Evaluation of the Performance of Road Embankments over North Jakarta-Soft Soils

Évaluation de la performance de remblais routiers sur les sols mous du Nord de Djakarta.

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ABSTRACT: R.E. Martadinata road located in North Jakarta is a 7.3 km long - arterial road connecting the Tanjung Priok Port and the Western part of Jakarta. It was initially built 30 years ago crossing over the reclamation of Ancol area. Its structure consisted of the embankment with flexible pavements over North Jakarta-soft alluvial deposit which is classified as CH-MH soil based on USCS classification system. To compensate settlement, the pavement level was raised several times. The first embankment failure is 100 m long, occurred at KM 2+250 in September 16, 2010 at 03.16 AM. This collapsed segment was already repaired. However, another indication of an embankment failure appeared at Km. 4+100 m in March 2011. To avoid another possible failure, a more comprehensive stability and settlement analysis of the road embankment using a more detailed site investigation was conducted. This paper presents geotechnical data collection, geotechnical characterisation, geotechnical analyses at 4 zones which probable prone to stability and settlement problems, and some proposed design to strengthen the road embankment.

RÉSUMÉ : La route R.E. Martadinata, située au nord de Djakarta est une artère longue de 7,3 km reliant le port de Tanjung Priok et la partie occidentale de Djakarta. Elle a été construite il y a 30 ans dans la zone Ancol gagnée sur la mer. Sa structure se composait de remblai surmonté de chaussées souples, sur les dépôts alluviaux mous du nord de Djakarta, classés comme sols de type CH-MH selon la classification USCS. Pour compenser le tassement, le niveau de la chaussée a été rehaussé à plusieurs reprises. La rupture d'un premier remblai de 100 m de longueur s'est produite au PK 2+250 le 16 septembre 2010 à 3h16. Ce tronçon effondré a déjà été réparé. Cependant, d'autres signes de rupture de remblai sont apparus au PK 4+100 en mars 2011. Pour éviter une nouvelle rupture potentielle, une étude plus approfondie de stabilité et de tassement a été entreprise, basée sur une reconnaissance géotechnique plus détaillée. Cet article présente la synthèse des données géotechniques, la caractérisation géotechnique, les analyses géotechniques de 4 zones sujettes à des risque de rupture et de tassements, et quelques unes des mesures préconisées pour renforcer le remblai.

KEYWORDS: slope stability, settlement, raising, lightweigth material, ground anchore

1 INTRODUCTION

R.E. Martadinata road which was originally constructed over 30 years ago is an arterial road linking the Tanjung Priok port in northen part of Jakarta and the western part of Jakarta. Along 7.5 km of this road, from Simpang Lodan to Gate 3 of the port, consists of embankment which lies over soft deposit aluvium soil classified as CH soil based on USCS classification system and flexible pavement.

The first collapse of a road embankment of R.E. Martadinata Road occurred at Km 2+250 on September 16, 2010. Investigation indicates that the road embankment failure was significantly triggered by the riverbed and slope embankment scour coupled with the decline in sea water level which was suspected to be at the lowest level at the failure (Rahadian et al, 2011). The raise of pavement thickness also contributes to reduce the factor of safety (FS) value. The rehabilitation of this collapsed road was successfully done by Ministry of Public Works.

On March 2011, another potential collapse of a road embankment occurred at KM 4+100. In order to investigate potential problems that will lead to failure, an extensive site investigation was carried out.

This paper presents stability and settlement analysis, and geotechnical data collection for detailed engineering design to prevent potential loss due to the collapse of Martadinata Road. Numerical analyses of four zones were performed by using Plaxis software.

2 SITE CONDITIONS AND SOIL PROPERTIES

Soil parameter determined from both field and laboratory testing. The field investigation consists of traffic volume survey, topography and bathymetry survey, tidal measurements, 14 bored holes and 17 Cone Penetration Tests (CPT on shore) on road embankment, 35 CPT tests in Japat River (CPT off shore) parallel to the road (Institute of Road Engineering, Ministry of Public Works. 2011). Soil borings were carried out on the shoulder of the road towards Tanjung Priok while tests on the road lanes towards West Jakarta were not done due to insufficient space. CPT tests were done both on the road and the Japat River.

