Deflection analysis of rigid pavement on clay soil with vertical drain

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Abstract. Rigid pavements are often used on clay soils with long-term settlement history and are subject to damage from traffic loads. It must be analyzed for deflections in rigid pavements built on clay to prevent damage and extend pavement life. If deflection exceeds the permit, the pavement will experience damage. One way to minimize these problems is by installing vertical drains to improve the soil. Installing a vertical drain on the soil can increase the modulus of the subgrade reaction represented as soil-bearing capacity and minimize the potential for pavement deformation. This research aims to analyze the deflection of rigid pavement on clay soil with vertical drains. The finite element method is utilized to analyze the deflection. The pavement is modeled as a 10 m long and 7 m wide slab with thickness variations ranging from 150 mm to 350 mm. Static loads are used to model vehicle loads with load positions at the pavement's center, ends, and edges. For all slab thicknesses subjected to varying center, end, and edge loads, the maximum deflection of rigid pavement over vertical drain soils is lower than that of soils without vertical drains. It can be concluded that rigid pavement deflection can be reduced using vertical drains for soil improvement.

1 Introduction

Improving pavement performance supports economic growth and community mobility [1,2]. Appropriate assessment of road pavement is essential to ensure the safe movement of people and goods. Road pavement is influenced by various factors that affect overall performance, one of which is the condition of the soil under the pavement. These factors can reduce the age of infrastructure and reduce the comfort of vehicle circulation in the transportation network [3]. One of the critical factors influencing pavement sustainability is the type of soil. One type of soil that influences the continued performance of rigid pavement is clay. Clay soil is included in soft soil with several problems, including high compressibility, low porosity, long-term consolidation, and low shear strength, and ultimately is categorized as soil with low bearing capacity [4]. Low-bearing capacity soils can cause severe problems in pavements, such as excessive deformation, ultimately reducing service life and increasing maintenance costs. Therefore, soil strength, which refers to the ability of the soil to support the load imposed by the structure ideally without causing failure, is significant [5].

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In soil conditions with low bearing capacity, soil improvement becomes necessary [6,7]. Soil improvement is an effort to improve the geotechnical properties of the soil to obtain the desired and optimal soil-bearing capacity [8]. Soil improvement can be done mechanically, chemically, or hydraulically. One method of soil improvement that has been studied intensively is vertical drain. Soil improvement using vertical drainage is considered adequate because excess pore water pressure can dissipate quickly in the horizontal direction through vertical drainage [9–12]. Installing a vertical drain on the soil can increase the modulus of the subgrade reaction represented as soil-bearing capacity and minimize the potential for pavement deformation [13,14].

One critical aspect to consider in soil improvement with vertical drain is an analysis of the deflection of the overlying rigid pavement. Deflection is a structural response to traffic loads and stress distribution within a pavement that reflects the strength of the pavement and structure [15]. If soil conditions have low bearing capacity, pavement deflection can increase, thereby increasing the risk of structural damage. This research investigates the effect of vertical drains as a soil improvement measure on rigid pavement deflection.

2 Method

The data follows the research from Yang and Zhou [16] the analysis using the finite element method. Deflection analysis is carried out in the transverse and longitudinal directions according to the position of the vehicle wheel load and maximum deflection.

The rigid pavement was modeled as a 10 m long and 7 m wide slab with variations in slab thickness of 150 mm, 200 mm, 250 mm, 300 mm, and 350 mm modeled as shell elements. The concrete used for the rigid pavement is P-grade concrete, with a compressive strength of 37,35 MPa and a modulus of elasticity of 28,72 MPa.

