Effective and Cost Effective Stabilization of Various Soils by Using Subnano Molecules

Sourabh Manjrekar, Ishita Manjrekar
Sunanda Speciality Coatings Pvt. Ltd., Mumbai, India
Email: ssm@sunandaglobal.com

Abstract：Rains, floods, landslides and other natural disasters result in the loss of lives and property. Buildable stable land with natural load bearing capacity is scarce in most cities and construction on poor soils results in failures and devastation of structures. Soil stabilization is the process of maximizing the suitability of soil for construction purposes. Chemical Grouting is the process of injecting a solution or a mix of solutions into the soil for in situ soil stabilization. It improves stability, strength, compressibility, permeability, durability and load carrying capacities of the soil. By adopting appropriate chemical engineering and chemistry, grouts with nano particle sizes in the range of 5 to 10 nanometers have been prepared in our laboratory. These nano particles behave as a fluid and penetrate deep into the soil and then later react to form a solid, semisolid or a gel at a pre-determined time. This gel is a precipitated binder of high quality at lower concentrations of reaction components. These nano particles are amorphous and since they have higher specific areas (120 – 260 m^2/g) they distribute themselves evenly and bind the entire soil matrix. Laboratory tests of various combinations of the grout have been done, followed by field tests to determine the best engineering properties for soil stabilization. These nano particle grouts enhance the stability of the soils. This saves land, structures and human lives as well.
Keywords: soil stabilization; water control; tunneling; soil bearing capacity; nanotechnology; nano grouts.

1. Introduction

In July 2014, the collapse of a building in Chennai raised suspicions about the soil conditions not being favorable for a high-rise building as the site where the building was coming up was a huge wetland and water catchment area for the Porur Lake until a few years ago. In Delhi, the Yamuna floodplains and wetlands are home to almost one-fifth of the city's population. Structures (legal and illegal) in these high-density population areas (from northeast Delhi to Noida, Okhla, Badarpur and Faridabad in Haryana) are highly vulnerable because they have been built on soft alluvial soil. These buildings virtually float on a high groundwater table that keeps weakening their foundations due to the continuous erosion/damage by the Yamuna river water. Delhi's floodplains are located in seismic zone IV, the second highest earthquake hazard zone in India. Even medium intensity tremors can lead to liquefaction of soil, a condition resembling quicksand, causing the sinking of all the structures resting on water-saturated grounds along the Yamuna River. To solve this problem, in many cities across the world, the idea of freeing rivers is gaining ground. In the US, New Orleans is breaking its floodwalls to allow the storm water to come into the city by building new canals and ponds. (Figure1).

After building dykes to keep water from entering the country for 800 years, the Netherlands is now implementing the 'Room for the River' project. (Figure 2)

The Netherlands government also demolished numerous houses and shops to make room for their rivers. (Figure 3).

However, demolishing houses or relocating a fifth of its population is not an option for Delhi. Therefore, effective stabilization of the suspect soil can be a very good solution. Soil Stabilization is extremely important in enhancing the engineering properties like hydraulic conductivity, compressibility, strength, and density.

Soil Stabilization can also be very useful for prevention of the collapse of soil while carrying out tunneling applications, increasing the soil bearing capacity and reducing settlement in foundations of existing buildings. [1]

Conventionally stabilization of soil is done using lime, cement or micronized cements as grouts; however, these methods are inefficient and give only partial results. This paper highlights the current research at Sunanda Speciality Coatings Pvt. Ltd. for the development of nano grouts to increase the efficiency and performance of soil stabilization operations. [2]

