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Technical Note

THE SWELLING OF EXPANSIVE SUBGRADE AT WATES-PURWOREJO ROADWAY, STA. 8+127

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Catatan Redaksi:

Kerusakan struktur bangunan dan perkerasan jalan karena tanah ekspansif merupakan masalah yang banyak terjadi di Indonesia. Salah satu kerusakan perkerasan jalan yang terjadi karena tanah ekspansif adalah kerusakan perkerasan jalan di Sta. 8+127, Jalan Raya Purworejo-Wates. Technical Note ini menyajikan penyelidikan penyebab kerusakan perkerasan jalan tersebut. Penulis menyimpulkan bahwa tanah dasar di lokasi tersebut adalah tanah ekspansif dengan tekanan mengembang yang sanggup merusak struktur perkerasan jalan di atasnya.

Note from the Editor:

Damage of structures and road beds due to expansive soil are common in Indonesia. One example is the deterioration of a road section at Sta. 8 + 127 of the Purworejo-Wates Highway. This Technical Note presents the investigation of the cause of the deterioration of the road bed. The author concludes that the sub grade is an expansive soil and the swelling pressure is able to lift the overlaying pavement and cause considerable cracking.

BACKGROUND

Expansive soils are widely distributed in the world and found in more than 60 countries and regions. The problem of expansive clay is a worldwide issue. Kaczyński and Olszewska [1] showed that swelling soil in Poland had brought relatively many failures of structures. An investigation undertaken by Shi et al [2] reported that China was one of the countries with a large distribution of expansive soils, occupying nearly 600,000 km^2. Expansive soil constitutes the most vulnerable natural hazard to buildings on shallow foundations in China. Yanjun-Du et al [3] indicated that the most detrimental effect of embankment and roadbeds in Ning-Liang highway were due to ignorance of this problem. A serious damage and financial lost was also experienced in Oman. These problems were mainly caused by expansive soil and rock, which undergo volumetric change upon wetting and drying [4]. Erguler and Ulusay [5] reported that the expansive soils in Turkey were found in abundance in central, western and southern parts of Ankara city which was the capital of Turkey, due to the fact that some lightly trafficked roads were rough and damages to low-rise buildings.

Cohesive soils present in a region of Yogyakarta are highly sensitive to the action of weathering. At natural conditions, weathering causes soil disintegration and leads to deterioration of the physical and mechanical properties of cohesive soils. Some clay soils exhibit a certain level of swelling–shrinkage even if their swelling grades are relatively low. The swelling–shrinkage is most influenced by the mineral composition and clay content. The dynamic of swelling is also influenced by various factors such as soil lithology, availability of exchangeable cation, percentage of carbonates, structure and microstructures, and the environmental effects (water table fluctuation, moisture content, degree of compaction, and drainage system). When, the clay soil was in the disturbed conditions and compacted, and then used for roadway subgrade, foundation, embankment or road-bed, their natural structures were destroyed. This phenomena will take effect on some changes such as broken cementing bonds, increased water content, higher dry density and increased swelling–shrinkage indexes. This results in decrease in bearing capacity and increase in deformation of foundation. The soil may become high swelling grade expansive soil. This swelling–shrinkage cycles play fundamental role in this process and bring about serious damage.

Muntohar [6] reported that the swelling pressure of expansive subgrade might generate some pavement distress at Yogyakarta – Wates roadway. Similar case was observed at Wates – Purworejo roadway (Figure 1). The pavement cracking at this route should be paid a great attention since the roadway links two provinces, D.I. Yogyakarta and Central Java. This route is also called as the Southern Route (Jailor Sultan), which is an alternative route beside the Northern Route (Jailor Pentair Tara). This paper presents the investigation on the swelling charac-

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teristics and change in bearing capacity of subgrade at STA. 8+127 Wates–Purworejo roadway. The research is addressed to highlight the properties of subgrade that caused pavement deterioration.