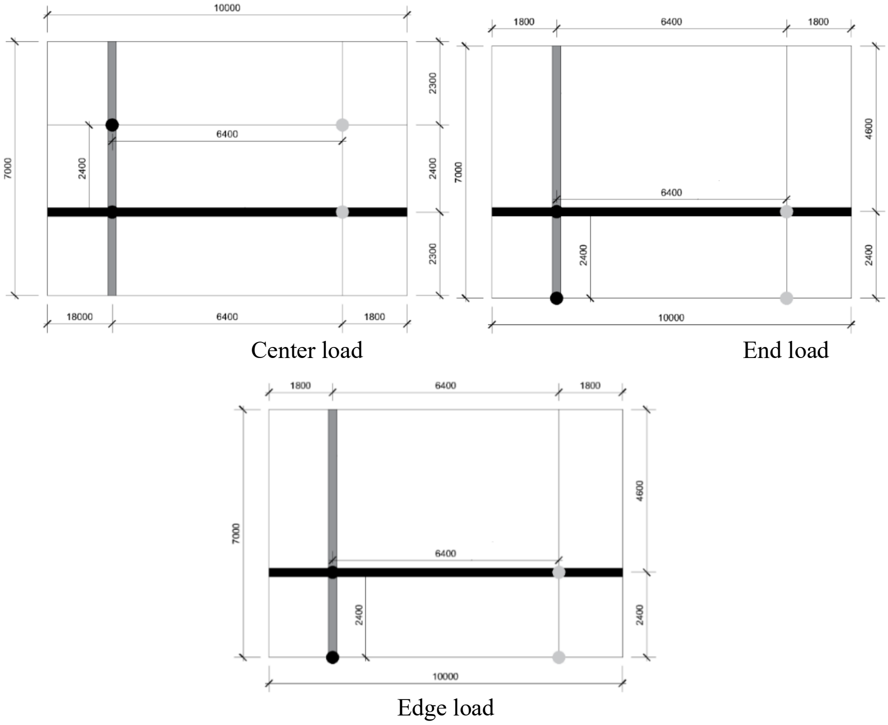

Fig. 1. Load position.

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The soil in the finite element method analysis was modeled as spring with modulus of the subgrade reaction based on FEMA 356. The modulus of the subgrade reaction without vertical drain was 22.419 kN/m^2/m, while the improvement was 23.089 kN/m^2/m. The soil parameter data used in the finite element method analysis were Poisson's ratio of 0,4, void ratio of 1,346, and conus resistance of 784,53 kPa. According to AASHTO, the soil type is A-7-5(41), and according to USCS, it is CH.

Vehicle loads on the rigid pavement were modeled as static loads based on load contact with vehicle tires. The rigid pavement in this research is for class I roads with the heaviest axle load of 10 tons. The distance between the front and rear wheels is 6,4 mm, and between the right and left wheels is 2,4 mm. At the same time, the loading is carried out at 3 (three) positions: center, end, and edge, as seen in Fig. 1.

3 Results and discussion

Deflection is the vertical displacement associated with the volume change caused by a load. If the subgrade is in poor condition and unable to carry the load of passing vehicles, the rigid pavement will begin deflection. This deflection will damage and reduce pavement life. The slab is considered a straight beam supported by an elastic medium in performing the slab deflection analysis. The beam is subjected to a vertical force that causes it to deflect downwards. The soil reacts to the forces distributed over its surface as an elastic medium. Deflection analysis of rigid pavement is developed based on the assumption that the reaction force at any point will be proportional to the deflection at that point.

3.1 Center-loading deflection analysis results

Deflection analysis is carried out in the transverse and longitudinal directions according to the position of the vehicle wheel load and maximum deflection.

The deflection of rigid pavement in the transverse direction due to the center load at each slab thickness for conditions without vertical drain is in Fig. 2, and conditions with vertical drain are in Fig. 3.

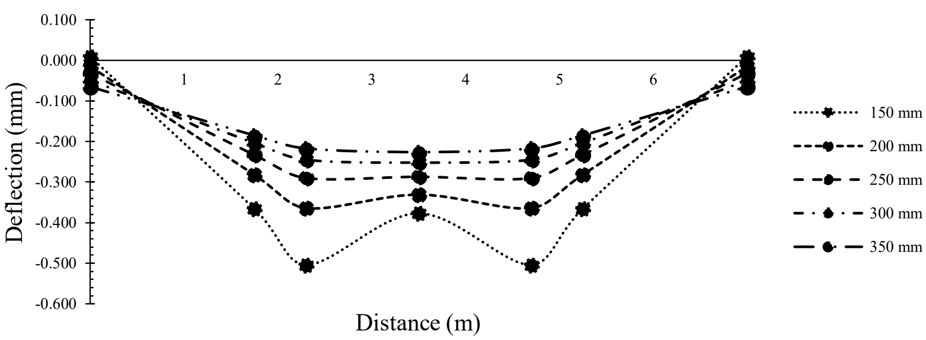

Fig. 2. Transverse deflection for center load without vertical drain.

