Sub Grade Improvement Using Stone Column for Semi High Speed And Heavy Axle Load – A Case Study on Actual Implementation on Doubling Work of Kharagpur Division

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Synopsis:

RVNL was mandated for implementation of Panskura – Haldia doubling work to cater steep growth of traffic arising from Haldia port. The project location is very near to sea shore and most of the working area remains submerged throughout the year and a very limited period is available for execution at site. The sub soil of the said area was not suitable to take vertical load of high bank and as such, there was failure of sub soil. Subsequently a detailed study was undertaken involving RDSO and the problem was sorted out by using sub grade improvement using stone column. The technique of improving the ground soil using stone column was implemented successfully and in this paper efforts has been made to highlight as a case study which can be very use full for implementation of semi high speed and high axle load in time to come.

1. Introduction:

1.1 Rail Vikas Nigam Limited was entrusted with the work of doubling of 24.4 Km section between Tamluk Junction and Basulya branch line in Kharagpur Division of South Eastern Railway on 08.04.2011. The section has four block sections.

1.2 The project was targeted to complete within 30.04.2015 of four Block Sections. But on completion of the formation work, ballasting

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and linking of track was in progress, suddenly the sub soil of the portion of bank has subsided and crumbled between section Keshabpur and Mahishadal about 500 m length at the approach of Major Bridge No. 69 where the bank height was more than 9 m.

1.3 All the precautionary measures were taken during construction of embankment like removal of top organic soil by filling sand and compacted with the standard RDSO design profile of the formation has been followed. The top width of formation is 6.85 m with a side slope of 2:1 upto 6m height and had a 3 m wide berm at an intermediate level after which further bank slope is maintained at 2.5 :1. The embankment was constructed in layers of 300 mm. A layer of 1.3 m of Moorum was laid on the top of embankment. The construction was done in accordance with RDSO specifications as contained in contract documents.

1.4 The sub-soil was taking load of newly constructed bank upto 7 m height but the sub soil of that area was not able to take the vertical load from 7 to 9 m as the height bank height was 9 m at Bridge Approach to give vertical clearance on this bridge for navigation purpose. Just after the bridge there was Halt Station on Island platform which added further constraint and load on newly constructed bank.

A few pictures taken after the incident are placed below.

2. INVESTIGATION OF THE FAILURE AND REMEDIAL MEASURES RECOMMENDED

Immediately the RVNL authority engaged Geotechnical Consultant and detailed soil boring were undertaken by doing 8 bore holes.

One of the reason of subsidence was primarily caused due to fast pace of construction due to less working period availability and chasing from user department for speedy completion of the work which did not allow the pore water pressure of the underlying soft clay layer of approximate thickness of around 10.0 m below ground to dissipate. As a result, the underlying layer having inadequate bearing capacity was unable to withstand the loading and failed in a typical base failure.

There are methods like pre loading, vertical drain, stone column prescribed in IS Code for sub grade ground improvement. As pre-loading is a long time taken method and a vertical drain being found unsuitable for such situations, the stone column deep into the underlying layer as the most suitable method according to modern Engineering practice as per IS Code guideline for a faster consolidation of sub-soil to complete the project.

2.1 Subsoil Investigation :

Eight boreholes were taken on predetermined locations after subsidence. Following are the major soil strata into which the underlying soil can be divided. Is presented below :

