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Experimental Study of Subgrade Bearing Capacity and Deformation Behavior of Rigid Pavement Due to Wet-Dry Cycles

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Abstract: Pavement deterioration is a process in which damage to pavement begins to develop due to combination impact of traffic loads and environmental conditions around location of the road. Deterioration of road pavement function has a relatively large impact on the level of service, safety and quality of road driving. In general, researchers seek to analyze the extent to which changes in the deformation behavior of support layers under rigid pavement layers are hampered by a dry and wet cycle. This research focuses on the problem of physical behavior, soil mechanics as a foundation material, focused on the impact of wet-dry cycle treatment on soil. The mechanical parameters examined are the CBR value and the unconfined compressive strength in wet-dry cycles scenario as well as the analysis of the performance of pavement models. Laboratory investigation results showed that due to wet-dry cycle, the CBR and UCS values had decreased, particularly during the initial cycle when the CBR and UCS values dropped dramatically by 82 and 85%. Moreover in second and third cycle, the decrease in CBR and UCS values is not too significant. This relatively large decrease is influenced by changes in the formation of soil microstructure particles, the binding particles of which become tenuous due to the presence of water. While the pavement model test shows that the correlation between load and soil deformation at 21 and 31% moisture content shows almost the same behavior while for 41% moisture content relatively a bit different this phenomenon shows the role of water in very large soil masses. This result can be considered in the implementation of road construction in tropical climate zones where the wet-dry and dry-wet cycle is a very important factor in the behavior of the road layers. One of the measures to be taken to solve this problem is to use chemical stabilization to increase the mechanical index of water content modification. One of material considered as used is zeolite. For this reason, this study also uses the soft soil-zeolite stabilization as a comparison.

Key words: CBR, dry-wet cycle, road pavement, unconfined compressive strength, road construction, wet-dry cycle

INTRODUCTION

Deterioration of pavement function has a relatively large impact on the level of service, safety and quality of road. Ideally, the quality of the newly constructed pavement will decrease and operate very slowly over the first 10-15 years of service plan life then its quality will deteriorate rapidly, especially, if the maintenance program is not performed properly. Basically, the geotechnical characteristics are determined by 3 main components, namely: the working load, the type and nature of the soil material itself and the water that influences the body or the soil layer. The working load will cause internal stresses in different directions as a resistance reaction of the soil structure. For the type and nature of soil materials, depending on the formation process, the type and amount of minerals it contains each soil material will react differently to the load or environmental factors that apply to the soil itself. The water component itself may be in the form of a volume of water that is deposited in the pores of the soil mass or a volume of water that enters and/or evaporates in a mass of soil. The water component of this soil mass contributes greatly to the geotechnical characteristics.

The actions of soaking and cyclic wet-dry may affect the shear strength of mixture but the related investigations are still scarce (Wang *et al*., 2019). This reduction of shear strength with drying-wetting cycles might be due to the changes of particle arrangement and the grain size distribution, decrease of pore volume and void ratio or due to the formation of micro-cracks and fissures (Md *et al*., 2016). However, the magnitude of the deformation decreases with the increase in the drying-wetting cycle, failing to restore the initial state which confirmed an irreversible influence of the drying-wetting cycle on the deformation properties of the soils (Ye *et al*., 2018). The absolute swelling ratio increases with the increasing wetting-drying cycles while the relative swelling rates decrease with the cycles and both of them reach the final equilibrium at the last cycle

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for the natural and modified soil samples (Bao-Tian *et al*., 2015). These soils that have low moisture content would heave when applied pressure is reduced and/or their moisture content is increased. On the other hand, the soils with high water content would shrink when their moisture content is decreased (Ikizler *et al*., 2014). Expansive soil is a kind of special cohesive soil, the kind of soil can significantly become to soften after it absorbs water and it also can become to contract after its losses water (Wang and Liang, 2014). The expansive soils experience periodic swelling and shrinkage during the alternate wet and dry seasons. Such cyclic swell-shrink movement of the ground cause considerable damage to the structures founded on them (Rao *et al*., 2001). Significant modification of soil structure is often observed after wetting and after drying a soil sample because of swelling and shrinking phenomena (Rabot *et al*., 2018). Generally, clayey soils with high plasticity need more W-D cycles to reach the equilibrium state than silty or sandy soils (Tang *et al*., 2011). A decrease in the expansive behavior, corresponding to a reduced water absorption capability was observed when the soils were alternately wetted and partially shrunk (Basma *et al*., 1996). As they get wet, the clay minerals absorb water molecules and expand; conversely as it dried it shrink, leaving large voids in the soil (Mokhtari and Dehghani, 2012).