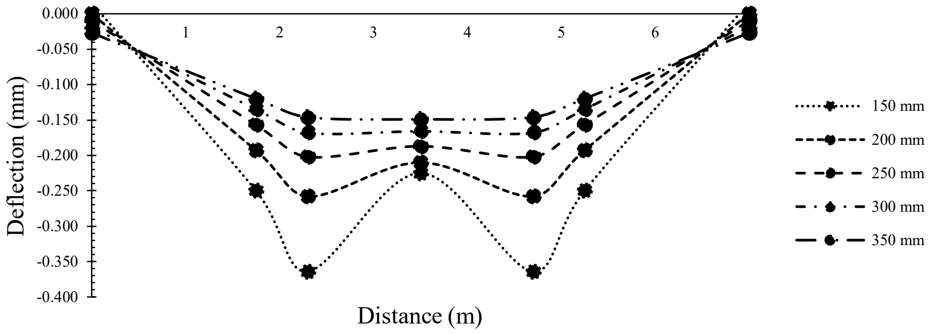

Fig. 3. Transverse deflection for center load with vertical drain

Based on Fig. 2 and Fig. 3, the results show that the transverse deflection that occurs due to the center load for conditions without or with vertical drain has a symmetrical pattern caused by the similarity of the wheel loads. Apart from that, the thickness of the rigid pavement affects the deflection; the thicker the rigid pavement plate, the smaller the deflection.

The deflection of rigid pavement in the longitudinal direction due to the center load at each slab thickness for conditions without vertical drain is shown in Fig. 4 and for conditions with vertical drain in Fig. 5.

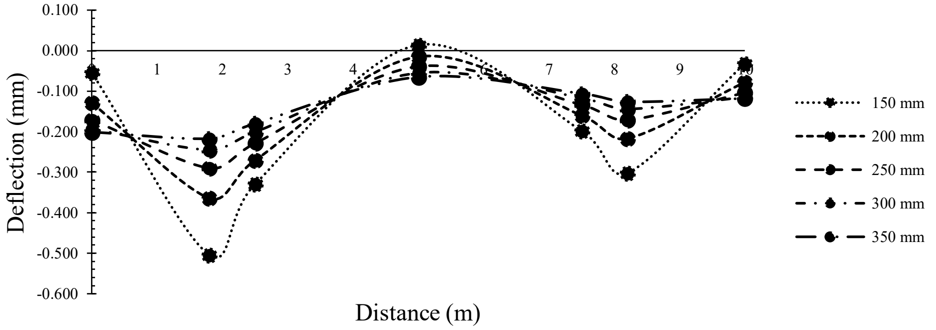

Fig. 4. Longitudinal deflection for center load without vertical drain.

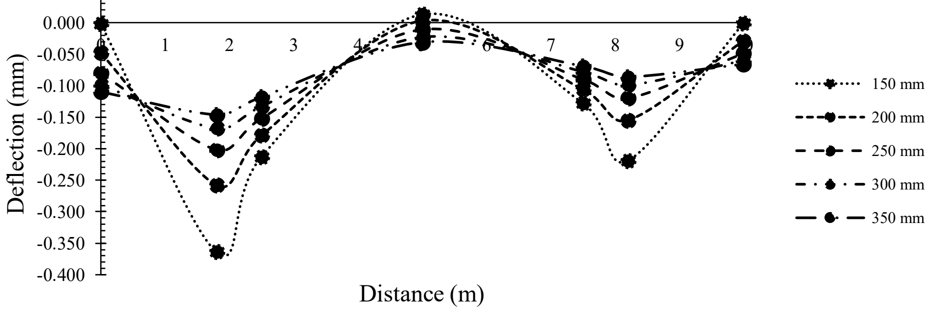

Fig. 5. Longitudinal deflection for center load with vertical drain.