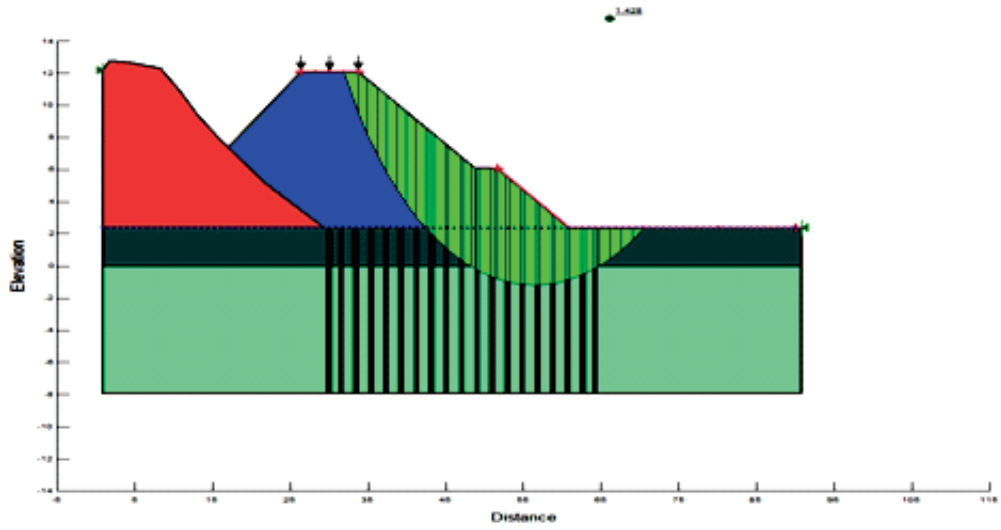
Layer Details				Avg. N value	Bulk density (t/m^2)	LL (%)	PI (%)	Shear strength
No.	Description	Depth below EGL (m)						
I	Filled up by soil, fly ash etc	0.00	1.2	-	-	-	-	-
II	Soft/firm grayish silty clay	1.2	2.80	3	1.83	48	23	C = 2.7 t/m^2
III	Very soft silty clay	2.80	11.60	0 – 4	1.68	57	28	C = 1.7 t/m^2
IV	Firm to very stiff silty clay with calcareous nodules	11.60	14.4	9 – 19	1.88	40	20	C = 6.1 t/m^2
V	Stiff/very stiff sandy silty clay	14.4	17.5/ 20.10	8 – 23	1.89*	30	15	C = 6.6 t/m^2*
VI	Medium/very dense silty fine to medium sand	17.5	20.10	25 - 56	1.90*	Non Plastic		C = 0.0 t/m^2 Phi = 30^0*

3.0 APPOINTMENT OF INDEPENDENT CONSULTANT AND INVOLVEMENT OF RDSO

RVNL has further appointed Sri R.R. Jaruhar, former Member Engineering Railway Board as an Independent consultant to advise RVNL on the subject with following broad terms of reference:

- To study and examine Geotechnical Consultants' Report
- To advise the most suitable remedial measure to enable re-construction of formation of the affected portion safely in the most optimum timeframe by taking into account technical feasibility, mode of construction, cost and site conditions.

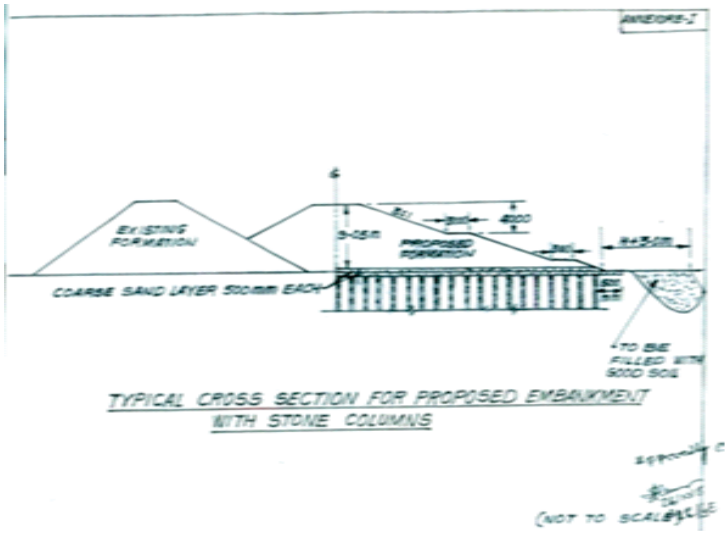
Before commencement of Ground Improvement work, RDSO was involved to give final recommendation. The stone column and slope stability analysis was done based on the site condition and the stability analysis was done based on Bishop /method on computer iteration process to achieve factor of safety of atleast 1.4 for effective stress on soil. The typical stability graph which is shown below



RDSO communicated their final recommendation for stone column and flattening of bank vide their letter dated 26.10.2015 the details are :

