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REVIEW ON EXAMINING CRACK WIDTHS AND DISTRIBUTION ACROSS THE SLAB

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Abstract

Developing and validating models that predict crack behavior in steel–concrete composite beams under fatigue loading. By incorporating the spacing of transverse reinforcement into the existing equations, the proposed formula offers a more realistic estimation of average crack spacing. This improvement could potentially enhance the accuracy of structural performance assessments. The beam–slab and reinforcement–concrete interface behaviors are critical under repeated loading. The model integrates fatigue behavior, a significant aspect for structural longevity, making it suitable for applications involving repetitive stress. The results derived from the model rely on efficient numerical methods, which ensure the practicality of the approach. These models can be highly beneficial for engineers in designing safer and more efficient composite structures by accurately predicting crack propagation and ensuring serviceability over the beam's lifespan. The experimental tests you conducted add substantial credibility to your models, as they show the real-world applicability of the numerical and analytical predictions.

Keywords: Crack behavior, Transverse reinforcement, Beam–slab and reinforcement, composite structures, serviceability

Introduction

In concrete structures, cracks form when the tensile stresses surpass the tensile strength of the concrete. Concrete inherently has low tensile strength and is much more effective in compression. Hence, when a concrete element, such as a beam, is subjected to tensile forces, the concrete first attempts to resist these stresses. However, once the tensile capacity is exceeded, the concrete cracks, and the reinforcement steel takes over to carry the tensile loads.

This behavior is fundamental to the design of reinforced concrete structures. The steel reinforcement is placed strategically to handle the tensile forces and prevent the concrete from failing. The interaction between concrete and steel ensures that the structure maintains integrity, with the steel reinforcing bars providing the necessary ductility and tensile strength. Proper design and placement of reinforcement are crucial to minimize crack widths and control the cracking behavior of concrete.

Otto Terjesen et al (2024) this study investigates the performance of various crack width prediction models, highlighting the Modified Tension Chord Model (MTCM) as a significant advancement. A substantial dataset, consisting of 203 experimental crack width measurements from reinforced concrete (RC) members under bending and tension, was analyzed. The evaluation of these models included upcoming formulations and validation against the database, emphasizing the modeling uncertainty through comparison with experimental data using a log-normal distribution.

The findings reveal that the fib Model Code 2010 and MTCM yielded the most accurate predictions. Notably, MTCM stands out due to its minimal mechanical simplifications and the absence of empirical adjustments, unlike Eurocode 2 and other Model Code approaches. While Eurocode 2 and the original Model Code are practical for standard dimensioning tasks and offer a decent level of accuracy, the MTCM presents a more refined, physically grounded prediction without relying on data-specific fitting. The study emphasizes that the MTCM could form a foundational framework for the future development of crack width models, with the potential for broad application across various structural scenarios.

Asvitha Valli S et al (2023) cracking in concrete structures is indeed a major area of concern as it directly affects the structural integrity and durability of buildings. The formation of cracks and cavities not only compromises the load-bearing capacity but also poses significant risks to the waterproofing and overall tightness of the structure, potentially leading to long-term failures if left untreated. Mechanisms behind Concrete Cracking Understanding the mechanics of concrete cracking is essential for developing effective prevention methods. Here’s a deeper look into the phenomena. The field continues to evolve, with cutting-edge studies exploring new materials and technologies to enhance the performance and longevity of concrete structures. These advancements reflect a concerted effort to address the vulnerabilities associated with cracking, ultimately leading to safer and more durable infrastructure.

Plastic Shrinkage Cracking:

Occurs when concrete is still in its plastic state, typically within the first few hours after placement. Caused by rapid moisture loss due to evaporation, which can be faster than the bleeding rate, leading to tensile stresses on the surface. Influencing factors include high temperatures, low humidity, wind speed, and insufficient curing.

Plastic Settlement Cracking:

Arises when the heavier components of concrete, such as aggregates and cement, settle, and the lighter components, like water, rise to the surface (bleeding). If settlement is obstructed by reinforcement bars or formwork, cracks can form over these obstructions.