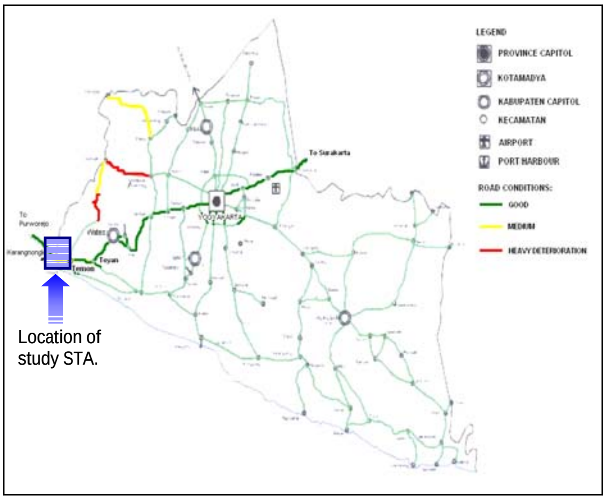

Figure 1. Map of road deterioration conditions and location of the study.

LABORATORY TESTS SCHEME

The soil samples were obtained from the site at near STA. 8+127 Wates – Purworejo roadway. The undisturbed samples were taken in a depth between 0.5 – 1.0 m from ground surface, at three different locations along the roadway. Series of laboratory tests were undertaken to investigate the index and some engineering properties, like grain size distribution, consistency limits, specific gravity, Proctor's standard compaction, California bearing ratio (CBR), and swelling test. The CBR and swelling tests were carried out for both disturbed and undisturbed soils. The soils tested for CBR was assessed in two conditions i.e. soaked and unsoaked. The CBR test is in accordance to ASTM D1883-99. The disturbed soils were compacted using Proctor's standard compaction mold at the optimum moisture content (OMC) to attain the maximum dry density (MDD).

The swelling test was done in accordance to Method-A of ASTM D4546-90. The undisturbed or disturbed-compacted samples were molded in a 50 mm diameter and 20 mm height. The soil specimen was restrained laterally and loaded axially in a consolidometer with access to water. The specimen was inundated and allowed to swell vertically at the seating pressure. Pressure of at least 1 kPa (20 psi) was applied by the weight of the top porous stone and load plate until primary swell is completed. The specimen was loaded incrementally after primary swell has occurred until its initial void ratio/height is obtained.

RESULT AND DISCUSSION

Index Properties

The laboratory test carried out has been focused to investigate the particle size distribution, level of compaction (maximum dry density), optimum moisture content, soil bearing ratio, and the potential to heave vertically of the subgrade. Table 1 presents the results of index properties of investigated soil.

Table 1. The index properties of tested soil samples

Location	Specific Gravity	Natural Moisture	Liquid Limit	Plastic Limit	Plasticity Index	Shrinkage Limit	Liquidity Index	Clay Size Fraction
	Gs	w_N(%)	LL (%)	PL (%)	PI (%)	SL (%)	LI	< 2 m (%)
WP-1	2.56	45.50	85	41	44	16	0.10	32
WP-2	2.56	45.07	88	43	45	13	0.05	46
WP-3	2.66	45.12	55	32	24	14	0.57	15

According to the data given in Table 1, the soils are classified into elastic silt soil or MH in accordance to ASTM classification and A-7-5 according to AASHTO. The soils are in plastic state range in nature as indicated by value of the liquidity index. The liquidity index measures the state or potential state of consistency of a natural soil [7]. The most important consistency index is the plasticity index, PI. In general, the larger the plasticity index implies the greater engineering problems associated with the use of the soil as an engineering material, such as road subgrade, foundation support for residential building, etc.

Many soils properties and engineering behaviors have been correlated with the plasticity index including swelling-shrinkage potential. Eventhough, most of the correlation should be cautiously treated, some are reasonably reliable, but many are slightly better than guesses. Seed et al [8] and Chen [9] proposed a very simple model using plasticity index parameters to assess the swelling potential of clay soils as given in equation (1) and (2) respectively:

$$SP = 60\ K\ (PI)^{2.44} \tag{1}$$

$$SP = B\ e^{A(PI)} \tag{2}$$

Where, SP is swelling potential, K = 3.6 x 10^{-5}, A = 0.0838, B = 0.2558 are constants, and PI is plasticity index. Using equation (1), the swelling potential for each tested location is 22%, 24%, and 5% respectively for soils at WP-1, WP-2 and WP-3. Predicting the swelling potential using equation (2) results 10%, 11%, and 2% respectively for tested soils at WP-1, WP-2 and WP-3 location. Further, the degree of expansiveness of the soil can be classified into medium to high according to Seed et al [8] classification and low to high according to Muntohar [10] as presented in Table 2.