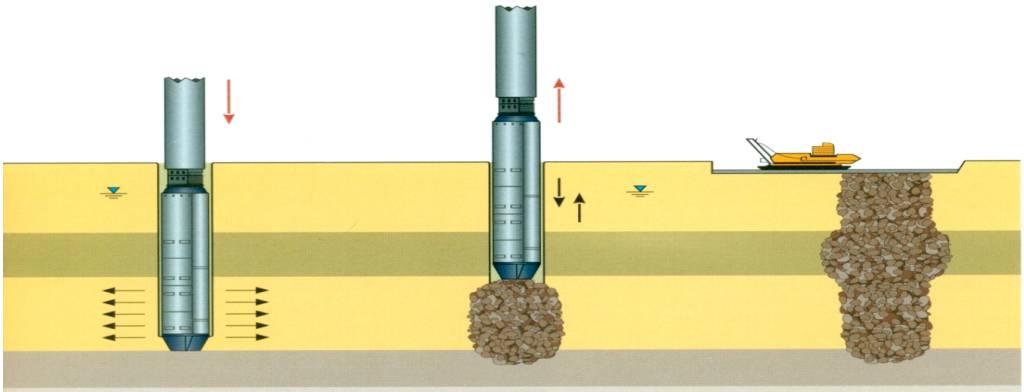
- The effectiveness of stone column should be ascertained by doing plate load test as mentioned in IS : 15284 (Part-I) – 2003.
- Actual settlement in field is much more than calculated settlement, therefore it is desirable that monitoring of settlement be carried out at every stage of construction as per provisions of Guidelines on Soft Stage Construction Method Guideline No. GE : G-5April-2005.

- Design consultant should be involved in execution and quality control.
- Coarse sand layer of 50 cm thickness below GL (at the top of stone column) should be provided and it should be extended 50 cm beyond toe, as shown in Annexure-I.
- As reported by the RDSO officials after inspection of the site, a pond is existing very near to the toe of failed embankment. Normally the distance of pit/pond should be situated (H+3) m away from toe of embankment where H is the Height of the embankment to avoid base failure. Before commencing the work, the pond should be filled with good type of soil upto (H+3) m, distance beyond toe with proper compaction, as shown below



4. THE PROCESS OF STONE COLUMN

The sequence of work shown in following figures :



3 Penetration

The vibrator displaces the soil and is lowered to the design depth, aided by the compressed air and by the vibrocat's pull-down.

4 Compaction

After reaching the maximum depth the vibrator is pulled up slightly, causing the aggregate to fill the cavity created. During re-penetration the aggregate is compacted and pressed into the surrounding soil.

5 Finishing

The stone column is built up in alternating steps up to the design level. During the final levelling, the surface requires to be re-compacted or a blinding layer is required as an alternative.

View of the cut off level after Vibro Replacement

Benefits of working with the bottom feed vibrator:

- The aggregate is always fed directly to the tip of the vibrator, creating a continuous column.
- Only a single penetration is required.
- The collapse of the hole is not possible due to the compressed air even in critical soils.
- The leader ensures the verticality of the columns.
- No water is required, eliminating the necessity to dispose of any mud otherwise created.

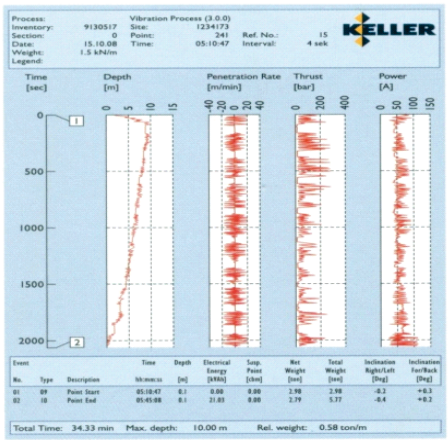
For all vibro techniques, electronic measuring devices can be employed to ensure and record constant high quality of workmanship.

The measuring device

To control the process, monitor the quality and for production records, the relevant construction parameters for each compaction probe can be measured, saved and printed as proof of production and quantities.

The measurement device consists of

- The display unit in the operator's cabin,
- The CPU with data storage,
- PC with printer at the site office,
- Dot-matrix printer mounted on the base unit for real time printout (optional).