Based on the drilled bore logs and CPT, the soil beneath the road up to 30m deep is classified into 4 layers (see Fig. 1). On top is a quite thick layer of alluvium clay deposit to a deep of about 11 m-16 m with the cone tip resistance qc values are around 784 kPa. Beneath this layer, a layer of sandy silty clay with average 4 m thick. The third layer is a layer of dense sand with the average thickness about 8 m with the cone tip resistance qc values are around 4923 kPa. The last layer is a layer of sandy silty clay founded between 25 m and 30 m deep. A 1m- lens of dense sand also founded between 28 m – 29 m deep at BH 10.

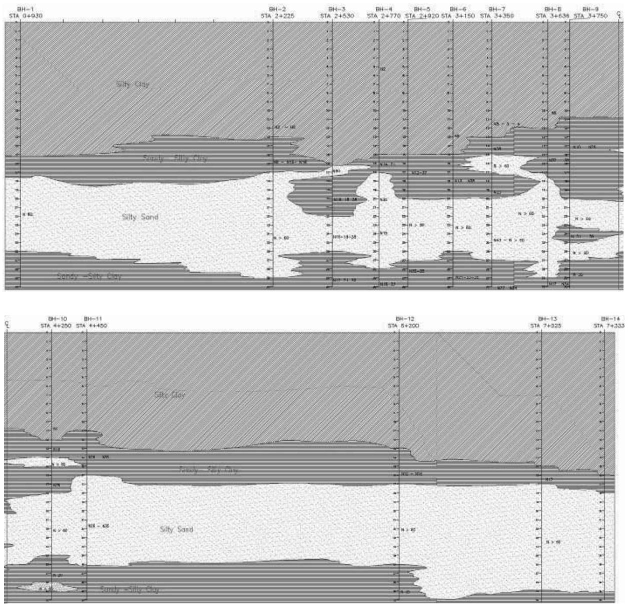

Figure 1. Soil stratigraphy of RE. Martadinata Road.

2.1 *Laboratory testing*

Based on plot of Atterberg limits value (liquid limit, LL, and plastic limit, PL), moisture content, the liquidity index and consistency index versus depth; the soil has a very soft to soft consistency. The water content of the soil is also close to its liquid limit.

Atterberg limits values can be used to determine the classification of cohesive soil by plotting the values of LL and PI on the plasticity chart based on the study of Casagrande (1932). By plotting a value of PI and LL on a USCS plasticity chart, the majority of dots being around A line that can be classified as inorganic clays or inorganic silt with high plasticity CH-MH (See Fig. 2).

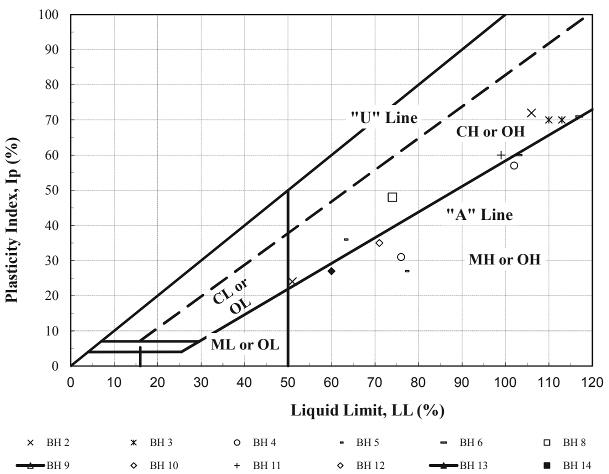

Figure 2. USCS plasticity chart

3 STABILITY AND SETTLEMENT ANALYSIS

Stability and settlement analyses were performed at 4 zones whereas Zone 1: Sta. 2+050 – Sta. 2+376, Zone 2: Sta. 3+275, Zone 3: Sta. 3+400 – Sta. 3+860, and Zone 4: Sta. 3+750 and Sta. 6+497 – Sta. 7+333. Traffic loading for long term stability is taken as 15 kN/m^2.

3.1 *Zone 1: STA. 2+050 - STA. 2+376*

Raising and stone works had been done at this zone. Potential problems in thiz zone are stability and settlement. Analysis of proposed design in this zone is based on the road cross-section at approximately Sta. 2+275.

Design parameters such as the friction angle, modulus of elasticity obtained by correlating the CPT #4 off shore and evaluation of laboratory tests on undisturbed soil samples in BH2 at Sta. 2+275.

The results of stability analysis of the existing road condition indicating the road is relatively in critical condition due to FS = 1.05. Predicted magnitude of settlement was 0.36 m at the center of the road, 0.41 m at the middle and of the road towards to Tanjung Priok, and 0.47 m at the edge of the road towards Tanjung Priok. The time required to reach the amount of settlement is 6800 days.