Figure 1. Building of new canals in the city of New Orleans

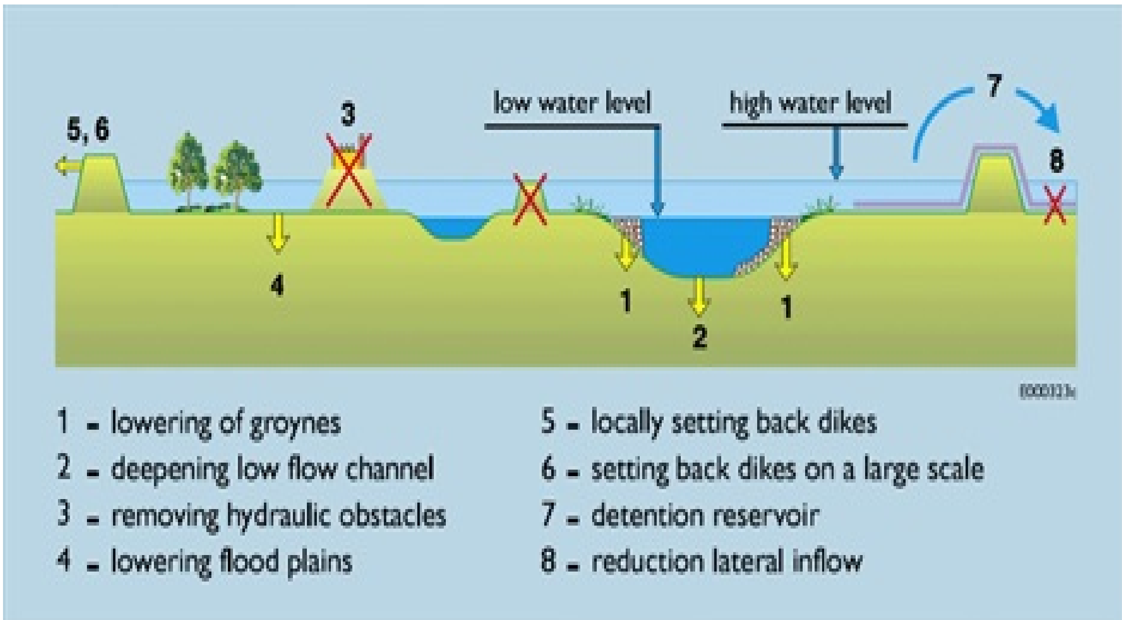

Figure 2. Steps taken in the Netherlands for the 'Room for the River' project

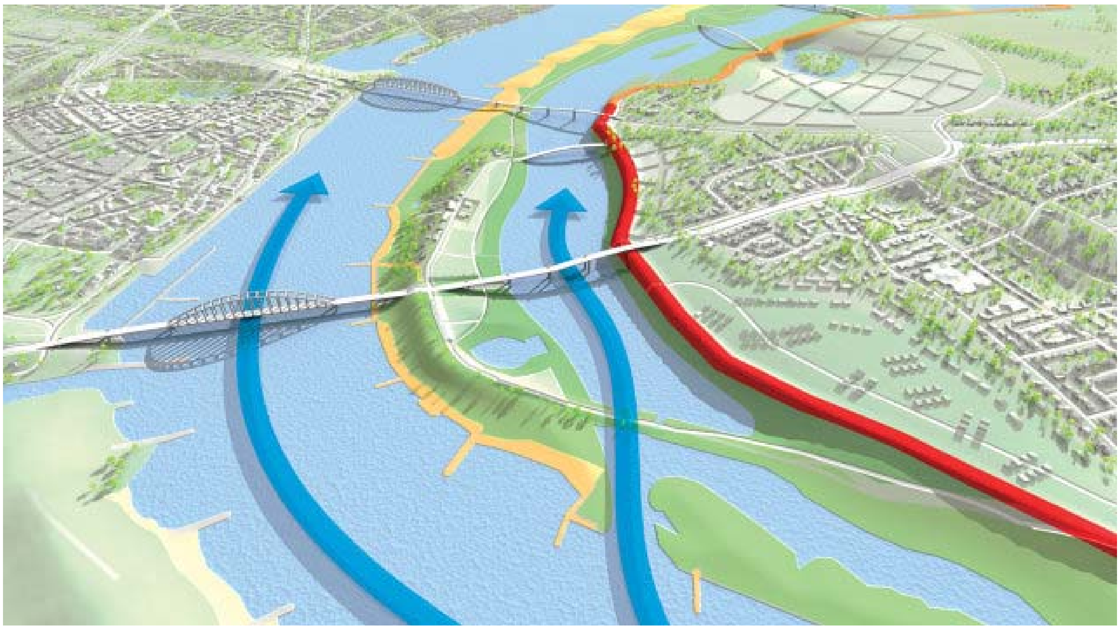

Figure 3. Demolition and relocation of shops and houses in the Netherlands to make room for their rivers

2. Conventional methods of soil stabilization

Suspect soil is conventionally stabilized by methods such as:
1) Replacement of the entire treacherous soil with good quality soil imported from elsewhere
2) Compaction of the soil using mechanical means
3) Using cement and / or lime
4) Using cement grouts
5) Using micronized cementitous grouts

All of the above measures though useful are seen to give partial results. Also, they are labour intensive and very time consuming processes. In cementitious / lime or mixed grouts, the suspended particulate matter i.e. cementitious matter has a well-defined size and as a result cannot penetrate deep enough to reach till the last void. Most times this cementitious material simply goes as a filler material (wherever it reaches). In addition it has limited binding capacity due to overhydration. [3]

