience during construction are summarized below:

5.1 *Installation of PVD*

The procedure for installation of PVDs varied with site conditions. Since the site was very soft, it was necessary to construct a working platform to support the construction equipment loads. For this purpose, the top 500 to 750 mm of topsoil was excavated and was filled back with compacted sand, which also served as a drainage blanket. The installation of PVD is shown in photo 1 below.

Photo 1. Installation of PVD.

5.2 *Data collected*

The actual settlement of reinforced soil wall during construction is summarized structure wise in Table 2 depending on height of wall and foundation soil parameters. The settlement data shows that the panel settlement is less than the settlement of fill soil showing a classical elastic deformation pattern. The settlement is maximum at centre of embankment and gradually reduces to minimum at panel location.

Table 2. Panel settlement data (till 15th October, 2005).

Structure	Maximum Fill/Design Height (m)	Recorded Panel Settlement (mm)	Recorded fill soil Settlement (mm)**
Package WB-I			
17.438	9.395	350	367
17.600*	9.080	682	765
21.980	7.895	726	832
23.831	9.580	750	784
24.600*	9.205	255	325
26.100	11.080	835	850
Package WB-II			
Rupnarayan	8.645	180	–
Kolaghat	9.770	221	237

* Under construction: Fill height 7.7 m in 17.6 and 4.5 m in 24.6
** Settlement due to construction of pavement structure is not included. Due to construction of pavement the fill soil has settled by another 100-200 mm.

The maximum allowable differential settlement considered in design is 1 in 100 (Table 22, BS 8006: 1995). Slip joints at every 1.0-1.5 m height difference were provided to cater for excessive differential settlement in longitudinal direction (approach length direction). Differential settlements have been observed in both cross and longitudinal direction (refer Tables 2 and 3) of the structure.

Table 3. Differential settlement data (till 15th October, 2005).

Structures	Chainage (m)	Panel Height (m)	Panel settlement (m)	Differential Settlement
Structure at Km. 17.400	17390 17240	8.795 6.920	0.342 0.330	 1 in 12500
Structure at Km. 21.980	21850 21760 21690	6.355 4.480 3.170	0.702 0.332 0.214	 1 in 243 1 in 648
Structure at Km. 23.831	24100 24200 24270	8.980 6.170 3.920	0.736 0.556 0.242	 1 in 555 1 in 222
Structure at Km. 26.100	650 510 400	9.355 6.170 2.980	0.758 0.406 0.193	 1 in 397 1 in 516

5.3 *Problems encountered and its rectification*

5.3.1 *Structure at km 26.1*

Problem: The wall failed in slip circle once the height of fill reached 7.5 m (just after Stage-II hold period) for a length of 120 m starting at 12 m away from abutment (see Photo 2).

Photo 2. Slip circle failure during Stage-III construction at Km: 26.1 Loop, Kona Expressway, WB-I (Ch. 760 m to 870 m).

Analysis: Four numbers of borehole were carried out to study the geotechnical properties of soil at the locations after the failure. The undrained shear strength profile from available field and laboratory tests are listed in Table 4 and the corresponding design values used in the original design of RS wall are listed in Table 5. The comparison of the undrained shear strength indicates:

1. Undrained shear strength considered in the original design for soil outside the embankment between depth 2 m and 4 m below original ground surface is higher than the actual.
2. Undrained shear strength considered in the original design for soil underneath the reinforced soil wall between depth 0 m and 4 m below original ground surface is higher than the actual.

Table 4. Undrained shear strength (actual).

Location	Elevation (m) with respect to original ground surface		Undrained shear strength
	Top of layer	Bottom of layer	
Outside of embankment	0	2.5 m	32 KPa
	2.5 m	10.0 m	19 KPa
Underneath embankment	0	10.0 m	$s_u/\sigma'_v = 0.22$

Table 5. Undrained shear strength used in the original design of the RS wall.

Location	Elevation (m) with respect to original ground surface		Undrained shear strength
	Top of layer	Bottom of layer	
Outside of embankment	0	2.0 m	30 KPa
	2.0 m	4.0 m	25 KPa
	4.0 m	12.0 m	20 KPa
Underneath embankment	0	2.0 m	$s_u/\sigma'_v = 0.36$ to 0.37
	2.0 m	4.0 m	$s_u/\sigma'_v = 0.27$ to 0.30
	4.0 m	12.0 m	$s_u/\sigma'_v = 0.22$ to 0.18

The failure was due to two major reason:

1. Rapid construction (loading) and discrete foundation soil properties and could not be linked with the performance of PVDs. The gain in shear strength was not sufficient. Since it happened just after continuous rainfall for 3 days, increase in pore water pressure in foundation soil lead to the failure.
2. Subsurface investigation completed prior to the incident relied on SPT and the undrained shear strengths estimated from laboratory testing for the assessment of undrained shear strength of the fine grained foundation soils underlying the site. The lack of alternative in-situ measurements of undrained shear strength prior to the original design to verify the inferences based on SPT and laboratory strength testing may be viewed as a general limitation of the subsurface geotechnical investigation programs upon which the original design of the RS wall had to rely.

