American Transactions on Engineering & Applied Sciences

http://TuEngr.com/ATEAS

# Expert System for Slope Stabilization on Bangkok Clay

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**ARTICLEINFO**

*Article history*:
Received January 05, 2015
Received in revised form February 13, 2015
Accepted February 16, 2015
Available online February 16, 2015

*Keywords*:
Agricultural soil;
SHANSEP;
SlopeEx;
Soil series map.

**ABSTRACT**

SlopeEx is an expert system for slope stabilization on Bangkok Clay. The knowledge was created based on the 3 sources, the expert opinions, the past failure cases and the theoretical considerations. Such knowledge was integrated with fundamental engineering theories. The soil database for this system was developed the relationship between agricultural soil and engineering soil. From plotting the coordinates of specific soil bore holes on the GIS agricultural soil series map from Land Development Department of Thailand, LDD, 39 soil series were identified and classified into four main categories according to their engineering properties by SHANSEP theory. While the inference procedure is based on forward chaining. The C++ builder program was used as an expert shell. Users can input vicinity of slope failure then the program will identify three suitable methods and recommend the most effective stabilization method by weighted score. Furthermore the program will propose guideline engineering drawings, factor of safety and associated costs. The SlopeEx program was tested by using a scenario of slope failure on three different soil series areas: (1) embankment on soft soil on Chachoengsao series; (2) filled slope on Ayutthaya series; and (3) river bank on Petchaburi series. The program shows most suitable methods as (1) Cement column; (2) Benching slope and (3) Counterweight berm respectively.



## 1. Introduction

The Central Plain of Thailand is divided into upper and lower parts. The Upper Central Plain originates from the Ping, Wang, Yom and Nan Rivers flowing from the north, combined to the Chao Phraya River in the Pak Nam Pho district, Nakhon Sawan province. The Lower Central

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Plain or Chao Phraya Plain, has an average elevation of 5 m above the present mean sea level. It begins from Chainat province, where the Chao Phraya River flows southward through a flat plain until it reaches the Gulf of Thailand at Samutprakarn province. Bangkok clay or the soft marine clay, very soft clay deposit, is the clay that occupied on the Lower Central Plain or Chao Phraya Plain, consisting of soft marine clay to an average depth of 15 m in Bangkok (Sinsakul, 2000), (Triramongkol, 1983).

Most of soil slope failures in this area are found as circular deep-seated failure. Soil slope failures are occurred both of on natural slopes and man-made slopes. They can cause losses of both asset and life. Although the official database is not well systematically established, during 2010-2014 on lower central plain area failures are shown in Table 1.

**Table 1:** The data of soil slope failure between 2010 to 2014.

| No | Location | Type of failure | Cause of Failure | No of failure | Sources |
|---|---|---|---|---|---|
| 1 | River bank | Slide | Erosion | 58 | 1, 2 |
| 2 | River bank | Slump | Drawdown | 12 | 1, 2 |
| 3 | Excavated earthen pond | Earth slump | Deep excavation | 2 | 2 |
| 4 | Road embankment | Slump | Rapid drawdown | 2 | 2 |

Sources: 1. GERD(KU) (2013).
2. Manager Newspaper (2014), Thairat (2013), Posttoday (2014).

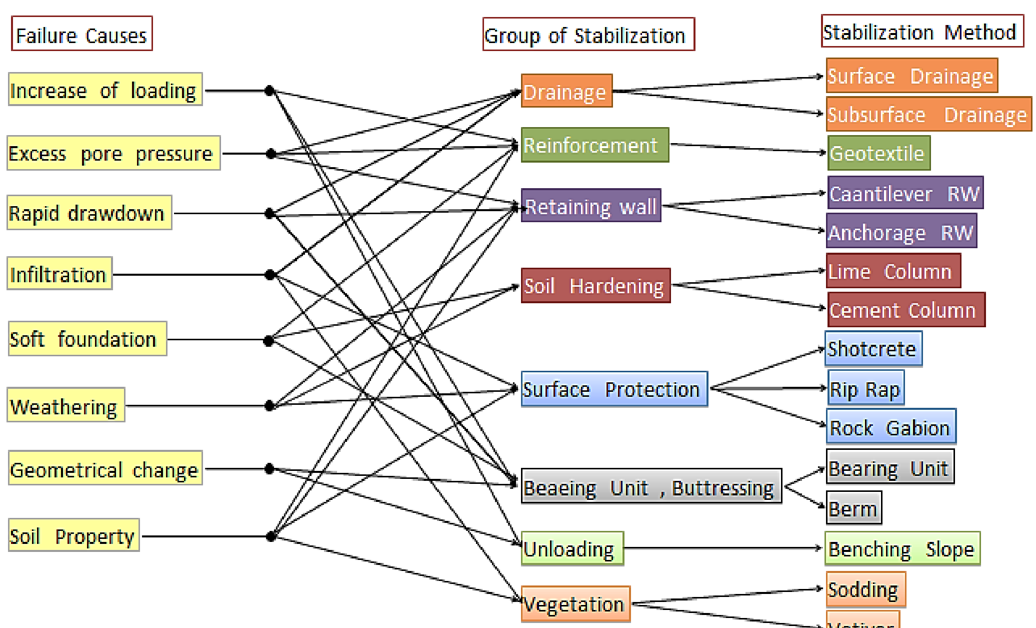


**Figure 1:** The schematic diagram for analyzed the suitable rules

The choosing of slope stabilization method depends on the individual's skill. Although various methods of the slope stabilization were attempted, but no systematic ways of approach were stated. SlopeEx is the expert system for soil slope stabilization on Bangkok clay area of Thailand to search for the systematic guidelines for the soil slope stabilization. The expert system consists of decision rules, soil data, instruction of geotechnical's design and guideline of engineering drawings. The result will give three suitable methods of stabilization with decision weighted score for final engineer's selection.