3. Chemical Grouts

Chemicals grouts that developed as pore sizes in soils were very small and as a result conventional cement grouts could not percolate into these pores. Cements typically have a particle size of 15 microns or 15,000 nanometers and microfine/ultrafine cements have particle sizes in the range of 3 to 7 microns or 3000 to 7000 nanometers. (Figure 4)

Figure 4. Particle Sizes of Standard cement and ultrafine cement grouts

Hence, Nanotechnology can be a novel approach to conduct soil manipulation at the atomic or molecular scale, which is facilitated by introducing the concept of nano particles as an external factor to soil. These nano particles have a particle size of 5 to 10 nanometers which is almost 3000 times smaller than cement. In chemical grouting two chemically reactive solutions are mixed together to react and form a precipitate after a predetermined time which fills the voids/pores in the soil, consolidates the soil making it more dense which in turn increases its bearing capacity and reduces the water flow [3, 4]. This reaction is analogous to the formation of natural sandstone, which is formed by gluing together loose sand. The subsequent important geotechnical properties of soil can be determined in the laboratory after completion of the grouting process. Grouted samples can be subjected to alternate freeze-thaw and wet-dry cycles to determine their durability properties. The chemical compositions and microstructure of soils can be analyzed using x-ray diffraction and scanning electron microscopes. However, nano grouts have the limitation in that they are often more expensive than particulate grouts. To compensate for this, large voids are typically grouted with cementitious grout first and then chemical grouting is done as needed.

4. Case studies

4.1 Case Study 1: Increasing the soil bearing capacity (by using SUNGEOGROUT – nano grout) of an existing five star hotel in Florida, USA in order to construct 2 additional floors.

This was a case of an existing 5 star hotel in Florida, USA where the client wanted to construct 2 additional floors. The Soil composed of 62% sand, 16% silt and 22% clay and had a soil bearing capacity of 14.16 T/m^2. In order to construct 2 additional floors, the required soil bearing capacity needed to be 19.63 T/m^2.

This was achieved by injecting an engineered liquid nano grout (SUNGEOGROUT) through vertical and inclined injection ports under each of the foundations (Figure 5 & 6). The soil bearing capacity was checked after 72 hours and 14 days respectively where it showed an increase of 38 %, reaching the required soil bearing capacity of 19.63 T/m^2. (Figure 7)

4.2 Case Study 2: Prevention of collapse of sandy strata while constructing an underground tunnel for a metro railway project in India

The tunnel was to be constructed 24 m below the street level (Figure 8). The soil was composed of 80% sand, 15% silt and 5% clay. There was a tremendous amount of ground water pressure due to which the sandy strata would collapse making excavation very difficult (Figure 9). Cement grouting and micro-fine cement grouting were not very useful as they could not percolate into the pores of the sandy strata. In this case a nano grout was used for water control and was successful as it could percolate much deeper than conventional cementitious grouts, after which it would solidify to fill the pores and arrest the flow of ground water which made excavation a lot more manageable and efficient saving a lot of time and money for the contracting company (Figure 10). The nano grout was grouted from the top street level via numerous grouting ports using Tube-à-Manchette (TAM) grouting. (Figure 11)

