

SETTLEMENT BEHAVIOR OF ROAD SURFACES CAUSED BY DISSOLUTION OF SALT LAYERS

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ABSTRACT: This research was aimed at studying the settlement behavior of road surfaces caused by the dissolution of salt layers that in turn create cavities. The dissolution can happen naturally or occur from salt mining. The proposed project's site was Highway 2229 from km066+4 to km 275+4, Kud Ruakham Sub-district, Ban Muang District, Sakonnakhon Province. The 2015 soil layer drilling survey revealed layers of hard clay and compact soil or shale with low plasticity. Cavities were found at the depth of 42 meters over sand stone layers. The analysis of road surface settlement was based on the Empirical Method and theories of Peck(1969), O'Reilly and New(1982), and Rankin(1969) to determine the i and V_s parameters based on S_{msx} from the surveys of road surface settlement from 2013 to 2018. Using the survey results, the analysis by the theory of O'Reilly and New(1982) showed i at 21 m and V_s ranging from 83.24% to 85.14% of V_s . The analysis based on the survey data and Rankin's theory (1969) showed i equal to 19.16m and V_s between 91.23% and 93.32% of V_s . The analysis of the surveyed data showed the end of surface settlement in 2016, which was consistent with the drilling survey in 2017 from which no cavities were found on the sand stone layers.

Keywords: Settlement, Salt layer, Cavities, Empirical Method

1. INTRODUCTION

The Northeast of Thailand is principally composed of mountains and glades. The two major glades are Korat Glade and Sakonnakhon Glade; the soil underneath of each contains layers of Mahasarakham rock group as shown in Figure 1, with alternate layers of halite and clay [1].

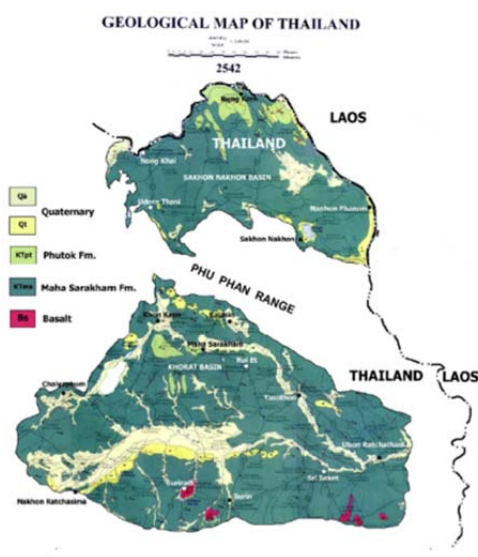


Fig. 1 1999 Geological map of Korat high plain in the Northeast containing Phu Tok and Mahasarakham rock groups - scale 1:1,000,000[2]

The Mahasarakham rock group is mainly composed of halite, which, in a great amount and in thick layers, naturally and physically becomes plastic, that is, deformable, flowable, and unbreakable. Salt is able to flow from the edge of a glade towards the center or from top to bottom under pressure. Movement of salt is termed 'salt tectonic' (Figure 2)[2]. The geological study of the Mahasarakham rock group hierarchy as discovered from the generally drilled pits indicates 4 characteristics of the rock are as following.

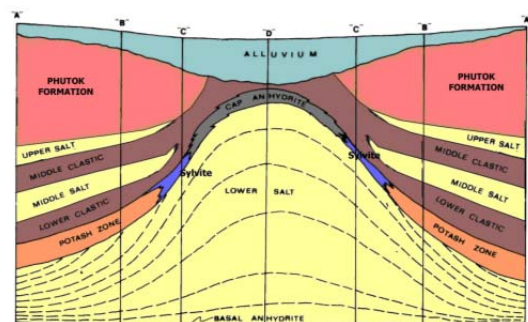


Fig.2 Structures of halite and potash classified under Mahasarakham rock group [2]

- Three salt bed
- Two salt bed
- Potash-bearing one salt bed
- Potash-barren one salt bed

