The problem found in many rigid pavement concrete slabs is the occurrence of cracks. Research on the width of cracks in rigid pavement due to the influence of reinforcement ratio is necessary because the stiffness and strength of concrete slabs are related to slab thickness, concrete quality, reinforcing steel quality and reinforcement numbers. This study aims to determine the cracking behavior of rigid pavements subjected to monotonic static line loads due to variations in reinforcement ratio experimentally. Specimens tested in the laboratory were 2×0.6×0.2 m concrete slabs placed on 30 cm thick soil with 6 % CBR value as a support. The variation of reinforcement ratio was ρ=0.004; ρ=0.007; ρ=0.01; ρ=0.02. Concrete quality f_c=30 MPa, steel quality f_u=580 MPa. The results shows at small reinforcement ratios the results are close to the average crack width of the formula from the regulations and at large reinforcement ratios the results are further away from the average crack width based on the formula in the regulations. The largest crack width observed in this study occurred in rigid pavement with a reinforcement ratio of ρ=0.004, under a load of 210 KN, resulting in a crack width of 0.519 mm. It was found that the relationship between crack width and the reinforcement ratio follows a linear equation across all variations. The research also revealed variations in crack width between experiments conducted under different design codes, with results closely aligning with the average crack width determined by rule-based formulas, especially for a small reinforcement ratio (ρ=0.004). Conversely, for a larger reinforcement ratio (ρ=0.01), the results deviated further from the crack width predicted by the code-based formula

***Keywords:** reinforcement ratio, cracking behavior, crack width, rigid pavement, concrete, load*

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IDENTIFYING THE INFLUENCE OF REINFORCEMENT RATIO ON CRACK BEHAVIOUR OF RIGID PAVEMENT

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1. Introduction

In this modern era, with rapid population growth, ongoing urbanization, and increasing mobility, road infrastructure has become a crucial aspect in maintaining connectivity and distribution. The appearance of cracks in stiff concrete slabs is a common issue that can result in serious damage if it is not addressed. therefore, long-lasting and high-performing concrete pavements are an essential component of environmentally friendly road infrastructure. Therefore, a deeper understanding of the factors that influence the cracking behavior of rigid pavements is essential. Modernizations and economic growth demand more durable, safe and sustainable highways. In view of this, scientific research on this topic is becoming increasingly relevant to ensure efficient and reliable road infrastructure.

The results of this studies therefore have significant practical implications. The findings can provide a solid scientific foundation for highway engineers and construction practitioners to design rigid pavements that are more resistant to cracking. This will reduce road maintenance costs, and extend the service life of the infrastructure. In addition, the results of this studies have the potential to improve existing technical guidelines and contribute to stricter standards in highway construction and maintenance.

2. Literature review and problem statement

Cracking in concrete is a common problem encountered in structural engineering. One aspect that is highly relevant in this regard is the prediction of crack width and spacing. Nonetheless, a part of the problem that remains unexplored from this statement is "prediction of service life of precast concrete slabs based on crack mechanics [1]. In the research on the prediction of the service life of precast concrete slabs based on crack mechanics seems to be an aspect that has received less attention in this study. Therefore, it is important to understand how these cracks develop and an unexplored part of the problem is the prediction of their characteristics. Solid road concrete is recognized as a type of road structure that has high durability and stiffness [2]. There is a lack of studies detailing how cracks in road concrete develop and how their characteristics can be predicted. Therefore, more in-depth analyses are needed to identify the factors that influence cracking in road concrete and develop more effective methods to predict the properties of these cracks.

A part of the problem that remains unexplored is the susceptibility of concrete to fatigue cracking in hardened road concrete layers. Fatigue cracking is a common type of damage that occurs on roads due to repetitive loads from traffic. These cracks arise due to repeated load cycles, which can cause the stress on the road surface to be lower than the tensile strength of the concrete [3]. However, concrete cracking due to external loads can include flexural cracking and shear cracking, each with different characteristics. Flexural cracking mainly occurs in the tensile region of the concrete, and the largest crack width is located at the surface, close to the neutral line where the crack becomes zero. The dependence of crack width on a number of factors, and previous research has established an aesthetically acceptable range of crack widths, which is between 0.25 mm and 0.38 mm [4]. An area of concern that remains unexplored is how these factors quantitatively affect crack width in concrete, especially in the context of concrete tensile stress. Although research has measured the tensile stress of concrete using concrete cylinder tests under uniaxial tensile force [5], there is no explanation that includes sufficient detail on how the crack width is calculated.

