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Analysis of Plain Concrete Pavement Deflection due to Swelling on Expansive Soil

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***Abstract*—This research was conducted on the Surakarta-Gemolong-Geyer road, which is suspected to be built on expansive land. Every day, this road is always passed by large vehicles, so it is feared that it will be easily damaged if it is not routinely carried out maintenance. This study aims to analyze the damage to the rigid pavement on the highway using ATENA 3D software. The damage analyzed in this study is the deflection. The factors that make the crack large and wide were added to the heavy vehicle load and swelling. The swelling test on the soil carried out in the laboratory was 37 kPa. The results obtained after analysis with 3D ATENA showed differences in deflection at each loading variation. The variation of the middle loading with swelling pressure has a value of -15.49 mm; without swelling pressure, it is -16.37 mm. The middle loading variation with swelling and without pressure has a value of -15.33 mm and -12.4 mm, respectively. Corner loading variation with swelling and without pressure has a maximum deflection of 1.28 mm and -0.26 mm, respectively. This research can be used as a reference and prediction in identifying cracks that occur so that the government can carry out maintenance and rehabilitation before the road is damaged.**

***Keywords*— Rigid pavement; swelling pressure; expansive soil; ATENA 3D software.**

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I. INTRODUCTION

One method of promoting national growth is transportation. The challenges, such as transportation issues, are growing along with the expansion of human needs in numerous areas. To always support transportation, suitable facilities and infrastructure are required to solve this transportation issue. The highway is among the most significant pieces of transportation infrastructure. Roads are one of the infrastructures that play a crucial role in Indonesia, a nation made up of many islands, in getting the distribution of necessities to each region. In this situation, the road must be planned as effectively and efficiently as possible to ensure that it can deliver the best services for the sustainability of transportation. One of the supporting factors so that the highway can always be categorized as good and suitable for use is the supporting soil under the construction of the highway itself. Various types of soil are spread throughout Indonesia, but one type of soil is very vulnerable when road construction is built on it, namely the expansive soil. If a region has expansive soil, rigid pavement is the best surface for construction [1].

Expansive soil is soil or rock that can shrink due to changes in water content, meaning that those changes significantly impact it carrying capacity [2]. Expansion or swelling in the soil is a prevalent issue with expansive soils. Swelling is a crucial factor in determining how expansive the soil is [3]. Because expansive soil experiences considerable volumetric changes when exposed to moisture variations, it has been identified as a concern that could endanger structural stability [4]. Typically, this soil will enlarge during the rainy season and contract again during the dry season. This soil experiences varying swelling and shrinkage from one site to another, which can result in differential movement. The road construction there may also suffer harm because of this. Highway pavements on expansive subgrades often need expensive maintenance and repair before the pavement reaches its design life because expansive subgrades produce a lot of damage problems [5]. When the amount of water in the soil changes, expansive soil will expand and contract. When more water is in the soil, as during the rainy season, it will expand; yet it will contract when the soil is dry. The soil expands and becomes incredibly soft (reduces soil shear strength) in wet conditions (rainy season), causing it to distort vertically and horizontally and harm the pavement above it. The water in the soil will evaporate under dry conditions (dry season), causing the soil to contract, particularly in the layer close to the surface. Additionally, this problem will result in cracks and harm to the pavement above it. Rigid pavements are frequently employed in soils with irregularities or low carrying capability. The best course of action for handling difficult subgrades is rigid pavement. However, if the concrete's thickness and quality are not calculated, it will cause considerable deflection [6].

Some of the damage that usually occurs in rigid pavements on expansive soils is the occurrence of deflections in rigid pavements. Deflection in the subgrade provides an overview of changes in the shape of a pavement structure in an elastic state [7]. The impact of excessive deflection causes cracks on the surface. If the cracks are not treated immediately, it will reduce the design life of the pavement construction [8]. On the other hand, potential damage could be caused by blast load, as reported by Sofia et al. [9]. The research also used a numerical approach to solve the problem and concluded indicated the slab thickness should be raised if the primary design goal was to lower the dynamic deflection, the vertical shear force, and the maximum flexural stress along the edge of the plate.

Early deflection detection in the rigid pavement can be done using software analysis, one of which is ATENA. Cervenka Consulting offers a full and demo version of this product [10]. This software can be used to analyze problems in concrete structures based on the finite element method. The finite element method is a numerical procedure that can solve various engineering physical problems. When solving the slab problem, the original continuous is split up into a number of plate elements connected by straight or curved meeting lines and share the same material characteristics as the original plate [11].