Halite can be destroyed by water. When halite under soil surface has continuously been destroyed

by the water retained in the same layer, a cavity is formed. This cavity, if wide and if the soil-rock layers above fail to bear the load, will collapse into a sinkhole. The majority of sinkholes in Korat and Sakonnakhon Glades have been found in areas where saline water was pumped up for rock salt mining purpose and also in areas adjacent to the rock salt fields. Sinkholes in salt fields are usually not disclosed. However, if they are in the areas nearby, especially near communities or residential areas, the sinkholes will be reported on the news. Sinkholes threaten the lives and assets of people living in the vicinity [3, 4 and 5]

Singh (1992) explained that such a collapse takes place as a result of interference from external stress. Changes of stress affect the forms and movement of rock and soil layers. The extent of settlement depends on the degree of stress and the size of the cavity or pit hole which lead to instability. Therefore, soil surface collapse or settlement is the function of soil tectonic activity arising from a collapse of a cavity underneath. Soil surface settlement in general results in vertical as well as lateral slides. Soil surface settlement is caused by 3 factors, namely: 1) cracks, splits, or different degrees of cracks, 2) sinkholes or holes, 3) water puddles or soil depressions [6].

Elashiry et al. (2008) conducted a study of surface soil settlement of a phosphate mine by comparing the efficiency of the settlement equations proposed by Bal, Peng, Knothe, and Peck. In so doing, they compared the true measurement parameters against the steepness, curve, and plasticity. The method proposed by Peck yielded the parameters closest to the reality, with the coefficient accuracy over 0.9 [7].

This study was conducted on the settlement of road surface using the Empirical Method for the analysis. The survey data of road surface settlement from 2015 until 2018 were analyzed along with the data from soil survey by drilling in 2015 and 2017 comprising both vertical and horizontal soil movement (Figure 3 and Figure 4).



Fig.3 Field investigations (2017)



Fig. 4 Horizontal movement (2017)

2. METHODOLOGY

The study site was Highway No. **2229** from km **066+4** to km**275+4** I Kud Rua Kham Sub-District, Wanonniwat District, Sakonnakhon Province. The information retrieved showed that the highway was constructed before 1975 and the settlements were detected in 2012. The aerial survey showed saline water pumping from underground for a rock salt mining purpose (Figure 5).

Chaian Hinthong and Adul Charoenprawat (1990) indicated that they found sinkholes in the area of Ban Jampadong School in Khu Sakham Sub-District, Wanonniwat District, Sakonnakhon Province. There were detected sinkholes at Dinso Brook and along the brook's line. Sinkholes of 2-3 m size were also found at the school's fence. Based on the Nares Sattayarak's tectonic movement information, it is believed that the saline layer lies within the 70 m level [8].

The drilling survey of soil layers in 2015 (Figure 6) shows that the depth of 0-2 m is the road's fill soil layer. The depth of 2-10 m is a soft to rigid clay layer, the depth of **10-11.50** m contains clay and transformed wood, the depth of **10.50-39.50** m is hard to very hard soil, the depth of **39.50-39.85** consists of cavities, and the depth of **39.85-42.00** m consists of fine sand, assumed to result from collapse of the cavity walls above. The cavity height was estimated at 2.50 m before the collapse.

Settlement data collection, the road surface settlement data was obtained from the profile leveling method done along the centerline of the road, and the inflection parameters were recorded as per Figure 7, which were the data collected from 2015-2018. The extent of settlements began from km **115+4** to km**245+4**. The greatest settlement was detected at km**180+4**. All through the 4 years, the data showed: $S_{max} = 1.24$ m, **1.61** m, **1.75** m, and **1.75** m, respectively. The road surface settlement had a tendency to decrease and the settlement ceased in 2017, which is consistent with the drilling survey of soil layer in 2017 when no cavity over sandy rock layer was found (Table 1).