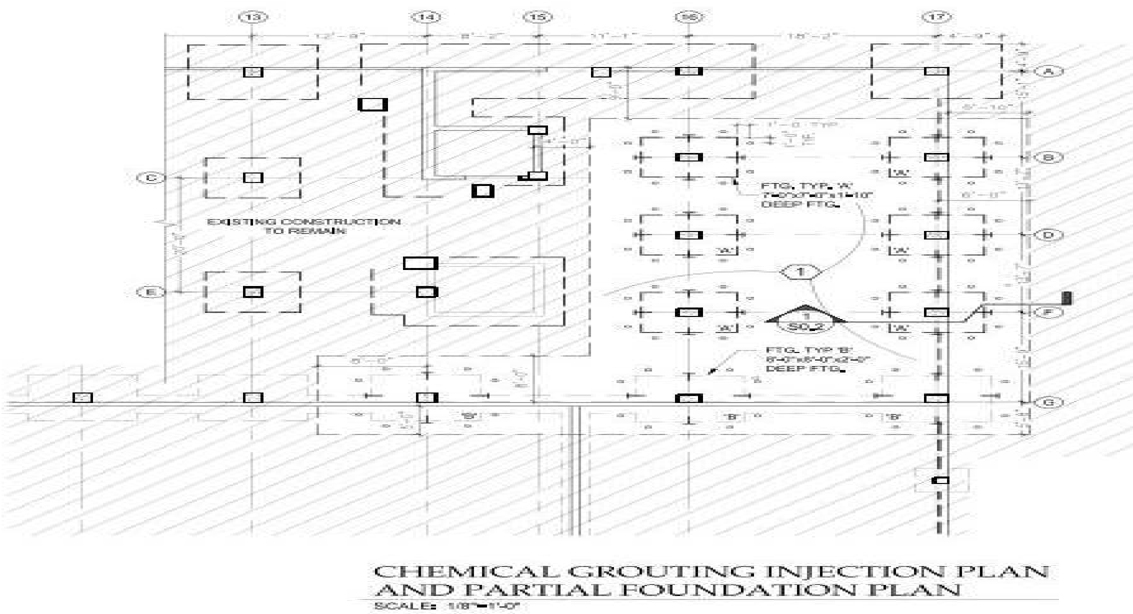

Figure 5. Chemical Grouting Injection Points under each foundation

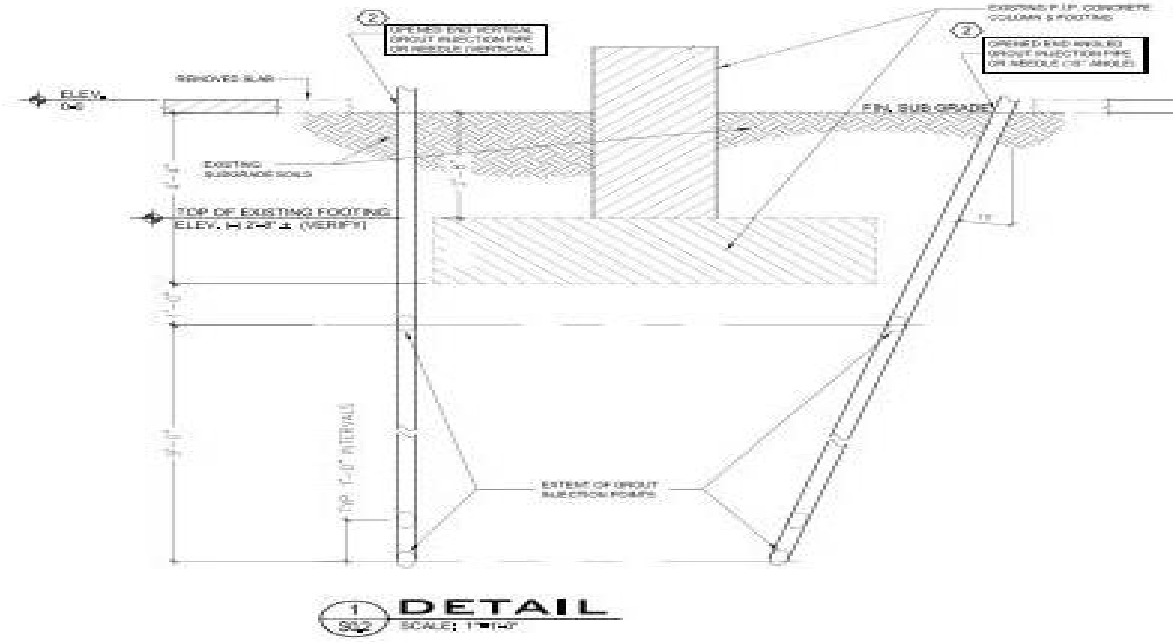

Figure 6. Vertical & Inclined grouting detail under each foundation

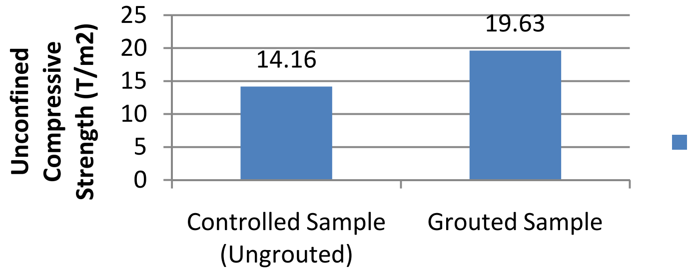

Figure 7: Increase in Unconfined Compressive Strength Results by using the nano grout

