FINITE ELEMENT ANALYSIS OF REINFORCEMENT DESIGN OF VOIDED CONCRETE DECK SLAB

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I/We* hereby declare that I/We* have checked this thesis/project* and in my/our* opinion, this thesis/project* is adequate in terms of scope and quality for the award of the Bachelor Degree of Civil Engineering

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I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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ABSTRACT

Voided concrete deck slab is one of the options for concrete bridge deck design. The most common problem that a deck slab will usually face is that the numbers of reinforcement provided are not sufficient to sustain the load with the increased number of vehicles. Therefore, it is necessary to check whether the reinforcement is adequate to sustain the loads. Unfit or improper design can lead to the failure of a structure. A model of voided concrete deck slab was analysed by manual calculation and also designed in ANSYS software. There are several methods can be used to analyse the behaviour of voided concrete deck slab. However, among all these methods, finite element method and probabilistic method will be a very effective method to obtain the strength and behaviour of voided concrete deck slab. This analysis is to investigate the adequacy of reinforcement bar in a concrete bridge deck slab and also to determine the response behaviour of voided concrete deck slab. This research will mainly focus on the reinforcement and the probabilistic analysis of a voided concrete deck slab. The length of deck slab that will be tested is 20m. The values for the input variables are generated randomly by using Monte Carlo Simulation with given mean values and standard deviation or as prescribed samples using Response Surface Method. 10000 simulations had been made to make sure the analysis values obtained are more precise and uniform. Here, the study was conducted to prove that a voided concrete deck slab under the existence of randomness and uncertainty can be analyzed quickly and efficiently by applying probabilistic finite element analysis using ANSYS.

ABSTRAK

Papak geladak konkrit beruangan adalah salah satu pilihan untuk reka bentuk dek jambatan konkrit. Masalah yang paling lazim dihadapi oleh dek jambatan konkrit ialah bilangan tetulang yang disediakan tidak dapat menampung mbeban dengan peningkatan jumlah kenderaan. Oleh itu, adalah wajib untuk memeriksa sama ada tetulang adalah mencukupi untuk mengekalkan beban. Reka bentuk yang tidak sesuai atau tidak wajar boleh menyebabkan kegagalan sesuatu struktur. Model papak geladak konkrit beruangan telah dianalisis dengan pengiraan manual dan juga direka dalam perisian ANSYS. Terdapat beberapa kaedah yang boleh digunakan untuk menganalisis kelakuan papak geladak konkrit beruangan. Walau bagaimanapun, di antara semua kaedah ini, kaedah elemen terhingga dan kaedah probabilistik akan menjadi kaedah yang sangat berkesan untuk mendapatkan kekuatan dan tingkah laku papak geladak konkrit beruangan. Analisis ini adalah untuk mengkaji kecukupan bar tetulang dalam papak dek jambatan konkrit dan juga untuk menentukan kelakuan tindak balas papak geladak konkrit beruangan. Kajian ini akan memberi tumpuan kepada pengukuhan dan analisis kebarangkalian papak geladak konkrit beruangan. Panjang papak dek yang akan diuji ialah 20m. Nilai-nilai bagi pemboleh ubah input dijana secara rawak dengan menggunakan Simulasi Monte Carlo dengan nilai minimum dan sisihan piawai atau sampel yang ditetapkan menggunakan Kaedah Surface Response. 10000 simulasi telah dibuat untuk memastikan nilai analisis yang diperoleh lebih tepat dan seragam. Di sini, kajian ini dijalankan untuk membuktikan bahawa papak geladak konkrit beruangan di bawah kewujudan rawak dan ketidakpastian boleh dianalisis dengan cepat dan cekap dengan menggunakan analisis elemen terhingga probabilistik menggunakan ANSYS.