The different approaches in conducting tensile testing on concrete beams with cracks and analyzing the tensile stress in concrete caused by adhesion forces [6]. An unexplored part of the problem is how adhesion between concrete and other materials, which affects cracks, quantitatively affects the tensile stress in concrete. Although previous studies have used elasticity analysis to describe the longitudinal tensile stress in concrete as a circular shape between two adjacent flexural cracks, there has not been an in-depth explanation that covers the factors that affect this relationship in more detail. Where as the study conducted a two-dimensional finite element analysis used to evaluate the effects of adhesion forces on concrete [7]. The results showed that the maximum tensile stress of concrete occurs at the steel reinforcement, and its magnitude varies along the length of the reinforcement. In this case, the maximum crack width was calculated by comparing the maximum tensile stress with the tensile strength of the concrete.

Another study, took a more in-depth theoretical approach, using energy criteria and strength criteria in crack mechanics to analyze crack spacing and width [8]. They found that crack spacing is strongly influenced by the axial strain of steel reinforcement, reinforcement spacing, bar diameter, fracture energy of concrete, and its modulus of elasticity.

A study also conducted tensile tests on reinforced concrete cylinders to predict the average crack width [9]. The results showed good agreement between predicted crack widths and practical measurements. Some researchers conducted a two-dimensional finite element analysis used to evaluate the effect of adhesion forces on concrete [10]. The results showed that the maximum tensile stress of concrete occurs at the steel reinforcement, and its magnitude varies along the reinforcement. In this case, the maximum crack width was calculated by comparing the maximum tensile stress with the tensile strength of the concrete.

A more in-depth theoretical approach, using energy criteria and strength criteria in crack mechanics to analyze crack spacing and width [11]. They found that crack spacing is strongly influenced by the axial strain of steel reinforcement, reinforcement spacing, bar diameter, fracture energy of concrete, and its modulus of elasticity. In addition, some researchers conducted tensile tests on reinforced concrete cylinders to predict the average crack width [12]. The results showed good agreement between predicted crack widths and practical measurements.

The cracking behavior of reinforced concrete slabs has been extensively investigated through analyses and experiments driven by repetitive loads [13]. What remains unexplored is a more in-depth research focus on how certain factors, such as reinforcement type, repetition form, or repetitive load characteristics, specifically affect the cracking behavior of reinforced concrete slabs. While there is already research investigating cracking in reinforced concrete slabs due to repetitive loads, there is an opportunity to further explore the influence of certain variables in more specialized situations.

The research on the effect of static monotonic loads on highways, including on multi-layered asphalt pavements and concrete pavements over elastic clay. This is an important consideration in highway maintenance to ensure integrated and synergistic performance of the pavement structure [14]. A part of the problem that remains unexplored is how the influence of monotonic static loads specifically affects concrete pavement structures used as hard pavement layers. Although numerical analyses have been conducted to investigate the stresses generated by monotonic loads on concrete slabs as pavement layers, as well as experiments testing the structural response of hard road pavements to moving truck loads, there is still a need to further explore the specific impacts of these monotonic loads on concrete pavement performance, to perform numerical analyses aimed at investigating the stresses generated by monotonic static loads on concrete slabs used as hard pavement layers, by applying various modelling approaches and different types of loads, including sand layers as subgrades [15].

An unexplored part of the problem is how variations in modelling approaches used in numerical analysis can affect the results. In addition, research could also explore the impact of different types of loads, including sand layers as subgrades, in the context of monotonic static loads on concrete slabs. Further research is also needed to identify the most significant parameters in influencing the stress and response of concrete slabs. Furthermore, experimental studies have examined the structural response of rigid pavements to moving truck loads, with the aim of predicting the performance of rigid pavements in response to the loads received [16].