## 2. Concept of Expert System for Slope Stabilization

Expert system, a computer system, designs to solve complex problems by reasoning about knowledge. The system is divided into two sub-systems, the knowledge base and inference engine. The knowledge base represents facts and rules. The inference engine applies the rules to the known facts to deduce new facts (WIKIPEDIA, 2014).

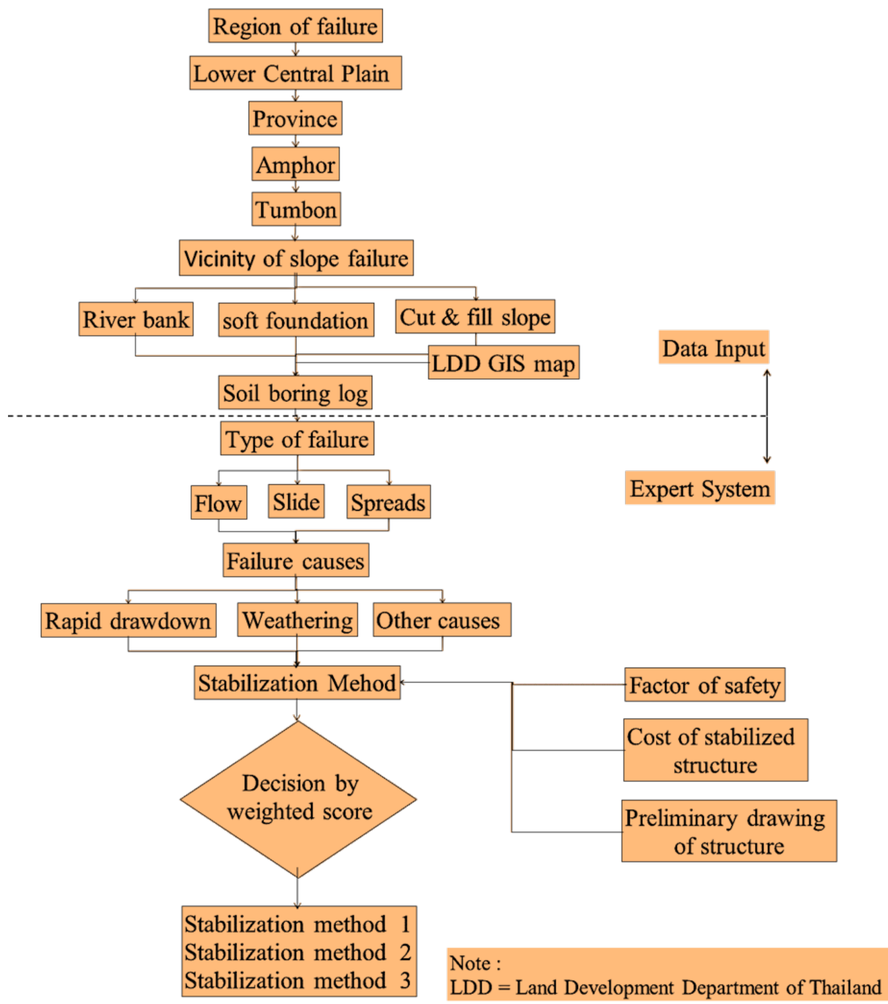


**Figure 2:** Flow chart of SlopeEx program.

The knowledge base of SlopeEx was created based on the knowledge acquired from three

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sources.

1. The database of possibly failure modes of soil slopes, in which the data are derived from the technical papers and interviewing the experts in this field.

2. The database for slope stabilization methods, deriving from the expert opinions, the past failure cases stabilization and the theoretical considerations.

3. The database of construction cost. The cost data are from Department of Internal Trades, Ministry of commerce Thailand and other relevant government organizations such as Department of Highways, etc. (BTEI (2014), DOH (2014), RID(2014)).

Such knowledge for possibly failure mode of soil slope and slope stabilization methods were integrated with fundamental engineering theories to develop a knowledge base. Figure 1 shows schematic diagram for analyzing the suitable inference rule.

The inference rule of SlopeEx program derived from synthesis those knowledge base to suitable method for stabilized of each failure type and causes. The inference procedure uses forward chaining; the chaining procedures starts from a set of conditions and moves toward conclusion. The flow chart of SlopeEx program is shown in Figure 2.

## 3. Soil Database and Expert Shell of Expert System

The limitation of engineering soil database concentrated on the city or economic area only. But the agricultural soil series map of Land Development Department of Thailand (LDD) are almost cover all this area. LDD studied agricultural soil about 2-3 meters from ground surface and classified into 45 soil series by using soil taxonomy according to United States Department of Agriculture (USDA) system. Then the GIS techniques are used to find the relative of soil data derived from the existing boring logs and the agricultural soil series's map from LDD. When no soil data used, this relation calculates and gives the safety factor of the construction of the stabilization method.

The stability analysis program used in SlopeEx program is KUslope, developed by Geotechnical Engineering Research and Development center (GERD) Kasetsart University Thailand (Rattatham, 2004). The three suitable stabilization methods are derived from weighted scores by the analytic hierarchy process (AHP). The weighted and scores of each items are derived from expert opinions. Table 2 shows details of each score. **The lowest of weighted score is the most feasible stabilization method.** SlopeEx guided method with cost of construction in a prescribed circumstance only. However users can use different method from the recommendation of program.