5. EXECUTION AND MANAGEMENT OF STONE COLUMN AND MATERIAL

- Execution of stone column for ground improvement is widely accepted methodology in Highway, Airport Development etc. but this is the first time in Indian Railway, the method has been utilized for ground improvement to sub grade to complete the work in a short span.

- On open tender basis stone column execution was awarded to M/s Keller – Shivam (JV) who are pioneer in this field. 600 mm dia displacement type vibro operated stone column 4551 nos. were executed at site. The work was started on 09.10.2015 and completed on 12.02.2016.

- The supply of stone aggregate by road was not possible to feed the huge requirement of stone aggregate in short time span for progressing the stone column work which consumed around 14 rakes of graded stone aggregate just in three months from Railway approved ballast quarry.

6.0 Completion of Ground Improvement Work for sub grade as per Guideline of RDSO vide letter dated 26.10.2015.

Accordingly, 600 mm dia stone column have been provided @ 2 m C/C for embankment height upto 6m and @ 1.6 m c/c for

embankment height above 6 m. upto toe of bank in the entire subsidence portion. Other recommendations of RDSO have also been complied like: -

1 **Plate Load Test :** The effectiveness of Stone columns have been ascertained by Plate Load Test as per provision in IS : 15284 (Pt. I) - 2003. One additional Test on virgin untreated soil according to IS 1888 : 1982 was also done and found that after stone column, the bearing capacity has been increased more than 5 times in comparison to the bearing capacity of virgin soil even though bank load is yet to come which will further consolidate the soft clay layer below of bank due to consolidation thus increase in bearing capacity further. The Plate Load Test are tabulated below :

Test Location (Chainage)	Date	Column Number	Load at 12mm settlement	Design load (t)	Plate Area (sqm)	Safe Bearing Capacity (t/sqm)
Load Test on treated soil just after stone column but without bank load						
7340 to 7360	15/12/2015	1263	49.00	49.00	4.0	12.35
7560 to 7580	28/12/2015	3149	45.85	46.00	4.0	11.46
7480 to 7500	22/01/2016	2467	50.00	50.00	4.0	12.70
7260 to 7280	02/02/2016	489	50.00	50.00	4.0	12.70
7340	06/02/2016	1127	50.00	50.00	4.0	12.70
7420 to 7440	11/02/2016	18656	50.00	50.00	4.0	12.70
7460 to 7480	13/02/2016	3372	50.00	50.00	4.0	12.70
Load Test on Virgin Soil at same location without treatment						
7260 to 7280	06/01/2016	On Virgin Soil	28.00 (25mm settlement)	8.8*	4.0	2.2

2 Monitoring of Settlement during and after construction :

As per theoretical calculation, due to ground improvement there will be primary settlement by 163 mm and secondary settlement of 73 mm of soft clay layer (of thickness around 10 m) existing below bank base. Therefore total settlement predicted 236 mm.

After installation of stone columns, settlement points were fixed on top of the stone column after laying 500 mm thickness of coarse sand for horizontal drainage of pore water.

