# Settlement Analysis of Pakpanang Closure Dam


K. Petchgate

*King Mongkut's University of Technology Thonburi, Bangkok, Thailand*
*wspc@wspc.com*

Chirdchanin Modmoltin

*Department of Civil Engineering, Siam University, Bangkok, Thailand*
*chirdchaninm@yahoo.com*

P. Voottipruex

*King Mongkut's Institute of Technology North Bangkok, Bangkok, Thailand*
*pnv@kmitnb.ac.th*

A. Pirat

*King Mongkut's University of Technology Thonburi, Bangkok, Thailand*



Abstract: This paper proposed the settlement predictions of Pakpanang closure dam constructed on soil-cement column. The spacing of studies soil-cement column was over the limitation of Broms&Boman (1977) and Sweroad (1992) methods. The assumption of equivalent footing at the depth of 2L/3 length of column and at the end of column for conventional method were therefore applied. Settlement analyses were conducted using Terzaghi&Peck (1948) and Duncan&Buchignani (1976) theories. The coefficient of vertical consolidation ($C_v$) calculated by Asaoka (1978) method conforms to the actual settlement. Asaoka's graphic method was the best predictor with 3 percent different from the actual settlement rate. Furthermore, lateral displacements were determined. The maximum lateral displacement was found at 12$^{th}$ month, which is 24.53 mm at the center of the closure dam in the direction of downstream.


## 1 INTRODUCTION

Pakpanang Closure Dam and the Embankment No. 2 of the Pakpanang River are the part of Pakanang water gate project (Fig. 1) which is constructed at the narrowest part of Pakpanang River, Pakpanang district, Nakornsrithamaraj, Thailand. This project is constructed to separate Pakpanang flood plain area from Pakpanang bay. The total length of the project is 222 m. This site overlies on the soft clay. In order to solve the soft ground problem, the soil-cement column is applied with 1.6 m in diameter, 10 m in length and 3 m in spacing of cement column. Embankment No. 2 is the embankment connected from closure dam. Its total length is 105.80 m supported on cement column which has diameter 1.6 m with pile tip -12.00 m and column spacing 2.77 m.

## 2 GEOLOGICAL CONDITIONS

Pakanang project was constructed in the alluvial deposit soil. From the subsoil exploration, the top soil layer about 6-17 m is soft to very soft clay with gray-black color. This layer has low bearing capacity and high compressibility. The next layers are the medium clay and stiff to hard clay with gray-brown.