MATERIALS AND METHODS

In order to classify the material used in this experimental study, laboratory investigation program was carried out to evaluate the basic properties and mechanical properties of the soil. The soft soil material was brought from Engineering Faculty Hasanuddin University, Gowa, South Sulawesi, Indonesia.

Unconfined compression test and California Bearing Ratio specimen was remolded according to standard method ASTM D 1883-07 and ASTM D 2166 with 6 inches in diameter and 7 inches high for CBR and 2 inches diameter with 4 inches high for UCT. Specimen tested at curing time 7, 14 and 28 days.

The research method to be performed can be classified as a form of experimental research in a laboratory that can be defined as a scientific and systematic approach in which the researcher manipulates one or more variables and controls and measures each variable of other variables.

The research is designed by making objects and laboratory test models to examine, process, observe, study and finally summarize in a research conclusion on the phenomena and objectives to be achieved. Basically, the research methodology is illustrated in the following flowchart. Generally, the methods used in this research showed in Fig. 1, flowchart of the research.

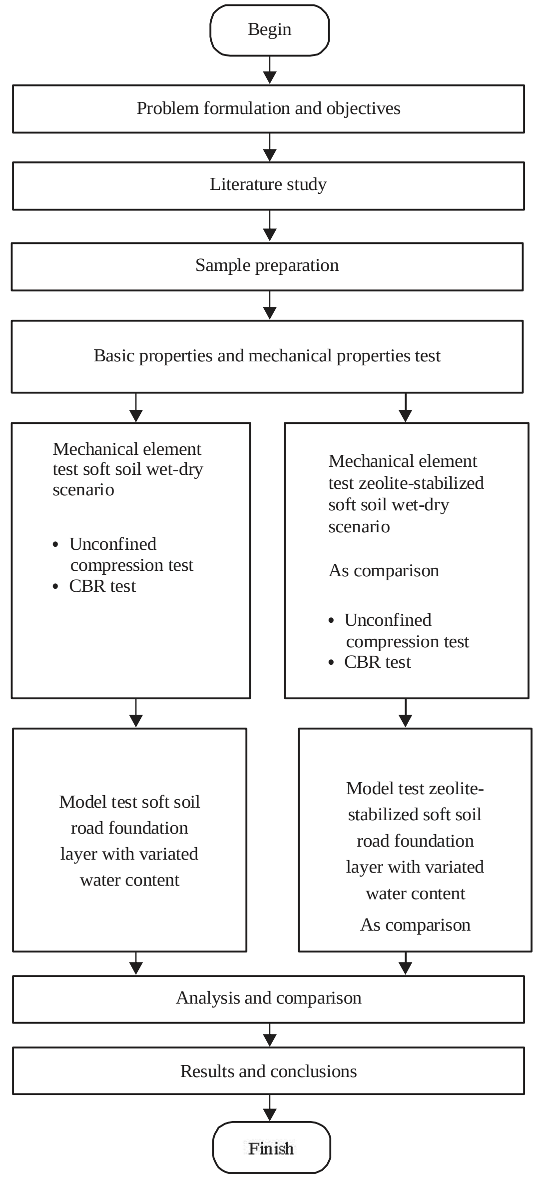

Fig. 1: Flowchart of the research

RESULTS AND DISCUSSION

Based on the results of the laboratory tests, the soil used in this study is classified as high plasticity clay/CH based on the unified soil classification system. The results of the test are detailed in the Table 1.

According to AASHTO, the soil used in this research are classified in category A-7-6, clayey soil. Overall, the test results show that the soil used is classified as soft soil.