In addition to the load, another factor that influences the cracking behavior of concrete slabs is the construction characteristics of the slab itself. The stability of hard pavements depends on many variables, such as the distance between reinforcements, steel grade, concrete grade, and slab thickness [17]. Thicker and stiffer slabs tend to produce smaller cracks. In some studies, a recommended minimum thickness for hard pavement slabs has been proposed [18].

An unexplored part of the problem is the effect of reinforcement ratio on crack size in hard pavements, considering factors such as the spacing between reinforcements, slab thickness, and concrete quality [19]. Although previous research has considered some of the construction characteristics of concrete slabs, further research is needed to comprehensively explore how these factors interact and affect the crack size in concrete slabs. More in-depth analyses will help in understanding how to design and construct more durable and crack-resistant hard pavements.

Placement of reinforcement in the areas of highest stress can control the width of flexural cracks [20]. This is due to the fact that the regions subjected to the highest stresses in concrete slabs are the regions that are more prone to the formation of flexural cracks. With proper placement of reinforcement in these regions, flexural cracks can be controlled and minimized, making the concrete slab more resistant to deformation and damage. Therefore, placement of reinforcement in the regions subjected to the highest stress is an important strategy in the design of reinforced concrete slabs to ensure optimal structural performance and long-term durability.

However, an unexplored part of the problem is the extent to which variations in the reinforcement ratio can affect the width of flexural cracks, especially when the reinforced concrete slab is subjected to monotonic static loads. While there have been studies evaluating the effect of varying the reinforcement ratio on the stresses generated at the surface of concrete slabs [21], more research is needed to understand this impact in greater depth and how various factors such as reinforcement type, concrete characteristics and slab thickness affect crack behavior.

The use of numerical models to predict crack size and distribution in concrete slabs with various reinforcement ratios. The results of this study provide a deeper understanding of the factors that influence cracking [22]. Several researchers have analyzed the effect of varying the spacing between reinforcement bars in concrete slabs on cracking behavior [23]. They analyzed the differences in crack thickness and crack distribution in the context of variations in reinforcement spacing. Some researchers have also attempted to optimize the design of reinforcement ratios to minimize the risk of cracking in concrete slabs [24]. They proposed a design method that considers variables such as slab thickness, concrete grade, and steel grade. In addition, several researchers conducted computer simulations to understand how repetitive loads affect crack formation in concrete slabs with various reinforcement ratios [25]. The results can provide further guidance for the design of durable rigid pavements.

All this allows to assert that it is expedient to conduct a study on identify the effect of reinforcement ratio on the cracking behavior of rigid pavements.

3. The aim and objectives of the study

The aim of this study is identifying the regularities crack behaviour in rigid pavement, by directly using a soil base.

To achieve this aim, the following objectives are accomplished:

– analyse the relationship between reinforcement ratio (ρ) and crack width (*w*) on rigid pavement;

– analyse the relationship between crack width (*w*) and stress (f_s) as it varies with changes in the reinforcement ratio;

– analyse the reinforcement ratio (ρ) influence crack width in reinforced concrete pavement across different road classes.

4. Materials and methods

The specimens were reinforced concrete slabs with dimensions of 0.6×2×0.20 m, which were provided with reinforcement variations of 3D13, 5D13, 5D16, and 10D16. The dimensions of the rigid pavement concrete slabs and reinforcement variations can be seen in Fig. 1, 2. The test specimens were designed with the characteristics of compressive strength (f_c) of concrete grade 30 MPa, and steel grade ultimate strength (f_u) 580 MPa. The soil used as the concrete slab foundation has a CBR of 6 %.

Table 2 presents the variation of reinforcement ratios in the specimens including the number of reinforcements, diameter of concrete reinforcement, and area of reinforced concrete. This table provides an overview of the variation of these parameters in this study.