Research that has been done previously only focused on examining the rigid pavement so that the soil beneath it is only an assumption [12], [13]. In addition, some only examine the expansive soil aspect without examining the consequences for the building on it [14], [15]. This study attempts to combine and investigate two connected features, namely between expansive soil and rigid pavement above it, based on references from numerous studies that have been conducted. The researcher tries to analyze the effect of expansive soil on the rigid pavement. This research was made as closely as possible to the conditions in the field, then modeled for further analysis using ATENA software. The triangle approach is the foundation for the swelling model below [16]. The analysis of this study should be able to forecast the damage that would occur, allowing the appropriate agencies to do routine maintenance and rehabilitation.

II. Materials and Method

This study uses experimental techniques to build structural models using the ATENA program and quantitative analysis methods to examine the flexural behavior of stiff pavement slabs caused by swelling on expansive soils. Because it is believed that the Surakarta-Gemolong-Geyer route, presented in Figure 1, may have expansive soil, this research is being conducted there.

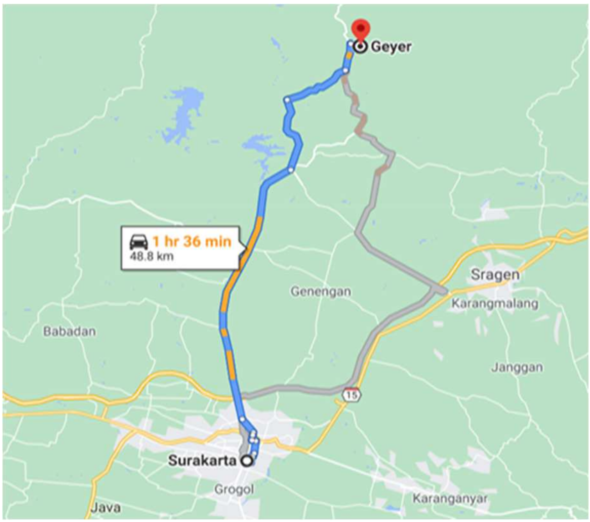

Fig. 1 Research site map

Then, soil samples from the area were collected for laboratory analysis. Both the soil properties test and the swelling pressure test are among the outcomes of laboratory soil testing. The test results would eventually serve as the input for analysis with the ATENA 3D program. The rigid pavement data was taken from the data as a built drawing of the Central Java Provincial Public Works Office in 2019. Table I presents the rigid pavement data used for analysis in the ATENA software:

TABLE I
RIGID PAVEMENT DATA

Data	
Slab thickness	25 cm
Slab dimension	6 x 3.5 m
Concrete quality	K350
Poisson's ratio	0,16
f'c	29000 kN/m^2

The ATENA 3D software was then used to further analyze the deflection and crack patterns using the existing soil and rigid pavement data. The crack pattern that develops in the pavement structure because of the load acting on the pavement can be described and calculated using the ATENA program. The general data required for the complete ATENA program input can be seen in Table II:

TABLE II
GENERAL DATA STRUCTURAL ANALYSIS OF ATENA PROGRAM

Information	ATENA Program
Input	Compressive strength Modulus of Elasticity Poisson's ratio Swelling value Dimension of slab Traffic load
Output	Deflection Crack pattern Structure picture

The ATENA 3D software was then used to further analyze the existing input data to produce output data in the form of deflections, crack patterns, and structural model drawings. Fig. 2 to Fig. 5 An illustration of the modeling and load placement that have been entered into the ATENA program is shown below:

