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Strengthening of the Foundation using Deep Mixing and Stone Column Techniques for Large Earth Cum Rock Fill (ECRF) Dam for an Irrigation project

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Abstract

A Large Earth Cum Rock Fill, ECRF Dam is under construction in the state of Andhra Pradesh in India. The Embankment crest width of the dam is 12.5m and base width is of approximately 136.75m with a stepped sloping height of 27m on both upstream/downstream sides. Plastic Concrete Diaphragm wall of 1.2m thick is constructed along the longitudinal central axis to avoid seepage to depths of 96m below the existing bed levels. The functional efficiency of plastic concrete cutoff wall is designed for the high underwater scouring and discharge velocity of river during the peak flood season. Deep Single Mixing (DSM) Columns and Stone Columns are evenly arranged under the footprint of ECRF Dam for smooth transition of stresses by gradually reducing stiffness moduli from Centre to Toe of Embankment. The stiffness moduli reduce gradually towards the Toe facilitating settlements within allowable limits. The paper discusses the installation of the DSM Columns along the Diaphragm wall and field trails carried out for establishing the desired stiffness modulus of DSM Columns.

Keywords: Earth Cum Rock Fill Dam, Deep Mixing, Stone columns, Laboratory tests, Field Trials

1. Introduction

The Government of Andhra Pradesh Irrigation and Command Area development (I&CAD) Department proposed to construct a multipurpose dam across the river Godavari near Polavaram village, Andhra Pradesh, India (Fig 1). Bauer is the subcontractor of the project to build Earth Cum Rock Fill (ECRF) dam for a length of 1750m across the Godavari River. Ground improvement using Deep soil mixing (DSM) is proposed by Bauer along the existing plastic concrete diaphragm wall (upstream side and downstream side) to ensure overall stability of ECRF dam by improving the stiffness of the stiffness of soils at GAP I and GAP II locations. Deep Soil Mixing (DSM) is introduced for the first time by Bauer in India at this project and it's a very sustainable solution replacing the traditional ground improvement techniques.

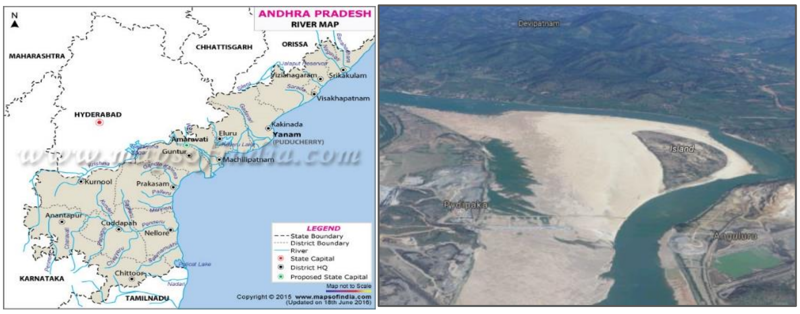


Fig. 1. Location of ECRF DAM at Polavaram

2. Need for the Installation of the DSM Column below the ECRF Dam

The DSM columns will form a transition treatment between the existing the Cut-off Wall and proposed ground improvement by stone columns below the footprint for ECRF Dam. The DSM columns act as transition of the deformation modulus of the ground from the centre of the dam to the toe of the dam embankment. The soil improvement works consists of Single Column Deep Soil Mixing (DSM) and shall be carried out along the installed Plastic Concrete Diaphragm Wall /Cut-off Wall in the clay sections as shown in the Figure 2. As the stiffness of Diaphragm Wall is higher than the stone columns, so this DSM treatment will provide intermediate stiffness by transition. Installation of DSM columns shall confirm improvement of the initial soil stiffness by 5 times.