Based on Fig. 4 and Fig. 5, the results show that the longitudinal deflections that occur due to the center load in conditions without or with vertical drain have more significant deflections on the rear wheels because they have an enormous load than the front wheels. In addition, the thickness of the rigid pavement also affects the deflection, the thicker the rigid pavement's slab, the smaller the deflection.

The maximum deflection of the rigid pavement due to the center load at each slab thickness for conditions without and with vertical drain is shown in Fig. 6.

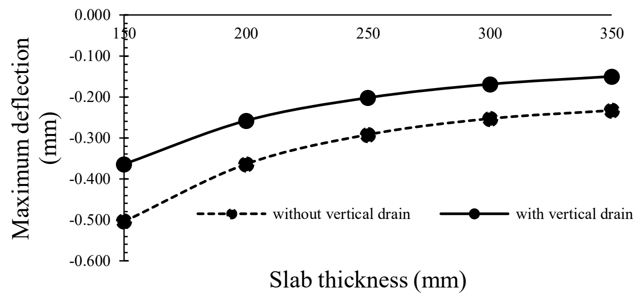

Fig. 6. Maximum deflection for center load.

The maximum deflection for conditions without a vertical or vertical drain reaches the maximum deflection value requirement of 0.800 mm. Based on this, the soil can install the vertical drain for center load. In addition, the deflection of rigid pavement conditions with vertical drain for center loads has a smaller value than those without vertical drain because efforts to improve the soil by using vertical drain can increase the subgrade reaction's modulus as the pavement support [13,17,18]. The most significant deflection occurs below the loading area, and the further away from the loading area, the smaller the deflection will be. The slab's thickness affects the deflection distribution due to vehicle load. The thicker the slab, the stiffer it is, and the smaller the deflection.

3.2 End-loading deflection analysis results

Deflection analysis is carried out in the transverse and longitudinal directions according to the position of the vehicle wheel load and maximum deflection.

The deflection of pavement in the transverse direction due to the end load at each slab thickness for conditions without vertical drain is in Fig. 7 and with a vertical drain in Fig. 8.

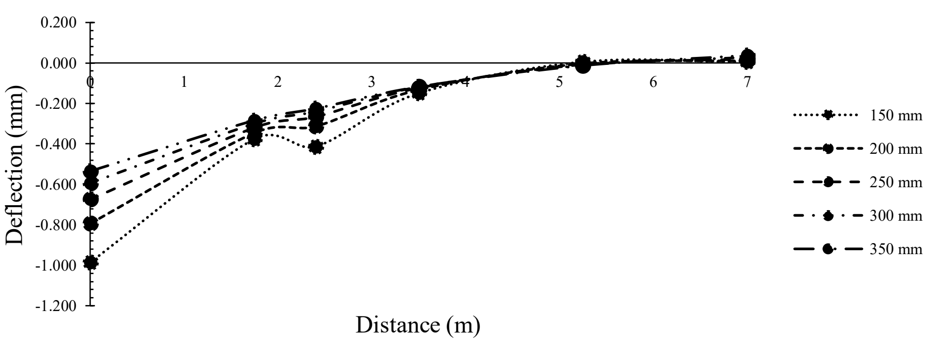

Fig. 7. Transverse deflection for end load without vertical drain.

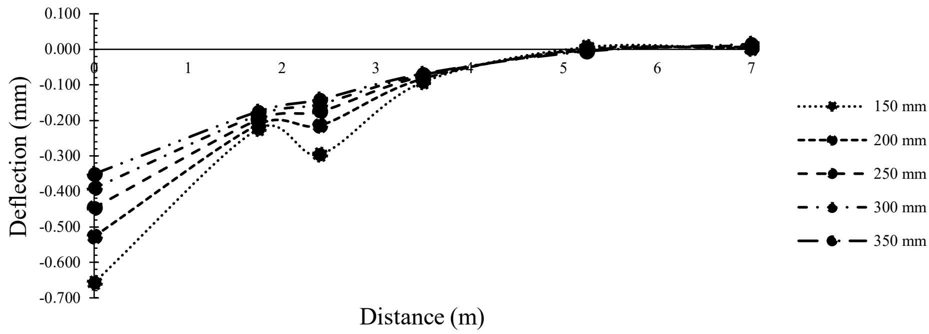

Fig. 8. Transverse deflection for end load with vertical drain.

