Soil Nailing for Highway Construction

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Abstract -- **In the construction industry, slope or excavation failure is a common issue and to avoid its risk on human lives and properties, Soil nailing technique is widely used since last two decades. It consists of solid or hollow steel bars which behave as passive reinforcement encased in grout at an inclination to the horizontal into the soil with definite horizontal and vertical spacing. In general, when compared to other traditional stabilization methods like retaining walls, the soil nailing system has the advantages of lower cost, quicker construction procedure and less impact on the adjacent ground structure. To study about soil nailing, its important parameters need to be reviewed. This paper presents applications of soil nailing and some previous researches for improvement of slope stability and stabilization of a vertical cut.**

Keywords: Soil nailing, Slope failure, Slope stabilization, Reinforcement techniques,

I. INTRODUCTION

SOIL Nailing is widely used in civil engineering. In early 1970s, concrete gravity and semi-gravity type earth retaining structures were in vogue to retain the earth structures in highway projects [1]. If excavation support system is required to retain the soil slope then internal bracing for excavation is needed. For this, numerous alternative wall-retaining system have been introduced. In highway projects many of these earth retaining systems like mechanically stabilised earth (MSE) wall, reinforced soil slopes (RSS); anchored wall, diaphragm wall, sheet pile; and *in-situ* reinforced wall system such as soil-nailed wall and micropile walls etc. are used O'Rourke and Jones [2] suggested changes and development in the earth retaining system in highway construction during period 1970-1990. According to them due to growth in underground construction, there is a requirement for advances in construction material and equipment for anchored wall system, advances in the use of polymeric material for MSE wall construction and the use of soil nailing technique to support the excavation. There has been growing demand of these earth retaining systems in highway projects during 25-year period after 1970 and they lead to cost and time savings.

Over the past few years, increasing demand of soil nailing in highway and railway construction was observed particularly in hilly regions. There is large scope of soil nailing in road widening projects due to less impact on moving traffic vehicles. The term 'soil nailing' comes from New Australian Tunnelling Method, where rock bolts were applied to support underground excavation in rock followed by shotcrete. In soil nailing method, closely spaced tendons are inserted in soil slope at some inclination to horizontal to restrain the soil or improve the shear strength of soil. These tendons known as nails behave as passive reinforcement to the soil structure. Origin of technology, types of construction, construction process and design methods, etc. are discussed in this paper.

II. ORIGIN OF SOIL NAILING TECHNOLOGY

Soil nailing has been widely used during last 30 years in various civil engineering projects as it proved to be more cost effective and time saving method than other conventional methods of retaining the earth structure. The origin of soil nailing comes from rock bolting in tunnelling (NAT method) in 1960 and then extending to relatively less cohesive material like soil [3]. After its application in rock, the nailing method extended in less cohesive materials like silt, gravels and sands with application in metro tunnels during 1970 in Frankfurt and in construction of a double tube subway station in Nuremberg. Use of soil nailing technique has been growing rapidly in Europe and North America since the early 1970s. In 1972, the first recorded use of soil nailing was in Europe for an 18 m high cut slope in sand as part of a railway widening project near Versailles, France [4]. The first major research project titled 'Boden-vernagelung' with 'Boden' meaning soil and 'Vernagelung' meaning nailing, thus the technical word soil nailing comes in application and undertaken in Germany from 1975 to 1980 by the University of Karlsruhe and the construction company Bauer [5]. In 1976, U.S. first used soil nailing for the support of a 13.7-meter deep foundation excavation for an extension of Good Samaritan Hospital in Portland, Oregon [6]. In 1986, a 4-year research project named CLOUTERRE was initiated in France to promote soil nailing for temporary and permanent soil nailed walls in excavation involving private and public participants with special emphasis on safety and durability [7]. Meanwhile the new technique soil nailing became popular in North America [8] with the name of 'lateral earth-support system' [9, 10], United Kingdom [11], Australia [12] and Hong Kong [13], Brazil [14], and Japan [15]. The use of soil nailing was reported as a

permanent retaining wall for subway underneath a busy national highway in India [16]. In India, soil nailing technique is also rapidly increasing and design guidelines have been formed by Indian Road Congress (IRC) with the help of Indian Institute of Science, Bangalore [17] wherein till date guidelines given by FHWA are adopted.