Capillary Action and Surface Finishing:

Excessive surface finishing when concrete is still bleeding can weaken the surface layer. Capillary pressure changes also contribute to the tensile stress development, influencing crack formation. Techniques to Mitigate Cracking Several preventive techniques have been explored to address plastic cracking, focusing on reducing moisture loss and enhancing the tensile properties of early-age concrete:

Fogging and Surface Moisture Control:

Maintaining a high humidity environment around the fresh concrete through fog sprays or misting reduces the rate of moisture evaporation. Applying curing compounds that form a protective film on the surface helps retain moisture.

Using Fewer Fine Particles:

Optimizing the mix design to minimize the content of fine particles can help reduce the shrinkage potential. A well-graded aggregate mix ensures a denser and more uniform concrete matrix, reducing the risk of cracking.

Incorporation of Fibers:

Adding synthetic or steel fibers to the concrete mix enhances the tensile strength and ductility of the material. Fibers act as micro-reinforcement, controlling crack propagation and improving the crack resistance of the concrete. Ongoing research has introduced several advanced techniques for crack prevention and monitoring:

Self-Healing Concrete: Incorporating bacteria or encapsulated healing agents that activate in the presence of water to seal cracks autonomously.

Smart Concrete: Embedding sensors within the concrete to monitor real-time stress, temperature, and moisture variations, providing valuable data for structural health monitoring.

Use of Admixtures: Developing shrinkage-reducing and superabsorbent polymer admixtures that mitigate plastic and drying shrinkage.

Fragkoulis Kanavaris et al (2023) a critical review of the mechanisms and impacts of reinforcement corrosion in concrete structures, with a focus on chloride-induced corrosion. The emphasis on understanding the relationship between crack width and corrosion progression is particularly relevant to assessing and enhancing durability in reinforced concrete. Here's an elaborated summary of the key points you are likely examining:

Chloride-Induced Corrosion: This is one of the most studied corrosion mechanisms affecting reinforced concrete. Chlorides can penetrate concrete through cracks, reducing the protective alkalinity surrounding the steel reinforcement and initiating corrosion. Your review likely discusses the factors influencing chloride penetration, including concrete quality, environmental exposure, and crack characteristics.

Carbonation-Induced Corrosion: Though briefly discussed, carbonation-induced corrosion occurs when carbon dioxide from the air reacts with the calcium hydroxide in concrete, lowering the pH and compromising the passivity of the reinforcement. This mechanism is usually slower than chloride-induced corrosion but is still a significant durability concern, especially in urban environments.

Crack Width and Corrosion: The limitation of crack width is a common prescriptive measure used to prevent significant corrosion. Your research likely analyzes the effectiveness of different crack width limits in mitigating corrosion risk, along with the existing research findings on how crack size and distribution impact corrosion rates.

Guidelines and Standards: Your paper also explores various international guidelines and standards developed to manage and limit corrosion risks in reinforced concrete structures. These may include codes that specify maximum allowable crack widths, concrete cover thicknesses, and material quality requirements to ensure durability.
This review is significant as it systematizes current knowledge and provides a basis for developing improved corrosion prevention and control strategies in reinforced concrete, emphasizing both service life and structural performance.

David Z. Yankelevsky et al (2022) discussing an advanced theoretical framework for predicting crack behavior in reinforced concrete structures, with a particular emphasis on bridge applications. This method involves an analytical approach that accurately accounts for the interplay between concrete and reinforcement through principles like equilibrium, constitutive laws, and kinematic relationships. Here’s a breakdown of the approach. This analytical approach can be extremely beneficial for designing durable and efficient reinforced concrete structures, providing insights into crack propagation and control strategies that are vital for maintaining structural integrity and serviceability over time. Let me know if you’d like more details on any specific aspect, such as the closed-form expressions or the assumptions behind the bond-slip model.

Crack Width Analysis: The proposed method allows for an accurate calculation of crack widths, which are crucial for structural performance, especially in critical infrastructures like bridges. By using closed-form expressions, this method can immediately yield results like. The cracking load levels. The relationship between crack width and applied load. The number and spacing of cracks

Interfacial Bond Stress-Slip Model: A linear bond stress-slip relationship is adopted to represent the behavior at the interface between the concrete and reinforcement. This approach focuses on small slips that are consistent with limited crack widths, ensuring a realistic simulation of tension-stiffening effects.