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LIST OF SYMBOLS

b	width
d	effective depth of section
h	height
r	radius
α_{cc}	coefficient of long term effects on compressive strength
β	centroid ratio
f_{yk}	characteristic yield stress of the reinforcement
f_{av}	average stress
A_s	area of steel reinforcement
F_s	force of steel
M_{Rd}	moment equilibrium
γ_s	partial safety factor for steel
γ_c	partial safety factor for concrete
∅	diameter
π	pie
x	distance
E_s	Modulus of Elasticity
ε_{cu2}	ultimate concrete compressive strains
$>$	greater than
$<$	lesser than

LIST OF ABBREVIATIONS

2D	Two Dimensional
3D	Three Dimensional
BBH	Distance between Holes
BBOT	Bottom Width
BCNL	Bridge and Civil Non Linearities
BM	Middle Width
BTOP	Top Width
BS	British Standard
CDF	Cumulative distribution function
CivilFEM	Civil Finite Element Method
DOF	Degree of Freedom
DS_OK	Designed OK
EC2	Eurocode 2
ELM_OK	Elements OK
E View	Elevation View
FEM	Finite Element Method
GAUS	Gaussian
LS	Load Step
MP	Mileage Point
MZ	Moment at Z Direction
NADD	Addition of a Fixed Number of Start States
NH	Number of Holes
Num	Number
PDS	Probabilistic Design System
PDF	Probabilistic Density Function
PlotCtrls	Plot Controls
P View	Plan View
REINFACT	Reinforcement Factor
ROTX	Rotation about X
SELECTVC	Selection with Variable Coefficients
SS	Sub Step
TBOT	Bottom Thickness
TM	Middle Thickness
TTOP	Top Thickness

CHAPTER 1

INTRODUCTION

1.1 Background

Voided concrete bridge decks are reinforced concrete slabs in which voids allow the whole bridge structure to reduce the volume of concrete used. A hollow biaxial slab with the same capabilities was to be created and replaced a solid slab, but with considerably less weight due to the elimination of excess concrete. (Ashish et. al 2016)

A simple model of voided concrete deck slab will be proposed and modeled by the software ANSYS, then finite element calculation were carried out through the software to obtain the deflection, stress and strain of the deck slab. All these analysis were based on finite element method. Probabilistic analysis will be carried out by changing the input parameters to find out which affect the slab effectively.

Finite element analysis is to replace the complicated problems with relatively simple problems and then solving. Since most practical problems difficult to get the accurate solution, and the finite element calculation not only high precision, but also can adapt to various kinds of complicated shapes, and therefore become an effective means of. However, in recent years, usage of finite element analysis had amplified due to advancement of expertise and abilities of computer software and hardware. (Ismail et.al, 2011) It has now become an effective mean for engineering analysis of concrete structural components. Elements can be modeled faster and with more precision.

1.2 Problem Statement

Even with the complex and advanced technology of pre-stressing and post-tensioning of the construction method of concrete bridges, the most common problem that will usually face is that the number of reinforcement provided with the increased number of vehicles regardless the vehicle size as the population growing bigger with time. The concrete bridge constructed will be having some allowance of loading imposed to solve problem like increase of number of vehicles. Therefore, in this study,

it is important to check whether the existing concrete bridge deck slab will be able to sustain the increase number of vehicles (Load) in the coming year.

As mentioned, the increased of population will eventually increase density of vehicles on the road. With this, the existing bridges will eventually responsible to carry the loading from vehicles to the deck slab. The reinforcement in the deck slab will only able to carry extra loading to some extent, but the loading increased is not an immediate problem, there will be a problem in coming years as the population keep growing; therefore by checking the adequacy of reinforcement on the concrete deck slab will be able to know the ability of the deck slab to carry the loading before transferring the load to the concrete piers.

. Unfit or improper design can lead to the failure of a structure. There are several methods can be used to analyzes the behavior of voided concrete deck slab. However, among all these methods, finite element method will be a very effective method to obtain the strength and behavior of the structure.

Most of the times, engineers need to find out an accurate data of deflection and stress for the structure before he start design. A lot of time had been wasted for that works. By applying the probabilistic analysis, a range of result can be obtained by inputting the load. So, engineers works can be reduced and save more time for others.

