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Behavior Analysis of Highway Rigid Pavement on Clay Soil with Beam on Elastic Foundation Approach

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Abstracts: An important consideration in designing road infrastructure is the study of the behavior of rigid pavement structures and subsurface soils. Vehicle loads received by the rigid pavement are transferred to the soil which provides the required response and bearing capacity. To examine this problem the beam on elastic foundation (BoEF) approach can be used. The purpose of this research is to identify and assess the relationship between pavement stiffness and the soil that supports it. The object of this research is Solo Yogyakarta - NYIA Kulonprogo Toll Road section 1 STA 2+949 to STA 2+973. The pavement is modeled as a finite element resting on a series of springs that represent the characteristics of the subgrade soil. The structural analysis results show that the pavement should be designed with appropriate thickness and sufficient elastic modulus to withstand various traffic loads. In addition, an understanding of pavement deformation and soil response to loads is essential in minimizing road damage.

Keywords: Beam on Elastic Foundation, Rigid Pavement, Finite Element Method, Structural Analysis.

1. INTRODUCTION

In road planning, the road surface must be considered effectively and efficiently. Rigid pavement is a type of pavement that usually consists of a cement-concrete mixture as the top layer, while granular materials are used as the bottom layer. The construction of this road layer is intended to protect the road from water damage and traffic loads. Nowadays, concrete roads are relatively frequently used on major city roads with high traffic volumes. Relatively high vehicle loads and increasing traffic are the main reasons for choosing concrete roads (rigid pavements). When a structure is placed on top of soil, it is assumed that the soil has a very high stiffness so that it will not deform. However, in reality soil is not a material with infinite stiffness and will deform under load [1]. The global behavior of a rigid pavement over soil depends on the load, the strength and stiffness of the slab, and the response and bearing capacity of the underlying soil. If this is not properly considered when planning the base thickness, slab and concrete quality, then when receiving a high load, it produces a large deflection, while the problematic soil only produces a small total stress, resulting in potential cracking, pumping or faulting of the slab joints [2]. The use of BoEF (Beams on Elastic Foundation) beams with the finite element method simplifies the analysis of concrete slab pavements in the mechanical calculation of the behavior of slabs on the ground receiving vertical loads. Several researchers have applied the concept of using BoEF to various structures [3]-[7]. Thus, it is expected that a structure has a good level of safety in resisting the load it receives and has a size that is economical enough to be able to produce the ability to withstand the load it receives.

2. MATERIEL AND METHODS

2.1 Materials

Modulus of Soil Reaction

The soil subgrade reaction coefficient, better known as the modulus of subgrade reaction, is a number that describes the relationship between the pressure exerted on the soil and the amount of settlement that occurs. This value is measured through a plate load test [8]. The formula for the value of the subgrade reaction coefficient (kv) for rigid plates is given in equation (1).

k_v=P/δ (1)

with,

k_v= soil subgrade reaction modulus value (kN/m^2 〖.m〗^(-1))
p = pressure (kN/m^2)
δ = slab deflection (m)

Beams on Elastic Foundation (BoEF)

In the analysis using the BoEF method, it is assumed that the slab is considered similar to a beam, so the approach used to calculate deflections, moments, rotations, and latitudinal forces in the slab uses equations similar to those used to calculate deflections, moments, rotations, and latitudinal forces in beams [9]. The beam is loaded by vertical forces that cause the slab to curve downward. In response to these vertical forces, the soil as an elastic medium exerts reaction forces that are uniformly distributed along the support (soil) as can be seen in Figure 1.

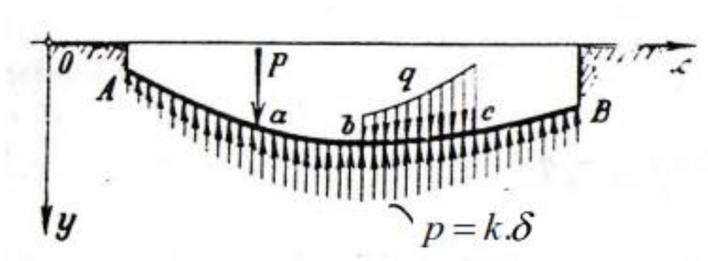

Figure.1 Behavior of continuous beams loaded over elastic media

Winkler simplified BoEF with his theory, namely:

$$\delta = e^{\beta x}(c_1 \sin\beta x + c_2 \cos\beta x) + e^{-\beta x}(c_3 \sin\beta x + c_4 \cos\beta x) \quad (2)$$

with,

C_1, C_2, C_3, C_n = constant of integration
x = calculated distance from the load (m)
λ = characteristic length $\sqrt[4]{\frac{k}{4EI}}$
E = modulus of elasticity of the plate
I = moment of inertia of the plate

