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## Emerging Innovative Solutions Enhancing Practical Geotechnical Engineering

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## **EMERGING INNOVATIVE SOLUTIONS ENHANCING PRACTICAL GEOTECHNICAL ENGINEERING**

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### **ABSTRACT**

This paper presents two case histories, wherein double twisted hexagonal wire mesh crates and netting were used as a solution for geotechnical problems that aroused while execution. One of which is worldwide known and one of the most prestigious projects of India - Konkan Railway, and second is internationally noted tourist spot- Amby Valley Sahara lake city. In Konkan Railway project, double twisted wire mesh was used as a basic material for variety of problems like rock fall prevention, Gravity walls at the base of rock slopes, Baby Gabions as ballast retention for railway tracks, Platform Gabions etc. Adoption of Gabions and rock fall netting was one of its types of innovative solutions for this project. For Amby Valley Sahara lake city project, global instability of high cuttings in soil and heavy landslides were the major geotechnical problems. Many traditional solutions have failed at the site. Gabion retaining walls were adopted of heights ranging from 2 m to 13 m. Though there were initial failures mainly due to faulty construction, the same system of Gabion walls was continuously adopted due to its flexible, permeable and environment friendly nature.

### **INTRODUCTION**

Civil Engineers always come across critical problems with unique site conditions. Many a times, instead of following the same path of traditional solutions, they may need to adopt innovative ideas which will best suit as the problem solution with economy and utmost effectiveness.

As far as Geotechnical Engineering is concerned, the intensity of such critical problems is more, as we, Geotechnical Engineers, need to deal with soil, rock and inside strata of the earth to study the particular site, before going for construction. Many uncertainties always persist with unique characteristics of each region. But, for all major and important civil engineering works, such Geotechnical surveys and relative studies are highly necessary.

While executing any such projects, the documentation of the experience, new learning and many innovative solutions adopted successfully, can be kept and referred back as a Case History in future. Case histories play an important role to arrive at a solution, not only for practicing engineers as a guide, but also for professors and students as a reference literature and sometimes also for experienced professionals in the field. In Geotechnical Engineering practice, designers many times come across a problem, for which giving the

conventional solution may not serve the purpose and need of innovative techniques arises.

Case histories of Konkan Railway project and Amby Valley Sahara lake city project are discussed in subsequent paragraphs with respect to project brief introduction, geotechnical problems faced while execution and solutions adopted.

### **KONKAN RAILWAY PROJECT, MAHARASHTRA, INDIA**

#### Project Brief History

Until Konkan Railway started its operations, the two important port cities Mangalore (in Karnataka State of India) and Mumbai (in Maharashtra State of India) were not directly connected by the railway network. Even though economic reasons provided a strong need to connect these two cities, the region through which the railway track passed was geographically very tough and would be an engineering challenge.

The Konkan Railway is the first railway project in India, which was taken on 'BOT' (Build-Operate and Transfer) concept. The 760 km long Konkan Railway route passes through large number of cuttings, tunnels, bridges and embankments, in Maharashtra, Goa and Karnataka states of India, along foothills of Western Ghat section and west coast. The work in construction began in the year 1990, and the entire rail line from Roha (Maharashtra) to Thokur (Karnataka) was commissioned on 1<sup>st</sup> May 1998. With the construction of this Broad Gauge line, the rail distance from Mumbai (Bombay) to Mangalore and Delhi to Mangalore has been significantly reduced.

The client of this project was Konkan Railway Corporation Limited (KRCL) and number of small contractors were involved to carry out the works.

The task was formidable. As Karlis Goppers pointed out in his Swedish International Development Cooperation Agency (SIDA) report in July 1997: With a total number of 2,000 bridges and 92 tunnels to be built through this mountainous terrain containing many rivers, the project is the biggest and perhaps most difficult railway undertaking during this century, at least in this part of the world. The various problems had been carried out efficiently and in a very short time.

#### Geotechnical Data of the Terrain

The terrain through which Konkan Railway passes consists mainly of Basaltic rocky strata due to presence of Sahyadri mountains, and lateritic soil. As the railway line is parallel to the western coast from Mumbai to Mangalore, the entire terrain is subjected to heavy rainfall (around 3000 to 4000 mm) in the monsoon season. These Basalt rocks are igneous, extrusive rocks which have been erupted as lava flows, about millions of years ago from deep inside the earth and spread on the surface of different layers. Over hundreds of years, the top cover of the Basalt rock has been subjected to weathering, thereby forming a red laterite soil crust of variable thickness on top of the rock.