**Table 2:** Detail of weighted and score of each item.

| Items | Weighted | Level of score | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| Related construction time (months) | 0.2 | 0-3 | 4-6 | 7-9 | 10-12 | >12 |
| Related cost (Bahts/unit) | 0.3 | 0-2,500 | 2,501-5,000 | 5,001-7,500 | 7,501-10,000 | >10,000 |
| Type of Machine Required | 0.2 | 0-2 | 3-4 | 5-6 | 7-8 | >8 |
| Labour Requirement (Persons) | 0.1 | 0-5 | 6-10 | 11-15 | 16-20 | >20 |
| Related maintenance cost (Bahts/unit) | 0.1 | 0-1,250 | 1,251-2,500 | 2,501-3,750 | 3,751-5,000 | >5,000 |
| Related working area($m^2$) | 0.1 | 0-50 | 51-100 | 101-150 | 151-200 | >200 |

The $C^{++}$ builder program was used as an expert shell because of the interfacing capability with the other programs such as stability analysis program (KUslope), Microsoft office program (Word and Excel) and Adobe acrobat program (PDF).

## 4. Relationships of Engineering Properties and Agricultural Soil Series Map

Soil survey and classification in Thailand began in 1941 (before LDD) by Dr. R. L. Pendelton, a soil scientist from USA with Dr. Saroj Montrakul and Mr. Rerm Buranarerk by applied USDA system. The first soil map was in 1:2,500,000 scale and the soils were classified into series level. After Dr. Pendelton, soil survey and classification was carried on by Dr. Saroj Montrakul until 1961, after that transferring to Land Development Department (LDD) in 1963. LDD by supporting from United Nations and USDA etc., then developed many versions of soil maps until present. The soil series map used in this research was created in 2005 with scale 1:250,000. LDD studied properties of soil both of agricultural and engineering. In engineering properties LDD studied about the agricultural usage only and studied about 2 – 3 meters from ground surface (LDD, 2013).

Engineering soil's database used in this research have 2 parts: first soil data collected and stored in the subsoil database system called "ESDS-KU" system (Engineering Subsoil Database System – Kasetsart University) about 4,137 bored hole and adapted by Amorkun (2010) and second soil database received by soil exploration companies about 127 bored hole. Engineering soil bore holes were plotted according to latitude and longitude position on the agricultural's map. Soil data had about 2,325 bore holes all over studied area. The position of bore hole showed the name of soil's series, as shown in Figure 3.

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The relationship between engineering and agricultural soil properties can be known and 39 soil series were identified. The maximum number of bored hole is Thon Buri (Tb) series has 605 bored holes and the minimum is Hua Hin(Hh) series has 2 bored holes. The average soil strength (SPT vs depth) of 39 soil series as shown in Figure 4 (Number in parentheses is number of bored holes).