Therefore, some proposed trial designs were analyzed to fulfill minimum FS as follow:

3.1.1. *Corrugated prestressed concrete sheet piles*

The first trial design to strengthen the road is by using corrugated prestressed concrete sheet piles (see Table 1) to a depth of 16m (up to silty clay soil, firm to very firm).

Table 1. Design parameters of corrugated concrete type 5

Sheet pile type	*Type*	*Cracking Moment (kN.m/m)*	*I (m^4)*	*A (m^2)*
Corrugated concrete type 5	Elastic	269	3.5x10^{-3}	0.1835

To simulate the corresponding field condition i.e. water level fluctuation, two finite element models were developed to evaluate the infuence of the highest and lowest water level on the road stability. The results of stability analysis indicated FS = 1.22 at the highest water level, while FS at the lowest water level is 1.16 with large moments working on the sheet pile.

Predicted magnitude of settlement was 0.36 m at the center of the road, 0.41 m at the middle and of the road towards to Tanjung Priok, and 0.47 m at the edge of the road towards Tanjung Priok. The time required to reach the amount of settlement is 6800 days.

3.1.2 *Concrete sheet pile and ground anchor*

Strengthening of the road with a combination of concrete sheet piles (see Table 1) and ground anchor. The results of the analysis by considering the road reinforced with sheetpile (type 5) combined with additional ground anchors with an inclination from the horizontal of 40^o. Giving prestressed ground anchor on presstress modeled with extreme force drawn from the total normal stress / FK, i.e. 91.15kPa / 3 = 30.38 kN/m/m. Extreme total normal stress obtained based on the forces acting on the parts that have the greatest displacement. The results of the analysis showed that the stability of the road which is reinforced with sheetpile and supplementary reinforcement combined with ground anchors provide FS = 1.3.

Predicted magnitude of settlement was 0.29 m at the center of the road, 0.33 m at the middle and of the road towards to Tanjung Priok, and 0.36 m at the edge of the road towards Tanjung Priok. The time required to reach the amount of settlement is 6900 days.

3.1.3 *Secant pile walls*

Another strengthening method is by installing secant pile walls with diameter 0.8 m (see Table 2) to a depth of 25 m from the surface of the existing road. The results of stability analysis provides FS = 1.67.

Table 2. Design parameter of secant pile walls (plate model)

Element	*Type*	*EA (kN/m)*	*EI ($kN.m^2/m$)*	*W (kN/m^2)*	*n*
Secant pile	Elastic	$1.2x10^7$	$3.6x10^5$	14.4	0.15

Predicted magnitude of settlement was 0.39 m at the center of the road, 0.40 m at the middle and of the road towards to Tanjung Priok, and 0.38 m at the edge of the road towards Tanjung Priok. The time required to reach the amount of settlement is 6500 days.

Summary of settlement and time rate of 3 observation points as mentioned above can be seen in Table 3.

Table 3. Comparation of settlement value at Sta. 3+750.

Settlement	*Existing Road*	*Corrugated concrete*	*Secant Piles*
At center line	0.36 m	0.29 m	0.39 m
At middle	0.41 m	0.33 m	0.40 m
At edge	0.47 m	0.36 m	0.38 m
Time (days)	6800	6900	6500

3.2 Zone 2: Sta 2+376 – Sta. 3+401

In this Zone, there is a section of the road that had been strengthened by using sheet piles and stone works, while the other have not exist handling. Construction sheet pile implemented in 2011. This Zone is very vulnerable to both submerged from overflow of Japat River and from the surrounding environment (see Fig. 3), so raising works should be considered to be implemented.

Analysis of proposed design in this zone is based on the road cross-section at approximately Sta. 3+275. Design parameters such as the friction angle, modulus of elasticity obtained by correlating the CPT #5 on shore and CPT #17 off shore and evaluation of laboratory tests on undisturbed soil samples in BH6 at Sta. 3+150 and BH7 at Sta. 3+350.

The results of stability analysis of the existing road condition indicating the road is relatively in critical condition due to FS = 1.09. Predicted magnitude of settlement were 0.40 m at the center of the road, 0.51 m at the middle and of the road towards to Tanjung Priok, and 0.64 m at the edge of the road towards Tanjung Priok. The time required to reach the amount of settlement is 580 days.