III. DESIGN APPROACH OF SOIL NAILING

Soil-nail retaining system are designed to satisfy the requirement of stability, serviceability and durability of their design life. Other issues like the cost, time and the environmental impacts are also important in the design of the soil retention systems. In design approaches, the initial design considerations include wall layout (wall height and wall length), vertical and horizontal spacing of nail, the inclination of nail, orientation of nail and nail length, soil nail material and relevant ground properties. After considering all these parameters, the design engineer has to be evaluate the nail length and maximum nail force. Nail length, nail diameter, and nail spacing typically control external and internal stability of the wall. These parameters could be adjusted during design until all external and internal stability requirements are met. After the initial design is completed, final design progresses where the soil nail wall is tested for external and internal failure modes, seismic considerations and aesthetic qualities. Drainage, frost penetration and external loads such as wind and hydrostatic forces also have to be determined and included in the final examination of the design.

IV. ELEMENTS OF SOIL NAILING

The typical soil-nail system consists of the following basic elements:

(*a*) Reinforcement bar, (*b*) centralizer, (*c*) grout, (*d*) nail head connecters (hex nut, washer and plate), (*e*) facing and (*f*) drainage.

Reinforcement Bar or Nail: Soil nail is a structural member consisting of passive reinforcement used to resist the shear, bending and tension forces. These reinforcements are generally known as nails. They can be hollow or solid type of nails. Solid nails are used when soil conditions are stable to drill hole and grouting, when soil is not able to withstand drilling then hollow nails are used with drilling and grouting process simultaneously. These nails are placed close to one another at some spacing when construction proceeds from top to down. These nails can be driven or pre-bored and grouted type depending on the soil condition. Soil nail should also be corrosion protected. Grouting acts as lower level of corrosion protection in hollow soil nails but in case of solid nails when driven, there is tendency of corrosion when nails get contact with soil and that depends on the corrosion potential of surrounding soil. So, the composite form of grouted, corrosion protected nail is highly dependent on the *in-situ* condition and in turn governs the installation process for these soil nails. Hence based on different installation techniques, soil nails can be classified as: grouted soil nails, self-drilling soil nails, jet-grouted soil nails and driven nails.

Facing: Facing of soil nailing wall acts as an additional support to prevent outward deformation of soil-nailed system. It is also used to improve the aesthetic appearance of the nailed structures. Facing material used should be of non-corroded type as it is exposed to atmosphere. Facing can be temporary or permanent. The facing consists of welded wire mesh carried by shotcreting of cement water and aggregate of fixed ratio as permanent facing. Shotcrete may be wet shotcrete or dry shotcrete. Dry shotcrete is preferred for small construction work. For vertical slope, thicker facing is used in comparison of inclined slope.