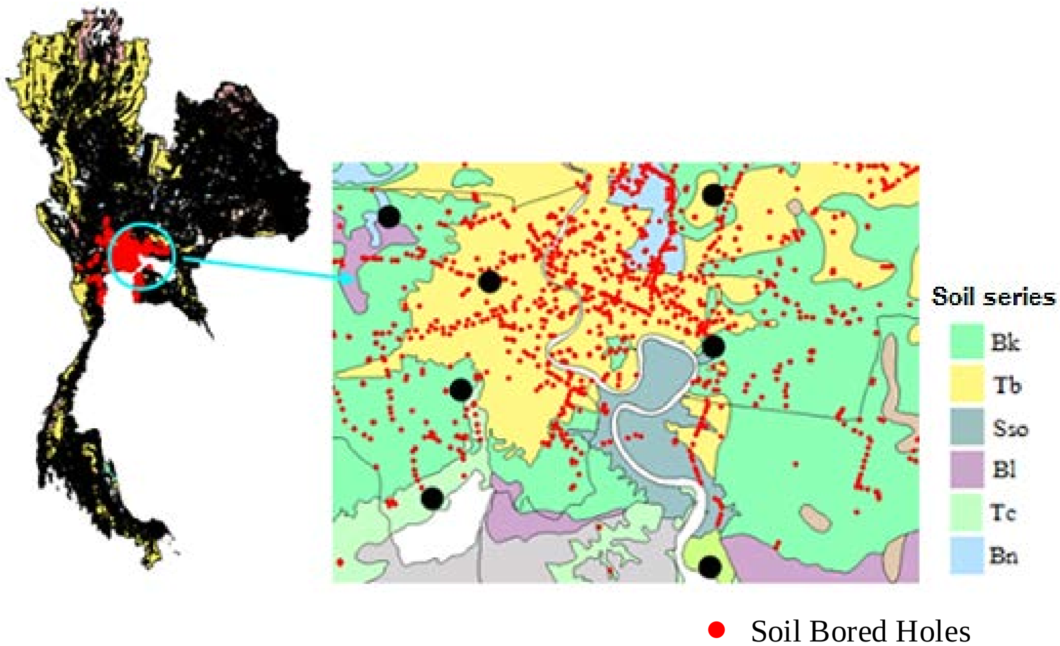


**Figure 3:** Agricultural GIS map with soil bore holes

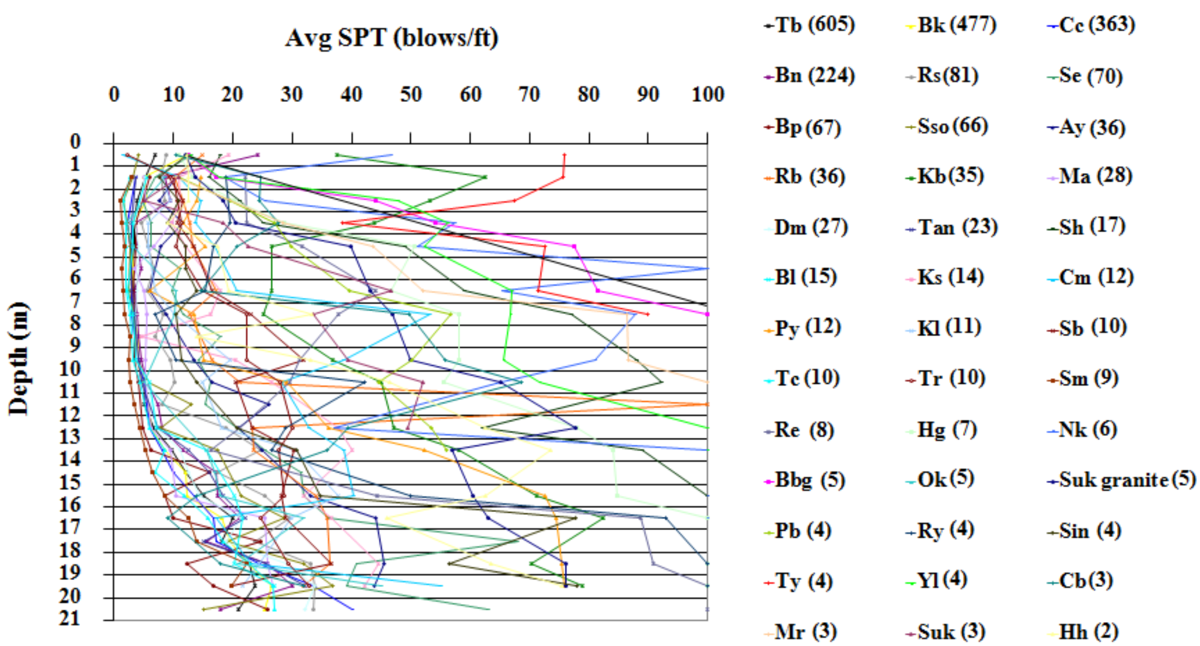


**Figure 4:** Relation of strength (SPT) vs depth(m) of 39 soil series.

From Figure 4 some soil series have soft clay's behavior. So SHANSEP theory equation (**S**tress **H**istory **A**nd **N**ormalized **S**oil **E**ngineering **P**roperties by Ladd and Foott (1974)) as shown in equation (1) was adapted to classified and grouped data of soil series.

$$\frac{S_u}{\sigma'_{vo}} = S(O.C.R.)^m \qquad (1),$$

where Su = Undrained Shear Strength (ϕ=0),
$\sigma'_{vo}$ = Effective Overburden Pressure,
S = Strength Ratio,
OCR = Overconsolidation Ratio,
m = 0.7-0.9 Ladd (1977).

But in this research use SPT as the shear strength in clay by using the relation of Su vs SPT (Chearnkiatpradab, 2014) as

$$S_u\ (\text{Ton/m}^2) = 0.6\ \text{SPT} \qquad (2),$$

So the adaptation of SHANSEP equation used SPT instead Su is shown in equation (3)

$$\frac{SPT}{\sigma'_{vo}} = 1.67S(O.C.R.)^m \qquad (3),$$

SPT = Standard Penetration Testing Number (Blows/ft) (Chearnkiatpradab, 2014).

Equation (3) was applied to evaluate and classify groups of soil series into four main groups. Each groups containing an upper limit line, average limit line and lower limit line of SPT as shown in Figure 5, except the forth soil series group has no soil relationship.

The trend of these relations is according to SHANSEP theory about 14 meters from ground surface, average thickness of clay stratum. The trend of relation of depth over 14 meters from ground surface difference from SHANSEP theory because influence of sand layer and OCR.

The soil group1 have 13 soil series. The thickness of weathered crust is about 3.0 m. SPT of this group decreased from ground surface until the end of weathered crust because of soil desiccation after that SPT increase with depth. The SPT increase distinctly after 12.0 m depth until 20.0 m. The soil group 1 covers Bangkok(Bk) , Bang Len(Bl) , Bang Khen(Bn) , Bang