Therefore, some proposed trial designs were analyzed to fulfill minimum FS as follow:

3.2.1 Corrugated prestressed concrete sheet piles

The first trial design to strengthen the road is by using corrugated prestressed concrete sheet piles (see Table 1) to a depth of 14 m (to sandy silt clay soil, firm to very firm).

To simulate the corresponding field condition i.e. water level fluctuation, two modeling analysis were conducted, which are to evaluate the influance of the highest water levels and the lowest water level measured on the tides. The results of stability analysis indicated FS = 1.15 at the highest water level, while FS at the lowest water level is 1.08 with large moments working on sheet piles 230 kN.m/m.

3.2.2 Corrugated prestressed concrete sheet piles + horizontal bars

Alternative proposed design is by using concrete sheet piles (see Table 1) and horizontal steel bars reinforcement (see Table 4) placed across the road which binds sheet piles with continuous slab constructed on the left side of the road. Stability analysis indicates FS = 1.4.

Table 4. Design parameter of horizontal steel bars

Steel grade	*Nominal diameter (mm)*	*Ultimate stress (MPa)*	*Cross section area (mm)*	*Ultimate strength (kN)*
150	45	1035	1716	1779

Raising 0.7m should be performed at this Zone to prevent the road submerged from overflow of Japat River and from the surrounding environment. Stability analysis indicates FS after raising is 1.3 with tensile force on a horizontal rebar is 176.7 kN/m. Predicted magnitude of settlement were 0.40 m at the center of the road, 0.35 m at the middle and of the road towards to Tanjung Priok, and 0.25 m at the edge of the road towards Tanjung Priok. The time required to reach the amount of settlement is 677 days.

3.2.3 Concrete sheet pile and ground anchor

Strengthening of the road with a combination of concrete sheet piles (see Table 1) and ground anchor. The results of the analysis by considering the road reinforced with sheetpile (type 5) combined with additional ground anchors with an inclination from the horizontal of 40^o. Giving prestressed ground anchor on presstress modeled with extreme force drawn from the total normal stress / FK, i.e. 211kPa / 3 = 70.33 kN/m/m. Extreme total normal stress obtained based on the forces acting on the parts that have the greatest displacement. The results of the analysis showed that the stability of the road which is reinforced with sheetpile and supplementary reinforcement combined with ground anchors provide FS = 1.55.

Predicted magnitude of settlement was 0.40 m at the center of the road, 0.35 m at the middle and of the road towards to Tanjung Priok, and 0.25 m at the edge of the road towards Tanjung Priok. The time required to reach the amount of settlement is 702 days.

3.3 Zone 3: Sta. 3+400 – Sta. 3+860

Analysis of proposed design in this zone is based on the road cross-section at approximately Sta. 3+750. There is a temporary construction using bamboo and stone masonry. This location is expected to potentially experience stability problems and settlement.

Design parameters such as the friction angle, modulus of elasticity obtained by correlating the CPT #9 on shore and evaluation of laboratory tests on undisturbed soil samples in BH9 at Sta. 3+750.

The results of stability analysis of the existing road condition indicating the road is relatively in critical condition due to FS = 1.02. Predicted value of settlement during 4600 days was 0.60 m at the centerline, 0.68 m in the middle of the road directions to Tanjung Priok, and 0.75 m at the edge of the road way to Tanjung Priok. The time required to reach settlement is 4600 days.

As mentioned above, the existing road condition at Sta. 3+750 is in relatively unstable condition due to FS value = 1.02. Therefore, some proposed alternative designs were analyzed to fulfill minimum FS as follow:

3.3.1 Concrete sheet piles and ground anchor

Strengthening of the road with a combination of concrete sheet piles (see Table 1) and ground anchor. The results of the analysis by considering the road reinforced with sheetpile (type 5) combined with additional ground anchors with an inclination from the horizontal of 40^o. Giving prestressed ground anchor on presstress modeled with extreme force drawn from the total normal stress / FK, ie 91.15kPa / 3 = 30.38 kN/m/m. Extreme total normal stress obtained based on the forces acting on the parts that have the greatest displacement. The results of the analysis showed that the stability of the road which is reinforced with sheetpile and supplementary reinforcement combined with ground anchors provide FS = 1.3.