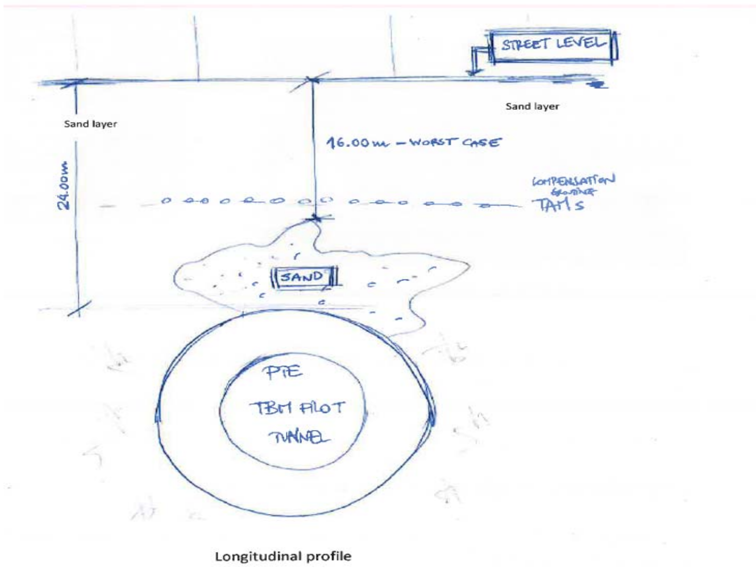

Figure 8. Location of tunnel 24 m below street level

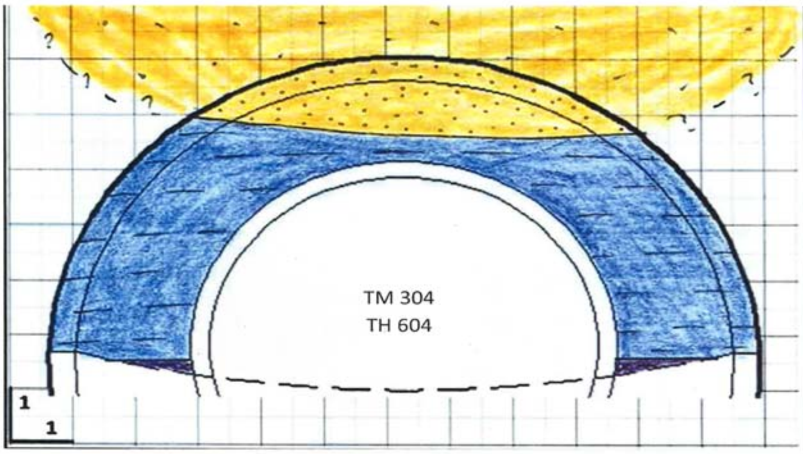

Figure 9. Sandy strata highly saturated with water

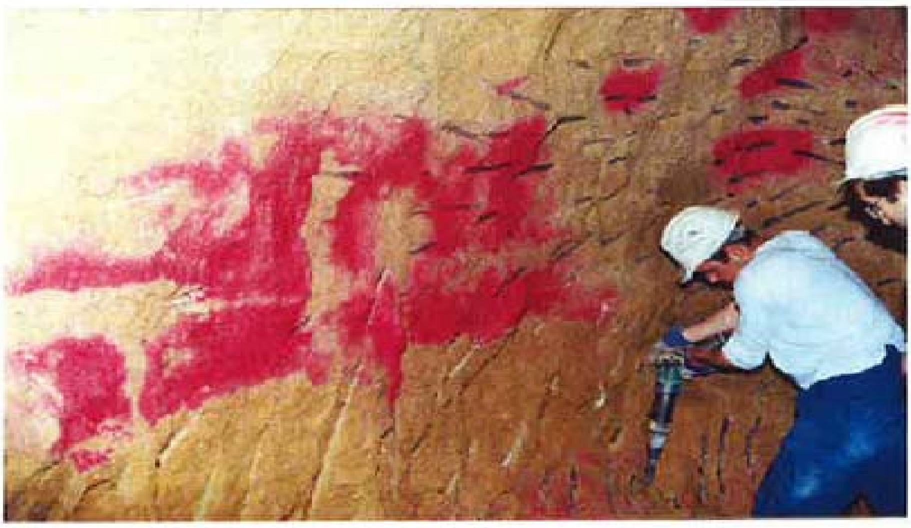

Figure 10. Ease of excavation due to grouting (pink in color) carried out prior to excavation