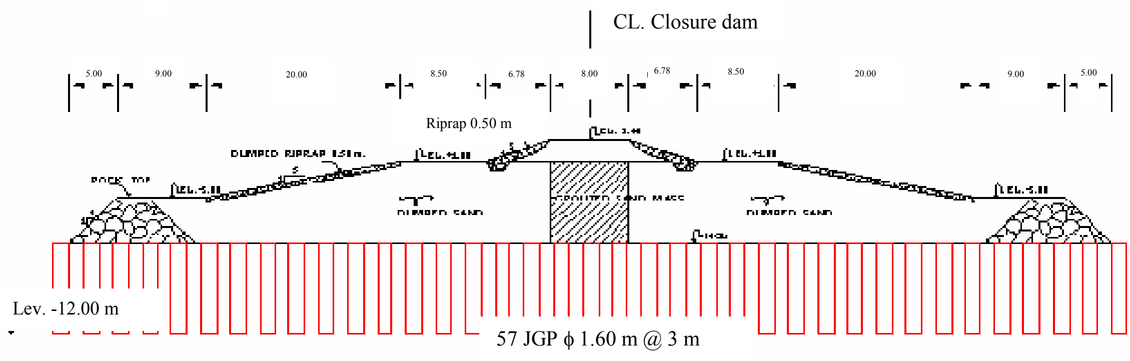


Fig. 1.Cross section of Pakpanang Closure Dam Project

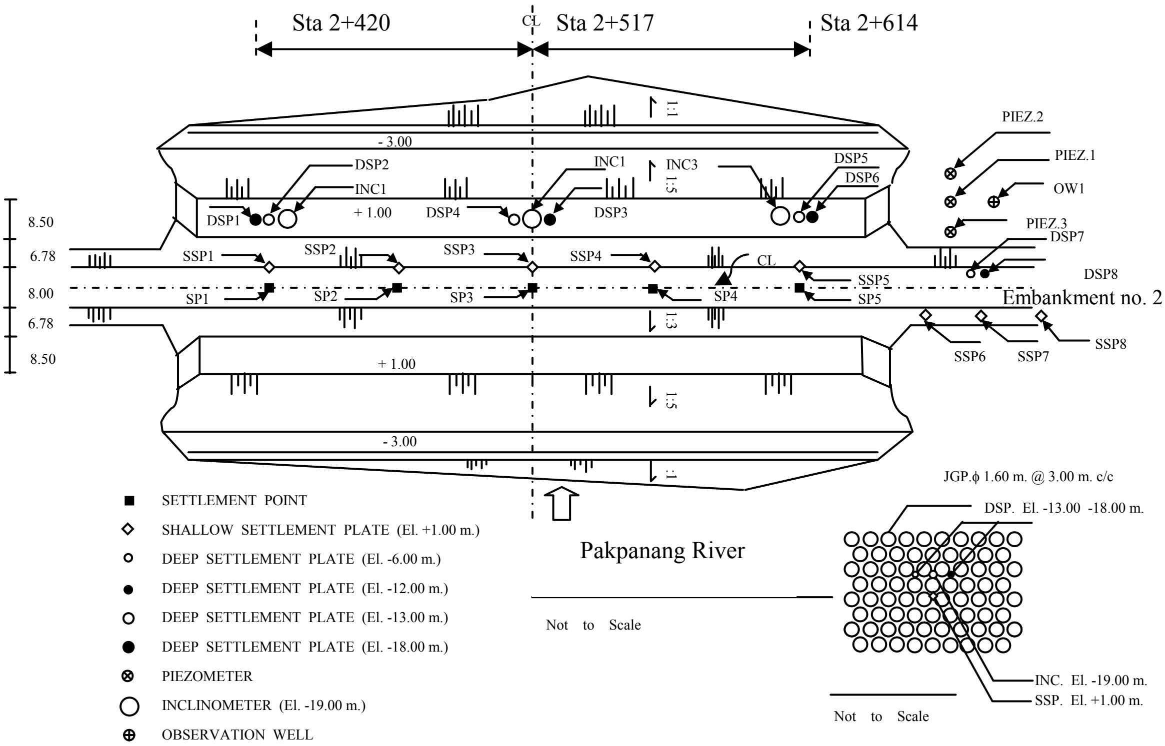


Fig. 2. Location of instruments in plan view

## 3 METHODOLOGY

The study focused on settlement analysis of closure dam and embankment. The data was obtained from both boring logs located on right and left sides of the river which were 23.00 and 20.00 m depth, respectively. The undisturbed samples were collected for strength parameters conducted in laboratory test. The 5 settlement points, 8 surface settlement plates, and 8 deep settlement plates were installed to observe the actual settlement. The lateral displacement was observed by 3 inclinometers. The positions of the instruments are shown in Fig. 2.

Settlements were calculated using Terzaghi&Peck (1948) and Duncan&Buchignani (1976) methods and compared to the actual observed settlement in the field during 590 days. In the closure dam, the assumptions of equivalent footing at the depth of 2L/3 length of column for conventional method were applied. The stress distribution was calculated by 2V: 1H, Tomlinson (1971), and Osterberg (1957) methods.

In the case of assumption of equivalent footing at the end of column for settlement analysis, the pile tips were penetrated in the hard soil layer. 2V: 1H and Osterberg (1957) methods were therefore applied for stress distribution at Sta.2+420, Sta.2+517, and Sta. 2+614. In order to determine settlement of Embankment No. 2, the assumption of equivalent footing at the depth of 2L/3 length of column for conventional method was applied. The stress distribution was calculated by 2V: 1H, Tomlinson (1971), and Osterberg (1957) methods.