The main engineering problems that are presently encountered in dealing with lateritic soil encompass stability of slopes during excavation, presence of lithomargic clay extending to considerable depth which might result in instability to slopes, land slides, cavity formation in tunnel works and settlement of foundations of structures. In the area of operation both in Karnataka, Goa and Ratnagiri regions of the Konkan Railway project, peculiar type of the soil has been made which consisted of large depth of impervious lithomargic clay strata underlying the porous hard lateritic layers. Due to heavy rain in this area, water seeps through the porous lateritic soil, which has a tendency to gush out at the interface between these layers. This has caused slips of cutting slopes, cavities in tunnel excavation and drainage problems. This has caused safety problems and unforeseen delay in the project.

#### Problems faced And Solutions Adopted

The 760 km line passes through complex terrains. This

formidable terrain and the short construction period necessitated the use of several technological innovations. The construction and widening of the track called for large quantities of cutting in rocks of lateritic and basaltic origin. The exposed lateritic terrains are subjected to heavy rainfall and in the presence of water; the laterite loses all of its cohesiveness, strength and become very vulnerable to cause heavy slides and slips. This further called for the necessity of proper retaining walls and rock fall prevention measures.

Another problem was the limited space available for the tracks. The ballast which is laid below the tracks primarily serves the purpose of load dispersion apart from giving added resilience. Conventionally, a ballast layer of depth 250 mm is adopted below the sleepers with a depth of 500mm on the sides, sloping outwards. This requires a greater utilization of space on the sides, with sufficient width for embankment. Further over a period of time, due to the repeated use of track, the ballast has a tendency to roll out of tracks. Also, as an innovative solution and for speedy construction, Gabions were used to construct the platforms of various stations along the route.

There have been many instances of boulder/ rock falls and rock slips in small quantities from the rock cutting slopes towards the track, particularly in monsoon period. The trains have hit the infringing / fallen boulder over the track and caused damage to cattle guard / loco and even to rail track / Sleepers. In order to prevent such isolated boulder fall / small rock slips, innovative and cost effective measure, namely, 'Boulder netting' over the rock slopes have been extensively used in vulnerable and high depth cutting locations. Boulder netting solution is mainly identified only in the locations,

- (i) Where the rock strata is fairly strong, but jointed and blocky in nature, with no definite pattern / orientation of joints.
- (ii) Where rock mass is shattered with wide /deep and uneven cracks, which cannot be removed by loose scaling.
- (iii) Where big size sub rounded boulders are seen in top rock slopes, partially embedded in laterite soil.



Fig.1 Gabion box made of Hexagonal double twisted wire mesh (Maccaferri)

This solution has been effective in preventing / arresting loose, detached boulders rolling down towards the track or by

guiding the boulders towards bottom of rock slopes in the side drains, thereby arresting accidents on number of occasions.

Double twisted hexagonal wire mesh manufactured by Maccaferri Environmental Solutions Pvt. Ltd. (MESPL) was used as the basic material for all of these solutions. Gabion is basically a rectangular box strongly made up of steel wire mesh, which can be assembled on site and filled with quarried stones. The gabion boxes come in several sizes from 2m to 4m in length, 1m wide and from 0.3m to 1m in height. The steel wire mesh of gabion is hexagonal, double twisted and galvanized/ PVC coated to prevent its corrosion. The assembled components are securely tied together and braced, and finally, gabions themselves are firmly wired together. 50,000 cum of Gabions and more than 1,00,000 sqm of netting were used for all the solutions. In the following paragraphs, all the solutions are described elaborately.