Fig. 1. Dimensions of f_c 30 MPa concrete slab specimens

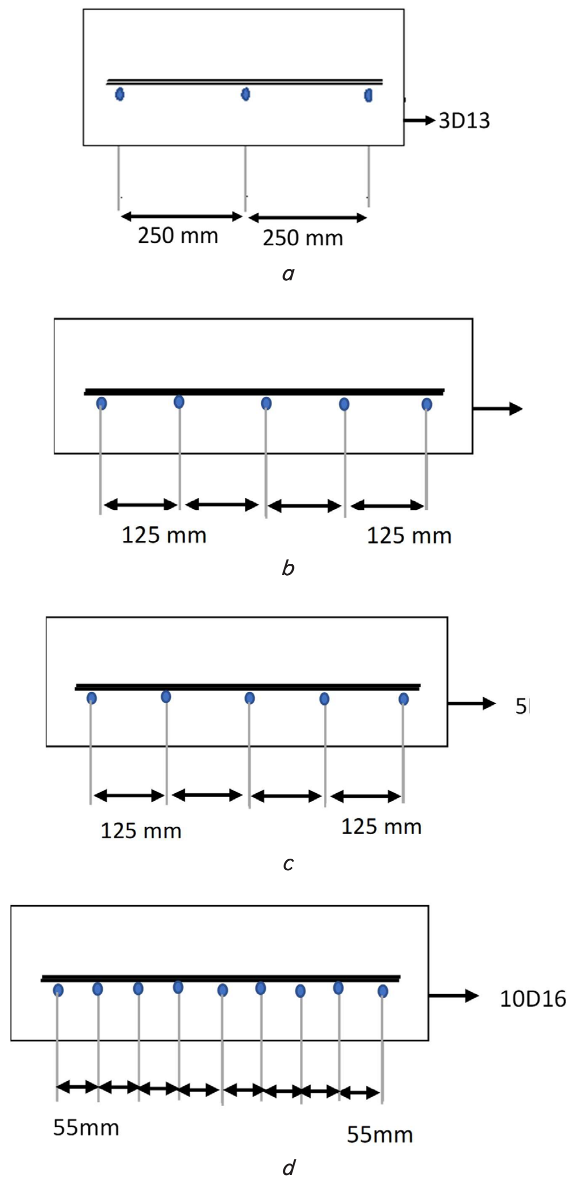

Fig. 2. Reinforcement composition: *a* – variation 1 ($\dot{\rho}=0.004$); *b* – variation 2 ($\dot{\rho}=0.007$); *c* – variation 3 ($\dot{\rho}=0.01$); *d* – variation 4 ($\dot{\rho}=0.02$)

The specimen was placed on 30 cm thick soil as a pedestal. The loading type used a repetitive monotonic static load (cyclic) with a capacity of 200 kN. The loading position was at the centre of the plate, assuming vehicle wheel loading as a line load. The loading position on the specimen as shown in Fig. 3.

Table 2

Variation of reinforcement ratio in specimens

Variation	Unit	1	2	3	4
Number of reinforcement	pieces	3	5	5	10
Diameter of concrete reinforcement	mm	13	13	16	16
Area of reinforced concrete installed	mm^2	398	664	1005	2011
Reinforcement ratio		0.004	0.007	0.01	0.02
$\rho_{min}=\sqrt{f_c/(axf_y)}$		0.0024			
$\dot{\rho}_{max}$		0.025			

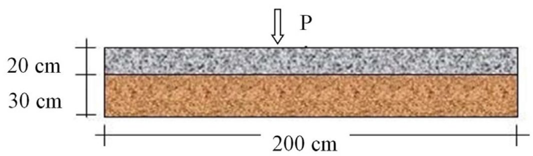

Fig. 3. Loading position in the middle for concrete slabs on the ground

Fig. 3 shows the position of the ground as the base of the test piece, and then the hydraulic load is applied to the test piece, as shown in Fig. 4.