Based on the optimum proctor condition, maximum dry density of soft soil 1.41 g cm^{-3} and zeolite-stabilized soft soil 1.46 g cm^{-3} Fig. 2. The standard proctor test result shows that addition of zeolite increases soil's

Table 1: Recapitulation of basic properties and mechanical properties of soft soil

Index	Results	Unit
Basic properties		
Sieve analysis		
Gravel fraction	13.4	%
Sand fraction	23.2	%
Clay and silt fraction	63.4	%
Atterberg limits		
Liquid Limit (LL)	61.19	%
Plastic Limit (PL)	28.37	%
Shrinkage Limit (SL)	13.21	%
Plasticity Index (IP)	32.82	%
Activity (A)	0.52	-
Specific gravity	2.62	-
Standard proctor		
Optimum moisture content	30.76	%
Max dry density	1.41	g cm^{-3}
Mechanical properties		
CBR	6.96	%
Unconfined compressive strength	0.187	kg cm^{-3}
Classification		
AASHTO	A-7-6	
USCS	Clay-high plasticity	

Table 2: Recapitulation changes in mechanical index due to wet-dry cycle

Values	0	1	2	3
Wet				
UCS (kg cm^{-2})	0.18700	0.023	0.014	0.010
CBR (%)	6.96911	1.560	0.750	0.670
Dry				
UCS (kg cm^{-2})	0.18700	0.148	0.101	0.078
CBR (%)	6.97000	4.320	2.250	1.950

density, so, it can be assumed decreases pore ratio which possibly filled by water. While the optimum moisture content obtained for the soft soil 30.78% and zeolite-stabilized soft soil 32.64%. Zeolites contain silica which causes pozzolanic reactions in the reaction with water, so that, increasing the number of zeolites increases the optimum water content required for pozzolanic reactions with the soil. The soft soil specimens are then compacted according to optimum proctor condition and then tested using a wet-dry cycle treatment. The soft soil test results from the wet-dry cycle scenario are shown in the following Table 2 and Fig. 3.

Based on Fig. 3 and Table 2, it appears that in first cycle, the CBR and unconfined compressive strength values have drastically decreased by 82 and 85%, respectively as in the wet-dry cycle, 1, 38 and 20% then on the second and third cycle, the values of CBR and UCS have not decreased significantly compared to first cycle but there is a difference between the wet-dry cycle and the dry-wet cycle as in the dry-wet cycle the values of CBR and UCT decreased significantly compared to soil in the wet-dry cycle. Based on Fig. 3, the CBR and UCS values dropped drastically, describing the process of water filling the pores, after first cycle, the values CBR and UCS doesn't decreases significantly indicating that water is

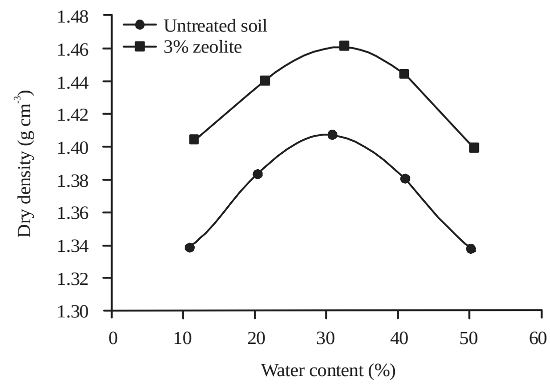

Fig. 2: Relation between dry density and water content

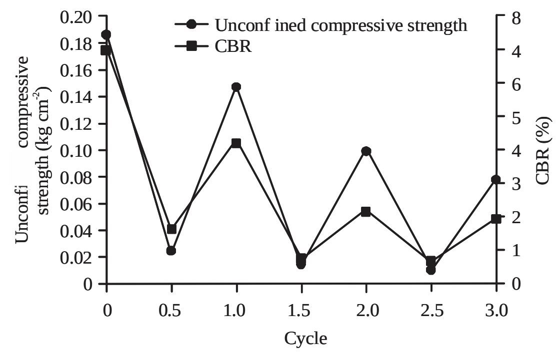

Fig. 3: Relation between CBR value and unconfined compressive strength against dry-wet cycle

beginning to be absorbed and reacts with clay minerals as clay has the ability to absorb water. In addition, to obtain more detailed results, the samples are then tested with different moisture contents. In this case, the water content is determined by 3 variations: 21, 31 and 41%, taking into results of the standard proctor test.

Figure 4 and Table 3 shows the CBR test result on soft soil and zeolite-stabilized soft soil show an increasing value for the stabilized soil. For 21% water content, increases 12 and 31% water content increases 19 and for 41% increases 14% compared tow untreated soil. This increase in variation is dependent on the moisture content where at 21% it is suspected that the moisture content did not produce an adequate cementation process while at 31% the moisture content is to promote the cementing process. With respect to the 41% water content, the cementation process weakens again as it is suspected that the excess water content may dissolve the added zeolite material.