Nonlinear Force-Displacement Relationship: The method can describe the entire nonlinear force-displacement behavior of a reinforced concrete element once cracks develop. It models the tension-stiffening phenomenon, which illustrates how concrete between cracks contributes to the overall stiffness of the element even after initial cracking.

Tension-Stiffening Effect: The method captures how tension-stiffening varies as the crack width evolves under increasing load. This is a crucial aspect for structural analysis, as it influences the overall deformation and load-bearing behavior of the structure.

Validation with Experimental Data: The model's accuracy has been validated against experimental results, showing very good agreement. This indicates the method's reliability for practical applications and highlights its potential as a tool for both design and assessment of reinforced concrete structures.

Seyed Vahid Razavi Tosee et al (2022) this research investigates the use of a hybrid Grey Wolf Optimizer (GWO) Neural Network Model to predict the crack width in reinforced concrete (RC) slabs strengthened with carbon fiber-reinforced polymers (CFRP). The study focuses on RC one-way slabs of dimensions 1800 × 400 × 120 mm, strengthened with CFRP sheets of varying lengths (1800 mm, 1100 mm, and 700 mm), which were subjected to four-point bending tests. The goal was to compare the crack behavior of CFRP-strengthened slabs with conventional RC slabs.

Crack Width Reduction: The experimental results indicated a reduction in crack width with increasing CFRP length and width. Slabs retrofitted with CFRP laminates experienced a notable decrease in maximum crack width at the tensile zone during final load steps.

Effectiveness of CFRP: The strengthened slabs showed an approximately 80% increase in resistance to crack width compared to strengthened RC slabs, demonstrating the efficacy of CFRP in enhancing crack control.

Eurocode 2 Assessment: When comparing the observed crack widths to predictions based on Euro code 2, the findings revealed that Euro code 2's crack width estimates were conservative for CFRP-strengthened slabs, underlining the need for improved or alternative design approaches for retrofitted structures.

Hybrid Model Performance: The integration of an Artificial Neural Network (ANN) with the Grey Wolf Optimizer algorithm proved effective in predicting crack widths. The model incorporated several input parameters, including applied load, CFRP dimensions, crack positions, and stresses in steel reinforcement and concrete, to achieve reliable and accurate estimations.

Implications for Design and Rehabilitation.These results are valuable for the structural engineering community, offering insights into the behavior of CFRP-strengthened RC slabs and the limitations of existing design codes like Eurocode 2. The hybrid GWO-ANN model presents a promising tool for predicting crack widths, aiding in the design and retrofitting of deficient RC structures with CFRP for improved performance and safety.

Mikael Basteskår et al (2019) This paper provides a comprehensive review of the literature concerning the design of reinforced concrete structures under serviceability limit state (SLS) conditions, with a particular focus on controlling crack development. The emphasis is on "controllable cracks," which refer to cracks resulting from imposed loads or deformations on hardened concrete, or from restrained volume changes in young hardening concrete—cracks that structural engineers can reasonably predict and mitigate.

The study highlights the need for a more systematic and consistent approach in SLS design, especially in distinguishing between crack width requirements for different purposes, such as aesthetics, durability, and structural tightness. It suggests that current design codes should more clearly define durability-related terms and differentiate between various requirements. Moreover, the paper critiques the existing methodologies used in leakage and tightness prediction formulas, indicating a need for re-evaluation and improvement based on current research findings. It also discusses the potential benefits of distinguishing crack width variations across the cross section of concrete elements, which could lead to more refined and reliable crack width control. The paper concludes with recommendations for improving code requirements to enhance the serviceability and longevity of reinforced concrete structures.

Nawir Rasidi et al (2015) the research you've summarized provides valuable insights into the analytical modeling and crack width prediction in reinforced concrete one-way slabs. Here's a more detailed breakdown of the key points:

Crack Width Prediction and Variables: The investigation highlights the inconsistency among researchers in identifying the most significant variables affecting crack width. Various formulas use different sets of variables, underscoring a lack of consensus despite extensive experimental research.