Table 2. Classification of degree of swelling

Degree of expansion	Swelling Potential (%), Seed et al [8]	Swelling Potential (%), Muntohar [10]
Very high	> 25	> 27.8
High	5 – 25	16.3 – 27.8
Medium	1.5 – 5	7.1 – 16.3
Low	0 – 1.5	0 – 7.1

The potential to swell vertically indicates percentage of the volume change of the soil in nature. When the expansive soils are soaked, the water rise vertically to the surface. The potential vertical rise (PVR) depends on the surcharge load and percentage of volume change. The PVR value and potential to swell vertically, so far is considered to have an effect on the larger deformation of road surface [11].

Swelling properties and soil bearing capacity

The vertical swelling test in the laboratory gives two swelling properties, percent of free swell and swell pressure. Free swell is determined after the seating pressure was unloaded and the specimen was inundated to allow the vertical swell. Table 3 presents the swelling properties of the tested soils.

Table 3. The swelling properties of tested soil samples

Locations	Natural dry density (kN/m³)	Free Swell (%)		Swell Pressure (kPa)	
		Undisturbed	Compacted	Undisturbed	Compacted
WP-1	11.5	1.55	6.61	22	196
WP-2	11.7	0.72	6.05	22	238
WP-3	12.4	0.55	1.71	11	39

Vertical swelling of the subgrade will decrease the bearing capacity since it increases void ratio and water content. The vertical heave of the undisturbed soils does not exhibit extreme degree of expansiveness. It can be categorized into low expansive, however, the swelling increase after compacting at their MDD about 300, 700, and 200 percents respectively for tested soil at location WP-1, WP-2, and WP-3. This characteristic is possibly caused by increasing of the density and reduction of water content as shown in Figure 2. The soil at location WP-3 exhibits lower swelling compared to the other although its dry density in nature is higher. It is possibly owing to the soil contains lesser clay fraction and the soil incline to behave a liquid state in nature. El-Sohby and Rabba [12] also mentioned that there are three factors that most influence the swelling and swelling pressure of clayey soils i.e. initial water content, clay fraction, and initial dry density.

During vertical heave, the vertical pressure occurs and then crack propagation develops at pavement surface. The strength and stiffness of the pavement layers have to be able to restrain the uplift pressure to prevent the cracks. A low swelling pressure will not cause any extreme distress of the pavement. The investigation shows that after compacting to their MDD, the swelling pressure of the soil samples increase 4–11 times from the natural conditions (undisturbed). This characteristic, that compaction would result in greater vertical swelling and swelling pressure, should be noticed. However, on the other side, compaction is an easy and cheap method to enhance the soil bearing and reducing soil compressibility of cohesive soils. Table 4 shows that the CBR values of compacted soils are higher than the undisturbed soils. In general, the soils at the observed location have a lower bearing capacity i.e. 1.1% to 2.8%.

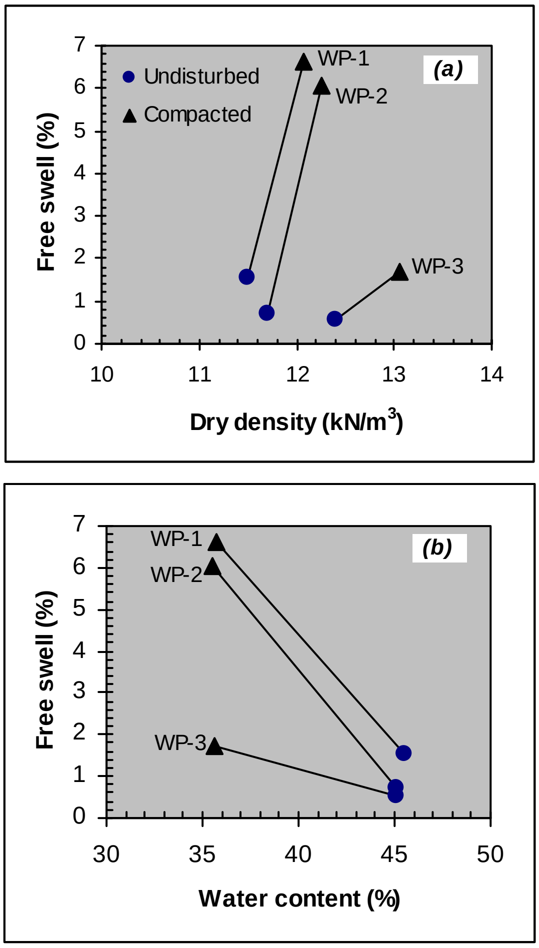

Figure 2. Effect of (a) dry density and (b) water content on vertical swell.