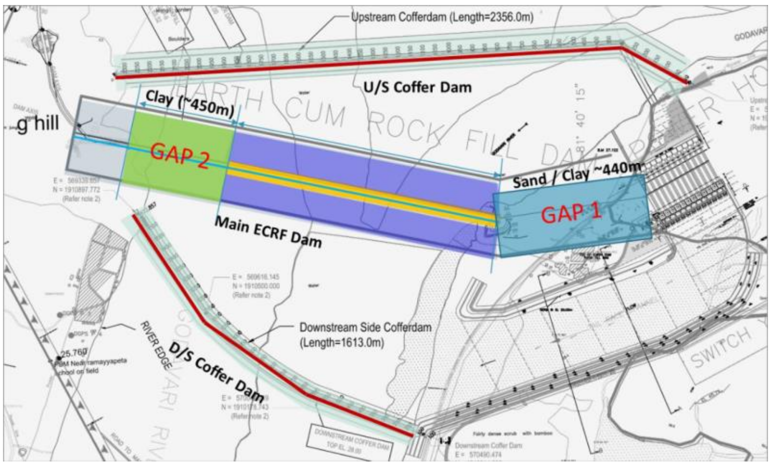


Fig. 2. Plan of Deep Soil Mixing Works at GAP I and GAP II

3. Designing the DSM Columns for protection works

For soil treatment beneath the rock fill embankment, Stone Columns (Deep Vibro Floatation Method) and Rigid Columns (DSM method) are used for ground improvement. Field trials are conducted near the GAP I area to establish the design parameters and mix design of the DSM columns to be installed at the site. The data obtained from the trials shall be used for execution of DSM column production at GAP I and GAP II.

3.1 Summary of the Geotechnical Data at the Job Site

Based on the available geotechnical information for the site, the summary of the grain size distribution at the locations of improvement by Deep soil Mixing (DSM) are summarized below in Table 1.

Table 1. Summary of the Soil profile of the site

Location	Chainage, m	Clay %	Silt %	Sand %	Gravel %
GAP 2	1365-1195	34.3	49.8	7.5	8.4
GAP 2	1195-1025	24.4	46.1	22.2	7.3
GAP 2	1025-910	<50	<50	>50	>50
GAP 1	250-425	16.7	48.6	30.3	4.5

3.2 Methodology for trial works for Deep soil Mixing

Field trials are conducted prior to commencement of the main works to ensure performance of the proposed ground improvement scheme for both Vibro Stone Columns and Deep Soil Mixing columns. The tentative trial locations at the GAP I and GAP II are as shown in the Figure 3. The results of field trials establish correctness of the assumed material properties (elastic modulus) which were considered in the numerical modelling for the case of post ground improvement scenario, in dam foundation design. The anticipated post treatment stiffness in case of stone columns is 2 times of the in-situ stiffness whereas it is expected to be 5 times improvement for deep soil mixing.

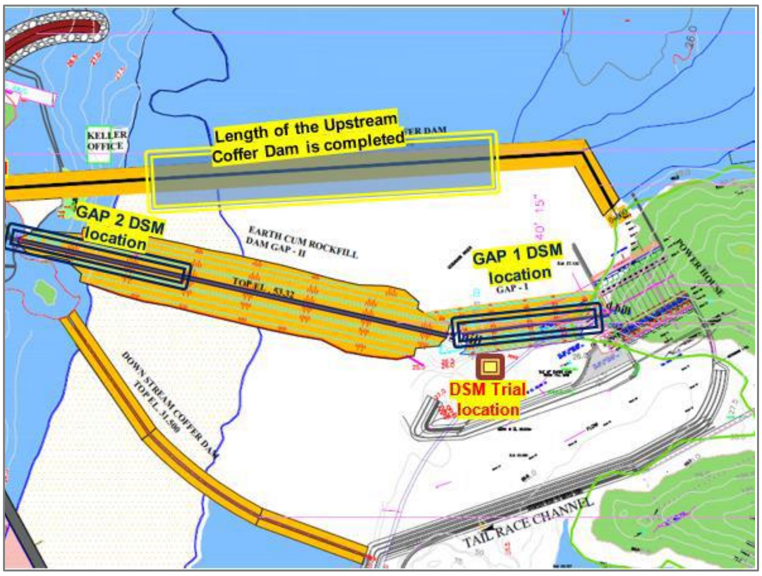


Fig. 3. Tentative location of the DSM Works and proposed Trial Locations

3.3 Trial Columns

The field trial test section include installation of 18 nos of DSM columns. Layout of the DSM columns is shown below Figure 4. For a treatment area ratio of 40%, with column diameter of D_{col}=1m and spacing between the columns in a squared grid is considered at a = 1. m. However, the plan is to install trial columns with a 1.3 m spacing as per the tender specified for production. The quality control measures for the installation of the trial columns is specified in the Table 2.