Based on Fig. 7 and Fig. 8, the thickness of the rigid pavement affects the deflection; the thicker the rigid pavement plate, the smaller the resulting deflection.

The deflection of rigid pavement in the longitudinal direction due to the end load at each slab thickness for conditions without vertical drain is shown in Fig. 9 and for conditions with vertical drain in Fig. 10.

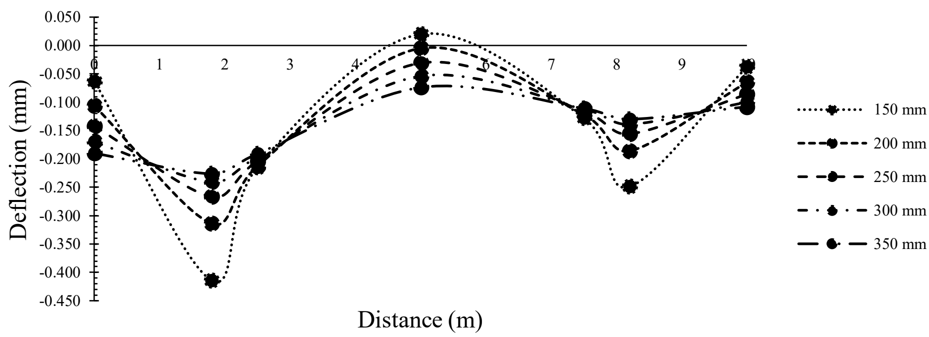

Fig. 9. Longitudinal deflection for end load without vertical drain.

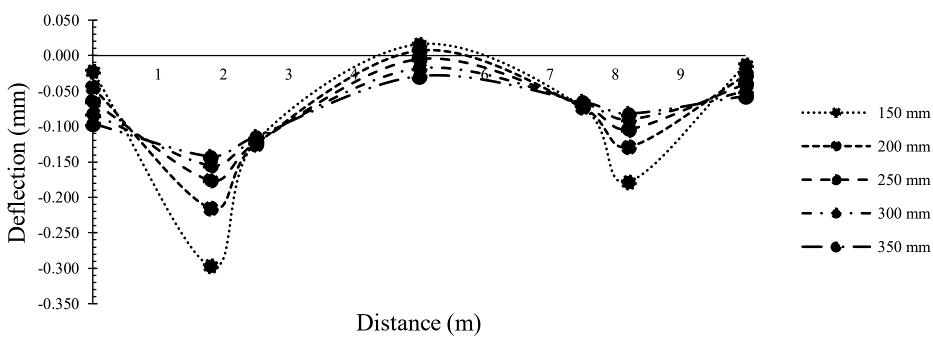

Fig. 10. Longitudinal deflection for end load with vertical drain.

Based on Fig. 9 and Fig. 10, the results show that the longitudinal deflections that occur due to the end load in conditions without or with vertical drain have more significant deflections on the rear wheels because they have an enormous load than the front wheels. In addition, the thickness of the rigid pavement also affects the deflection, the thicker the rigid pavement's slab, the smaller the deflection.

The maximum deflection of the rigid pavement due to the end load at each slab thickness for conditions without and with vertical drain is shown in Fig. 11.

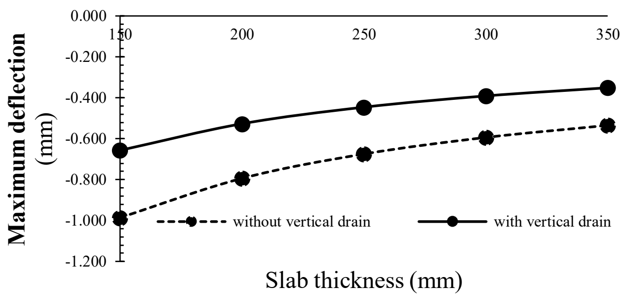

Fig. 11. Maximum deflection for end load.