Asaoka's graphic method in which early field settlement data was used to predict completion of primary settlement and the in situ coefficient of consolidation. In order to evaluate their similarity and differences, the theory and application as early part were compared in this paper.

## 4 TEST RESULTS AND DATA ANALYSIS

### *4.1 Laboratory test results*

Table 1. The properties of Pakpanang clay.

| Depth, m | Soil | w,% | LL | $\gamma$, $t/m^3$ | $q_u$, $t/m^2$ |
|---|---|---|---|---|---|
| 0- 8 | very soft clay | 66-78 | 71-86 | 1.49-1.60 | 0.05-1.42 |
| 8-17 | soft clay | 60-91 | 83-124 | 1.50-1.57 | 1.40-2.28 |
| 17-22 | medium clay | 38-42 | 77-80 | 1.68-1.78 | 8.04-17.60 |
| 22-23 | hard clay | 20 | 49 | 2.05 | 42.10 |

### 4.2 *The actual observed settlement in the field at 590 days*

#### 4.2.1 Pakpanang Closure Dam

The settlement values measured by settlement point (SP) and surface settlement plate(SSP) at level +2.40 m are shown in Table 2.

Table 2. Settlement values measured by settlement point (SP) and surface settlement plate (SSP) in mm.

| Position | Station2 | | | | |
|---|---|---|---|---|---|
| | +420 | +468.5 | +517 | +565.5 | +614 |
| SP(+2.40) | 121 | 148 | 191 | 109 | 49 |
| SSP(+1.00) | 114 | 164 | 187 | 121 | 75 |

The settlement values measured by deep settlement plate (DSP) at level +13.00 m (depth of 2L/3 length of column) and level +18.00 m (the end of column) are shown in Table 3

Table 3. Settlement values measured by deep settlement plate (DSP) in mm.

| Position | Station2 | | |
|---|---|---|---|
| | +420 | +517 | +614 |
| DSP(-13.00) | 62 | 139 | 44 |
| DSP(-18.00) | 46 | 110 | 53 |

4.2.2 Embankment No. 2

The settlement values measured by settlement point (SP) and surface settlement plate (SSP) at level +1.00 m are shown in Table 4. The values measured by deep settlement plate (DSP) at level -6.00 m (depth of 2L/3 length of column) and level -12.00 m (the end of column) were 63 and 64 mm, respectively.

Table 4. Settlement values measured by surface settlement plate (SSP) in mm.

| Position | SSP1 | SSP2 | SSP3 |
|---|---|---|---|
| SSP(+1.00m) | 34 | 49 | 43 |

4.3 *Lateral displacement at 12 months*

The lateral displacement of closure dam is quite low because the different water level of both side terraces is only 0.65 m. The maximum displacement was obtained 24.53 mm at 12.50 m depth in the direction of downstream.

4.4 *Data analysis*

4.4.1 Stress increment

The stress increment ($\Delta\sigma$) from the surcharge of closure dam was divided into 3 stages which were calculated at the depth of 2L/3 length of column and the end of column because the pile tip located in the hard soil layer. The surcharge of Embankment 2 was 2.8 m height, which was calculated only the depth of 2L/3 length of column because its pile tip was penetrated in the soft clay layer. The comparison among stress distribution methods showed that Osterberg (1957) method obtained the highest stress at the same depth (Osterberg > Tomlinson > 2V: 1H).

4.4.2 Coefficient of Vertical Consolidation ($C_v$)

The single drainage was applied in this analysis because there was no sand layer for drainage. The maximum of average coefficient of vertical consolidation ($C_v$) form the oedometer test was selected to calculation in order to obtain the highest settlement rate. The average $C_v$ of closure dam at the depth of 2L/3 length of column calculated by Taylor (1948) and Casagrande (1964) methods were 0.739 $m^2$/yr at Sta.2+517 and 0.784 $m^2$/yr at Sta.2+420 and Sta.2+614.