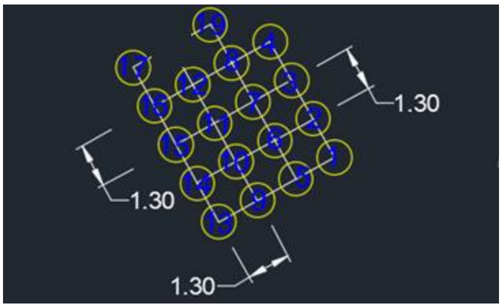


Fig. 4. DSM Field Trial Columns Setup

3.4 Deep Soil Mixing technology and work sequence at field trial works and main works

The Deep Soil Mixing technology implies mixing of existing soil with cement or compound binder (Lime, Fly Ash, Slag etc.,) and aims to achieve significant improvement of mechanical properties of the soil. The improvement becomes possible by strengthening with cement, bonding of soil particles and/or filling of voids by chemical reaction products. As a result of this mixing, soil-cement grout columns with higher strength than the natural soil are created. Along with improved strength, due to the known constitutive mechanical equation for cement-based materials, the DSM columns will have an improved stiffness.

Table 2. DSM Quality control requirements

ITEM	Description
Grout mix (W/C ratio)	1:1.2
Design Stiffness	150kPa
Target UCS of DSM columns	750 kPa
Amount of binding	150-300 kg/m3 of Soil
Methods of collection of samples (at various depths)	1. Wet grab sampling method 2. 3 samples at various depths 3. Backflow Sampling Method
Tests conducted on DSM samples	1. UCS Test 2. Stiffness measurement
Curing Period of DSM Samples	7,14 & 28 days

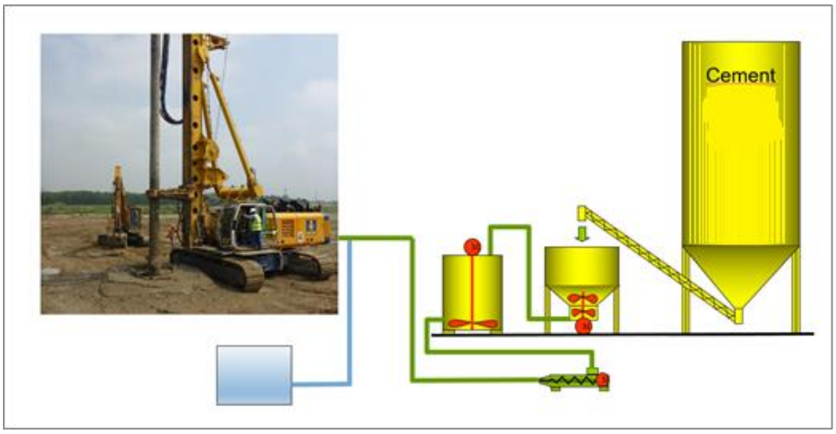


Fig. 5. Equipment for Deep Soil Mixing technology

Regarding the homogeneity it shall be noted that soil particles of fist to cobble size will remain unmixed in the DSM material which is subject to the mechanical mixing with the DSM mixing tool but are not deemed to compromise the column stiffness significantly. One of the major advantages of Deep Soil Mixing technology is an economical one in terms of no transportation and no purchasing of aggregates. The mass of excavated material and spoil that must be treated, transported, hauled, and dumped off site is also significantly reduced. This makes the method environmentally friendly as well. The complete process of the Deep Soil Mixing technology is depicted in the Figure 5. The deep soil mixing works are executed by single auger known Single Columns Mixing (SCM). Installed DSM trial columns will not be removed from the site after testing.

The wet method of Deep Soil Mixing is carried out by setting up drill rod with DSM mixing Equipment (Fig. 6) & tool at column position. The mixing tool penetrates to the desired depth of treatment with simultaneous disaggregation of the soil by mixing tool and water or binder can be used for liquefaction. The process is continued till the auger reaches the final depth of treatment. The Binder slurry is injected into the soil during withdrawal, optionally by additional down-and upwards strokes, where the mixing tool rotates in the horizontal plane and mixes the soil and the binder. The final column is formed in the ground as the auger is retrieved. The construction sequence of the DSM Column installation is as shown in the Figures 7 and 8.