1.3 Objectives

Research objectives are an important part for every project or thesis in order to conduct the research well. It acts as guidance for researcher to achieve the final objective and avoid researcher to digress. Objectives are also important for researcher to understand and remind themselves of the criteria and testing that should be done in a research. The main objectives of this research are:

i. To investigate the adequacy of reinforcement bar in a voided concrete deck slab.
ii. To determine the force and moment and deflection on voided concrete deck slab using ANSYS software.
iii. To carry out probabilistic analysis of voided concrete deck slab

1.4 Scope Of Study

By doing the checking on the reinforcement of the concrete deck slab of the bridge, the adequacy of the reinforcement will be checked for bar size of 32mm and the span 20m. Furthermore, along the span the opening or void will be situated at three places with two at both ends and one at the middle. In addition, the loading that will be considered will be only consisting of deck slab self-weight, dead load and surface load along the deck slab.

Therefore, by considering the above aspect in the ANSYS analysis will eventually get some result which either to be adequate or failed in future used of the flow of traffic along the concrete bridge. Reinforcement Factor will be produce if the code checking fail and the reinforcement specification or the size of element will be changed. The checking will be done again. With this, the analysis will enable the designer to quickly determine a more suitable and economical reinforcement design quicker and more accurate during design stage.

Finite element method (FEM) models were developed to simulate the behavior of voided deck slab from linear through nonlinear response and up to failure, using the ANSYS program. Modeling simplifications and assumptions developed during this research are presented.

The probabilistic analysis approach is applied to account for the variability in fabrication. Probabilistic methodology applied in finite element analysis provides another alternative ways of structural analysis of voided deck slab to achieve a robust and reliable design in a most efficient way. The following list divides the approach to achieve the research objectives into specific tasks. The tasks comprising the research program are:

i. To produce a reinforcement specification that passed the code checking.

ii. Conduct Monte Carlo simulation and Response Surface simulation to analyse the effect of parameter uncertainty for the voided deck slab.

REFERENCES

Ashish K. D. et. al 2016. Voided Slab Design: Review Paper. 2016 3rd International conference on Multidisciplinary Research & Practice. Maharashtra, India.

Brand, A.S. and Roesler, J. R., 2014. Finite element analysis of a concrete slab under various non-uniform support conditions. International Journal of Pavement Engineering. 15(5):460-470. https://doi.org/10.1080/10298436.2013.837463 (20 Sep 2013)

Chen, Z. and Zhou, Y. 2011. Dynamic analysis of hinge joint voided slab wide bridge. Abstract. 2011 International Conference on Electric Technology and Civil Engineering (ICETCE). Lushan, China: 22-24 April.

Chung, J.H.., Jung, H.S., Bae, B. et al. 2018. Two-Way Flexural Behavior of Donut-Type Voided Slabs. International Journal of Concrete Structures and Materials. 12: 26. https://doi.org/10.1186/s40069-018-0247-6 (20 March 2018)

Giuseppe Quaranta, 2011, Finite element analysis with uncertain probabilities, Computer Methods in Applied Mechanics and Engineering, Volume 200, Issue 1, pp.114-129.

G.Stefanou, 2009, The stochastic finite element method: past, present and future, Computer Methods in Applied Mechanics and Engineering, Volume 198, pp.1031-1051.

Hasan, M., Lu, M., Yi, C. and Zheng, C. 2018. Synthesizing engineering design, material takeoff and simulation-based estimating on a bridge deck reinforcement case. Abstract. 2017 Winter Simulation Conference (WSC). Las Vegas, NV, USA: 3-6 Dec.

Hock Tian, Cheng, Bashar S. Mohammed and Kamal Nasharuddin Mustapha, 2009, Experimental and analytical analysis of pretensioned inverted T-beam with circular web openings, International Journal of Mechanics and Materials in Design, Volume 5, No. 2; pp.203-215.

Inkscape, 2008, Electronic sources: A selection of Normal Distribution Probability Density Functions (online). http://en.widipedia.org/wiki/File:NormalDistribution PDF.svg

L.Figiel and M.Kaminski, 2009, Numerical probabilistic approach to sensitivity analysis in a fatigue delamination problem of a two layer composite, Applied Mathematics and Computation, Volume 209, pp.75-90.