The maximum deflection for conditions without a vertical drain for a slab thickness of 150 mm exceeds the maximum deflection requirement of 0.800 mm. Based on this, it is necessary to install a vertical drain in the soil to meet the maximum deflection value requirements for end-loading conditions. However, it has reached the maximum deflection requirement for other slab thicknesses. In addition, the deflection of rigid pavement conditions with vertical drain for end loads has a smaller value than those without vertical drain because efforts to improve the soil by using vertical drain can increase the subgrade reaction's modulus as the pavement support [13,17,18]. The most significant deflection occurs below the loading area, and the further away from the loading area, the smaller the deflection will be. The slab's thickness affects the deflection distribution due to vehicle load. The thicker the slab, the stiffer it is, and the smaller the deflection.

3.3 Edge-loading deflection analysis results

Deflection analysis is carried out in the transverse and longitudinal directions according to the position of the vehicle wheel load and maximum deflection.

The deflection of pavement in the transverse direction due to the edge load for conditions without vertical drain is in Fig. 12 and with a vertical drain in Fig. 13.

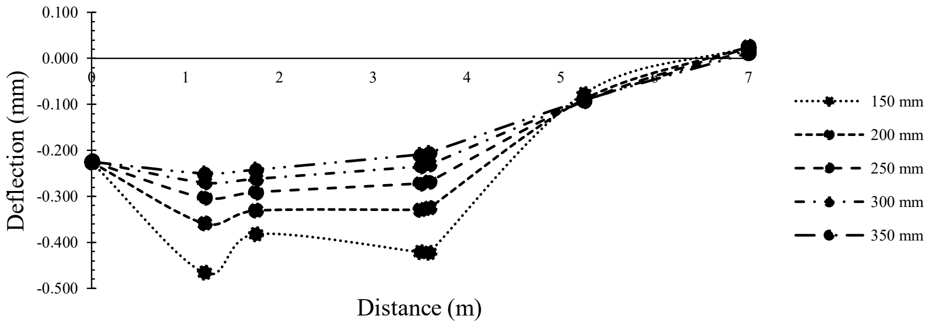

Fig. 12. Transverse deflection for edge load without vertical drain.

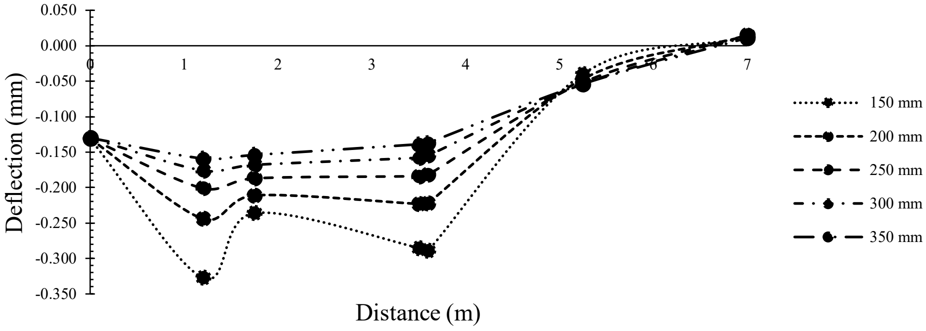

Fig. 13. Transverse deflection for edge load with vertical drain.

Based on Fig. 12 and Fig. 13, the thickness of the rigid pavement affects the deflection; the thicker the rigid pavement plate, the smaller the resulting deflection.

The deflection of rigid pavement in the longitudinal direction due to the edge load at each slab thickness for conditions without vertical drain is shown in Fig. 14 and for conditions with vertical drain in Fig. 15.