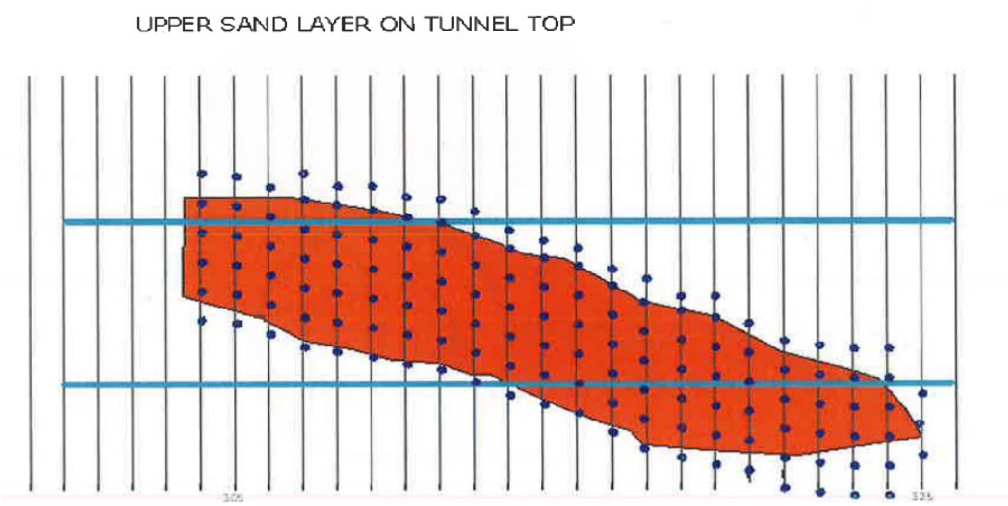

Figure 11. A nano grout was grouted from the top (street level) via numerous grouting ports using Tube-à-Manchette (TAM) grouting

4.3 Case 3: Settlement of a 'side arm charger in a coal handling plant' in INDIA

This was a case of the settlement of foundations of a coal handling plant under construction due to which further construction was put in hold (Figure 12). The remedial options under consideration were:

1) Installation of vertical and inclined micro piles to transfer the load from the foundations to micropiles by structurally connecting them with the pile caps. (Figure 13 & 14)

2) Demolishing and rebuilding the partially completed foundation.

3) Sungeogrout - Chemical grout engineered with nano particles.

Option i & ii were very expensive and time-consuming, hence rejected. Sungeogrout (nano grout) was the solution selected.