Ismail et.al, 2011, Nonlinear Analysis of RC Beam for Different Shear Reinforcement Patterns by Finite Element Analysis.

Kadhim Naief, Kareem R., 2018, Finite element analysis of concrete cofferdam.

Lai T., 2010, Structural Behavior of BubbleDeck Slabs and Their Application to Lightweight Bridge Decks.

Lei, Z. and Sun, W. 2011. Effect of superposed deck on the static performance of a prestressed concrete hollow slab girder bridge. Abstract. 2011 International Conference on Electric Technology and Civil Engineering (ICETCE). Lushan, China: 22-24 April.

Liu, Y. and Wu, X. 2011. Study on reinforce prestressed hollow slab by CFRP. Abstract. 2011 International Conference on Electric Technology and Civil Engineering (ICETCE). Lushan, China: 22-24 April.

Muhammad Sigit Darmawan, Probabilistic assessment of pitting corrosion effect on flexural strength of partial prestressed concrete structures in a chloride environment, *Journal of Civil Engineering and Architecture*, Volume 4, 2010, pp.25-32.

Nan Zhang and Chung C.Fu, Experimental and theoretical studies on composite steel – concrete box beams with external tendons, *Engineering Structures*, Volume 31, 2009, pp.275-283.

Purushottam, Y. J., & Hemantkumar, T. Y. (2016). Analytical Study of Solid flat Slab and Voided Slab using ANSYS Workbench. International Research Journal of Engineering and Technology (IRJET), 1000-1003

Sadeghi, J. and Fathali M. 2012. Grillage analogy applications in analysis of bridge decks. Australian Journal of Civil Engineering. 10(1):23-36.

SAS, ANSYS 11.0 Finite Element Analysis System, 2009, ANSYS Manual Set, ANSYS Inc., Southpoint, 275 Technology Drive, Canonsburg, PA 15317, USA.

Taejun Cho and Tae Soo Kim, 2008, Probabilistic risk assessment for the construction phases of a bridge construction based on finite element analysis, Finite Elements in Analysis and Design, Volume 44, Issue 6-7, pp.383-400.

Tie Ming, 2011, Application of Probabilistic Analysis in Finite Element Modeling of Prestressed Inverted T-Beam with Web Openings, Vol. 4, (04): 350-366

Wan, Y., Liu, Y., Song, X. 2014. Strength analysis and optimization of small steel railway bridge based on ANSYS. Abstract. 2014 IEEE Workshop on Advanced Research and Technology in Industry Applications (WARTIA). Ottawa, ON, Canada: 29-30 Sept.

Wang, L and Wang, S. 2011. A study of Jia-Musi highway bridge reinforcing materials test. Abstract. 2011 International Conference on Electric Technology and Civil Engineering (ICETCE). Lushan, China: 22-24 April.

Wu, S., Zhang, G., Han, J. et al. 2009. Fatigue performance of bridge deck pavement materials. Journal of Wuhan University of Technology-Mater. Sci. Ed. 24: 318. https://doi.org/10.1007/s11595-009-2318-7. (9 July 2009)

Wu, W., Shan, H., Yang, S. et al. 2018. Key Assumption to Evaluate the Mechanical Performance of Widened Voided-slab Bridge Due to Foundation Settlement. KSCE Journal of Civil Engineering. 22(4): 1225–1234. https://doi.org/10.1007/s12205-017-1382-3. (14 June 2017)

Yang J. 2010. Disease analysis and reinforcement methods discussion of several sorts of arch bridges. Abstract. 2010 International Conference on Mechanic Automation and Control Engineering. Wuhan, China: 26-28 June.

Yu Wang, Zijun Cao, and Siu-kui Au, 2010, Efficient Mote Carlo Simulation of parameter sensitivity in probabilistic slope stability analysis, Computers and Geotechnics, Volume 37, Issue 7-8, pp.1015-1022.

Yue, J., Wu, X., Huang, X. 2014. Effects of Live Load on the Deflection of Long-Span PC Continuous Rigid-Frame Highway Bridge Based on Midas. Abstract. 2014 7th International Conference on Intelligent Computation Technology and Automation. Changsha, China: 25-26 Oct