The average $C_v$ at the end of column were 0.706 $m^2$/yr at Sta.2+517 and 0.776 $m^2$/yr at Sta.2+420 and Sta.2+614. The average $C_v$ as 0.551 $m^2$/yr was applied in the case of Embankment 2.

The average $C_v$ of closure dam at the depth of 2L/3 length of column and the end of column calculated by Asaoka method at Sta.2+517, Sta.2+420, and Sta.2+614 were 36.504, 37.597, 84.556 and 15.917, 9.626, 23.526 $m^2$/yr, respectively.

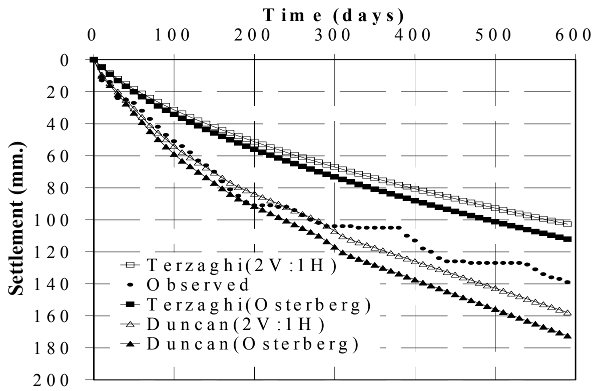


Fig. 3. Settlement of equivalent footing at the depth of 2L/3 length of column at Sta. 2+517.

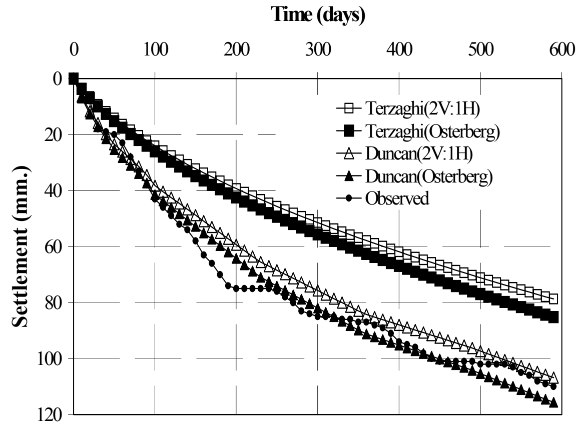


Fig. 4. Settlement of equivalent footing at the end of column ( Sta. 2+517).

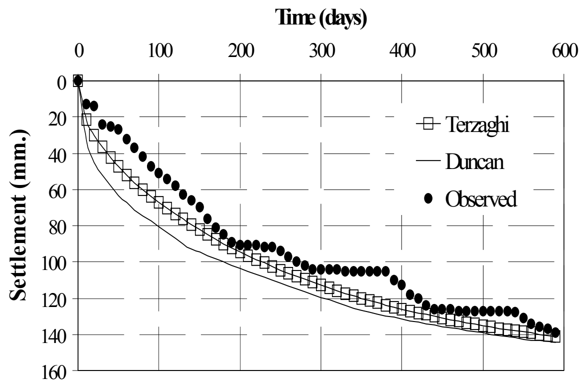


Fig. 5. Settlement of equivalent footing at the depth of 2L/3 length of column at Sta. 2+517 (Cv of Asaoka Method).