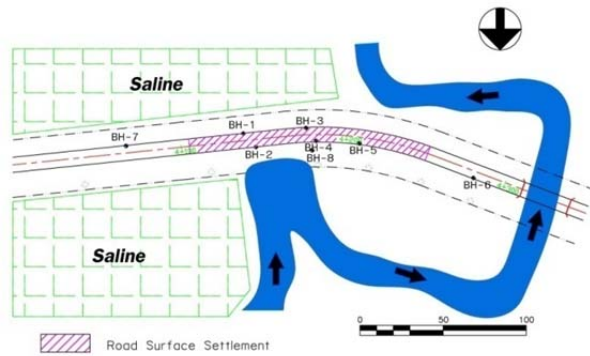


Fig. 5 Position of road surface settlement

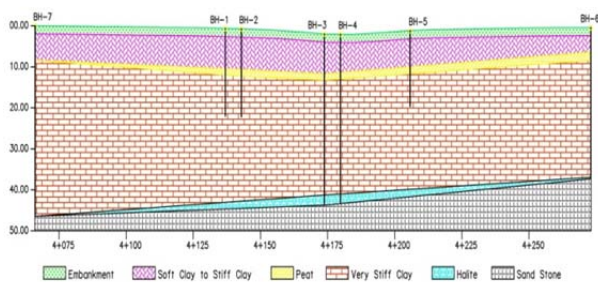


Fig. 6 Soil profile (2015)

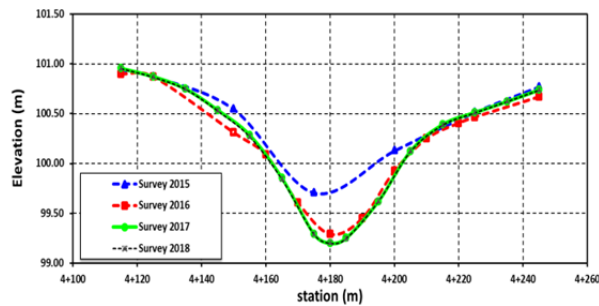


Fig. 7 Road centreline elevations

Table 1 Soil properties

| Soil type | Thickness (m) | γ (KN/m ³) | W_n (%) | LL (%) | PL (%) | S_u (KN/m ²) |
|----------------------|---------------|-------------------------------|-----------|--------|--------|----------------------------|
| Silty Sand (SM) | 0.00 – 2.00 | 18 | 9 | - | - | - |
| Stiff Clay (CL) | 2.00 – 7.50 | 18 | 28 | 44 | 22 | 90 |
| Very Stiff Clay (CL) | 7.50 – 42.00 | 19 | 26 | 47 | 22 | 300 |
| Sand Stone (RQD=0%) | 42.00 – 43.00 | - | - | - | - | - |

3. RESULT

The Result of the road surface settlement estimation based on the Empirical Method A comparison between the road surface settlement and the scope of the settlement was based on the Empirical Method of Peck's, the equation that

compares the field parameters using the maximum settlement - S_{max} , and the depth measured from the soil surface to the center of the cavity - Z_0 . From the field survey, the distance from the center of the cavity to the point where the curve i changed could be calculated in the case of clayey soil using the method of O'Reilly and New and Rankin (Table2).

From the data Table2, it was possible to calculate the settlement value according to Peck's theory and compare with the field data from 2015 to 2018. The results showed settlement of the surface according to Peck's, which was consistent with the real parameters obtained in the fields at the beginning of the route at km - **115+4** km **200+4**. At the end of the route at km - **200+4** km **445+4**, the real parameter measured was lower than the surface settlement based on Peck's theory. This was due to the non-equilibrium of the cavity which in turn, was caused by the slope of halite layers or by the fact that the settlement data was obtained from the profile leveling approach, and the curve at km **200+4** - km **445+4** led to discrepancies of the horizontal cross-section distance from the center of Cavity x. (Figure 8, Figure 9, Figure 10 and Figure 11)

A comparison was done between the calculation of the road surface settlement parameter by the Empirical ($V_{s_{Empirical}}$) as per Equation 7 and the road surface settlement parameter measured in the field. The results showed that the settlement in 2015 differed from other years because the distance of 25 m between each data collection point was too long leading to the amount of field data related to soil settlement being low. Therefore, we deleted the 2015 parameters and were able to conclude the amount of soil settled per one meter unit using the distance from the cavity center to the inflection. In the case of clayey soil, the method of O'Reilly and New showed $V_{s_{Empirical}}$ at 83.24 – 85.14% of $V_{s_{Survey}}$. The method of Rankin showed $V_{s_{Empirical}}$ at 91.23 – 93.32% of $V_{s_{Survey}}$. (Table 3 and Figure 12).

