Remedy of cut slope failure using soil nailing in Thailand
A case study: Map Ta Put railway Km. 188+467 to Km.189+080

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ABSTRACT: In this paper, construction techniques, interactions of soil nails and surrounding soil and a factor of safety of remedial slopes are presented. The different skin patterns of PVC tubes, which were used as a material sheathing for corrosion protection, are studied, namely, usual smooth skin tubes and heated punch tubes stamped at every interval of 0.5m, 1.0 m, 1.5 m and 2.0 m through the entire length. These tested nails were installed at different depths of 1.5 m, 2.5 m, 3.5 m and 4.5 m below the ground surface. From a field pullout test of 10 tons maximum required load, the nails where were punched at interval of 0.5 m and 2.0 m indicated a permanently displacement from 0.2 to 0.4 mm and 0.4 to 1.0 mm respectively. On the order word, the comparisons of nails at different depths were found that at 4.5 m and 1.5 m depth, the permanent displacements were 0.2 to 0.4 mm and 0.7 to 1.0 mm respectively. The safety factor during to remedy was 0.9 and increase to 2.08 after remedy by the soil nailing system.

Introduction
For over a decade, Thailand developments have been rapidly growing up and changing. Land transportation are then increasingly demanded as a key to achieve the targeting of the country. To increase these services subsequently created a number of problems and damages to road and railroad structures in various cases. In this regard, the government has each year spent a huge budget to this propose to maintain an infrastructure condition to be on the services safely.

Currently, the railroad networks in Thailand occupied all over the country, 80 % of whole route formed in single track of metric gauge. Tracks laid through each region in different circumstance and geometry as appearance of various kinds of railroad structures. Regarding track maintenance and remedial works, the site operation have inherent difficulties in some cases due to more frequent services recently causing window time in maintenance shortages. As well as, to introduce a heavy machine in a large-scale maintenance project in restricted area is also outstanding obstacle, therefore, to consider an applicable methodology and well traffic management is inevitable.

The cutting slope at Map Ta Put, where slope failure has been taken place, site condition is limited by unavailable area. Then, to remedy by re-cutting in more gradient can not possibly perform due to it will obtrude the proximate land. In addition, to reshape the slope turns into original geometry by without any stabilization or reinforcement is not adequate to ensure a stability of slope in long term. Thereby, special advantages of the insitu earth reinforcement so call soil-nailing technique introduced to exploit instead to be a normal conventional technique.
Project Background
In 1982 State Railway of Thailand (SRT) launched a feasibility study of extension railroad project from Sat Ta Hip to Rayong as shown on figure 1 in order to increase a potentiality and serviceability of the Eastern Seaboard Development Project about freight form deep seaport and proximity areas to Bangkok and elsewhere. The construction have been conducted in 1993 and completed in 1995. Which associated to many kinds of structure, the 21-km route length was through variety of geography and geology features altering both flat and hills area. In 1996, after track has serviced about five months, the cutting slope between km 188+467 to 189+080 in Map Ta Put was failure as shown in figure 2. On that period of time SRT has promptly taken off all concrete retaining wall, paving block and soil material away from the track so that reopen the traffic urgently. At the same time SRT assigned civil engineering department summarize and consider the countermeasure of this problem.
Because of cutting was on services in very short period after construction completed, this thing took SRT more realizing in validity of structures, therefore, design criteria in term of stability was significantly emphasized. From information of site investigation, soil strength seem to be majority influence of failure acceleration and complement with the original geometry of slope, weight of paving concrete block, the amount of infiltrative rainfall, and disfunctional well holes also. Then, beside soil nailing technique has exploited to restrain movement of cutting slope, the other treatments such as ground anchors at retaining wall, drainage system, slurry wall are supplementary as well.
Site Investigation

In the original state, slope geometry was about 12 m of critical height and formed in 1:1 of slope. The paving block concrete presumably weighting 1 ton per square meter covered up the whole slope surface area, at toe slope the gravity retaining wall was placed to withstand slope failure. After failure has been occurred, site investigation performed to gather all vital information for analysis. Many of significant defects were investigated such as the heavy weight of retaining wall were situated on soil bearing in soak condition throughout. Behind the wall disfunctional filter material was found as witness of blocked weep holes. On the crest of cutting slope has a local road being on service, beyond that the large catchment area of 6 km$^2$ was proximate.