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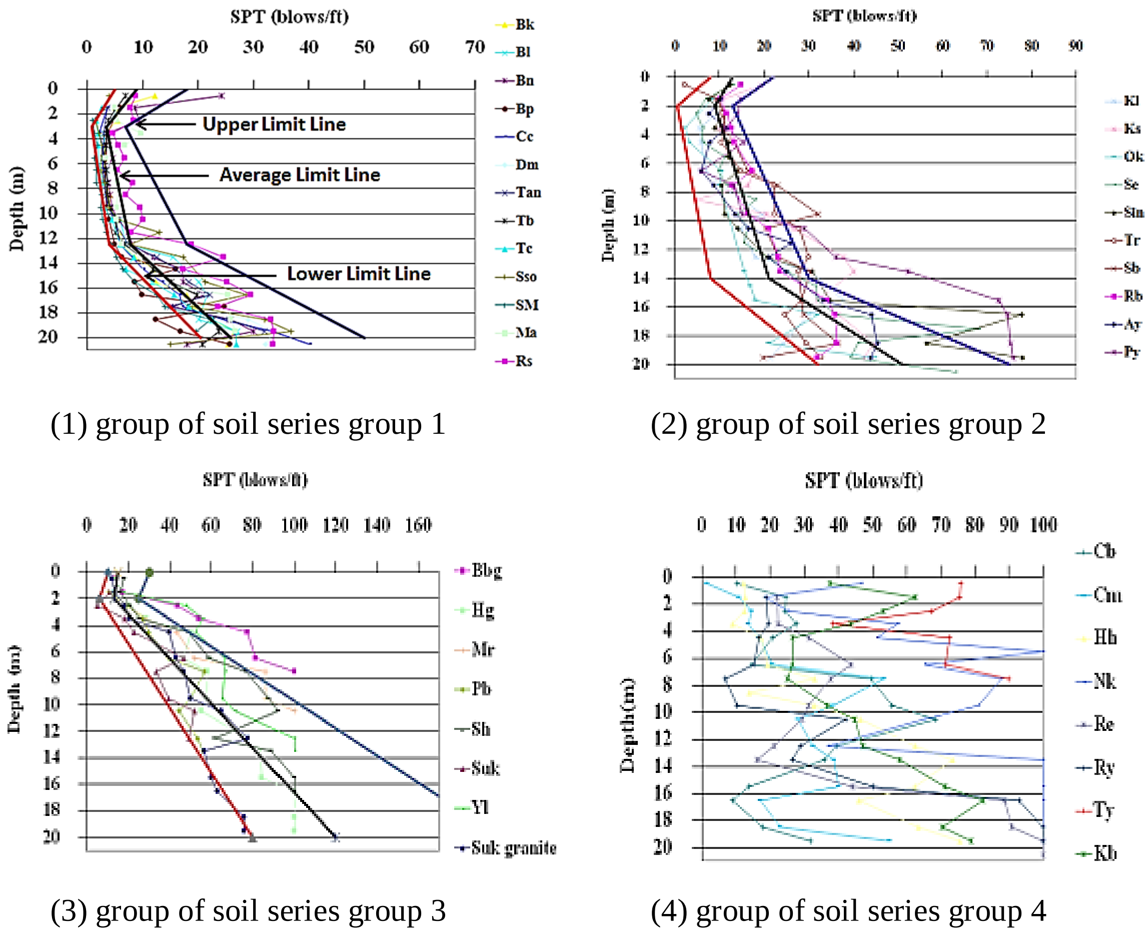
Nam Priao(Bp) , Chachoengsao(Cc) , Don Mueang(Dm) , Thanyaburi (Tan) , Thonburi (Tb) , Tha Chin(Tc) , Samut Songkhram(Sso) , Samut Prakan(Sm) , Rangsit (Rs) and Maha Phot(Ma) as shown in Figure 5. The group1 has total 1,995 bore holes.




(1) group of soil series group 1

(2) group of soil series group 2

(3) group of soil series group 3

(4) group of soil series group 4

**Figure 5:** The relation of SPT vs Depth of group soil series.

The soil group2 has 10 soil series. The thickness of weathered crust is about 2.0 m. SPT of this group decreased from ground surface until the end of weathered crust because of soil desiccation after that SPT increase with depth. The SPT increase distinctly after 14.0 m depth until 20.0 m. The soil group2 covers Ayutthaya (Ay), Ongkharak (Ok), Ratdhaburi ( Rb), Phatthaya (Py), Klaeng (Kl), Kamphaeng Saen (Ks) , Sarabur (Sb), Sena (Se), Sing Buri (Sin) and Tha Rua (Tr), as shown in Figure 5. Total 208 bore holes are in group2.

The soil group3 have eight soil series. The thickness of weathered crust is about 2.0 m. SPT of this group decrease from ground surface until the end of weathered crust, after that SPT increase with depth until 20.0 m. Group3 soil data covers Ban Bueng(Bbg) , Hup Krapong (Hg)

, Petchaburi(Pb) , Sattahip(Sh) , Mae Rim(Mr) , Satuk(Suk) , Yang Talat(Yl) and Satuk, granite derived variant(Suk-gra) as shown in Figure 5. Group3 has data from total 48 bore holes.

The soil group4 has eight soil series, consisting of Chon Buri(Cb) , Chiang Mai(Cm) , Hua Hin (Hh) , Kabin Buri(Kb) , Nong Kae(Nk) , Roi-et(Re) , Rayong(Ry) and Tayang (Ty) as shown in Figure 5. This soil group has no relation because the most of bore hole was located on the edge of the central plain area. The total bore holes in this group are 74 holes.

The soil strength with depth of each soil series group with Lower limit line, Average limit line and Upper limit line are shown in Table 3.

**Table 3:** The value of SPT with depth of group of soil series

| Group of soil series | Depth (m) | Standard Penetration Testing Number (SPT) | | |
|---|---|---|---|---|
| | | Lower Limit Line | Average Limit Line | Upper Limit Line |
| 1 | 0 | 5 | 9 | 18 |
| | 3 | 0.8 | 3.5 | 7 |
| | 12.5 | 4 | 7.7 | 18 |
| | 20 | 20.5 | 26 | 50 |
| 2 | 0 | 8 | 13 | 22 |
| | 2 | 0.4 | 9 | 13 |
| | 14 | 8 | 21 | 30 |
| | 20 | 32 | 51 | 75 |
| 3 | 0 | 10 | 15 | 30 |
| | 2 | 6 | 13 | 25 |
| | 20 | 80 | 120 | 200 |
| 4 | NO RELATION | | | |

## 5. The Case Study of Stabilization by SlopeEx Program

The SlopeEx program was tested by using a scenario of slope failures on three different soil series group areas following below:

(1) Soil series group 1, embankment on soft soil on Chachoengsao series that founded in Samutprakarn Province.