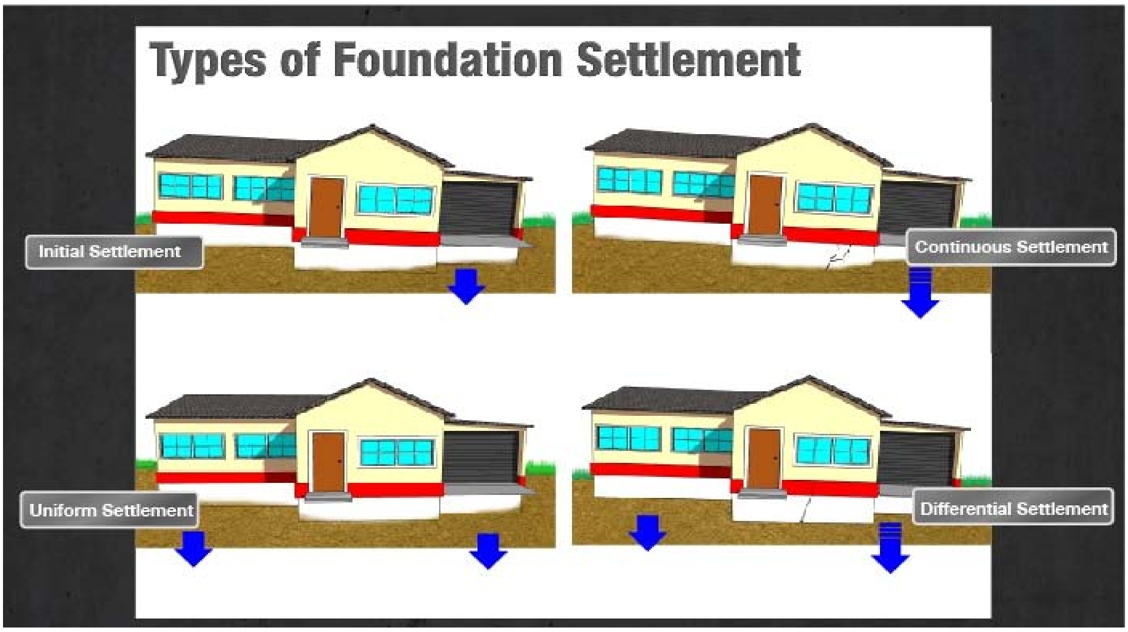

Figure 12. Typical settlement patterns

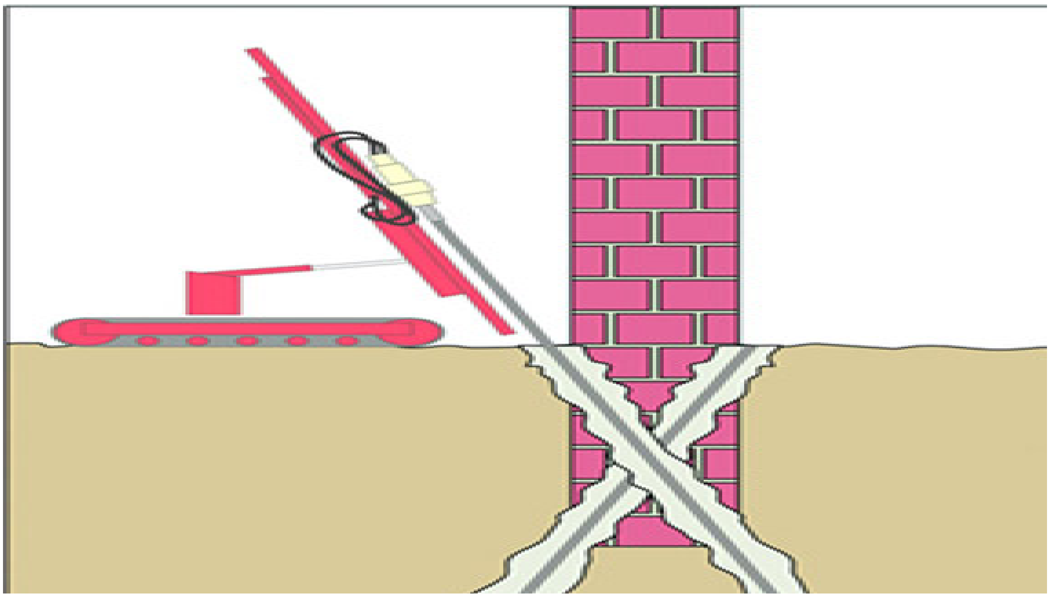

Figure 13. Typical installation of micro piles

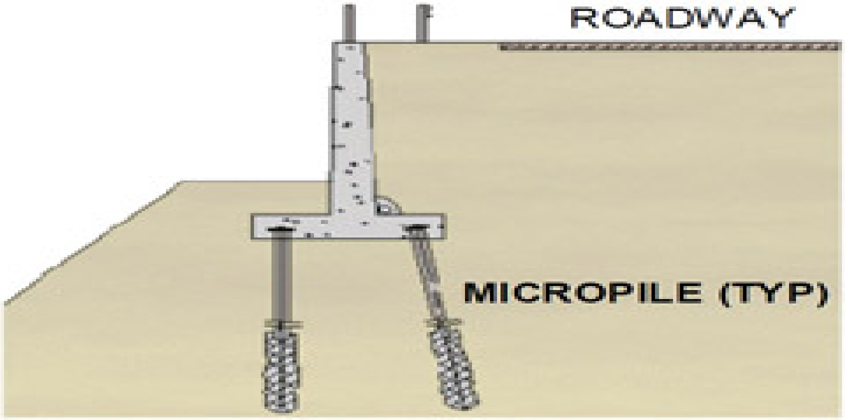

Figure 14. Typical structural connection of micro piles to foundations

4.4 Case Study 4: Stabilizing the soil along the boundary walls of a plot in North India, during the construction of the retaining wall

This was a case where the sandy strata along the boundary walls of a plot was stabilized in order to hold the soil in place and prevent collapse of the soil during the construction of the retaining wall. (Figure 15)

Figure 15. Collapse of soil during construction of retaining wall

5. Criteria while selecting a soil stabilization grout

While selecting a soil stabilization grout, the criteria are as follows:

1) Nature of the soil to be treated
2) Initial grout viscosity and the viscosity profile during gelation
3)Setting time of the grout
4)Particle size (Use of the grout):
   i. Reducing water ingress
   ii. Short term or long term consolidation
   iii. Increasing of Soil Bearing Capacity

5.1 Viscosity

Viscosity is an important parameter of successful penetration of the grout and among many other factors, viscosity is dependent on the particle / molecule size of the reactive chemicals as well as that of the vehicle. Hence lesser the molecule size of the grout, the more penetrative it will be and hence more effective. (Table 1)

Table 1. Relationship between Viscosity and Hydraulic Conductivity

Viscosity	Hydraulic Conductivity Relationship
Less than 2 cP	10^{-4} cm/sec
5 cP	Greater than 10^{-3} cm/sec
10 cP	Above 10^{-2} cm/sec

5.2 Setting time

The 'working time' or the 'gel time' of the grout can be engineered based on the type of application as per the need of the job. The grout setting time depends on:

1) Nature of grout
2) Grout and soil temperature - the higher the temperature, the shorter the setting time (Figure 16)
3) Type of activating nano molecules (Figure 17)
4) Nature of the soil