4.4.3 Comparison with field settlement at 590 days

4.4.3.1 Conventional method

The settlement obtained from Duncan&Buchignani (1976) method was higher than Terzaghi&Peck (1948) method as shown in Tables 5-7. The stress distribution by Osterberg (1957) method obtained the highest settlement. In Figs. 3&4, there were not the

Table 5. Comparison between actual and prediction settlements at the depth of 2L/3 length of column.

| Method | Terzaghi | | | Duncan | | |
|---|---|---|---|---|---|---|
| | 2V:1H | Tomlinson | Osterberg | 2V:1H | Tomlinson | Osterberg |
| Sta.2+420 | < 12.19% | < 15.76% | < 26.06% | < 71.39% | < 76.84% | < 92.56% |
| Sta.2+517 | > 26.12% | > 25.16% | > 19.35% | < 13.60% | < 15.10% | < 24.02% |
| Sta.2+614 | < 58.09% | < 63.11% | < 77.64% | < 141.50% | < 149.18% | < 171.34% |

Table 6. Comparison between actual and prediction settlements at the end of column.

| Method | Terzaghi | | Duncan | |
|---|---|---|---|---|
| | 2V:1H | Osterberg | 2V:1H | Osterberg |
| Sta.2+420 | < 17.91% | < 31.02% | < 57.72% | < 75.26% |
| Sta.2+517 | > 28.43% | > 22.53% | > 2.89% | < 5.11% |
| Sta.2+614 | < 2.34% | < 13.72% | < 36.89% | < 52.11% |

Table 7. Comparison between actual and prediction settlements of Embankment 2.

| Method | Terzaghi | | | Duncan | | |
|---|---|---|---|---|---|---|
| | 2V:1H | Tomlinson | Osterberg | 2V:1H | Tomlinson | Osterberg |
| Observed | > 54.68% | > 51.98% | > 45.35% | < 37.48% | < 45.67% | < 65.76% |

Table 8. Settlements at the depth of 2L/3 length of column ($C_v$ of Asaoka method).

| Method | Terzaghi | | | Duncan | | |
|---|---|---|---|---|---|---|
| | Sta.2+420 | Sta.2+517 | Sta.2+614 | Sta.2+420 | Sta.2+517 | Sta.2+614 |
| Observed | < 2.95% | < 1.47% | > 3.02% | < 5.40% | < 4.00% | > 2.52% |

settlement cures of stress distribution by Tomlinson (1971) method because its value closed to 2V: 1H method.

4.4.3.2 Asaoka's graphic method

Asaoka's graphic method in which early field settlement data was used to predict completion of primary settlement. The time was divided to interval as 10 days. The result of analysis was reliable with 3 percent difference from the actual settlement rate.

4.4.3.3 Conventional method using $C_v$ of Asaoka method

The settlement analysis by Terzaghi&Peck (1948) and Duncan&Buchignani (1976) methods using $C_v$ of field by Asaoka (1978) method were applied. It was found that both methods gave good agreement with actual settlement as shown in Fig.5. The settlement value from Duncan&Buchignani (1976) theory is higher than which of Terzaghi&Peck (1948) theory (Tables 8).

## 5 CONCLUSIONS

1. The settlement analysis using Duncan&Buchignani (1976) theory and stress distribution by 2V: 1H method with the load transmitted to the soil beginning at a depth of 2L/3 from the top of the pile and at the end of pile were different from the actual field settlement 13.60% and 2.89%, respectively. The settlement of Sta. 2+420 and Sta. 2+614 were calculated by Terzaghi&Peck (1948) theory and stress distribution using 2V: 1H method. The settlement of Sta. 2+420 were different from the actual 12.19% and 17.91% and the settlement of Sta. 2+614 were different from the actual 58.09% and 2.34% by the equivalent footing at the depth of 2L/3 length of column and at the end of column, respectively.

2. Asaoka's graphic method is the best predictor with 3 percent difference from the actual settlement. This method can predict the settlement in the period of 200-300 days with the error less than 10%.

3. The settlement analysis using coefficient of vertical consolidation ($C_v$) calculated by Asaoka (1978) method is better agreement to the actual settlement than which of Casagrande (1964) & Taylor (1948) methods.

4. The settlement of soil-cement column which the spacing is over the limitation of Broms&Boman (1977) and Sweroad (1992) methods can be successful predicted by the assumption of equivalent footing method.

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