### Rockfall Protection Measures – Boulder Netting and Gabion Toe Walls

To prevent rock fall from the side hill slopes, double twist hexagonal PVC Coated Maccaferri netting of type 10x12 was laid along the slope and then anchored into the trench using suitable anchoring techniques. It is called as Medium Strength Boulder Net (MSBN). This MSBN was used in many rock cutting locations along the route, which are of high depth, with subvertical to very steep slopes, close to track and still being patrolled due to vulnerability in monsoon season. Many such patrolling loacations were eliminated after provision of boulder net. Also, at some places HDPE (High Density Polyethylene) rope net had been extensively used in year 1998 and 1999. But, there had been some defects noticed in HDPE net, like easy burning of net on fire, cutting of net with sharp edged fallen stone and less strength of net etc. At such locations, these HDPE nets were successfully replaced by MSBN and they are performing well with no maintenance. Double twist mesh was selected over chain link mesh as it is not prone to unraveling. Their high tensile strength, punching resistance and low installation costs also helped the adoption of this system. PVC coating was used since the environment along the track was highly corrosive. Such type of mesh will not unravel, has high tensile strength and is yet flexible and cost effective.



Fig.2 Rockfall netting along Konkan Railway route

Gabions provide a versatile method of constructing retaining walls speedily and economically in place of conventional and rigid retaining structures, which are very costly. In Konkan Railway project, Maccaferri gabions were used as an effective toe support measure in many soil cuttings.



Fig.3 Gabion toe wall for Rockfall protection along Konkan Railway route

### Slope/Embankment Protection –Gabion Walls

At many places along the route, for slope and embankment stabilisation / protection, Gabions were used for constructing gravity retaining walls. Maccaferri Gabion walls with stepped rear face were adopted in many vulnerable stretches of hill cuttings of Konkan Railway. Backfill soil was carefully selected ensuring the omission of clayey soil. Additional arrangements included provision of transverse drainage system, comprising of heavy duty PVC pipes per metre, laid at a slope of about 1:20 to carry water away from the foundation. The foundation comprised basically of lateritic soil. Owing to the relatively high level of water table, the foundation depth was restricted to a minimum of 0.5m. At places where the foundation comprises of very fine clayey soil, Terram 1000 Geotextile was placed at the bottom of the Gabion Wall in addition to the backside in order to prevent the ingress of fines.



Fig.4 Gabion wall for Slope/ Embankment protection along Konkan Railway route

The biggest advantage of gabion wall support is its inherent flexibility. This enables it, without loss of structural efficiency, to deform or bend, rather than crack or collapse, under alternating tension and compression. No deep foundations or bearing piles are required for the structure. Another important feature of gabions, particularly in their anti-erosion applications, is their high degree of permeability. Drainage is in effect built-in and no weep holes are necessary.

The gabions are also cost effective and can speedily be constructed compared to conventional structures. The damage to gabion structure is usually localized and requires only small-scale repairs. The gabions can be constructed in rows, preferably staggered. They can be built to any height, size or shape, subject to a minimum width of 1m as recommended for toe walls. The design calculations for a permanent gabion walls follows the same principle as that of conventional gravity wall of masonry or unreinforced concrete. A rule of thumb method of calculating the required width of walls up to 6m high is to take it as being two thirds of the wall height at the base, reducing in steps to 1m wide at the top, if there is no surcharge or 2m, if there is a surcharge.

#### Baby Gabions for Railway Track Ballast Retention

The ballast, which is of around 500 mm thickness tends to spread under repeated loading and requires continuous maintenance. At this location, baby gabions of size 4x0.3x0.3m were used to prevent spreading of ballast. Such gabions requires less frequent maintenance compared to



Fig.5 Baby Gabions fro ballast retention along Konkan Railway route

#### Gabions for Platform construction

For construction of some of the Konkan railway platforms, instead of using conventional method, Gabion boxes were used. This innovative step resulted in easy and speedy construction of railway platforms. After successful installation at one platform, they found it a very cost effective solution. The cost was reduced to around 50% as compared to traditional construction methods. Platform Gabions were then used for construction of 12 platforms along the Konkan Railway route.



Fig.6 Platform Gabions at Kudal Railway station along Konkan Railway route

### AMBY VALLEY SAHARA LAKE CITY (AVSLC) PROJECT, MAHARASHTRA, INDIA

#### Project Brief History

Amby Valley Sahara Lake City (AVSLC) is a 10000 acres hill station city, approximately 100 km southwest of Mumbai, India. The project, by one of India's major corporations, Sahara India Pariwar, targeted an exclusive gated community residential and holiday home market, exclusive club memberships, local and international (particularly European) resort and sports tourism, institutional and high technology research and development, as well as non-exclusive theme park, recreational and real estate markets.