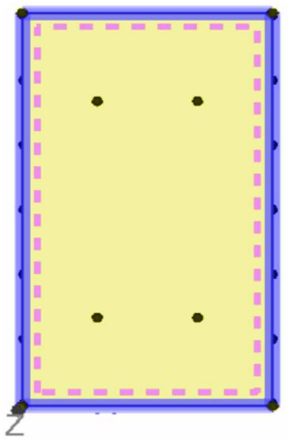

Fig. 2 Centre loading modelling

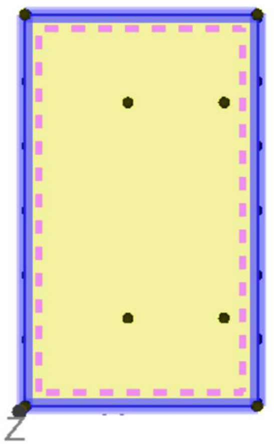

Fig. 3 Edge loading modelling

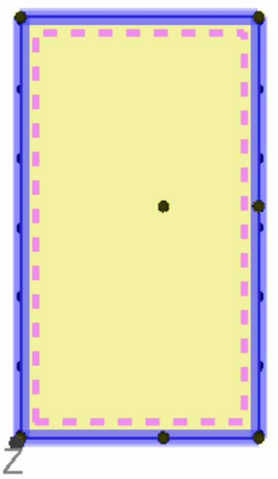

Fig. 4 Corner loading modelling

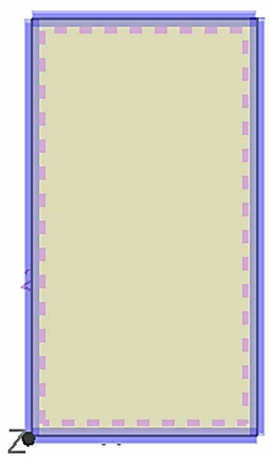

Fig. 5 No loading modeling

III. Results and Discussion

The ATENA program was used to assess the results of the soil properties test, which was performed in the soil mechanics laboratory. The results of the soil properties test can be seen in Table III:

TABLE III
THE PROPERTIES OF SOIL

Properties		**Results**	**Type of soil**
	Gravel (%)	0.00	
Grain Size Analysis	Sand (%)	28.65	
	Silt (%)	57.62	
	Clay (%)	13.72	
Specific Gravity (%)		2.61	Organic Clay
	LL (%)	69.56	
Atterberg Limit	PL (%)	36.00	
	IP (%)	33.56	
	SL (%)	5.46	

After being evaluated for soil qualities, the soil is subsequently examined for swelling and swelling pressure. The results of the swelling test can be seen in the Table IV:

TABLE IV
DATA SWELLING DAN SWELLING PRESSURE

Initial water content (%)	**Final water content (%)**	**Percentage of Swelling (%)**	**Swelling Pressure (kPa)**
2.07	45.77	7.50	37

The data were then entered into ATENA for additional study of the deflection that takes place. When all of the data has been entered into ATENA, the modeling yields the results shown below:

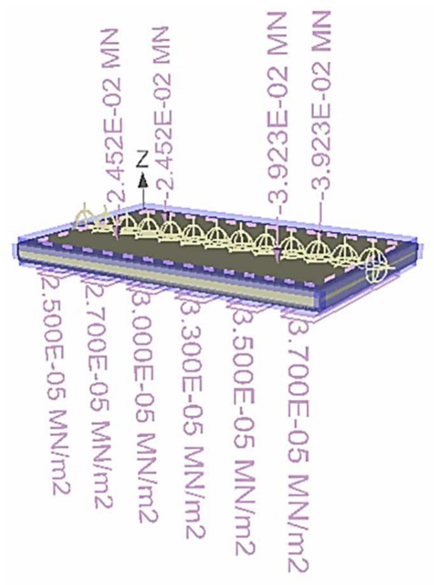

Fig. 6 Modeling results due to centre loading

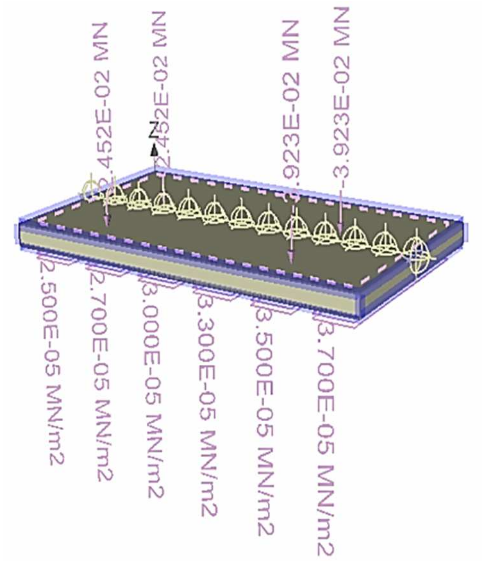

Fig. 7 Modeling results due to edge loading

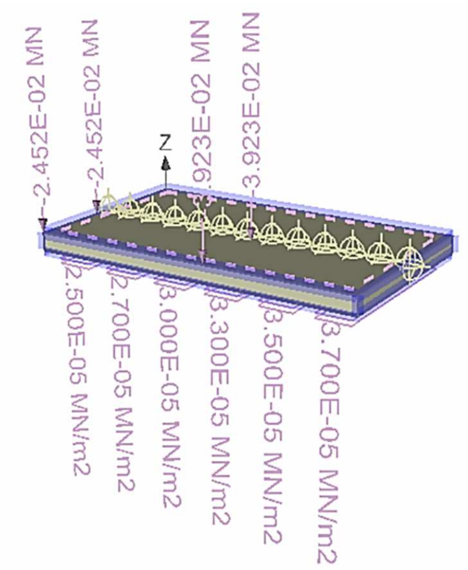

Fig. 8 Modeling results due to corner loading

The finished model was then analyzed by clicking the "run" button in ATENA. After a while, the results of the analysis will appear in the form of numbers and pictures. This study uses comparative data between soil without swelling pressure and soil experiencing swelling pressure. Table V to Table VIII below are the results of the deflection analysis that occurs in each load variation:

TABLE V
DEFLECTION WITHOUT LOAD

Monitoring points	Deflection (mm)
Monitor 1	5.99
Monitor 2	6.27
Monitor 3	6.54
Monitor 4	6.81
Monitor 5	7.14
Monitor 6	7.46
Monitor 7	7.80
Monitor 8	8.12
Monitor 9	8.45
Monitor 10	8.78
Monitor 11	9.05
Monitor 12	9.32
Monitor 13	9.58

TABLE VI
DEFLECTION DUE TO CENTER LOAD

Monitoring Points	Deflection (mm)	
	Without *Swelling Pressure*	With *Swelling Pressure*
Monitor 1	-7.00	-7.20
Monitor 2	-7.82	-7.96
Monitor 3	-8.61	-8.67
Monitor 4	-9.28	-9.27
Monitor 5	-10.10	-9.93
Monitor 6	-10.78	-10.56
Monitor 7	-11.53	-11.19
Monitor 8	-12.41	-11.37
Monitor 9	-13.26	-12.46
Monitor 10	-13.93	-13.17
Monitor 11	-14.67	-14.67
Monitor 12	-15.96	-15.14
Monitor 13	-16.37	-15.49

TABLE VII
DEFLECTION DUE TO EDGE LOAD

Monitoring Points	Deflection (mm)	
	Without *Swelling Pressure*	With *Swelling Pressure*
Monitor 1	-7.43	-9.43
Monitor 2	-5.76	-7.30
Monitor 3	-6.51	-8.17
Monitor 4	-7.34	-9.23
Monitor 5	-7.80	-9.56
Monitor 6	-8.44	-10.41
Monitor 7	-9.08	-10.95
Monitor 8	-9.89	-11.65
Monitor 9	-10.69	-11.20
Monitor 10	-11.65	-15.15
Monitor 11	-11.87	-14.10
Monitor 12	-12.16	-14.89
Monitor 13	-12.40	-15.33

TABLE VIII
DEFLECTION DUE TO CORNER LOAD

Monitor	Deflection (mm)	
	Without *Swelling Pressure*	With *Swelling Pressure*
Monitor 1	-0.26	1.28
Monitor 2	-2.60	-1.75
Monitor 3	-3.53	-3.10
Monitor 4	-4.09	-3.87
Monitor 5	-3.88	-3.81
Monitor 6	-3.5	-3.45
Monitor 7	-3.12	-3.08
Monitor 8	-2.67	-2.64
Monitor 9	-2.11	-2.08
Monitor 10	-1.48	-1.46
Monitor 11	-0.84	-0.82
Monitor 12	-0.19	-0.18
Monitor 13	-0.46	-0.48

Based on the results of the analysis from Table V to Table VIII, it can be concluded that the rigid pavement model without reinforcement with swelling pressure has a greater deflection than the rigid pavement without swelling pressure except for the variation of the middle load. The variation of the middle loading with swelling pressure has a value of -15.49 mm, while it is -16.37 mm without swelling pressure. Meanwhile, the middle loading with swelling and without pressure has a value of -15.33 mm and -12.4 mm, respectively. Corner loading variation with swelling and without pressure has a maximum deflection of 1.28 mm and -0.26 mm, respectively. The deflection in each variation still tends to be small but is sufficient to cause damage to the rigid pavement above it. A brief explanation can be seen in Fig. 9.