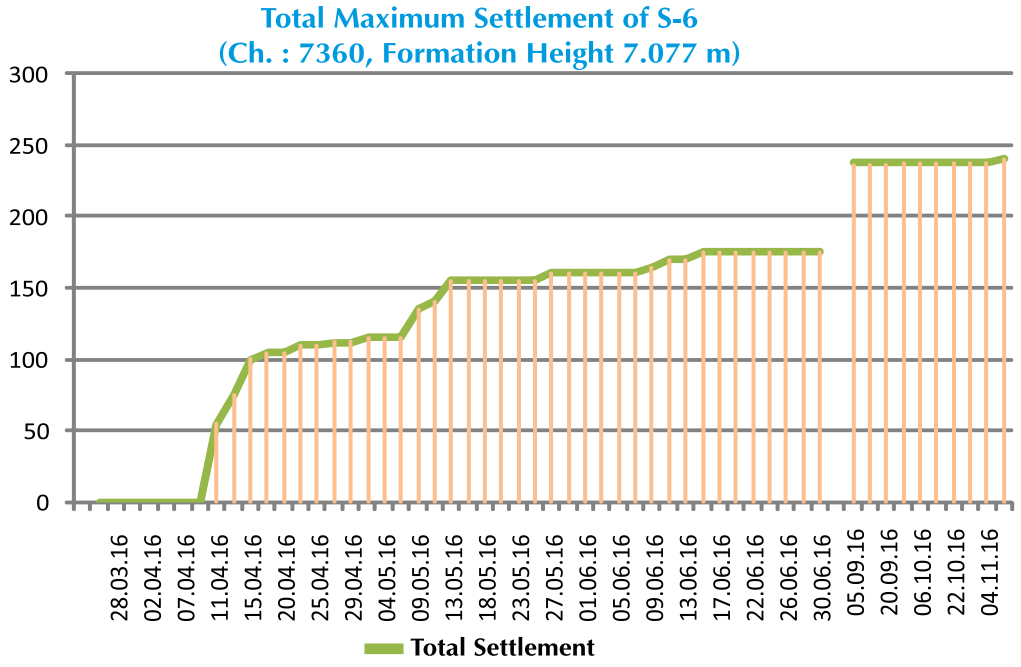
During construction of bank the height of pipe of settlement point were added till the final formation is completed. 8 such points were installed in a length of 500 m demarcated from S1 to S8 and settlement continuously are recorded.

After completion of formation before laying of track the settlement points were transferred to settlement marker again demarcated from S1 to S8 and settlement measurements were taken continuously are recorded.

Summary of Settlement record from 21.03.2016 to 12.11.2016

Location	Chainage (In m)	Bank (in m)	Settlement of Point (in mm)	Settlement of marker (in mm)	Total Settlement
S-1	7660	5.833	114	51	165
S-2	7600	6.004	116	57	173
S-3	7520	6.485	60	74	134
S-4	7480	6.474	166	73	239
S-5	7420	7.032	121	85	206
S-6	7360	7.077	175	65	240
S-7	7300	7.694	87	37	124
S-8	7240	7.669	147	61	208

While going through the settlement marker records, it is noted that the settlement is more or less stabled One typical plotting is given below. For S-6 where the total settlement was maximum and found very close to the total settlement of predicted value.



Settlement Marker Fixed from settlement Point

3. RDSO Recommended for deployment of DDC. M/s Bose Engineers, who was deputed for Soil Investigation and Methodology for ground improvement after subsidence, was engaged as Design Consultant for execution and Quality Control.

4. Coarse sand layer of 500mm thickness has been provided above stone column and extended upto 50 mm beyond toe as per sketch provided by RDSO.

5. The existing pond near toe of embankment has been filled up with good quality soil upto (H+3)m away from the toe of embankment (H = height of bank) and properly compacted.

6. As per advice of ED/RDSO during his site inspection on 27072016, the entire slope has been suitably turfed with natural grass and cross slope drain have been provided @ 50m interval.

7. After final development of bank track laid and 3 rakes of ballast and one rake of stone dust unloaded at site and performance found satisfactorily.

8. For final certification RDSO Inspected at site on 14 & 15.11.2016. and confirmed vide letter dt. 27.07.2016 regarding satisfactory compliance of all their guideline by RVNL.

9. The section was inspected by CRS on 25.11.2016 for commissioning and speed trial at 115 kmph with satisfactory performance was completed. Few photographs are shown below.




Conclusion :

The Guideline given by RDSO vide letter dated 26.10.2015 and during inspection dated 27.07.2016 the ground improvement by stone column according to IS Code 15284 (Pt. I) : 2003 has been carried out and thereafter bank has been constructed at full height. During construction of embankment and thereafter settlement has been monitored. The bank slope has been protected with turfing and the character of the bank is found almost stable. The series of vertical posts implanted 3 months before for fencing purpose at toe of 2nd berm also act as telltale has not shown any sign of misalignment which indicates stability of bank.

There is no deformation noticed at present and the performance of the bank after construction and is found satisfactory. This methodology can be used for handing such weak patches of sub grade for semi high speed and heavy axle load movement in near future. This will be very useful for speedy completion of project in weak soil area and the maintenance effort on newly commissioned track will almost be reduced .