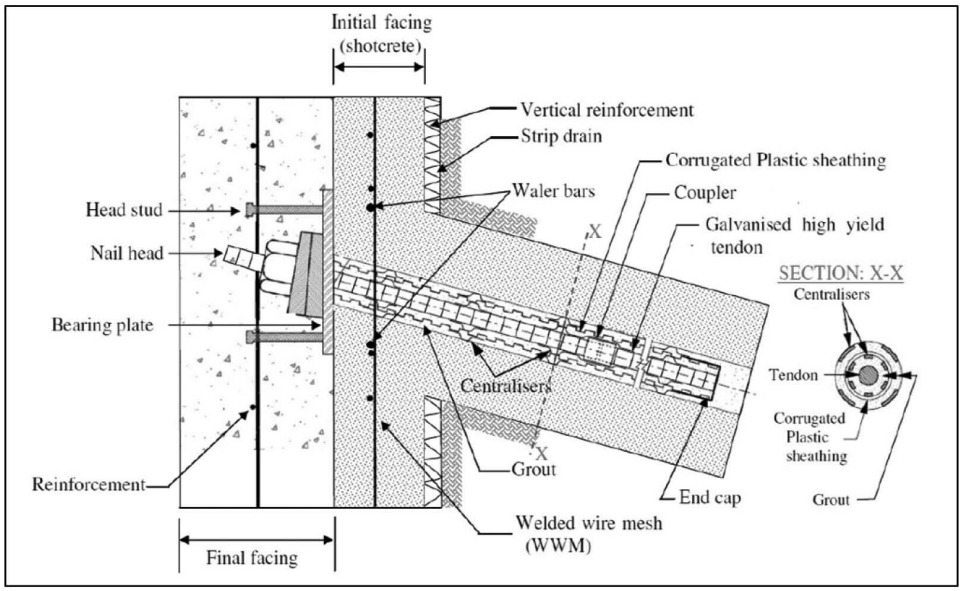

Figure 1. Typical cross-section of a complete soil nail wall.

Grout: When nail is placed in the borehole then to fill the annular spacing between the reinforcement bar and surrounding soil, the grout is injected into the borehole followed by centralizers. Grout acts as corrosion protection to the soil and transfers stresses to the soil to form stabilized bond between nails and soils. Moisture present in soil can corrode the nail by time but with the use of grouting, it prevents nails from corrosion. For grouting neat cement and water mix is used; sometimes cement, sand and water mix also used for the open-hole drilling. Pipe is used for injecting grout to the borehole.

Drainage system: It is necessary to provide a drainage system behind initial facing or adjacent excavation face. It regulates the pore water developed in soil slope and protects the facing and soil nail bonding. Usually vertical geocomposite strip drains are used as a drainage system.

V. ADVANTAGES AND DISADVANTAGES OF SOIL NAILING

Soil nailing technique has various merits and demerits addressed by Geoguide 7, FHWA-NHI-14-007 [2] and by other researchers as follows:

Advantages of soil nailing

- Soil nailing technique is more advantageous than other conventional techniques of slope stabilization *i.e.* retaining wall, ground anchors etc., as it is less disruptive to traffic and causes less environmental impact.
- Soil nailing is top down construction method so relatively faster in installation and uses less construction material.
- Soil nailing method requires less space for movement of equipment as they are comparatively small so can be advantageous for sites at remote location.
- Soil nailing technique does not use bracing to support excavation unlike other techniques so causes less congestion to excavation.
- Soil nailing technique is also well performed in seismic region.
- Facing of soil nailing gives good aesthetics to the structure and more natural appearance than other finishes.
- From cost point of view convention soil nails are more economical than concrete gravity walls and equivalent in cost or more cost-effective than ground anchor walls.

Disadvantages of soil nailing

- Soil nailing method is not recommended where strict wall movement exists, post tensioning of soil nails can be used for this shortcoming but it adds extra cost to the project.
- Soil nailing technique cannot be preferable near ground water condition. High ground water table causes difficulty in excavation during construction and ground water corrodes the reinforcement and grout water ratio disturbs.
- Soil nailing is not suitable for loose soil and cohesionless soil because during the drilling process, un-grouted holes can collapse.
- Underground drainage system, underground cables, pipes get disturbed during soil nailing process. So, for that proper care should be taken during installation of nails.

VI. APPLICATIONS OF SOIL NAILING

Soil nailing method has various applications:

- Slope stabilization
- Landslide prevention
- Deep excavation or vertical cut stabilization
- Stabilization of roadway and highway cuts
- Road widening under existing bridge abutments
- Tunnel portal in steep stratified and unsupported slopes
- Repair and reconstruction of existing retaining structures
- Use for deep vertical excavation in densely populated areas.
- Stabilizing of over steep existing embankments
- Protection and preservation of historical buildings.