For cohesive soils, the soils absorb much water during soaking process and then result in increasing of void ratio. The void between soil particles is filled with water and reduces the particle bonds. Consequently, the soil is in a looser condition and results in a lower bearing capacity. This characteristic is shown in Figure 3.

Table 4. The compaction and bearing capacity of the soil samples.

Locations	Compaction		CBR (%)			
	MDD (kN/m³)	OMC (%)	Undisturbed		Compacted	
			Normal	Soaked	Normal	Soaked
WP-1	12.1	35.74	2.8	1.6	7.8	3.8
WP-2	12.3	35.50	2.8	2.0	7.6	2.8
WP-3	13.0	35.58	1.1	1.1	6.2	3.5

In road construction, the pavement layers are designed based on the value of soil bearing capacity and the traffic load. In principal to prevent crack propagation, the weight of pavement has to be bigger than the swelling pressure. If the swelling pressure is higher than the pressure generated from pavement materials and traffic load, cracks will appear on road pavement as an initial deterioration. Figure 4 illustrates the load and pressure induced on pavement systems i.e. traffic load, $\sigma_{traffic}$, weight of pavement materials, $\sigma_{pavement}$, and swelling pressure, σ_{swell}. The total stress is defined as resultant of the stress working on the pavement. For the existing road observed, the pressures are calculated as follows, $\sigma_{traffic}$ = 16.4 kPa, $\sigma_{pavement}$ = 17.1 kPa. It is shown that the weight of the pavement layers is lower than the swelling pressures. Therefore the vertical heave pressure will lift the pavement and then caused larger deformation owing to traffic load. It is concluded that the swelling pressure of the subgrade attributes the roadway deterioration at STA. 8+127, Wates – Purworejo route.

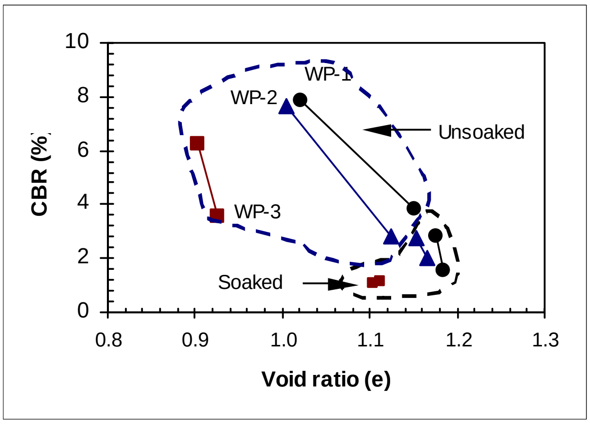

Figure 3. Effect of void ratio on CBR value of tested soils.

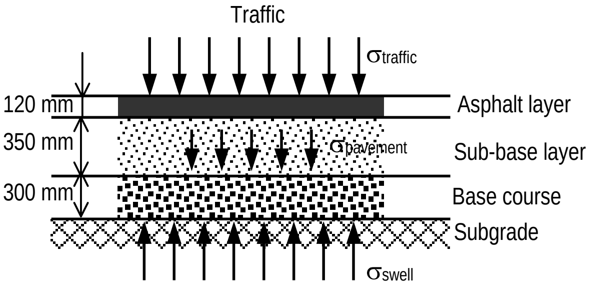

Figure 4. The schematic diagram of pressures induced on pavement.

CONCLUSIONS

The laboratory tests have been undertaken successfully, and the analysis has proven that the deterioration occurred at the tested location can be attributed to the swelling pressure of the expansive subgrade. Furthermore, the followings can be concluded:

1. The subgrade consists of predominantly silt and clay and was classified as highly expansive soils.
2. In natural conditions, the observed subgrade has a low bearing capacity and vertical swell, however, the swelling pressure has enough power to lift up the pavement layers.
3. The swelling and swelling pressure of the compacted subgrade highly exceeded the ones of the natural subgrade. The heave caused a decrease in the bearing capacity.
4. Compaction increased the bearing capacity of the subgrade, consequently with an increase in the swell and swelling pressure.

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