When considering the determination coefficient for more efficient method – with the value is closer to 1 – to find the surface settlement using the width of settlement hole i in the case of clayey soil between the methods of O'Reilly and New and Rankin; the results showed $R^2 = 0.96$ from O'Reilly and New method and $R^2 = 0.97$ from Rankin method, which agreed with Flashily.

The analysis of horizontal slide based on the Empirical Method by O'Reilly and New Theory (Figure 13), showed the horizontal surface slide. It was assumed that the soil slid toward the center of the cavity. As seen in the Figure, the slide began at km **115+4** and increased until the maximum at km **160+4** before it decreased again to zero at km **180+4**, where the settlement point was the peak. Then horizontal slide increased again to the maximum at

km 200+4, until it became 0 at km 445+4. Figure 14 depicts horizontal slides that resulted in cross-sectional cracks on the road surface. There were slides that coincided at the maximum settlement point, which resulted in swelling [8, 9 and 10].

Table 2 Inflexion (i)

| Year | Survey | | i (m) | |
|------|--------|-------|--------------------------------------|---------------------------|
| | Z (m) | S max | O'Reilly and New 1982 (K = 0.456) | Rankin 1969 (K = 0.50) |
| 2015 | 42 | 1.24 | 19.16 | 21 |
| 2016 | 42 | 1.61 | 19.16 | 21 |
| 2017 | 42 | 1.75 | 19.16 | 21 |
| 2018 | 42 | 1.75 | 19.16 | 21 |

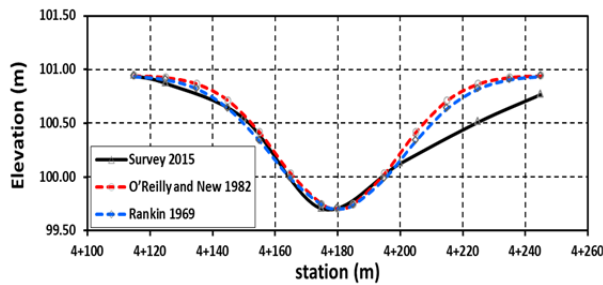


Fig. 8 Road surface settlement (2015)

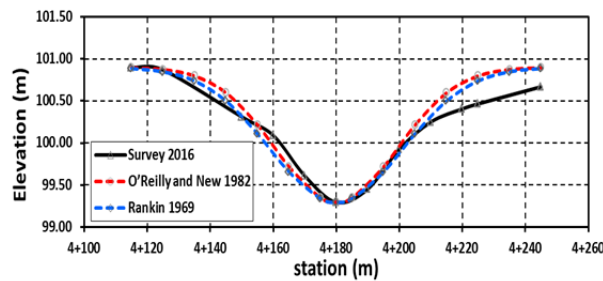


Fig. 9 Road surface settlement (2016)

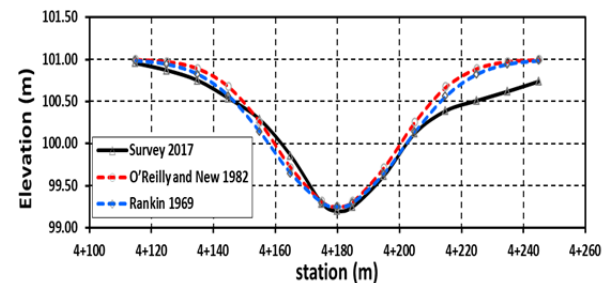


Fig. 10 Road surface settlement (2017)