Analytical Method: An analytical approach was developed to better understand concrete stress distribution near flexural cracks. This method focuses on reinforced concrete one-way slabs, specifically studying how different factors influence the spacing and width of cracks.

Curvature Calculations: The formula used in the study was developed based on numerous curvature values, which were determined from concrete and steel strain measurements at sections between adjacent cracks. The analysis involved a variety of composite precast deck slabs, and curvature values were calculated empirically to model the behavior between successive cracks.

Tension Stiffening Effect: The research method incorporates the tension stiffening effect—an important phenomenon where the presence of tensile reinforcement restrains crack openings, affecting the overall stiffness of the composite section. The proposed formula's effectiveness was verified through a comparison of the calculated fracture mechanics with experimental results from other studies.

Deflection Predictions: Using the developed formula, short-term deflections were predicted for numerous flexural members. These predictions were compared with measured deflections reported in the literature, and the findings suggested that the approach for incorporating tension stiffening into fracture mechanics was valid.

The study emphasizes the significance of incorporating tension stiffening in analytical models to predict deflections and crack widths in reinforced concrete structures. By using an empirical formula based on curvature values from concrete and steel strains, the research contributes to a more reliable method of predicting structural behavior in flexural members. Despite these advancements, the ongoing variability in crack width prediction methods highlights the need for further research and refinement.

Nawir Rasidi et al (2013) this research aims to predict crack width in precast composite deck slabs subjected to cyclic or repeated loading. The study addresses the ongoing challenge in crack width prediction, where existing formulas vary widely in terms of the variables considered and their relative significance. Even with extensive experimental work in the past, there has not been a consensus on a unified method. The research introduces an analytical approach to assess stress distribution near flexural cracks in reinforced concrete one-way slabs. It investigates the impact of various parameters on crack spacing and width, utilizing a formula derived from a tri-linear model. This model is based on the calculated strains in concrete and steel at sections between cracks for composite precast deck slabs.

Analytical Method: The method incorporates concrete stress distribution and the tension stiffening effect to predict crack characteristics.

Tri-Linear Model: This model is used to calculate strains in concrete and steel, serving as the basis for the empirical formula developed.

Validation: The formula is verified by comparing the calculated crack characteristics and fracture mechanics results with those from existing research. The comparison supports the accuracy and reliability of the method.

Tension Stiffening: The study effectively includes tension stiffening in the fracture mechanics calculations, enhancing the prediction of crack width and distribution.

The research provides a more refined prediction method for crack width, validated through comparisons with experimental data from other researchers. The proposed approach offers an acceptable means of incorporating tension stiffening effects in precast composite deck slabs, contributing to the field of structural analysis and design.

METHODOLOGY

Introduces an innovative method to measure average crack width in concrete structures under bending. The approach leverages a monitoring system that utilizes distributed optical fibers, extending the existing method described in Rodriguez et al. The study provides a detailed explanation of how this optical fiber-based technique can effectively assess crack width. Furthermore, it validates the results by comparing them with other experimental methods and finite element modeling (FEM), ensuring a comprehensive and reliable evaluation, including analysis of the compression zone.

To obtain the average crack width, the formulation you are referring to involves integrating the strain distribution over a characteristic length LLL. Here is a conceptual overview of the formulation process:

Strain Distribution: is measured along the concrete surface. The characteristic length LLL is defined as the length over which the strain exceeds the strain corresponding to the tensile strength of the concrete. This criterion identifies the region affected by cracking.

Tensile Strength Strain This is the strain at which the concrete first cracks under tensile loading. Beyond this strain, cracks start to develop in the material.

Integration for Average Strain To calculate the average strain integrate the strain distribution over the cracked length LLL. The average strain represents the deformation over this length, which is related to the opening of the crack.