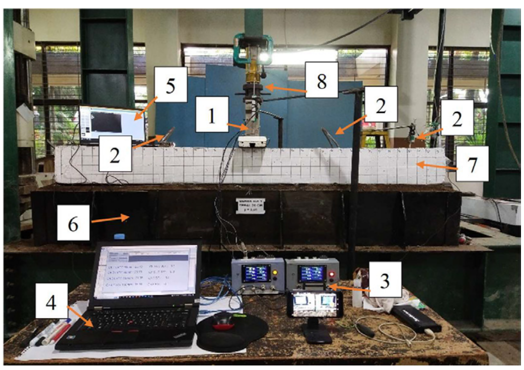

Fig. 4. Experimental setup: 1 – load cell; 2 – LVDT; 3 – logger data; 4 – laptop; 5 – crack detector microscope; 6 – soil in a box; 7 – specimen; 8 – hydraulic jack

Fig. 4 shows the experimental setup, the load is applied to the specimen using a hydraulic jack connected to a load cell, loading the specimen using a hydraulic jack and load cell. The loading range was 2–200 kN, using an LVDT measuring instrument. Strain measurements were taken using a strain gauge attached to the steel reinforcement. The LVDT and strain gauge were connected to a data logger to record the data. To measure the crack width, a crack detector microscope with an accuracy of 0.01 mm was used. The crack width data is directly connected to the computer.

5. Result of reinforcement ratio on crack width in rigid pavement

5. 1. The result of effect of reinforcement ratio on crack width due to load on rigid pavement

Fig. 5 shows the width of the cracks that form in rigid pavement plates because of the load on each plate and the different reinforcement ratios.

In general, the width of the experimental cracks that occur on rigid pavement plates is influenced by the magnitude of the load (P). The greater the load given, the greater the crack width that occurs.

The experimental results of the rigid pavement crack width with variations in the ratio of reinforcement (ρ) as shown in Fig. 5 above are then regressed, and the resulting approach is the formulas (1)–(4):

$$w=0.0026P+0.029 \text{ for } \rho=0.004, \quad (1)$$

$$w=0.0023P-0.0725 \text{ for } \rho=0.007, \quad (2)$$

$$w=0.0014P-0.0461 \text{ for } \rho=0.010, \quad (3)$$

$$w=0.007P-0.0103 \text{ for } \rho=0.020. \quad (4)$$

The crack width in all variations of the reinforcement ratio is in the form of a linear equation. With this formula approach, the crack width of rigid pavement at a certain load can be predicted.

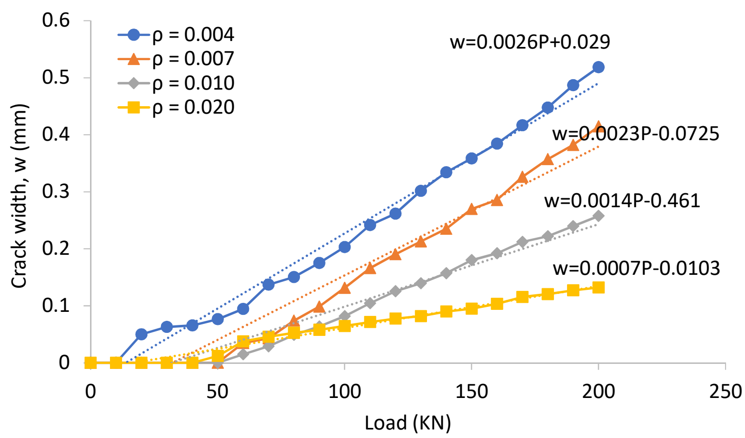

Fig. 5. Relationship between load (P) and crack width (w) due to variations in reinforcement ratio (ρ)

Fig. 5 shows the width of the cracks that happen in all rigid pavement slab samples with different reinforcement ratios. The results show how the reinforcement ratio has an effect on the width of the cracks. The greater the reinforcement ratio (ρ), the smaller the width of the crack that occurs on the rigid pavement plate. The largest crack width occurs in rigid pavement with ρ=0.004, 200 KN load of 0.519 mm. Based on the maximum crack width allowed by ACI Committee 224, which is 0.3 mm, ρ=0.004 occurs at a load of 96 KN, ρ=0.007 occurs at a load of 163 KN, while for ρ=0.01 and ρ=0.02 at a load of 200 KN have not reached the maximum crack width.

5. 2. Result of relationship between crack width and stress due to the effect of reinforcement ratio

Fig. 6 shows the relationship between steel stress (f_s) and crack width (w) for each variation of reinforcement ratio.