Regarding geological aspect, on top surface layer soft brown silty sand was encountered deeply 5-m approximately as young residual soils. SPT-N value at 5-15 and a 25-30 % of percent passing no 200 sieve presented. This silty sand overlaid 7 m or more of extremely weathering decomposes rock layer that SRT-N value takes more than 50. Ground water level was mostly found at a depth between 3-6 m below ground surface and rose upward 2 to 3 m presumably in a rainy time. The outcrops of fresh igneous rock are an underlying layer of decomposes rocks found some places during construction period but information concerning about engineering property of rocks is not available. During construction by cutting in this section has recognized the serious water problem, because ground water level was above the excavated level, the water flowed out from the open cut face.
Therefore, dewatering and drainage countermeasures were used to prevent the slope failure that might take place. Soil sampling has been conducted to identify soil parameter and classification for analysis.

**Assessment of failure mechanism and analysis**

From information of site investigation, ground water level is 6 m deeply in dry season and naturally rises up a few meters by surface runoff water from large catchment area and precipitation infiltrated down during heavy rain in rainy time. This phenomenon attributed that variation of ground water level in upward direction will theoretically decrease a negative pore water pressure and subsequently decreases shear strength of soil. At the same time, the other effects involved to accelerate the failure mechanism like the weight of paving concrete blocks on slope surface increasing a sliding force applied on the slope. In addition, almost whole weep holes were blocked and soil-bearing capacity beneath retaining wall was not sufficient in self-supporting thus they generated high water pressure thrust the retaining wall to turn over. In many of supplemental causes, consequence is a failure of slope taken place at last as the result.

**Remedial of cutting slope by soil nailing**

To remedy of cutting slope failure by soil-nailing technique undertaken by SRT seems to be a second pioneers application in Thailand, but it was first of railway. The familiarities and experiences of this construction technique still not feasibly well, this more or less affect to practicality of soil nailing performance here. But however the project has been successfully done. The pattern of stabilization as shown on figure 3, where combined with soil nails grouted into 150-mm diameter holes, slope surface are covered up by hard facing steel wire mesh and sprayed concrete comprising with weep hole at facing and horizontal drain fixed in ground. About nail feature consists of a 28 mm of high yield deformed bars inserting into PVC tube sheathing of 80-mm diameter as the corrosion protection material. The space among steel bar, PVC tubes and soil will be annulusly grouted by cement mortar as shown on figure 4.
Figure 3 Typical cross section of soil nailing schematic

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**Conceptual design**
The conceptual design of nail basically bases on newish BS 8006 and incorporate with DA Baker proceeding design referring the case history data presented by Bruce & Jewell. Ultimate Limit State is applied to this design by to impose the design strength equals at least or exceeds the design load. Therefore, the margins of safety that against attaining the limit states of collapse provided by using of partial material factor only, for loading factor that affect to increase disturbing force defined to be unity. Regarding serviceability limit for this criteria design, the horizontal movement of the crest of soil nail slope are specified be in the range 0.1 % of the slope height.

Firstly, the design procedure is to identify the actual failure plane in order to divide the active and resistant zone in reinforced soil separately. Theoretically, on the fundamental soil nailing design, two main stability checking must be envisaged to resist both internal and external force. To check stability of soil in reinforced zone conducted on the basis of to impose the bonding strength of nails in resistant zone exceeds the sliding force of weight in active zone. For the resistance of soil in reinforced zone from the thrust of soil in unreinforced zone is neglected in this design because the part beyond reinforced zone has a row of jet grouting slurry wall installed as shown on figure 3. This condition helpfully behaves to withstand and decrease the earth pressure due to soil beyond the reinforced zone applied.