2.2. Methods

The research method used in this study is a quantitative method using the finite element method to obtain the behavior of the slab on the ground receiving vertical loads. The model is a 24 x 12 m slab involving three layers, namely a drainage layer (base) with a thickness of 15cm, a 10cm lean concrete layer, and a 30cm thick rigid pavement layer. The base layer will use Base Class A material, while the lean concrete and rigid pavement layers will use ready mix concrete. The stages of this research are to conduct an analysis by modeling with the finite element method by varying the number of springs. The output is the amount of pavement deformation in each varied condition.

3. RESULTS AND DISCUSSIONS

3.1. Deflection of Rigid Pavement with variation of spring and thickness

The results obtained in this study are in the form of a graph of the deflection results on the plate due to static loads at the center loading with varying numbers of springs. The cross-sectional drawing of the model is presented in Figure 2.

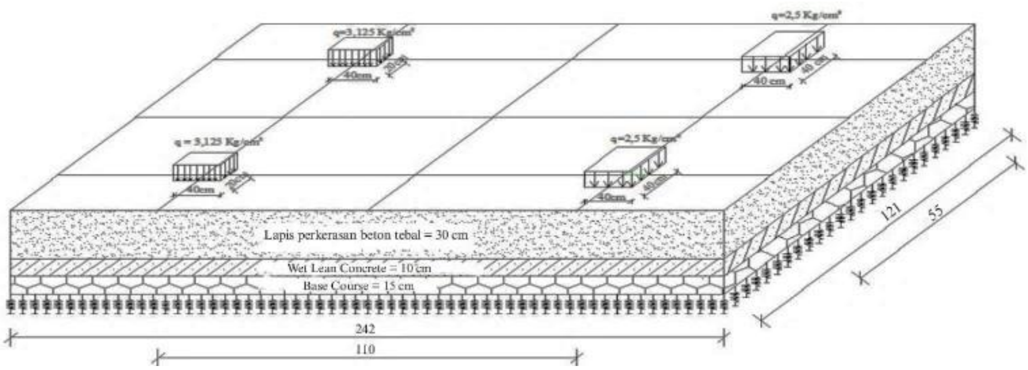

Figure 2. Modeling of structures with rigid pavement with static loading

The subgrade used to support the pavement layer is assumed to be an elastic support modeled as a spring. The spring stiffness values calculated based on the spring support model are shown in Table 1.

Table 1. Spring stiffness values based on spring distance

No.	Distance (cm)	k (kg/cm²)	k1 (kg/cm²)	k2 (kg/cm²)	k3 (kg/cm²)
1	1	32,6	81500	163000	326000
2	2	32,6	326000	652000	1304000
3	4	32,6	1304000	2608000	5216000
4	6	32,6	2934000	5868000	11736000
5	8	32,6	5216000	10432000	20864000

The spring stiffness value is calculated based on the spring support model. In this analysis, the spring support distance in the vertical and horizontal directions is 100 cm. Based on this data, the spring stiffness values k1, k2 and k3 can be seen in Figure 3 and can be calculated as follows:

- K1 = 50,00 × 50,00 × 32,6 kg/cm² = 81500 kg/cm²
- K2 = 50,00 × 100,00 × 32,6 kg/cm² = 163000 kg/cm²
- K3 = 100,00 × 100,00 × 32,6 kg/cm² = 326000 kg/cm²

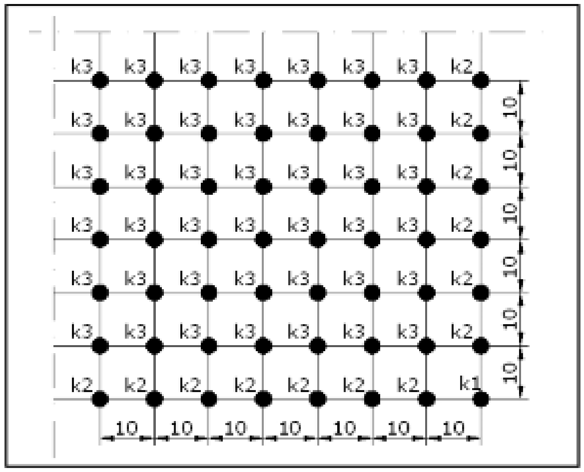

Figure 3. Spring support model of rigid pavement

Deformation describes the change in shape of the pavement structure in the elastic state. The allowable deflection is the critical limit of the road. If the allowable deflection exceeds the pavement structure, the structure is considered to have failed and does not conform to the design. The maximum allowable deflection at the base of the road structure is 2.7 cm. The analysis of the deflection of the foundation under the pavement structure due to the effect of static load of the center section with K350 grade concrete is presented in Figure 4.