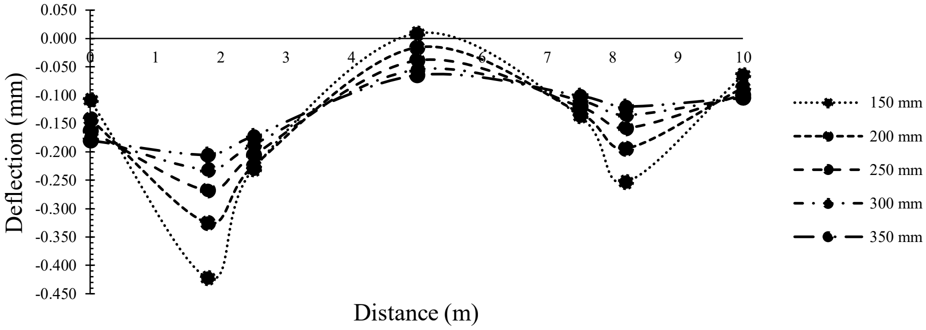

Fig. 14. Longitudinal deflection for edge load without vertical drain.

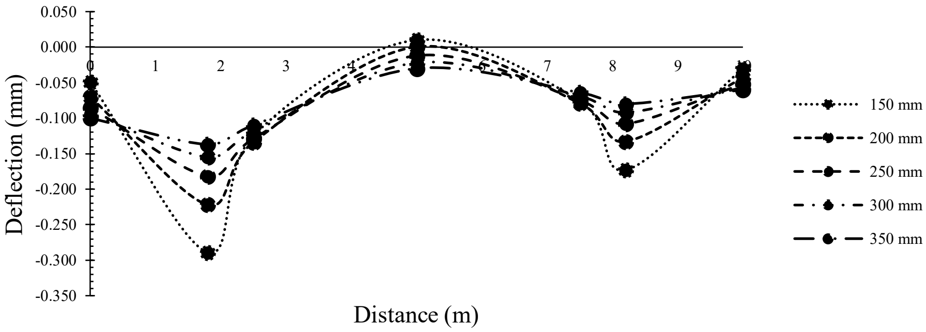

Fig. 15. Longitudinal deflection for edge load with vertical drain.

Based on Fig. 14 and Fig. 15, the results show that the longitudinal deflections that occur due to the edge load in conditions without or with vertical drain have more significant deflections on the rear wheels because they have an enormous load than the front wheels. In addition, the thickness of the rigid pavement also affects the deflection, the thicker the rigid pavement's slab, the smaller the deflection.

The maximum deflection of the rigid pavement due to the edge load at each slab thickness for conditions without and with vertical drain is shown in Fig. 16.

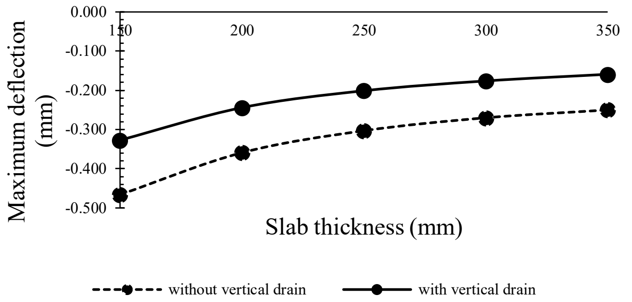

Fig. 16. Maximum deflection for edge load.

The maximum deflection for conditions without a vertical or vertical drain reaches the maximum deflection value requirement of 0.800 mm. Based on this, the soil can install the vertical drain for edge load. In addition, the deflection of rigid pavement conditions with vertical drain for edge loads has a smaller value than those without vertical drain because efforts to improve the soil by using vertical drain can increase the subgrade reaction's modulus as the pavement support [13,17,18]. The most significant deflection occurs below the loading area, and the further away from the loading area, the smaller the deflection will be. The slab's thickness affects the deflection distribution due to vehicle load. The thicker the slab, the stiffer it is, and the smaller the deflection.

4 Conclusion

Deflection of rigid pavement built on low soil bearing capacity will cause structural damage and reduce pavement life. Therefore, improving the soil to increase the soil-bearing capacity is necessary. The method that can be used is to install a vertical drain. Soil improvement using vertical drain can increase the modulus of soil reaction by 42%. Increasing the modulus of the subgrade reaction affects deflection. Namely, rigid pavement on soil with a vertical drain deflected less than soil without a vertical drain. The reduction in deflection reached 34%.

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