(2) Soil series group 2, filled slope on Ayutthaya series that founded in Supanburi Province.

(3) Soil series group 3, river bank on Petchaburi series that founded in Petchaburi Province.

The results of testing for each case are as follow:

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## 5.1 Result on Soil Series Group1, Chachoengsao Series

Testing on soil group 1, embankment height of 3 meters on soft soil failure, Chachoengsao series, Representative of the road embankment on soft soil. The profile of soil is soft clay from ground surface to 10.00 meter depth. The engineering properties of soil group 1 as shown in table 4

**Table 4:** The engineering properties of soil series group 1, Chachoengsao series

| Depth (m) | Soil Type | Soil data from | Engineering properties | | |
|---|---|---|---|---|---|
| | | | Su ($t/m^2$) | ϕ Degree | Density ($t/m^3$) |
| 0 – 15.00 | Clay | Soil boring | 1.43 | 0 | 1.6 |
| | | Soil relation | 1.33 | 0 | 1.6 |

**Remark:** Soil relation refers to relation between engineering soil and agricultural soil

The program show three methods, Counterweight berm, Cement Column and Bearing Unit or Plate form as shown in Table 5 with weighted scores and cost(Baht/m). In this case the weighted scores of cement column is the lowest so the cement column is the most suitable method. Figure 6 gives detail of cement column.

**Table 5:** The factor of safety, cost and weighted score of soil group 1, Chachoengsao series

| Title | Soil data from | Counterweight berm | Cement Column | Bearing Unit |
|---|---|---|---|---|
| Factor of safety | Soil boring | 1.815 | 1.809 | 2.375 |
| | Soil relation | 1.715 | 1.718 | 2.072 |
| Cost(Baht/m) | | 32,640 | 21,431.10 | 48,290.17 |
| Weighted Score | | 1.7 | 1.6 | 2.7 |

The weighted score derived from Table 6

**Table 6:** The detail of weighted score of soil group 1, Chachoengsao series.

| Items | Weighted | Level of score | | |
|---|---|---|---|---|
| | | Counterweight berm 32 m | Cement Column | Bearing Unit |
| Related construction time | 0.2 | 1 | 2 | 3 |
| Related cost | 0.3 | 2 | 1 | 3 |
| Machine Requirement | 0.2 | 1 | 3 | 2 |
| Labour Requirement | 0.1 | 2 | 1 | 3 |
| Related maintenance cost | 0.1 | 3 | 1 | 2 |
| Related Area of working | 0.1 | 2 | 1 | 3 |
| Sum of weighted Score | | 1.7 | 1.6 | 2.7 |

3 = Max , 2 = Mean , 1 = Min

## 5.2 Result on Soil Series Group2 , Ayutthaya Series

Testing on Soil series group 2, Filled slope on Ayutthaya series, Representative of earth filled slope for construction. The profile of soil from 0–7.0m is clay and 7.0–10.0m is sand. Table 7 gives engineering properties of soil group2.