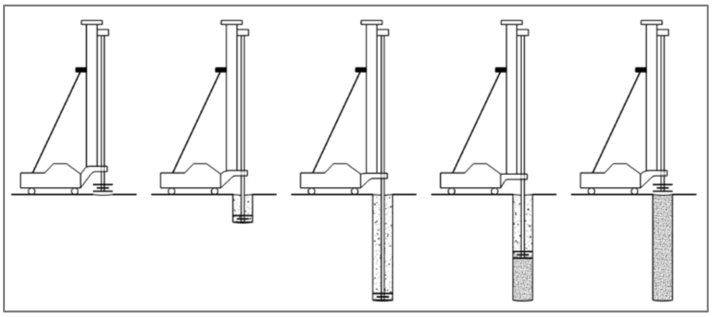
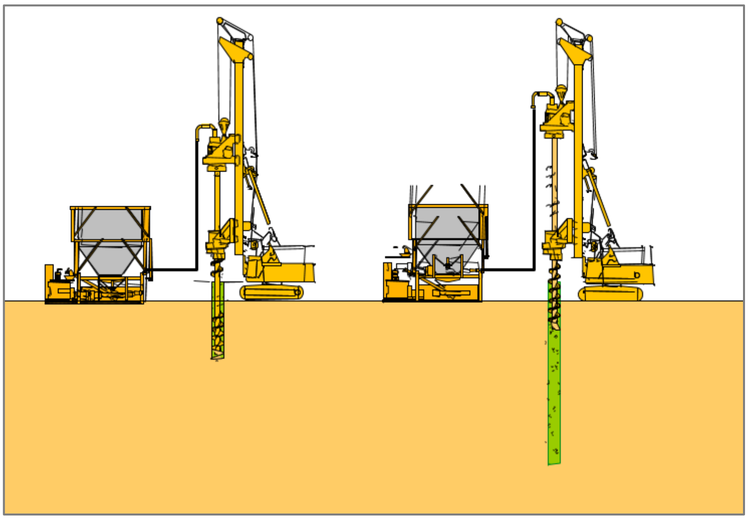


Fig. 6. Construction Sequence of DSM Columns



a. **Upstroke** **b. Downstroke**

Fig. 7. (a) Down stroke- Drilling down, pumping cement slurry (~70% of design) through the auger into the soil and mixing the soil with the slurry. (b) Up stroke-Withdrawing auger, pumping slurry (~30% of design) through the auger and proving the more homogeneous mix.

Fig. 8. DSM Mixing tool

3.5 Methodology of collection of samples at various depths

The samples of soil mixing will be collected using both wet grab sampling method and backflow sampling method for better quality. The process of Wet grab samples is collected using a wet grab sampling box, typically secured to the excavator arm/bucket, installation rig or crane and pushed into the freshly mixed column to collect an in-situ soil mix sample and casted in standard cylinder mounds (at least 3 samples at same depth). It is suggested to collect the samples from every column at 3 different depths and it covers every 1m depth among all columns (Fig.9). The max depth of samples is able to collect by wet grab method is up to 2m above the termination depth of DSM column Figure 10 shows typical set up of wet grab sampler.

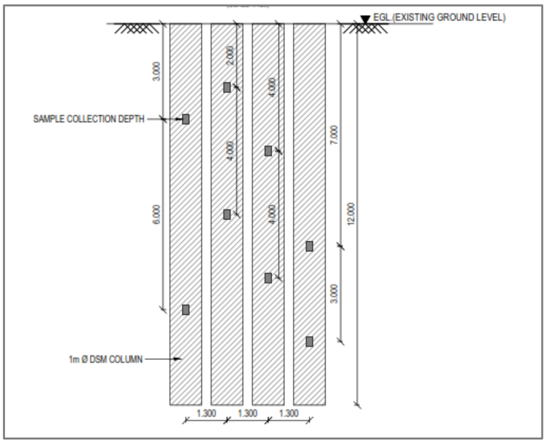


Fig. 9. Typical sample collection depths

Fig. 10. Typical pictures of wet grab sampler

In any condition wet grab samples are not able to collect from the desired depth, backflow samples shall be collected from surface for testing purpose. Back flow samples refer to the sludge generated during installation of wet mix column. Samples are collected from the sludge, casted in standard mould (cube or cylinder). At least 3nos of samples shall be collected from all columns after installation DSM columns for necessary stiffness testing.