In Fig. 5 the value of unconfined compressive strength shows a behavior relatively similar to the CBR value. About 47% increase in 21% moisture content, 29%increase for 31% water content and 20% increase for 41% water content. This increase in variation depends on

Table 3: Recapitulation UCS value of untreated and stabilized soil with variation of water content

		Unconfined compressive strength (kg cm^{-2})				
Mix	Water contents (%)	1	2	3	4	Average
Untreated soil	21	0.249	0.257	0.218	0.210	0.234
	31	0.265	0.280	0.296	0.311	0.288
	41	0.265	0.257	0.265	0.296	0.270
3% zeolite	21	0.327	0.319	0.335	0.397	0.344
	31	0.366	0.366	0.389	0.397	0.379
	41	0.319	0.304	0.319	0.350	0.323

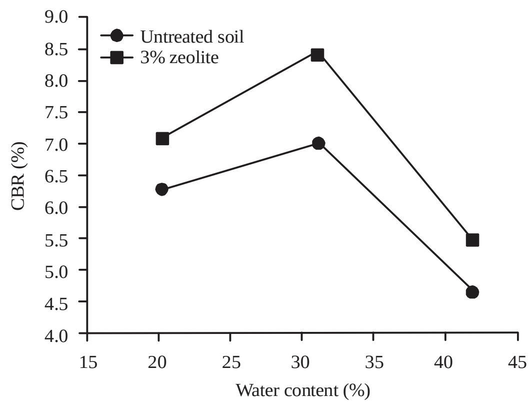

Fig. 4: CBR value with variation of water content

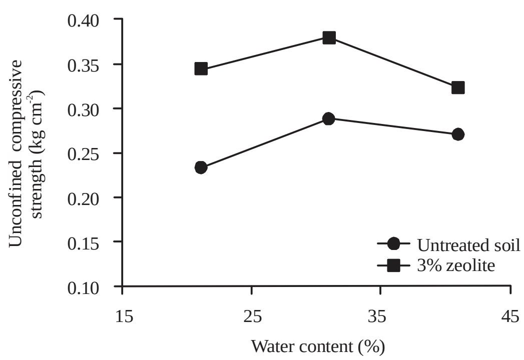

Fig. 5: Relation between UCS value of untreated and stabilized soil with variation of water content

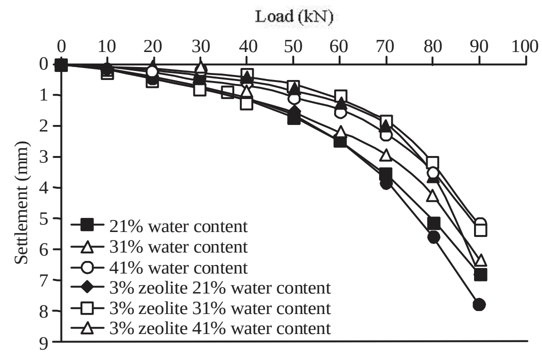

Fig. 6: Settlement-load behavior of subgrade layer model test

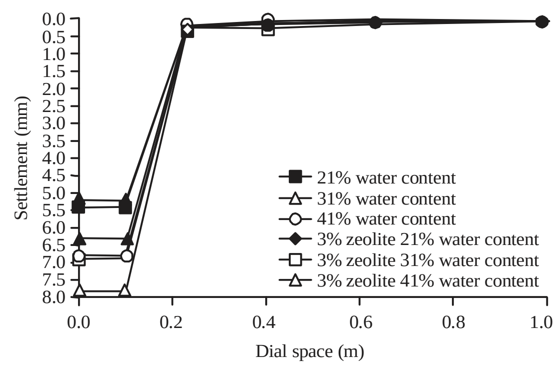

Fig. 7: Deformation pattern on subgrade layer model

the water content: at 21%, it is suspected that the moisture content did not produce an adequate cementation process while at 31% it encourages the cementation process optimally because it is close to the optimum value of moisture content. With respect to the 41% water content, the cementation process weakens again as it is suspected that the excess water content may dissolve the added zeolite material. The model test of the deformation behavior of the foundation layer is performed by a static loading test. This test is carried out to determine the deformation behavior which occurs in the untreated soil layer and the soil layer which is stabilized with 3% zeolite under optimum conditions of moisture content by water content of 21, 31 and 41% (Fig. 6).