**Material properties**
Back calculations were an initial proceeding to be ensured the reliability of material property by using the S-B slope program. The analyses have been carried out in the actual failure plane of slope in different cases of phreatic line level. The upper bound value of silty sand at 25 kPa of cohesion and 41 degree of internal fiction angle being available from soil investigation and $\phi$ equals 37$^\circ$ of extremely weathering decomposed rock were applied. The calculated results indicated that factor of safety was 1.05 in drying time and decreased to be 0.93 in rainy respectively, on which the value of 0.93 of safety factor are clearly coincident between theoretical analysis value and result of actual occurring failure. Therefore, the soil parameters applied in back calculation proceeding can reliably proved for further design. In order to keep the design be under safety, 1.5 of factor of safety value introduced to this design as material factor that is conservative enough to determine the soil shearing strength.

By the result of back analysis the effective shear strength can be summarized by soil parameter of silty sand having $C'$ of 25 kPa and $\phi'$ is 41$^\circ$, decompose rock $\phi$'is defined to equal 37$^\circ$.

**Reinforcement bond**

Soil interaction mechanism between soil and reinforcing element is defined to calculate in resistant zone only. The ultimate bonding strength of reinforcing unit that restrain sliding planes mobilization due to self weight of related active zone is presumed to use equally to the magnitudes of soil shear strength. In calculations of bonding strength of soil nail, the calculated shear strength of soil is determined by using the represented effective stress at the average height of slope apply to basic equation $\tau = \sigma\tan\phi' + c$ by to consider the lengths in the resistant zone only. The magnitudes of bonding force are able to determine by to multiply soil shear strength obtained with surface area of nail and apply the 1.5 of factor of safety to define the value of allowable bond capacity. On the basis of the material property the stabilized slope need 1.5 x 1.5 m spacing of 150mm diameter of soil nails at 10-m length to withstand the slope instability as shown on figure 3.

**Construction procedures**

As mentioned on the above, unfamiliarity of this construction technique leaded the shortages of modern and specific equipment in Thailand but however those problems have been disappeared by to modify the available domestic drilling rig instead to import the new one from abroad as shown on figure 5.
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The processes of inserting soil nails into the ground used the technique of drilled and grouted. Initially positioning of nails marked implemented and further mobilizing of the drilling rig to nail positions, the equipment would be supported by the heavy crane shown on figure 6. The sequence of drilling would drill from bottom to the top position in order to alleviate any disturbances of the further hole to the previous. First step of drilling, open hole technique are applied once through entire length of nail when the depths are achieved, withdraw the stem out. Insert the PVC tube sheathing component outside the stem auger and ahead them into the hole again as shown on figure 7. During reinserting, the stem would be rotated and injected the grouting material circularly and continually via the end of drilling head by applicable pressure controled to enhance the nail pull out capacity at the same time move the stem ahead continually until they attains the end of hole. Withdraw the stem auger drilling while leaves the PVC tube in the ground. Put the 28 mm deformed steel bar prepared, on which they are intervally mounted by the centralized control bars as shown on figure 8, into the installed PVC tube by extrude the screwed end of steel bar on the surface of facing. The completion of nail installation was finally performed by re-low pressure grout the mortar into the tube through the tremie. Continue the installation of further position in similar sequences of whole nails until completed as shown on figure 9. However as to be ensured the integrity of nails installed, to expose up the soil by digging has been performed that the figure 10 presented the perfect condition of soil nail clearly. Sub surface horizontal drain by 200-mm diameter of PVC tubes wrapped by geotextile are installed by drilling and insert them into the
ground. For facing unit was executed beyond the next of the nail installation have been completed. Hard facing type by steel wire mesh and sprayed concrete were introduced to this project, in during the proceeding weep holes were installed for effective control of ground water behind the face. When nail elements and facing formed completed, the connection between nail and facing are fastened by to thread the nuts in enough designed requirement force, the whole successful implement are shown on figure 11. Regarding to observe the horizontal movement of slope, the monitoring implemented by to measure the permanent fixed pole that set up a coordinate as an initial reading, continually, checking by a precise surveying equipment in a month period in first half year and less in further time. As the result of monitoring that compared the new reading value to initial value, indicated that the horizontal movement was very negligible.