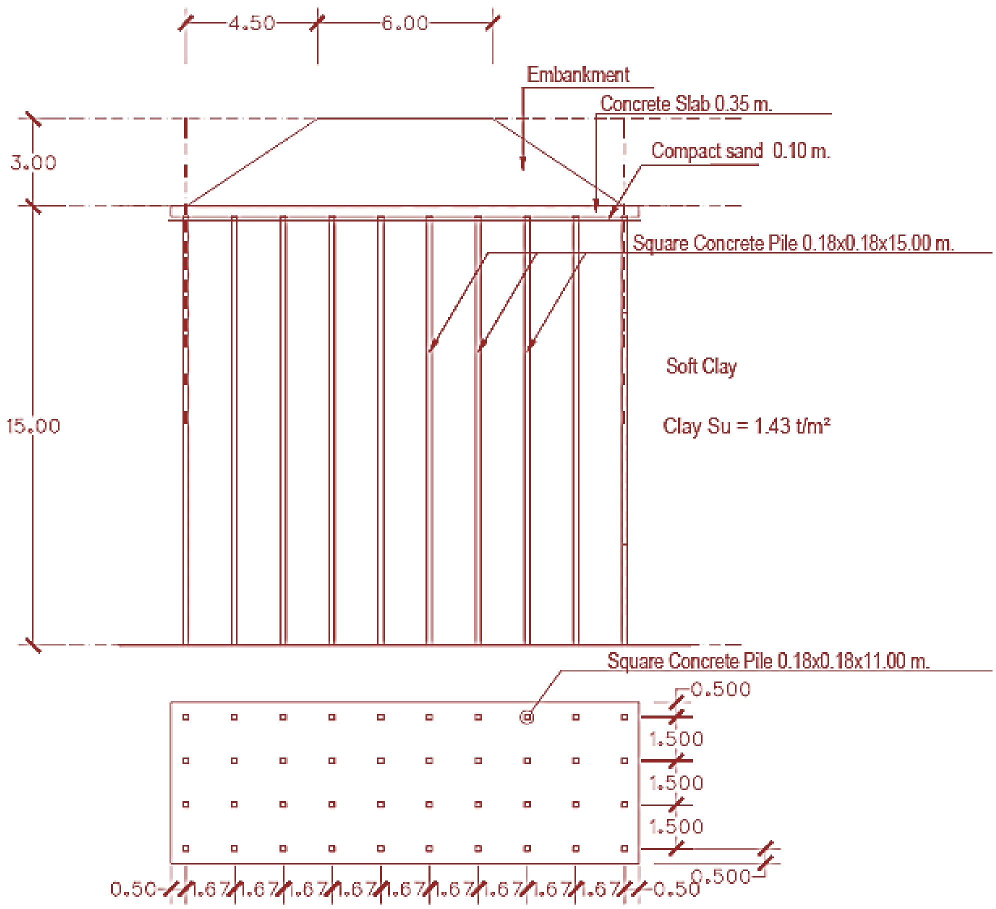


**Figure 6:** Detail of stabilized by cement column of soil group 1, Chachoengsao series

The program gives three methods for slope stabilization, Benching Slope, Rock Gabion and Retaining wall, as shown in Table 8 with weighted scores, cost and factor of safety. The detail of item and weighted of this case studies is the same as Table 6, different only level of score of each methods. In this case the weighted score of benching slope is the lowest, thus benching slope is the most suitable method.

**Table 7:** The engineering properties of soil group 2, Ayutthaya series

| Depth (m) | Soil Type | Soil data from | Engineering properties | | |
|---|---|---|---|---|---|
| | | | Su (t/m$^2$) | ϕ Degree | Density (t/m$^3$) |
| 0 – 7.00 | Clay | Soil boring | 7.3 | 0 | 2.07 |
| | | Soil relation | 2.57 | 0 | 1.75 |
| 7.00 – 10.0 | Sand | Soil boring | 0 | 33 | 2.18 |
| | | Soil relation | 0 | 28 | 1.8 |

The detail of benching slope as shown in Figure 7

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**Table 8:** The factor of safety, cost and weighted score of soil group 2, Ayutthaya series.

| Title | Soil data from | Benching Slope | Rock Gabion | Retaining Wall |
|---|---|---|---|---|
| Factor of safety | Soil boring | 6.748 | 6.462 | 6.696 |
| | Soil relation | 2.945 | 2.602 | 2.791 |
| Cost(Baht/m) | | 4,781.25 | 30,430 | 24,452.2 |
| Weighted Score | | 1 .4 | 2.5 | 2.7 |

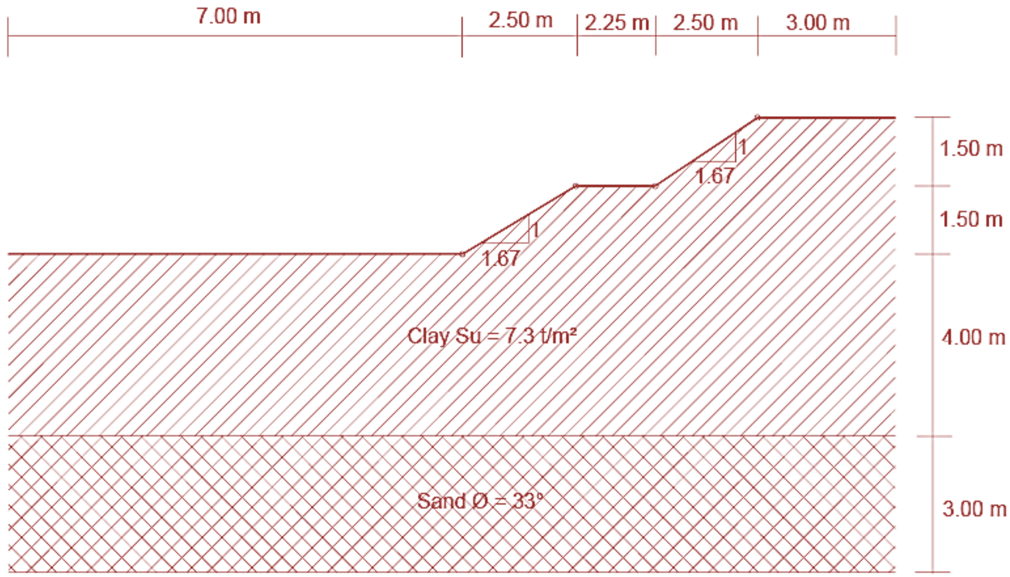


**Figure 7:** Detail of benching slope of soil group 2, Ayutthaya series

## 5.3 Result on soil series group3, Petchaburi series

Testing on Soil series group 3, river bank on Petchaburi series , Representative of river bank slope. The profile of soil from 0 – 2.75 meter is sand, from 2.75 – 5.5 meter is clay, from 5.50 – 8.50 meter is sand, and from 8.50 – 14.00 meter is clay. The engineering properties of soil group 3 as shown in Table 10.

**Table 10:** The engineering properties of soil group 3, Petchaburi series

| Depth (m) | Soil Type | Soil data from | Engineering properties | | |
|---|---|---|---|---|---|
| | | | Su (t/m$^2$) | ϕ (Degree) | Density (t/m$^3$) |
| 0 – 1.75 | Sand | Soil boring | 0 | 28.0 | 2.02 |
| | | Soil relation | 0 | 30.1 | 2.01 |
| 1.75 – 2.75 | Sand | Soil boring | 0 | 34 | 2.02 |
| | | Soil relation | 0 | 28.9 | 2.02 |
| 2.75 – 5.50 | Clay | Soil boring | 13.11 | 0 | 2.05 |
| | | Soil relation | 7.87 | 0 | 2.05 |
| 5.50 – 8.50 | Sand | Soil boring | 0 | 42.0 | 2.10 |
| | | Soil relation | 0 | 35.2 | 2.10 |
| 8.50 – 14.00 | Clay | Soil boring | 27.72 | 0 | 2.11 |
| | | Soil relation | 24.12 | 0 | 2.11 |

The program give three methods for slope stabilization: Counterweight berm, Rock gabion and Concrete sheet pile wall, as shown in table 11 with weighted scores , cost and factor of safety. The detail of item and weighted of this case studies is the same as Table 6, different only level of score of each methods. In this case the weighted score of counterweight berm is the lowest, therefore counterweight berm is the most suitable method. The detail of counterweight berm is shown in Figure 8.