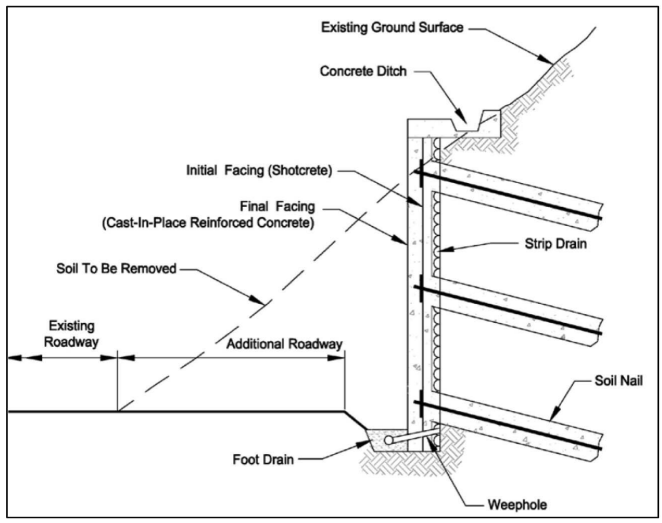

Figure 2. Roadway cut supported with soil nails. Modified after Porterfield *et al*. [25].

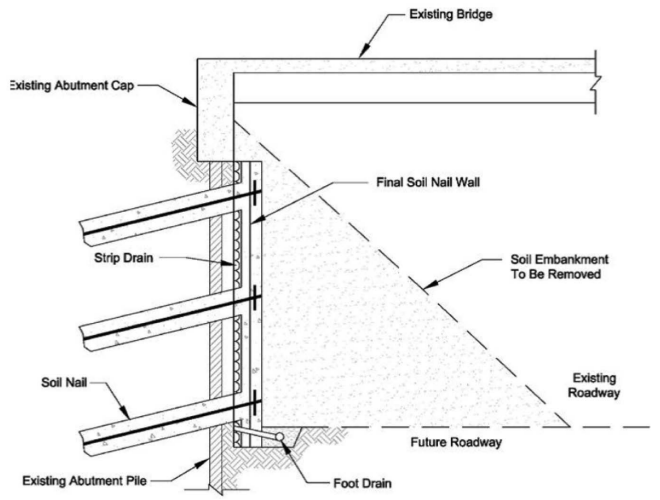

Figure 3: Road widening under existing bridge *et al.* [25]
Source: Porterfield

VII. ADDITIONAL REMARKS ON SOIL NAILING

According to research studies, a nail slope is a composite structure with elements of soil, nail, grout and wall facing. All these parameters affect the stability of soil nailed structure so they need to be checked before the construction proceeds. These parameters are briefly described in this section to study the characteristics and mechanics of soil nailing.

Jewell [18] investigated the effects of orientation of reinforcement bars on the shear strength of soil in a shear box. To maximize the shear strength of soiltrs the reinforcement should be placed in direction of principal tensile strain in soil and if the reinforcement is in direction of the soil compressive strain, there seems to be a decrease in the shear resistance of the soil.

Long *et al.* [19] studied the effect of number of nails on the factor of safety and concluded that it had a great effect on the failure surface location, and showed that as the nail spacing decreased, the factor of safety increased.

Schlosser *et al*. [20] using TALREN software stated that displacement of the wall increases by decreasing the global factor of safety while the later increases by increasing the nail length. Byrne *et al*. (1998) worked on the use of uniform or variable nail length and suggest that uniform nail lengths are used in areas where excessive deformations are not a consideration or concern because of competent ground conditions and absence of nearby structures sensitive to ground movements. Whereas If the wall deformation is critical, then a variable nail system can be selected.

Güler and Bozkurt [21] conducted soil stability analysis using TALREN software and showed that nails installed at angles above horizontal gave more factor of safety and less lateral displacement than nails installed at angle below horizontal.

Mittal and Biswas [22] showed that for cohesion-less soil as the nail length increased, the factor of safety increased. The nail length upto 0.8 times the height of cut is a reasonable length for providing a stable cut, minimum nail length of 0.7 m performs well in field.

Hossain and Islam [23] show that with the increase of inclination, the factor of safety of the slope increases, but after reaching the maximum value further increases of inclination, it decreases. The optimum angle of the nail was found at 30° with the horizontal.

Singh and Shrivastava [24] stated that nails inserted at 0° are more efficient in providing the stability to the slopes as compared to nails inserted at 15° and 30°. Also, nails installed in staggered pattern were found to be most efficient.

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