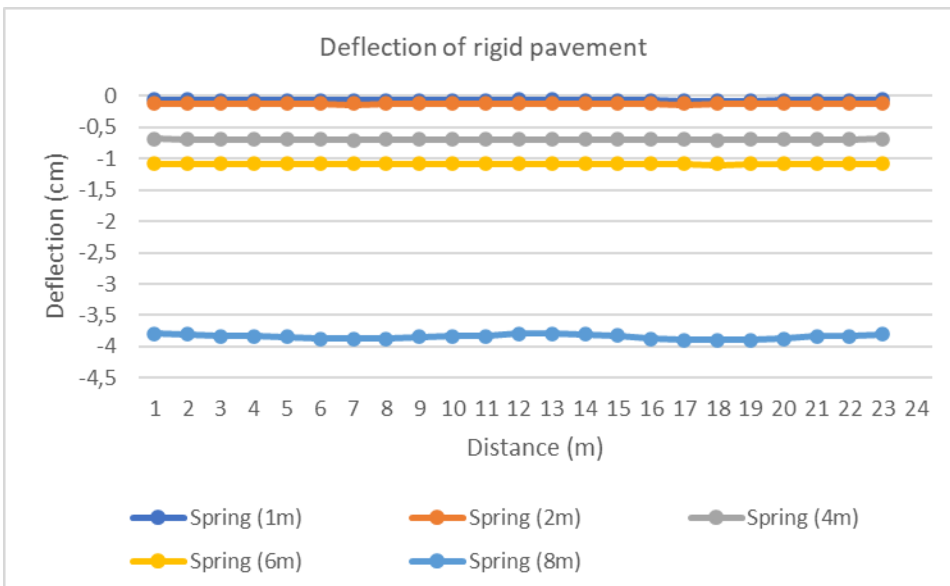

Figure 4. Deflection graph of rigid pavement with variation of spring placement

The largest maximum deflection occurred under static load with a spring distance of 1m at -0.0692, spring distance of 2m at -0.1240, spring distance of 4m at -0.6983, spring distance of 6m at 1.0842 and spring distance of 8m at -3.8971.

Table 2. Deflection in spring variation

Distance (m)	Spring 1m (cm)	Spring 2m (cm)	Spring 4m (cm)	Spring 6m (cm)	Spring 8m (cm)
1	-0,06221	-0,11906	-0,68429	-1,07807	-3,77813
2	-0,06231	-0,11906	-0,68453	-1,07818	-3,79704
3	-0,06356	-0,11964	-0,68825	-1,07825	-3,8036
4	-0,06426	-0,11964	-0,69097	-1,07874	-3,83155
5	-0,06501	-0,12155	-0,6916	-1,07967	-3,83807
6	-0,06632	-0,12253	-0,69354	-1,08027	-3,84587
7	-0,06716	-0,12356	-0,69741	-1,08185	-3,87096
8	-0,06747	-0,12402	-0,69831	-1,08337	-3,87633
9	-0,06715	-0,12365	-0,69741	-1,08185	-3,87096
10	-0,06632	-0,12253	-0,69354	-1,08027	-3,84587
11	-0,0651	-0,12155	-0,69161	-1,07967	-3,83807
12	-0,06438	-0,11964	-0,69097	-1,07818	-3,83155
13	-0,06231	-0,11906	-0,68825	-1,07825	-3,79704
14	-0,06222	-0,11964	-0,68825	-1,07919	-3,79704
15	-0,06438	-0,12155	-0,6916	-1,07967	-3,8036
16	-0,06499	-0,12253	-0,69161	-1,08061	-3,82367
17	-0,06773	-0,12365	-0,69161	-1,08185	-3,87096
18	-0,06924	-0,12402	-0,69741	-1,08355	-3,89385
19	-0,06924	-0,12365	-0,69832	-1,08427	-3,89707
20	-0,06924	-0,12356	-0,69741	-1,08355	-3,89385
21	-0,06643	-0,12155	-0,69354	-1,08185	-3,87096
22	-0,06499	-0,11964	-0,6916	-1,08027	-3,83807
23	-0,06438	-0,11906	-0,68989	-1,08018	-3,83155
24	-0,06222	-0,11887	-0,6857	-1,07967	-3,8036