Fig. 6 shows the large difference in crack width that occurs due to the influence of the number of reinforcements. The largest crack width occurs on rigid pavement with ρ=0.004, 489 MPa stress of 0.549 mm. At the same crack width, the greater the number of reinforcements, the smaller the stress that occurs. At the same steel stress, the greater the reinforcement ratio, the smaller the crack width that occurs.

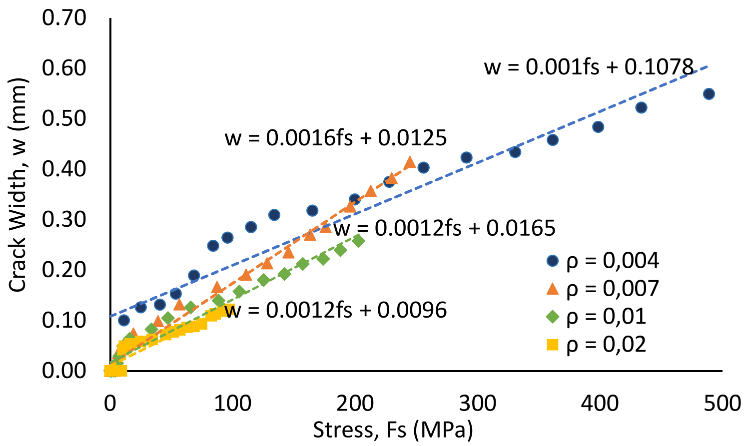

Fig. 6. Relationship between steel stress (f_s) and crack width (w) due to variations in reinforcement ratio (ρ)

The relationship between the experimental results of rigid pavement crack width (w) and steel stress (f_s) in each variation of reinforcement ratio (ρ) is then regressed, and the resulting approach is the equation (5)–(8):

$$w=0.0010f_s+0.1078 \text{ for } \rho=0.004, \quad (5)$$

$$w=0.0016f_s+0.0125 \text{ for } \rho=0.007, \quad (6)$$

$$w=0.0012f_s+0.0165 \text{ for } \rho=0.010, \quad (7)$$

$$w=0.0012f_s+0.0096 \text{ for } \rho=0.020. \quad (8)$$

The crack width in all variations of the reinforcement ratio is in the form of a linear equation. With this formula approach, the crack width of rigid pavement at a certain steel stress (f_s) can be predicted.

5. 3. Result of reinforcement ratio (ρ) influence crack width in reinforced concrete pavement across different road classes

If it is assumed that the loading for class I roads is a maximum loading of 100 KN and for road classes II and III, it is a maximum loading of 80 KN, the results can be seen in Fig. 7, 8.

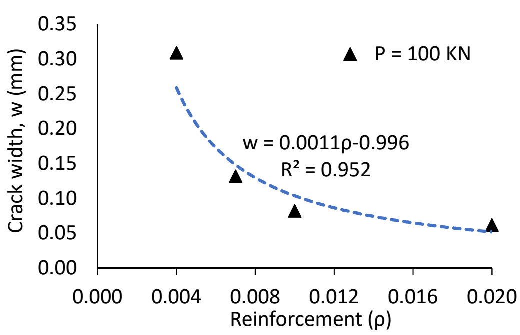

Fig. 7. Relationship between reinforcement ratio (ρ) and crack width (w) at a load of 100 KN

At a load of 100 KN, specimens with ρ=0.004 exhibited a crack width of 0.309 mm, while those with ρ=0.007 had a crack width of 0.132 mm, specimens with ρ=0.010 displayed a crack width of 0.082 mm, and specimens with ρ=0.020 showed a crack width of 0.062 mm. This behavior was approximated using a power equation formula: $w=0.0011\rho-0.996$.

Similarly, under an 80 KN load, specimens with ρ=0.004 had a crack width of 0.264 mm, specimens with ρ=0.007 exhibited a crack width of 0.074 mm, specimens with ρ=0.010 displayed a crack width of 0.069 mm, and specimens with ρ=0.020 showed a crack width of 0.054 mm, approximated by the formula: $w=0.0012\rho-0.921$.