3.6 Assessment of Improvement

The improved composite stiffness after treatment shall be calculated after achieving the actual DSM column stiffness values. An Improved composite stiffness of treated ground were established using below set of formula (Kitazume&Terashi, 2012).

$$E_{comb} = A_r\ E_{50,col} + (1\text{-}A_r)\ E_{50,soil} \quad \text{(Kitazume\&Terashi, 2012)} \qquad (1)$$

Estimation of degree of improvement in stiffness is as follows:
Step 1: Stiffness of original soils shall be established from either pre-treatment ECPTs or SPT N values from boreholes.
Step 2: Estimate the composite stiffness of treated ground as per formula shown in above.
Step 3: Compare the composite stiffness and stiffness of original soils. The degree of improvement in stiffness is the ratio of composite stiffness of treated ground to the stiffness of original soils.

3.7 Main works

As a result of the performed field trials, a variation of mixing slurry and other construction parameters are examined, which cover the construction parameters necessary for the construction work, i.e., Need to allow observing the dependence of the construction procedure and mechanical properties of installed columns. At main works, installing numerous DSM elements with previously established specific mixing parameters will be used to achieve the specified mechanical properties over the column depth and cross-section. For this, slurry mix designs and mixing parameters obtained from trial field shall be used.
In main works, same equipment proposed for trial field shall be used for the installation of the DSM Columns. Based on the field trial results the mix design and construction procedure shall be defined to achieve treated soil meeting the project specific acceptance criteria.

3.8 Post-performance criteria for DSM Works

The whole DSM Field Trial program is aimed to establish all necessary DSM parameters to achieve the following post-performance criteria for the DSM material. Based on the results of trials field and considering aspects of required stiffness and compressive strength, following requirements on DSM material was suggested by Project Authority. The required unconfined compressive strength (UCS) shall be proved as a characteristic value, tested at cylindrical specimen with minimum dimensions of 100 mm, at the age of 28 days shall be within 0.5 – 1.0MPa. The resulting average unconfined compressive strength shall correspond with an average design stiffness of the DSM columns respectively a deformation modulus of DSM material E within 40 – 135MPa. This deformation modulus is supposed to be evaluated as a tangent modulus from the stress-strain graph from the UCS test. A correlation shall be assessed from a representative series of test samples staken from UCS samples.

4. Details on the design and execution works

For the design study of Deep Soil Mixing (DSM) columns in Polavaram project, layout of the field at GAP I & II locations respectively (Fig 11). The goal to achieve was calculating the required characteristics compressive strength f_{cm} of the DSM material in a defined grid. The general idea was to achieve a composite modulus for a lower bound of 50 MPa and upper bound of 150 MPa. A transition zone that allows for a smooth and gradual transition of settlement between the areas treated with DSM columns and treated with stone columns is also implemented along with lower and upper bound. To allow a mutual understanding of the effect of the soil improvement, a numerical model of the dam and an idealized underground situation has been set up in Plaxis 2D. Theoretical settlements have been calculated for the situations 1) Lower bound and 2) with upper bound of treated soils, considering the differently treated areas perpendicular to the dam (or cut-off wall) axis, i.e., across the DSM-column zone, transition zone and stone-column zone. Although the total settlement values can be read only qualitatively, the comparison performed may help to decide for the necessary transition between DSM and vibro stone columns to smooth the incremental settlements across the dam.