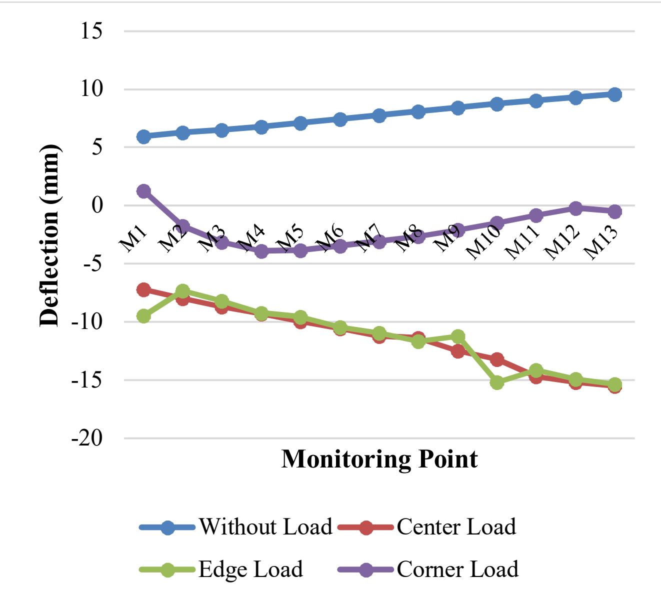

Fig. 9 Plain concrete pavement deflection pattern with swelling pressure

The graphic above only shows the deflection that occurs in the presence of swelling pressure because this research focuses on the soil beneath, which contains swelling pressure. Based on the picture above, it can be seen that the maximum deflection of rigid pavement for each variation of loading is at different monitor points. In summary, the maximum deflection value of rigid pavement at each loading can be seen in the Table IX.

TABLE IX
MAXIMUM DEFLECTION

Variation	Maximum Deflection	
	Monitor	(mm)
Without Load	13	9.58
Centre Load	13	-15.49
Edge Load	13	-15.33
Corner Load	1	1.28

The maximum deflection value of the pavement based on the table above is mostly located on monitor 13. This is because on monitor 13 the greatest swelling force occurs. This shows that in monitor 13 the ground below still contains a lot of water so that the possibility of expanding is still very large, or in other words that in monitor 13 it is assumed that the water started entering the soil. A more complete illustration can be seen in the Fig. 10.

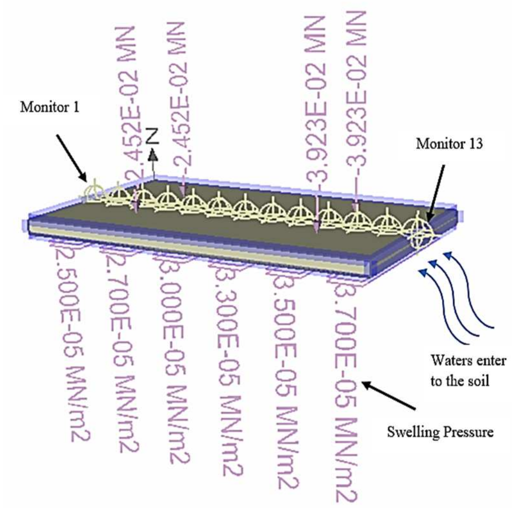

Fig. 10 Illustration of analysis model on ATENA

Based on the picture above, it is assumed that water enters the soil from the right side of the rigid pavement or closer to monitor 13. This is what causes the maximum deflection of 3 of the 4 load variations to be on monitor 13. Maximum deflection at center loading is -15.49 mm. Judging from the graph, this variation of the center loading has a trendline that is almost the same as the unloaded and the edge loading. However, in the middle load variation, the deflection shows a negative number, which means there is a decrease in the rigid pavement due to the vehicle load on it. The swelling force in the middle load does not have a significant effect because the load above it is much larger.

The variation of the edge loading shows that the deflection is not too far compared to the center loading, which is -15.33 mm. The location of the load on it that is not too far shifted causes the deflection rate at the edge loading to tend to be almost the same as the center loading. The most striking difference is in the variation in corner loading. The maximum deflection value is located on monitor 1 of 1.28 mm. This means that in monitor area 1, the rigid pavement above is actually lifted because the deflection value shows a positive number. While on monitors 2 to 13, it was negative. The location of the corner loading that is given close to monitor 1 is what causes this. If this (corner load) is placed around monitor 13, the maximum deflection value may occur on the monitor on page 13. It all just depends on where the corner load is placed and the monitor (monitoring point) only [17].

The deflection that happens in the rigid pavement depends on how the load is applied and where its bearings are placed. According to earlier studies, the loading's placement significantly affects the deflection that takes place [18], [19]. The more influential side loading gives a higher deflection result than the center loading. Another study suggests placing flexible pavement over rigid pavement to mitigate the harm that rigid pavement causes [20]. However, the sort of injury that occurred was not particularly mentioned in this study.

IV. Conclusion

Based on the results of the research conducted and the discussion of the results of this study, it can be concluded that the deflection of rigid pavement without reinforcement with swelling pressure has a value that tends to be higher than without swelling pressure. But in general, both with swelling pressure and without swelling pressure, the deflection trendline for each variation shows the same results.

The ATENA program, which is still hardly utilized in research, is employed for the analysis in this work. For maintenance and rehabilitation to be carried out before major damage develops and the service life of the road is achieved as anticipated, ATENA software can be used to examine the damage to rigid pavement structures.

Future research is expected to add variations to the existing loading, and different load locations will also produce different results. The model of the swelling pressure below it is also expected to be different because the swelling in the field also has various models.

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