3.3.2 Secant pile walls

Another strengthening method is by installing secant pile walls with diameter 0.8 m (see Table 2) to a depth of 25 m from the surface of the existing road. The results of stability analysis provides FS = 1.65. The improvement of vertical geometry was also considered in this analysis. There are two raising level modeled in the models which are raising 0.7m consisting of ± 0.25 m selected material, ± 0.15 m subbase foundation and ± 0.3 m concrete pavement; and raising 1.2m consisting of 1m raising using lightweight material (see Table 5) and 0.2m asphalt. The FS of the road which strengthened by secant pile walls combined with raising 0.70 m and 1.20 m are 1.31 and 1.37, respectively.

Table 5. Design parameter of raising material

Element	*Type*	*E* (*kN/m²*)	*c'* (*kN/m²*)	*ϕ' (deg)*	*n*
Lightweight	Non-porous	$3.0x10^4$	50	45	0.15

Settlement analysis were performed at some points over the pavement surface for all raising cases, i.e. at road centerline, at the middle and the edge of the road directions to Tanjung Priok, respectively. The result of settlement analysis can be seen in Table 6.

Table 6. Predicted settlement value at Sta. 3+750.

Settlement	*Raising 0.7 m*	*Raising 1.2 m*
Center line	1.24 m	0.79 m
Middle	1.29 m	0.67 m
Edge	1.30 m	0.51 m

3.4 Zone 4: STA 6+497 - STA 7+333

The condition of this zone is similiar to that of in Zone 2 where is very vulnerable to both submerged from overflow of Japat River and from the surrounding environment, so raising works should be considered to be implemented. Analysis of proposed design in this zone is based on the road cross-section at approximately Sta. 7+000.

Design parameters such as the friction angle, modulus of elasticity obtained by correlating the CPT #13 on shore and CPT #37 off shore and evaluation of laboratory tests on undisturbed soil samples in BH13 at Sta. 7+000.

Based on analysis result, the existing road remains relative stable with FS = 1.95. Eventhough the road seems to be stable, a potential problem in this zone is flood. There are two raising level modeled in the models which are raising 0.7m consisting of ± 0.5 m selected material, and ± 0.2 m concrete pavement; and raising 1.2 m consisting of ± 1m selected material and 0.2m asphalt.

The results of stability analysis shows that the road is relatively stable at the time of the raising 0.7 m and 1.2 m, with FS = 1.54 and FS = 1.37, respectively. If lightweight material is used to replace selected material in both raising 0.7 m and 1.2 m, FS = 1.93 and FS = 1.56.

The results of settlement analysis show that the predicted settlement of point A at the center line of the road after raising 0.7 m and 1.2 m using selected material are 0.35 m and 0.47 m within 449 days and 508 days, respectively. If lightweight material is used in raising, the predicted settlement will be 0.27 m and 0.31 m within 420 days and 452 days, respectively (see Fig. 4).

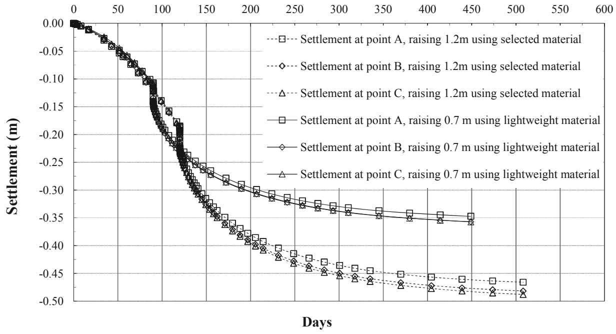

Figure 4. Time – settlement curve of raising using selected material and lightweight material at point A, B and C at Sta. 7+000

4 CONCLUSIONS

Based on the observations of field conditions, soil test results, evaluation of the existing condition of the road, and analysis result, performance of road embankments over North Jakarta-soft soil can be summarized as follows :

1. To fulfil stability and settlement analysis, the road at Zone 1, and 3 should be strengthened by secant pile walls combined with raising 0.7 m and in some places raising 1.2 m should be implemented. If this strengthening method is applied at Zone 1 and Zone 3, FS is 1.67 and 1.31-1.37, respectively.
2. To fulfil stability and settlement analysis, the road at Zone 2 should be strengthened by concrete sheet piles and ground anchor. If this strengthening method is applied, FS is 1.55.
3. Although the results of the analysis of the stability of the existing road at Zone 4 shows that the road is still in a stable condition, a potential problem in this zone is flood. Therefore, raising 0.7 m and in some places raising 1.2 m should be implemented. If this strengthening method is applied, FS is 1.31-1.37.

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