AVSLC is committed to business leadership in providing world class environment friendly residential, hospitality services and tourism solutions by focusing on people, customers, technology, quality and passionately driving the organization thereby creating value to Sahara India Pariwar, customers, partners in progress and society.

#### Geotechnical Data and Topography of the Terrain

This belt receives a very high intensity rainfall during monsoon from June to October, since the Lake city is situated over the Sahyadri hills (mountain range in Maharashtra state of India) and very high intensity of water falls also adds to the heavy rainfall. These Western Ghats consist of hills and plateaus and formed from different types of Lava flow resulting in different types of rocks and residual soil. However, the main soil deposits in this area are Lateritic Soil and Basaltic rocky strata. This in-situ soil has a cohesion value ranging between 5 and 20 kN/sqm and angle of internal friction is of the order of 20°. The density value is 18 kN/cum. This Lateritic soil is red to reddish brown in colour due to presence of iron oxides. They are highly porous and permeable. There is an increase in the seepage of water in cuttings and soil absorbs water due to its high porous nature, which increases its density but decreases its shear strength.

Table 1 below summarizes briefly the topography of the terrain.

Table 1 Geotechnical Data and Topography of AVSLC project

Total area	10000 acres
Temperature Average	Min 12 °C, max 32 °C
Average altitude	766 m above MSL
Peak height	908 m above MSL
Average annual rainfall	4,000 mm (155 inches)
Geographical Position	
Longitude	73 deg. 23 min East
Latitude	18 deg. 36 min North
Average humidity	Min 41 - max 68
Mist	Immeasurable

### Problems faced And Solutions Adopted

Soils are made by nature and not by man, and the products of nature are always complex. As soon as we pass from steel and concrete to earth, then omnipotence of theory ceases to exist. Natural soil is not uniform, its properties changes from point to point while our knowledge of its properties is limited to those few spots at which the samples have been collected.

Major Problems faced in this terrain were:

1. Heavy Landslides in deep cuttings
2. Heavy Rainfall
3. Lateritic Soil which has very good shear strength in dry conditions and loses shear strength in presence of water
4. High Seismic Zone

At many places while constructing roads, due mainly to deep cuttings heavy landslides occurred. The reason for land slides were, the excessive vertical cuttings, excessive overburden masses, inadequate surface and subsurface drainage and improper diversion of drainage. Also, this terrain faces heavy rainfall, which adds to the complexity of the geotechnical problems. This terrain is prone to seismic action, which is another important factor to be considered while in the design phase. All these problems lead to failure of many traditional solutions provided. In the following paragraphs, solutions provided are described elaborately, discussing their failures as well.

### Slope Protection Using Gabion Walls

In the period of monsoon, the major problem that occurred was landslides. Initially, the consultants of this project gave a proposal of traditional solution of concrete gravity retaining wall. But, during and after construction, these walls failed mainly due to global instability. Again, the road construction in the developemnt of this project could not continue because of the same problem, getting repeated in many locations.

MESPL, when approached by the officials of AVSLC project, suggested a Gabion wall solution. Gabion boxes were made of hexagonal double twisted Maccaferri wire mesh of opening size 10 cm x 12 cm, and with wire dia of 2.7 mm (ID) / 3.7 mm (OD) with Zinc and PVC coating.



Fig.7 Lateritic soil in AVSLC Terrain

A series of Gabion Walls have been provided in Sahara lake city along external/internal roads, mini club area, car parking area and lake front. At many of the stretches, solutions were offered to restore the complete slides. Emphasis was laid on the provision of an eco-friendly solution. Gabion walls for this project were designed to act for two purposes, viz.. to act as drainage toe to draw subsurface water flow and to act as a stabilizing weight against slip failure. The base area required for retaining walls founded on this type of soil was often more than the height of the retention.

In some of the stretches the wall had to be founded on undulating rocks. A concrete base is given to have a leveled surface and anchoring bars were provided between gabions and the base to counteract any unbalanced shear force at the base. In most of the stretches a stepped outer face is provided to enhance vegetation. The fill near the gabion was done with crushed rock fragments to enhance more effective drainage.