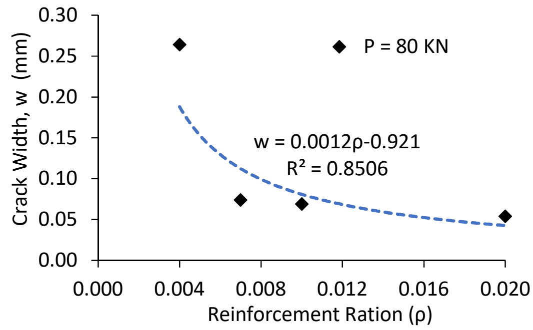

Fig. 8. The relationship between the reinforcement ratio (ρ) and the crack width (w) at a load of 80 KN

For Class I roads, which adhere to the approximation formula $w=0.0011\rho-0.996$, the maximum allowable crack width of $w=0.3$ mm corresponds to a recommended reinforcement ratio of ρ=0.036. On the other hand, for Class II and III roads, following the approximation formula $w=0.0012\rho-0.921$, a maximum crack width of $w=0.3$ mm corresponds to a recommended reinforcement ratio of ρ=0.025. Therefore, these specific reinforcement ratios are suitable recommendations based on the road class while maintaining crack widths within the allowable limits set by ACI Committee 224.

6. Discussion of relationship between applied load and reinforcement ratio to crack width

Fig. 5 shows the relationship between crack width and the applied load magnitude (P) on rigid pavement plates, taking into consideration the influence of the reinforcement ratio (ρ). The experimental observations clearly demonstrate that crack width in rigid pavement plates is directly affected by the magnitude of the applied load (P). Specifically, as the load increases, the crack width also increases. This finding aligns with the well-established understanding in structural engineering that higher loads induce greater stress, resulting in wider cracks. The relationship between load and crack width is of paramount importance in the design and maintenance of rigid pavement systems.

Furthermore, there is a significant impact of the reinforcement ratio (ρ) on crack width. As the reinforcement ratio increases, the crack width decreases. This inverse relationship underscores the role of reinforcement in enhancing the structural integrity of rigid pavement. Higher reinforcement ratios enhance resistance to cracking, which is a desired outcome for pavement durability.

Based on regression analysis of the experimental results, valuable predictive equations have been derived that describe the relationship between crack width (w), applied load (P), and reinforcement ratio (ρ). There is a linear relationship between crack width and the reinforcement ratio across all tested variations. This linear behavior simplifies the prediction process and underscores the reliability of the regression models. It implies that for every increase in the reinforcement ratio, a consistent decrease in crack width can be expected, making it an easily manageable factor in pavement design.

Furthermore, the importance of selecting an appropriate reinforcement ratio to ensure that rigid pavement structures meet or exceed industry standards for crack width is emphasized. Specifically, it is critical to ensure that the maximum crack width allowed by industry standards is not exceeded. This contributes to the overall longevity and performance of rigid pavements.

Fig. 6 shows a significant difference in crack width resulting from variations in the reinforcement ratio (ρ) within rigid pavement. The largest crack width is observed in rigid pavement with a reinforcement ratio of ρ=0.004, where the crack width reaches 0.549 mm at a steel stress of 489 MPa. This finding aligns with the common understanding that a lower reinforcement ratio tends to lead to wider cracks. As ρ decreases, the ability to inhibit crack formation and propagation diminishes, resulting in wider cracks under the same conditions.

Furthermore, the data shows that at the same crack width, an increase in the number of reinforcements corresponds to a reduction in the applied stress. This observation indicates that a higher density of reinforcements within the rigid pavement structure can distribute and mitigate stress more effectively, resulting in lower tensile stresses and, consequently, narrower cracks. This correlation emphasizes the importance of reinforcement not only in reducing crack width but also in reducing the magnitude of stress that occurs within the pavement.

The research results also demonstrate that crack width is influenced by the applied steel stress (f_s) within the pavement. As steel stress increases, crack width also increases. This finding aligns with fundamental principles of material science and structural mechanics, where higher stress levels lead to greater deformations and wider cracks. Additionally, the relationship between crack width and steel stress remains linear across all tested variations of the reinforcement ratio. This consistency simplifies the prediction process and underscores the reliability of the linear regression models, implying that, regardless of the reinforcement ratio used, the relationship between crack width and steel stress follows a consistent pattern, facilitating easier predictions.