Rectification: The entire stretch is rebuilt after dismantling only the top layer of panels and by providing a 6 m height (15 m wide) stabilizing berm on other side of panel. The outputs of stability analysis (static case) for both pre-consolidated and post-consolidated cases are shown in Figs 6 and 7. Since the top alignment got disturbed, a new pad level is constructed over the filled up soil and then the wall is rebuilt.

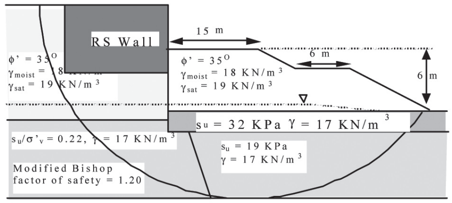

Figure 6. The modified Bishop method to check the pre-consolidated undrained stability of RS wall with berm, against deep seated rotational slip circle failure.

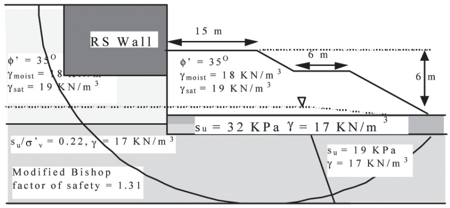

Figure 7. The modified Bishop method to check the post-consolidated undrained stability of RS wall with berm, against deep seated rotational slip circle failure.

5.3.2 *Structure at km 23.831*

Problem: Opening of slip joint at the interfaces of reinforced concrete (RCC) culvert (resting over pile) and reinforced soil wall resting over very soft foundation soil treated with PVD (Refer Fig. 8 and Photo 3) due to differential settlement and washout of filter material from slip joint due to dislocation of cover slab placed behind the slip joint.

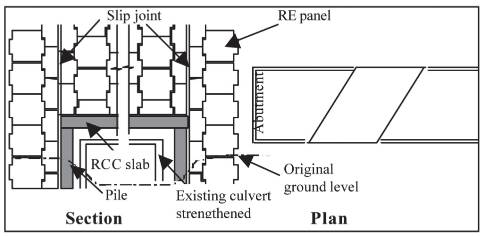

Figure 8. RS wall at culvert location, km 23.831.

Analysis: Opening of joint was due to the differential settlement of panels just near the pile cap and a meter away from the pile due to different soil stiffness created by pile influence zone. Due to this differential settlement the panels likely rotated away from the pile as a result the slip joint widened at top. The cover slab dislocated since the wall founded on the piled foundation has undergone negligible settlement whereas the adjacent area of PVD treated section has undergone substantial settlement. Since part of the cover slab is also resting on "rigid" foundation and part of it on soft PVD foundation, which has settled by more than 350 mm and due to this heavy differential settlement there has been a

Photo 3. Opening of slip joint at interfaces of reinforced concrete reinforced concrete culvert and reinforced concrete wall.

dragging effect which caused the dislocation of cover block and geotextile placed behind the panel, resulting in the migration of backfill materials. Non-woven geotextile was placed as filter behind the cover slab to prevent migration of fine particles from the joint. Also few strips near slip joint snapped from connection due to dragging of strips by settling soil since the strips were laid perpendicular to the facing instead of in skew.

Rectification: The wall length adjoining the slip joints are dismantled in two steps including crash barrier, pavement, panels, strips and back fill. The entire length of reinforced soil wall is then rebuilt.

6 CONCLUSIONS

This paper presents a unique case of construction of reinforced soil structures on very soft foundation strata improved with vertical drains and berms. The record of pore water pressure and settlement through the instrumentation process clearly indicates the satisfactory performance of PVDs that meet the expectations.

Construction requires harmony amongst various disciplines of design, site engineering and construction, instrumentation, field data analysis and monitoring. Critical linkages must also exits amongst all participating agencies in terms of design planning, construction and supervision of all activities as described above to enable successful completion of the works as desired, to maintain high quality standards in all respects and to avoid construction defects and failures.

Reinforced soil wall being a flexible structure can be constructed over very soft soil where the expected settlement is very large. However, special arrangement shall be provided to cater large differential settlement like provision of slip joints. The slip joint shall be placed at least a meter away from the rigid structure foundation interface. The slip joint location shall be better detailed so that the gaps are not visible from outside as they open during excessive settlement.

The interface location between any rigid and flexible foundation shall have the provision of special reinforced concrete cover slab behind the panels that shall be connected with steel strip reinforcement. A suitable transition shall be provided from any rigid to flexible founding zone by means of any semi-rigid footing.

Special attention shall be given against possibility of any slip circle failure from construction factors. If required high strength geogrid/geotextile/geocell mattress may be used in foundation as a stress transition layer.

REFERENCES

A.06/10, November 1990, "Reinforced Earth Abutment design manual".

AFNOR NF P 94-220, July 1992. "Soil Reinforcement, Backfilling structures with inextensible and flexible reinforcing strips or sheets." French Standard.

Barron, R.A. 1948. "Consolidation of fine grained soils by Drain Wells".

BS 8006 : 1995. "Code of Practice for Strengthened/reinforced soils and other fills." British Standard

CE ED-278-GB-A-05/2005, "Colbond Technical specification sheet"