The total scope of Gabions and mattresses in Sahara Amby Valley project is around 1 lakh cubic metres of which approximately 60% is completed so far. Gabion wall heights ranged from 2 m to 13 m, as per the requirement. A typical cross section of 7m high gabion walls is shown in Fig. 8.

At some of the locations, these gabion walls also failed in global and sliding stability. But, as the Gabion walls are made by connecting gabion boxes along their edges with selvedge wire, its failure have not resulted in severe damage and risk to human life. For the remediation, the same gabion boxes were used again at those locations. The characteristic of flexibility of Gabions allowed reusing them.

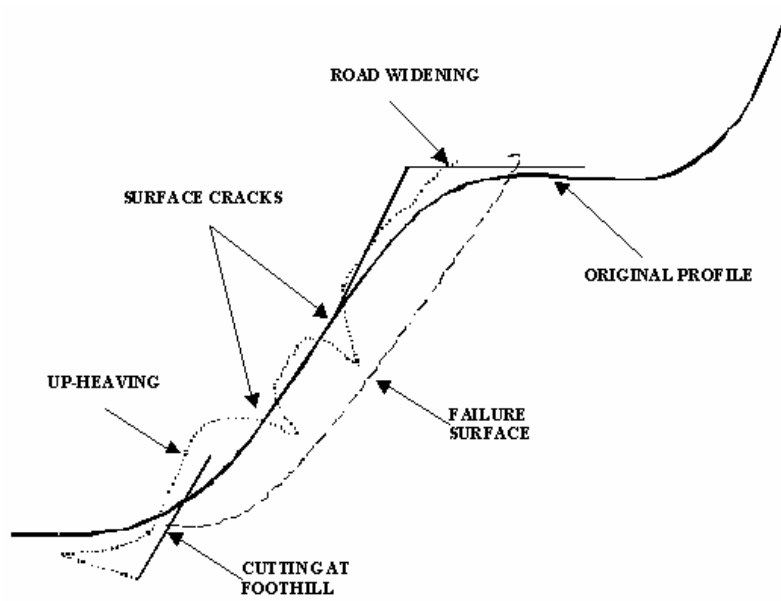
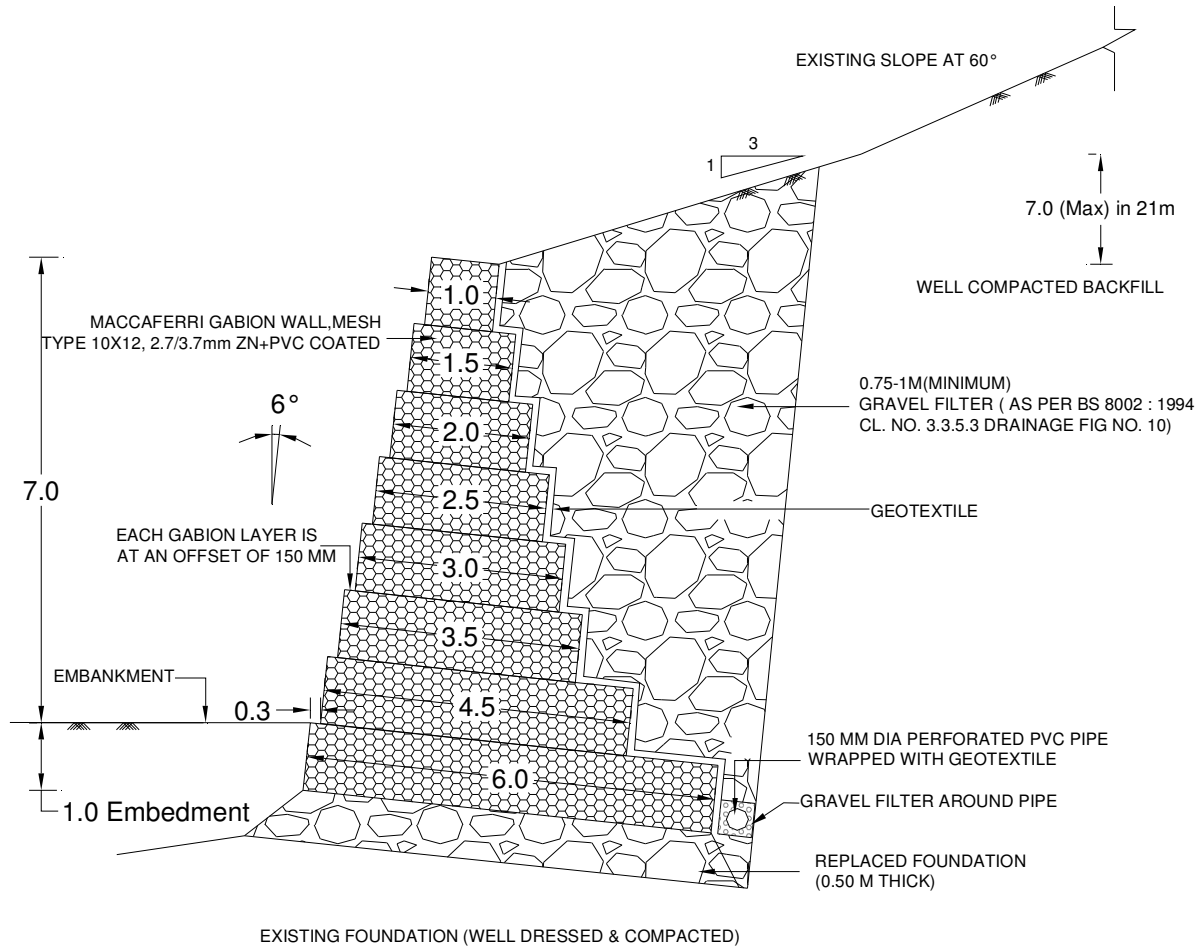