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Figure 7 To install the PVC tube into the ground by using stem auger guide

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Figure 8 To control the steel deformed bars by to mount the centralized bar
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Figure 9 Soil nails where have been completely installed
Figure 10: To check the installed nails by digging soil as to be exposed

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Nail testing
Generally, nail testing must be implemented after installation completed in order to ensure the pull out capacity of nails attain the force requirement and coincident to design assumptions. Static load test method has been conducted to this project in a single cycle of load application. Long-term creep characteristics have also investigated by maintaining the load for a half of hour periods or more until displacement consistent. This project introduced the PVC tubes as a corrosion protection material instead to use a specified sheathing material due to they were unavailable in the domestic market. The smoothness of PVC tube surface seem to be a problem that may behave a loosing of interaction strength between grouted material and tube surface and may consequently rupture before steel bar or bonding strength between nail and soil will reach. Hence, two different proposes of testing concerned, first is to determine the pull out capacity of nail having surface of PVC tubes in normally. The second is a special study concerning about the effectiveness of the frictional characteristic of PVC tube surface enhanced by to make a heated punching on tubes in different spacing as shown on figure12. Furthermore to be compared the results of distance of punching and soil overburden in term of pull out force and displacement when they are subjected by tested force in each different position as illustrated on table 1.

Table 1 The locations of nail where tested on site.

<table>
<thead>
<tr>
<th>Position name</th>
<th>Depth (m) / Punching spacing (m)</th>
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<tbody>
<tr>
<td></td>
<td>0.5</td>
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<tr>
<td>0.5</td>
<td>122(1)</td>
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There are 370 vertical rows or more than 1900 of nails installed, the tabulated 116, 117, 118 and 122 row are to be chosen for testing at site. The schematic of soil nail load test shown on figure 13 and 14, initial step of testing installation is to expose the topsoil surface at the end of nails and situate firmly the supporting unit by to seal a non-shrink cement underneath the plate, do wait until they gain in full compressive strength. Mount a stressing unit of more than 10 tons capacity at top of frame as well as fix a displacing unit that accurate in 0.02mm in right and firm position as illustrated on figure 14A. The testing procedures, to apply load are increased smoothly and incrementally.
from 0, 1.67, 3.33, 5, 6.67, 8.33 and up to the maximum tested load 10 tons. In each increment of applied load the load is sustained until nail displacement be constant.
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From a field pullout test of 10 tons on figure 15 and 16, where is to be plotted between tested load and nail displacement in a different grouping of depth and punching distance, illustrated clearly that a less punching distance and more deep soil will enhance the pull out capacity and decrease nail displacement. On the other word, in term permanent displacement on the figure 17 shows that at the depth 0-3.5m the punching distance significantly affects to displacement of nail while at depth more than 4 m the effect is negligible. Moreover, the nail punched at every 0.5m distance permanently mobilized from 0.2 mm to 0.4 mm while the nail at 2.0m of punching was permanently displaced by 0.4mm to 1.0mm. From the comparison of nails at different depths were found that at 4.5m depth and 1.5m depth the permanent displacement occurred 0.2mm to 0.4mm and 0.7mm to 1.0mm respectively.
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Figure 15 The comparison between pullout test load to displacement at different distance of punching
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Figure 16 The comparison between pullout test load to displacement at different depths of installation
Therefore, it can summarize that a short distance of punching the PVC tube will improve both bonding resistance and creep especially at shallow level from ground surface, on the order hand, soil overburden above nails influence to the bonding and displacement as well. In term of safety factor, it increases from 0.9 in original to 2.2 after remedy by the soil nailing system.