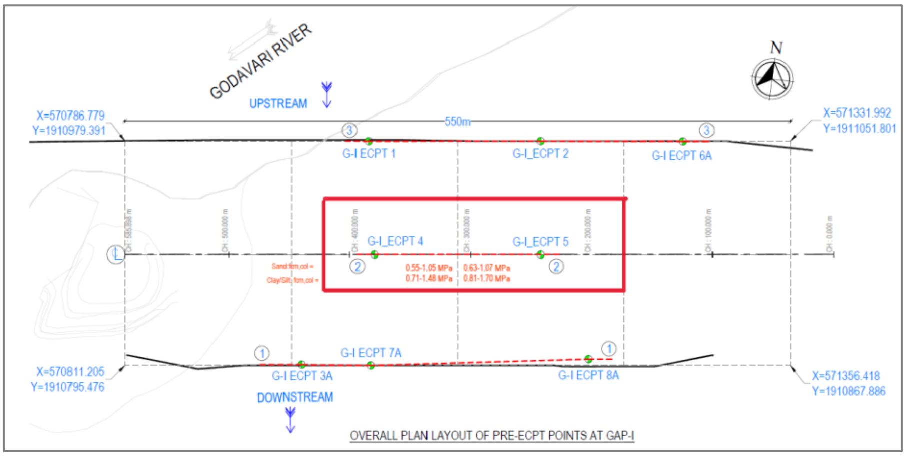


Fig. 11. Layout for GAP I with the range of f_{cm} values

4.1 Transition zone

To provide a smooth transition of settlements between the DSM columns and stone columns, a consistent or gradual decrease in oedometric modulus ($E_{oed,composite}$) must be maintained. The average values of the lower and the upper bounds between the oedometric modulus of stone columns and DSM columns results in range of 32.5 MPa to 82.5 MPa (Fig. 12).

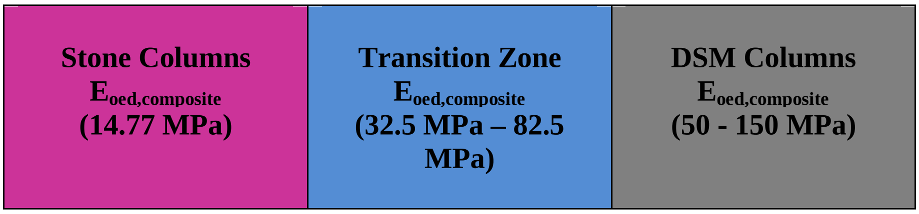


Fig. 12. Transition Zone Visualization

The length of the Transition Zone is taken to be 10m, which allows 5 rows of DSM columns between the stone columns. To utilize the transition zone to the optimal capacity and allow the stiffness modulus to shift along the profile, the first three layers of DSM columns in transition zone are taken at their original depth of 12m, whereas the depths of last two layers are reduced to 6m. The detailed summary of the DSM works in the main section and transition zone are provided in the Table 3.

Table.3 Overview of soil improvement dimensions

Particulars	**DSM upto 10m wide**	**Transistion Zone**				
		1st	**2nd**	**3rd**	**4th**	**5th**
Spacing , m	1.3	2	2	2	2	2
Diameter, m	1	1	1	1	1	1
Length of the DSM column, m	12	12	12	12	6	6
Length of the VSC column, m	17	17	17	17	17	17
Area / Column, m	0.79	0.79	0.79	0.79	0.79	0.79
Ratio of Replacement, %	46.47	19.63	19.63	19.63	19.63	19.63

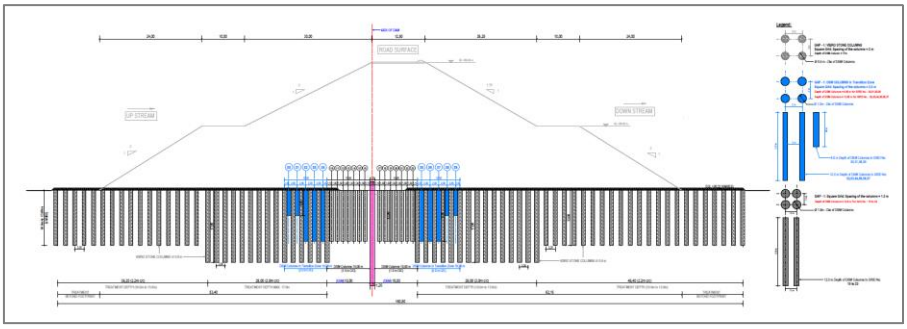


Fig. 13. Section Detailing of DSM, Transition zone (DSM + Stone Columns) and stone columns for GAP I

5. Conclusion

In this paper, use of the Deep Soil Mixing (DSM) technique for the ground improvement beneath the dam foundation is presented. Detailed design analysis is carried out to estimate the settements under different conditions like the dam being empty and flooded to the high flood levels. DSM acts as reinforcement element in providing protection to the plastic concrete cutoff wall along the axis fo the dam thus reducing the settlements and improving the deformation modulus of the ground. The paper describes the installation of the Deep Soil Mixing (DSM) methodology for ground improvement introduced for first time in India. The ground improvement by DSM is a sustainable solution and offers a alterative solution for the traditional ground improvement solutions by stone columns and other techniques.

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