Fig.8 Typical failure pattern for the slopes in AVSLC Terrain



7.0 M HIGH GABION WALL (AGL)

Fig.9 Cross-section details of 7 m high typical Gabion wall in AVSLC project



Fig.10 Gabion wall along roadside in AVSLC project.



Fig.11 Gabion wall on PCC foundation for undulating rock strata, AVSLC project.



Fig.12 Gabion wall in club house area, AVSLC project.

## CONCLUSIONS

1. For many Civil- Geotechnical engineering problems, where conventional methods are not feasible and effective to apply, provision of innovative solutions necessitates. Some of the major geotechnical problems discussed in the above case studies are those with mountainous terrain with lateritic nature

of soil which is unpredictable and is in itself a challenge to work with, heavy rainfall and high seismicity.

2. Gabions provide a very versatile solution, with its unique characteristics like flexibility, porous structure, strength and durability, cost-effectiveness, ease in handling and construction, and most importantly eco-friendliness.

3. Along Konkan Railway route, adopting various innovative measures, as listed above, has stabilized many rock-soil cuttings. However, there is vigorous monsoon in Konkan region with high to very high and continuous spell of rain in the months between June and September every year. This has resulted in signs of distress / instability even in stable looking cuttings, with instances of rock fall, soil slips during monsoon and sometimes leading in to accident/ derailment. Earnest efforts are, therefore, being made by Konkan Railway to implement various solutions viz., provision of erosion control net, medium/ high strength boulder net, Gabion toe walls for rock fall protection etc., gabion walls for slope stabilization, wherever required, so as to make rail travel completely safe.



Fig.13 Gabion walls perfectly integrated with flora, AVSLC project.

4. Also, Gabions were used for ballast retention for the railway tracks and at some places for the platform construction. Both these applications prove a very off-track, successful and innovative use of gabions.

5. The Konkan Railway case study reveals how a single innovative material/ solution could be very effectively used for variety of problems, with the added advantages over conventional methods. And most importantly, two main objectives of any Civil Engineer like complete integration with environment and economy were achieved with the use of Gabions and net.

6. In Amby Valley Sahara Lake City (AVSLC) project, the geotechnical problems were very critical, for which traditional gravity retaining walls could not serve the purpose. At this place, even after few initial failures mainly due to faulty construction, the same system of Gabion walls was continuously adopted due to its flexible, permeable and environment friendly nature. Gabion walls for this project were designed to act mainly for two purposes, viz.. to act as



drainage toe to draw subsurface water flow and to act as a stabilizing weight against slip failure.

7. In both the projects, all the solutions and structures (made of double twisted hexagonal wire mesh) like boulder netting and gabions, required very less or literally no maintenance after installation. They all are performing well till date.

8. Both the case histories can be referred for the use of non-conventional solutions for some typical geotechnical as well as unique kind of problems.

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