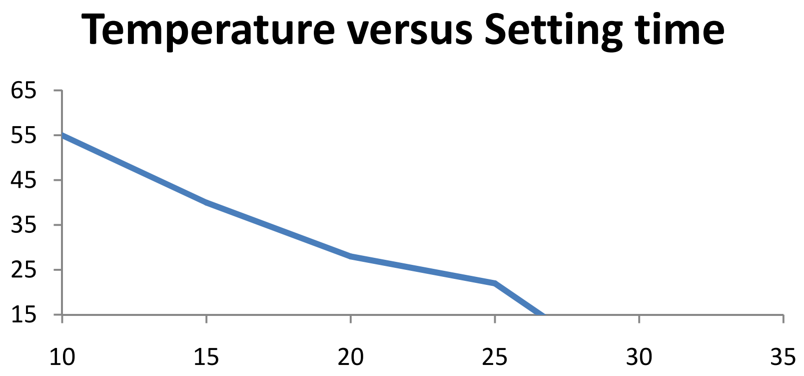

Figure 16. Temperature versus setting time of the grout

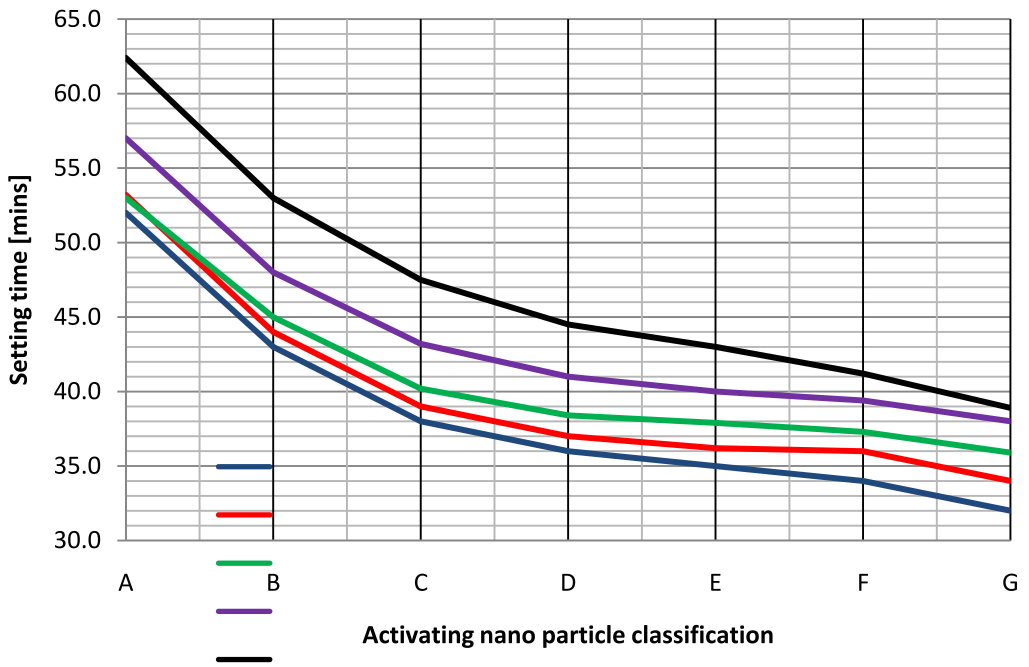

Figure 17. Variation in setting time of the grout at constant temperature of 20°C due to change in activating nano particle

5.3 Particle Size

One of the important factors in the forward reaction of any two chemicals is the particle or molecular dimensions. Thus molecular size along with optimum concentration become two important factors in the success of chemical grouting of the soil. The nano level dimensions of the molecules in grout can be achieved by a proper selection of components of the grout. By adopting appropriate chemical engineering and chemistry, it is possible to reach the Nano range where the average particle size of the grout fluid will be in the range of 5 to 10 nanometers. Such chemical reactions which are made to happen at the nano level can give a precipitated binder product of high quality at lower concentrations of reaction components. With the right chemistry, these precipitated binders can be made of amorphous character and have higher specific areas (120-260 m^2/g) so that they can evenly distribute themselves while binding the soil matrix. [5]

6. Conclusions

Chemical grouting is an established effective technique of soil stabilization. Nano particles of the grout improve the penetration capability of the grout. It is possible to explore various combinations of chemical grout reactants to enter into micron, nano and subnano zone. Entering into the nano zone may enhance the performance of the grout in terms of unconfined compressive strength and economics. As a result chemical grouts can be injected into soils containing voids that are too small to be penetrated by cementitious or other grouts containing suspended solid particles. Chemical Grouts once reacted become a material analogous to sandstone and hence have no detrimental effect on the soil and ground water. Chemical grouts have an adaptability over a wide range of applications. Nano grouts are the strongest and least toxic of the existing range of chemical grouts.

7. References

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