Fig. 7, 8 shows the crack widths under various load conditions (100 KN and 80 KN) and the corresponding influence of reinforcement ratios (ρ), which can be elucidated by the dynamic interplay of these factors. At a 100 KN load, it is evident that higher reinforcement ratios, such as ρ=0.020, effectively confine crack widths to 0.062 mm due to their superior ability to withstand tensile stresses. Conversely, at an 80 KN load, the impact of reinforcement ratios on crack width is less pronounced, resulting in relatively smaller differences in crack widths among various ρ values. The specific reinforcement ratios recommended for particular road classes (ρ=0.036 for Class I and ρ=0.025 for Classes II and III) align with these findings, ensuring that crack widths remain within acceptable limits established by ACI Committee 224. These results depict the intricate relationship between reinforcement ratios, load conditions, and crack width, offering valuable guidance for designing reinforced concrete pavements tailored to specific road classes while maintaining structural integrity and safety.

The particularity of this method lies in conducting the test using a plate placed directly on the ground (with spring support) which differs from approaches that apply a plate on two supports [22, 26, 27].

The limitation of this study is to rigid pavements, specifically Jointed Reinforced Concrete Pavement (JRCP), using concrete with a characteristic compressive strength (f_c) 30 MPa. The investigation involved behavioral analysis of JRCP slabs subjected to various support conditions based on variations in California Bearing Ratio (CBR). The crack analysis assumed plane stress conditions. The study aimed to observe and determine the relationship between the applied load and the deflection of the slab, as well as measure the strain, stress distribution, crack pattern, crack width, crack spacing, and crack propagation. Crack width measurements were taken from the sides of the slab, assuming uniform crack width distribution from one side to the other. In addition, this study did not take into account the effects of concrete shrinkage and slab rotation in its analyses.

The weakness of this study is that the test was conducted by applying a monotonous static load in the form of a line load at the centre of the distance, without considering traffic-related loads such as wheel loads, impact loads, and braking loads.

The results of this study provide recommendations regarding the reinforcement ratio that can be used according to the road class. This can serve as a basis for improved design and construction of roads that are more resistant to cracking. Meanwhile, the results of this study can be used as a basis for further research in the field of road structure and reinforcement. Further experimental testing or more detailed mathematical analyses can be used to confirm and extend these findings. However, the quality of concrete and steel materials, as well as variations in the field, may be factors that affect the experimental results. Managing this variability may be a challenge in this research.

7. Conclusions

1. The crack width (w) on rigid pavement is affected by the reinforcement ratio (ρ). At the same load, the greater the number of reinforcements (ρ), the smaller the crack width (w) of rigid pavement. Judging from the magnitude of the steel stress (f_s), at the same crack width, the greater the number of reinforcements (ρ), the smaller the stress that occurs. At the same steel stress, the greater the reinforcement ratio, the smaller the crack width that occurs.

2. The largest crack width occurs in rigid pavement with ρ=0.004, 210 KN load of 0.519 mm. The width of the crack that occurs in all variations of the reinforcement ratio is a linear equation. With this formula approach, the crack width of rigid pavement at certain steel loads and stresses can be predicted. Crack width between experiments with different codes resulting in different results. At a small reinforcement ratio (ρ=0.004) the results are close to the average crack width resulting from the rule

formula. And at a large reinforcement ratio (ρ=0.01) the results are farther from the crack width based on the formula in the codes.

3. At a load of 100 KN (Class I road), with the approximation formula $w=0.0011\rho^{-0.996}$ at a maximum crack width of w=0.3 mm, the reinforcement ratio will be obtained ρ=0.036 and at a load of 80 KN (Class II and III roads), with the formula approximation $w=0.0012\rho^{-0.921}$ the reinforcement ratio ρ=0.025. So, this reinforcement ratio can be recommended to be used according to the road class.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

Manuscript has no associated data.

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