Table 3. Deflection at varying thickness of rigid pavement

Distance (m)	30 cm	25 cm	20 cm	15 cm
1	-0,06221	-0,12124	-0,75025	-1,12991
2	-0,06231	-0,12124	-0,75032	-1,13009
3	-0,06356	-0,12209	-0,75038	-1,13014
4	-0,06426	-0,12309	-0,75062	-1,13028
5	-0,06501	-0,1241	-0,75103	-1,13047
6	-0,06632	-0,12511	-0,75137	-1,13054
7	-0,06716	-0,12520	-0,75162	-1,13071
8	-0,06747	-0,12536	-0,75163	-1,13073
9	-0,06715	-0,1252	-0,75137	-1,13071
10	-0,06632	-0,12511	-0,75062	-1,13054
11	-0,0651	-0,12410	-0,75032	-1,13047
12	-0,06438	-0,12209	-0,75029	-1,13028
13	-0,06231	-0,12124	-0,75033	-1,13014
14	-0,06222	-0,12124	-0,75103	-1,12991
15	-0,06438	-0,12209	-0,75137	-1,12991
16	-0,06499	-0,12309	-0,75152	-1,13009
17	-0,06773	-0,12410	-0,75167	-1,13054
18	-0,06924	-0,12511	-0,75167	-1,13071
19	-0,06924	-0,12602	-0,75167	-1,13081
20	-0,06924	-0,12511	-0,75152	-1,13071
21	-0,06643	-0,12309	-0,75137	-1,13054
22	-0,06499	-0,12209	-0,75103	-1,13009
23	-0,06438	-0,12120	-0,75062	-1,12991
24	-0,06222	-0,12124	-0,75038	-1,12982

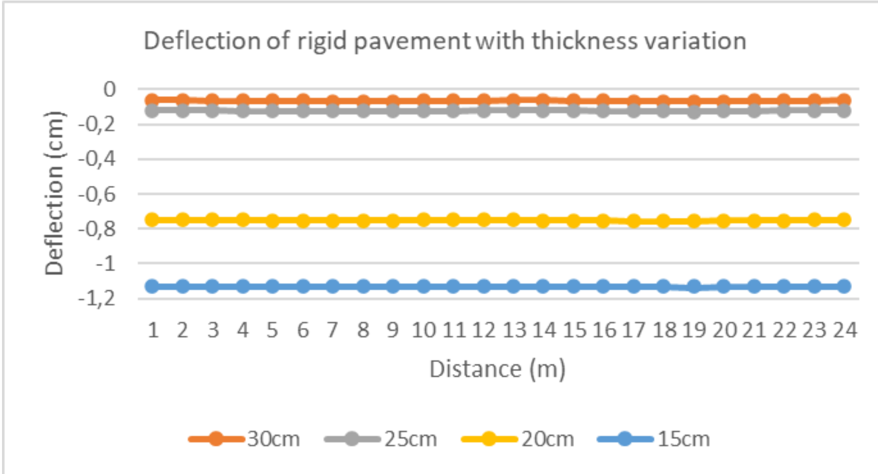

Figure 5. Deflection graph of rigid pavement with variation of rigid pavement thickness

3.2. Discussion

Based on the results of static loading analysis on the Solo - Yogyakarta - NYIA Kulonprogo toll road section 1 STA 2+949 to STA 2+973, the maximum deflection is obtained using a spring with a variation of 8m. When the number of spring supports is getting closer, there are more springs that support the structure so that the total force that must be supported by each spring becomes smaller. As a result, the deformation of each spring becomes smaller because the force received is smaller. Vice versa, if the number of spring supports decreases or gets less, the force exerted on each spring will increase and cause the deflection of the spring to be greater. When the number of spring pedestals increases, the structure will be more stable because with the increase in the number of pedestals, the load that will be received by each spring will be distributed and reduce the load per spring resulting in a small deflection. Then the maximum deflection that occurs in rigid pavement with thick variations is 15 cm thick. Thus, the thicker the pavement, the greater the structural stiffness. Higher stiffness allows the pavement to withstand loads without significant deformation.

CONCLUSIONS

The results of rigid pavement modelling with the Beam on Elastic Foundation approach on the Solo - Yogyakarta - NYIA Kulonprogo toll road section 1 STA 2+949 to STA 2+973 show that in the spring variations of 1m, 2m, 4m and 6m the deflections that occur are still within the permissible and safe limits but in the spring variation of 8m the deflections that occur exceed the permissible limits so that rigid pavements with spring variations of 1m, 2m, 4m and 6m have better stability and bearing capacity than rigid pavements with 8m variations. And rigid pavement thickness variations of 15cm, 20cm, 25cm and 30cm deflections that occur are still within the permissible and safe limits.

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