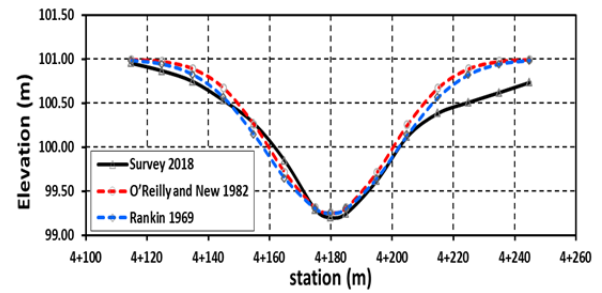


Fig. 11 Road surface settlement (2018)

Table 3 Road surface settlement

| Year | VsSurvey | VsEmpirical | | VsEmpirical/ VsSurvey (%) | |
|------|----------|-----------------------|-------------|-----------------------------|-------------|
| | | O'Reilly and New 1982 | Rankin 1969 | O'Reilly and New 1982 | Rankin 1969 |
| 2015 | 57.99 | 59.40 | 65.10 | 102.42 | 112.26 |
| 2016 | 92.65 | 77.12 | 84.53 | 83.24 | 91.23 |
| 2017 | 98.18 | 83.83 | 91.88 | 85.38 | 93.58 |
| 2018 | 98.45 | 83.83 | 91.88 | 85.14 | 93.32 |

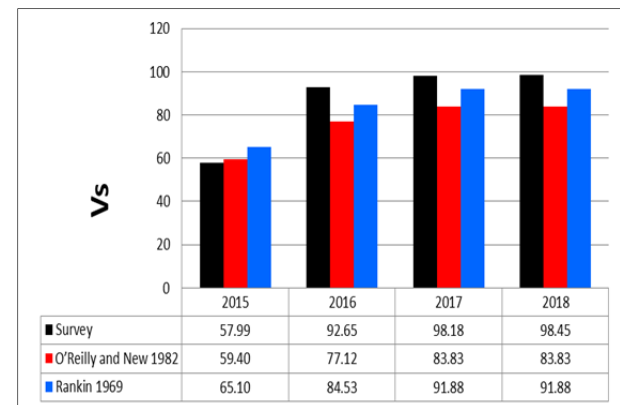


Fig. 12 The volume of road surface settlement

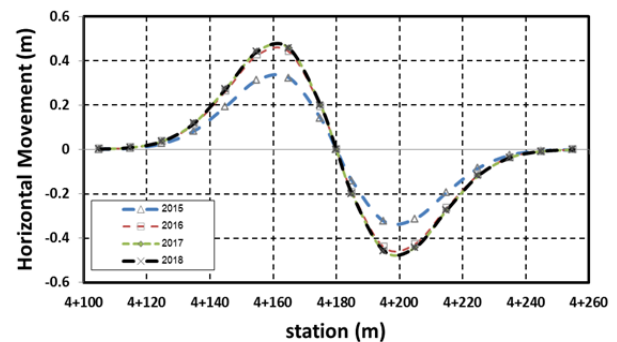


Fig.13 Horizontal movement



Fig. 14 Crack due to horizontal movement

4. CONCLUSIONS

1. The settlement of road surface was caused by solution of rock salt by water, which resulted in cavities at the depth of 42 m from the surface to the cavity center Z_0 .
2. The Empirical Method and Peck's theory gave the consistent road surface settlement value with the value measured in the field and coefficient of determination R^2 higher than 0.96.
3. The distance from the cavity center to the inflection in the case of clayey soil measured by Rankin method was 21 m. This means that the road surface settlement according to Peck's theory agreed with the real value measured in the field more than the method of O'Reilly and New. This was determined from the coefficient of determination of Rankin being $R^2 = 0.97$, which was higher than that of O'Reilly and New, where $R^2 = 0.96$.
4. The amount of the road surface settlement by the Empirical Method using the distance from the cavity center to the inflection i by O'Reilly and New method was 83.24 – 85.14% of $V_{sSurvey}$, whereas Rankin's calculation showed 91.23 – 93.32% of $V_{sSurvey}$.
5. The horizontal slide at the road surface led to tension between km – 115+1 km 160+1 and km – 200+4 km 245+4, which in turn caused cross-section cracks on the road surface. From km 160+1 to km 200+1, compression occurred from horizontal slides, causing swelling on the surface.

5. ACKNOWLEDGMENT

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