CONCLUSION

The study begins by summarizing current formulas and test data related to average crack spacing. A new formula for crack spacing is derived by incorporating the impact of transverse reinforcement spacing. Non-linear fitting methods are employed to adjust the formula and make it more accurate. The model accounts for fatigue loading effects in negative moment regions. It incorporates explicit formulations for slip at the beam–slab interface and the reinforcement–concrete interface. The model also considers stress distribution in the cracked section of the reinforcement. Experimental fatigue tests on two steel–concrete composite plate beams under hogging moment conditions are conducted. The results of the tests are then used to validate the numerical model. The numerical model provides more accurate crack width predictions compared to existing methods, aligning well with experimental data. This approach aims to enhance the understanding and prediction of crack behavior in composite beams, especially under fatigue conditions, which is crucial for long-term performance and safety evaluations.

REFERENCES

1. Otto Terjesen, Gianclaudio Pinto, Terje Kanstad, Reignard Tan “Performance study of crack width calculation methods according to Eurocodes, *fib* model codes and the modified tension chord model’ First published: 08 February 2024 https://doi.org/10.1002/suco.202300367 Citations: 2

2. Fragkoulis Kanavaris, Mário R. F. Coelho, Nuno Mesquita Ferreira “A review on the effects of cracking and crack width on corrosion of reinforcement in concrete” August 2023 Structural Concrete 24(6) DOI 10.1002/suco.202300227.

3. Asvitha Valli S [a], Ravi Kumar M S “Review on the mechanism and mitigation of cracks in concrete” Applications in Engineering Science Volume 16, December 2023, 100154 https://doi.org/10.1016/j.apples.2023.100154

4. David Z. Yankelevsky * , Yuri S. Karinski and Vladimir R. Feldgun “Analytical Modeling of Crack Widths and Cracking Loads in Structural RC Members” Infrastructures 2022, 7, 40. https://doi.org/10.3390/infrastructures7030040 https://www.mdpi.com/journal/infrastructure.

5. Seyed Vahid Razavi Tosee 1 , Iman Faridmehr 2 , Moncef L. Nehdi 3,* , Vagelis Plevris 4 and Kiyanets A. Valerievich “Predicting Crack Width in CFRP-Strengthened RC One-Way Slabs Using Hybrid Grey Wolf Optimizer Neural Network Model” Buildings 2022, 12, 1870. https://doi.org/10.3390/buildings12111870 https://www.mdpi.com/journal/buildings.

6. Mikael Basteskår, Morten Engen, Terje Kanstad “A review of literature and code requirements for the crack width limitations for design of concrete structures in serviceability limit states” January 2019 Structural Concrete 20(4) DOI: 10.1002/suco.201800183.

7. Nawir Rasid “Maximum Crack Width Prediction in Deck Slab Concrete Structure” IPTEK, Journal of Proceeding Series, Vol. 1, 2014 (eISSN: 2354-6026) 1 Nawir Rasidi is with Departement of Civil Engineering, Politeknik Negeri Malang, Indonesia. E-mail: abunawir@yahoo.co.uk

8. Nawir Rasidi, Agoes Soehardjono MD, Achfas Zacoeb “Prediction of Crack Width in Panel Composite Deck Slab Under Repeated Loading” Australian Journal of Basic and Applied Sciences, 7(10): 112-118, 2013 ISSN 1991-8178 Nawir Rasidi, Department of Civil Engineering, Brawijaya University and State Polytechnic of Malang, East Java 65145, Indonesia E-mail: abunawir@yahoo.co.uk

9. https://fprimec.com/3-methods-crack-depth-measurement-in-concrete/

10. Liu Y and Nayak S. Structural Health Monitoring: State of the Art and Perspectives. JOM, Vol. 64 No.7, 2012.Published on line July 10, 2012.

11. Coronelli D, Hanjari K.Z and Lundgren K. Severely Corroded RC with Cover Cracking. Journal of Structural Engineering. ASCE pp 221-232, February 2013.

12. Casas JR and Cruz JS. Fiber Optic Sensors for Bridge Monitoring. ASCE Journal of Bridge Engineering, 8 (6), pp 362-373, November/December 2003.

13. Culshaw B. Fiber Optic Sensors in Smart Structures: Achievements, Challenges and Prospects. SPIE Vol. 7982. Smart Sensor Phenomena, Technology, Networks and Systems. 798202-1 798202-9, 2011.