**Table 11:** The factor of safety, cost and weighted score of soil group 3, Petchaburi series

| Title | Soil data from | Counterweight berm | Rock gabion | Concrete sheet pile wall |
|---|---|---|---|---|
| Factor of safety | Soil boring | 8.784 | 7.887 | 8.607 |
| | Soil relation | 5.921 | 5.613 | 5.805 |
| Cost(Baht/m) | | 6,464.25 | 30,010 | 31,499.11 |
| Weighted Score | | 1.4 | 1.9 | 2.7 |

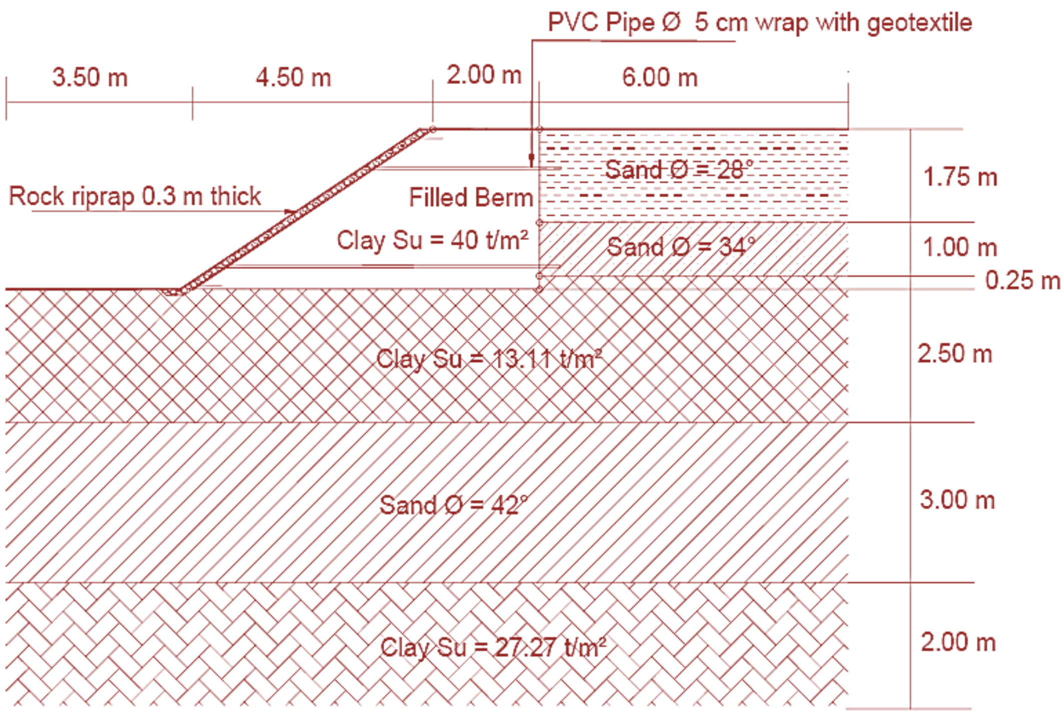


**Figure 8:** Detail of counterweight berm of soil group 3, Petchaburi series

## 6. Conclusion

### 6.1 SlopeEx Expert

1. The knowledge base acquired from three approaches:

- Slopes failure database derived from the technical papers and interviewing the experts.

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- Slope stabilization database derived from the expert opinions, the past failure cases stabilization and the theoretical considerations.

- Construction cost's database derived from relevant government organizations.

2. The inference procedure is based on forward chaining and C++ builder program was used as an expert shell.

3. The SlopeEx showed 3 stabilization methods accompany with weighted scores by AHP, construction cost , guideline engineering drawing and safety factor of each method.

4. The lowest weighted score is the most feasible stabilization method.

## 6.2 Soil Database

1. Database of engineering soil derived from ESDS-KU (Engineering Subsoil Database System – Kasetsart University) about 4,137 bored holes and soil exploration companies about 127 bored holes.

2. A number of bored holes (2,325 bored holes) were plotted on the LDD map and 39 soil series were identified on the studied area. Thon Buri (Tb) series has maximum bored hole 605 bored holes and Hua Hin(Hh) series has minimum bored hole 2 bored holes.

3. SHANSEP theory was used to evaluate and classified soil series to 4 groups.

4. The soil group 1 has 13 soil series with 1,995 bored holes. The soil group 2 has 10 soil series with 208 bored holes. The soil group 3 has 8 soil series with 48 bored holes. The soil group 4 has 8 soil series 74bored holes.

5. Soil group 1 to 3 have relation between soil strength (SPT) and depth but group 4 has no relation.

## 6.3 Case Study

Three case studies were used to validated the expert system as follow:

1. Soil series group 1, embankment on soft soil on Chachoengsao series in Samutprakarn Province the suitable method is cement column,

2. Soil series group 2, filled slope on Ayutthaya series in Supanburi Province the suitable method is benching slope

3. Soil series group 3, river bank on Petchaburi series in Petchaburi Province the suitable method is counterweight berm

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