Based on the test results presented in the Fig. 7, the deformation pattern between untreated and stabilized soils at 41% water content shows a similar trend but zeolite-stabilized soils show 19% less deformation compared to soft soils. This shows that soils stabilized with zeolite can reduce deformation up to 19%.

The soil deformation patterns at several points of observation show that the maximum deformation occurs at the loading point while outside the loading point, the decrease is relatively small as shown in the picture above. Occur at the point where the load is operated. Another thing to note is that adding zeolite does not add cementation to soil particles that change the behavior of soil bodies in solid material but remains in a plastic phase.

With the three loading and deformation models described above, it is intended to use zeolites to suppress the deformation of the clay. This decrease is relatively small because the zeolite content is not yet optimal for the stabilizing material because the zeolite contains lime which will react chemically with the elements of the soil requiring a reaction time, so that, the hardening can further increase the potential for improving the deformation.

Based on the overall test results, the soil bearing capacity due to the wetting and drying cycles was found to be a significant decrease from wet to dry conditions. Innovation in using zeolite as stabilizing materials shows a significant increase in the mechanical characteristics of the soil, showing the potential use of a natural zeolite material as an alternative foundation stabilization material able to reduce deformation. It is hoped that the results of this analysis, this research should serve as a reference for considering the implementation of road construction, especially in areas with a tropical climate.

CONCLUSION

Based on the results of the analysis described earlier in this study, it can be concluded as follows. The wet-dry cycle results in a decrease in CBR value and unconfined compressive strength, especially, during the initial cycle where CBR and unconfined compressive strength drop significantly to 82 and 85%. In addition, during cycles 2 and 3, the decrease in CBR and UCT values was not significant. This relatively large decrease is influenced by changes in the formation of soil microstructure particles whose binding is tenuous due to the presence of water. The correlation between the load and the deformation with water content of 21 and 31% shows roughly the same behavior whereas for the water content of 41% is slightly different, phenomenon shows the role of water in a very large soil mass. The results of this study can serve as a reference in road pavement planning, particularly in tropical regions where the soil moisture content fluctuates more actively and affects the mechanical properties of the soil.

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REFERENCES

Bao-Tian, W., Z. Can-hong, X.L. Qiu, J. En-yue and Z. Wen-hui, 2015. Research on wetting-drying cycles effect on the physical and mechanical properties of expansive soil improved by OTAC-KCl. Adv. Mater. Sci. Eng., Vol. 2015, 10.1155/2015/304276

Basma, A.A., A.S. Al-Homoud, A.I.H. Malkawi and M.A. Al-Bashabsheh, 1996. Swelling-shrinkage behavior of natural expansive clays. Applied Clay Sci., 11: 211-227.

Ikizler, S.B., M. Vekli, E. Dogan, M. Aytekin and F. Kocabas, 2014. Prediction of swelling pressures of expansive soils using soft computing methods. Neural Comput. Appl., 24: 473-485.

Md, S.H., K. Ling-Wei and Y. Song, 2016. Effects of drying-wetting cycles on saturated shear strength of undisturbed residual soils. Am. J. Civil Eng., 4: 143-150.

Mokhtari, M. and M. Dehghani, 2012. Swell-shrink behavior of expansive soils, damage and control. Electron. J. Geotech. Eng., 17: 2673-2682.

Rabot, E., M. Wiesmeier, S. Schluter and H.J. Vogel, 2018. Soil structure as an indicator of soil functions: A review. Geoderma, 314: 122-137.

Rao, S.M., B.V. Reddy and M. Muttharam, 2001. The impact of cyclic wetting and drying on the swelling behaviour of stabilized expansive soils. Eng. Geol., 60: 223-233.

Tang, C.S., Y.J. Cui, B. Shi, A.M. Tang and C. Liu, 2011. Desiccation and cracking behaviour of clay layer from slurry state under wetting-drying cycles. Geoderma, 166: 111-118.

Wang, J.J., Y.F. Zhou, X. Wu and H.P. Zhang, 2019. Effects of soaking and cyclic wet-dry actions on shear strength of an artificially mixed sand. KSCE. J. Civil Eng., 23: 1617-1625.

Wang, Z.J. and J.B. Liang, 2014. Engineering characteristics of expansive soil and its improved research development. Adv. Mater. Res., 884: 657-661.

Ye, H., C. Chu, L. Xu, K. Guo and D. Li, 2018. Experimental studies on drying-wetting cycle characteristics of expansive soils improved by industrial wastes. Adv. Civil Eng., Vol. 2018,