

# **UNIVERSITI PUTRA MALAYSIA**

A MODIFIED STRENGTH CAPACITY FOR COMPOSITE SLAB USING RELIABILITY APPROACH

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FK 2016 127



## A MODIFIED STRENGTH CAPACITY FOR COMPOSITE SLAB USING RELIABILITY APPROACH

By

## KACHALLA MOHAMMED

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

September 2016

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## DEDICATIONS

To my late wife Hajja Inna Abba (1987-2016)



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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the Degree of Doctor of Philosophy

## A MODIFIED STRENGTH CAPACITY FOR COMPOSITE SLAB USING RELIABILITY APPROACH

By

#### KACHALLA MOHAMMED

September 2016

## Chair: IZIAN ABD. KARIM, PhD Faculty: ENGINEERING

Design shear resistance coupled with lack of a probabilistic framework for the alternate deflection requirement check for reinforced concrete (RC) slab, and the uneconomical approach for profiled composite slab strength determination are main challenges that contribute to design conservatism. This thesis proposes to address these challenges by implementing a rational- based approach in developing schemes for limit state performance enhancement and a numerical function for profiled composite slab strength devoid of experimental procedure. Performance enhancement schemes employs the probabilistic safety appraisal in providing improvement measures to the concrete shear resistance function and the provision for a simplified probabilistic deflection check while maintaining an acceptable closed form solution. Hence, variable deflection,  $\lambda_{defl}$  and shear resistance,  $\lambda_{prop}$  factors are introduced to modify the existing limit state. Similarly, a procedural algorithm lead to the development of profiled composite slab strength determination function for both longitudinal shear estimation methods by considering section slenderness and deck characteristics. First, composite deck safety performance against the load ratio function leads to safety bounds definitions that takes into consideration section slenderness and sheeting deck characteristics values delineated through l/6and l/8, culminating in the formation of modified strength function. The probabilistic based optimisation scheme shows potentials to improve RC slab design by suggesting 4% design moment reduction. Similarly, the concrete shear capacity can be increased significantly with an enhancement  $\lambda_{prop}$  factor of 2.0, and a similar  $\lambda_{defl}$  value of 5.15 is also proposed to shore up the limiting deflection requirement check under the use of a concrete strength class of 30 MPa. Furthermore, the developed strength determination effectively performs well in mimicking the probabilistic deck performance and composite slab strength determination that shows improvement in strength load estimation difference between the two longitudinal shear methods to 12% from 26%. The strength test performance between the

developed scheme and the experiment based test results indicates high similarity, demonstrating the viability of the proposed strength determination methodology developed in this study.



Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

## KEUPAYAAN KEKUATAN DIUBAHSUAI BAGI PAPAK KOMPOSIT MENGGUNAKAN PENDEKATAN KEBOLEHHARAPAN

Oleh

## KACHALLA MOHAMMED

September 2016

Pengerusi: IZIAN ABD. KARIM, PhD Fakulti: Kejuruteraan

Rintangan ricih rekabentuk digandingkan dengan kekurangan kerangka kerja kebarangkalian sebagai alternatif semakan pesongan bagi papak konkrit bertetulang, dan pendekatan yang tidak ekonomi untuk penentuan kekuatan papak rencam berprofil adalah cabaran utama yang menyumbang kepada rekabentuk yang konservatif. Tesis ini bercadang untuk menangani cabaran-cabaran ini dengan melaksanakan pendekatan berasaskan-rasional dalam membangunkan skim untuk meningkatkan prestasi keadaan had dan rangkap berangka untuk kekuatan papak rencam berprofil tanpa menjalankan prosedur eksperimen. Skim-skim peningkatan prestasi ini menggunakan penilaian kebarangkalian keselamatan dalam menyediakan langkah-langkah penambahbaikan kepada rangkap rintangan ricih konkrit dan peruntukan bagi semakan kebarangkalian pesongan dipermudah disamping mengekalkan penyelesaian bentuk tertutup yang boleh diterima. Oleh itu, faktor pembolehubah pesongan,  $\lambda_{defl}$  dan rintangan ricih,  $\lambda_{prop}$  diperkenalkan bagi mengubahsuai keadaan had sedia ada. Begitu juga, satu prosedur algoritma menjurus kepada pembangunan rangkap penentuan kekuatan papak rencam berprofil untuk kedua-dua kaedah anggaran ricih membujur dengan mengambilkira kelangsingan keratan dan ciri-ciri geladak dibangunkan. Pertama, prestasi keselamatan geladak komposit terhadap rangkap nisbah beban membawa kepada definisi had keselamatan yang mengambilkira kelangsingan keratan dan nilai ciri-ciri kepingan geladak ditandakan melalui l/6 dan l/8 memuncak kepada pembentukan rangkap kekuatan diubahsuai. Skim pengoptimuman berasaskan kebarangkalian menunjukkan potensi untuk meningkatkan rekabentuk papak konkrit bertetulang dengan mencadangkan pengurangan 4% momen rekabentuk. Begitu juga, keupayaan ricih konkrit boleh meningkat ketara dengan peningkatan faktor  $\lambda_{prop}$  sebanyak 2.0, dan nila<br/>i $\lambda_{defl}$ sebanyak 5.15 juga dicadangkan untuk menyokong keperluan semakan pesongan yang dihadkan bagi penggunaan kelas kekuatan konkrit bergred 30 MPa. Disamping itu, rangkap penentuan kekuatan yang dibangunkan berkesan dalam mengajuk prestasi kebarangkalian geladak dan penentuan kekuatan papak komposit dengan menunjukkan peningkatan dalam perbezaan anggaran kekuatan beban antara kedua-dua kaedah ricih membujur sebanyak 12% daripada 26%. Prestasi ujian kekuatan diantara skim yang dibangunkan dan keputusan ujian berasaskan eksperimen menunjukkan persamaan yang tinggi, menandakan daya maju bagi kaedah cadangan penentuan kekuatan yang dibangunkan dalam kajian ini.



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Finally, this academic pursued would not have been complete without the wonderful supports by the University of Maiduguri for enabling the study fellowship and facilitating FGN TETFund support required to achieve this ultimate goal. I certify that a Thesis Examination Committee has met on 8 September 2016 to conduct the final examination of Kachalla Mohammed on his thesis entitled "A Modified Strength Capacity for Composite Slab using Reliability Approach" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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## LIST OF ABBREVIATIONS

$\lambda_i$	Eigen value of the covariance matrix
$t_i$	Eigen vectors of the covariance matrix
ů	The mean
δ	The variance
PDF	Probability Density Function
$\mathrm{CDF}$	Cumulative Density Function
J	Jacobian
$\alpha$	Sensitivity factor
SLS	Serviceability-limit state
ULS	Ultimate-limit state
$Q_k$	Variable load
$G_k$	Dead load
l	Span length
F	Design load
$\gamma_a$	Partial safety factor for $G_k$
$\gamma_a$	Partial safety factor for $Q_k$
$\hat{C}_{norm}$	Normal concrete cover
$\Delta C_{dev}$	Normal concrete cover deviation
a	Minimum concrete cover
$\phi_{link}$	Link diameter
$\phi_{bar}$	Flexural bar diameter
$l_y$	Long span length
$l_x$	Short span length
R.E.I.	Resistance, Separation and Insulation
h	Slab depth
$\beta_{sx}$	Slab boundary condition along $l_x$
$\beta_{sy}$	Slab boundary condition along $l_y$
$m_{sx}$	Design moment in the direction of $l_x$ axis
$m_{sy}$	Design moment in the direction of $l_y$ axis
$A_s$	Flexural reinforcement
$k^{++}$	Singly reinforced section identifier
$A_{s,min}$	Minimum Flexural reinforcement
$A_{s,min}$	Maximum Flexural reinforcement
N.A.	Neutral axis
d	Slab effective depth
b	Slab width
$\varepsilon_{su}$	Ultimate strain
$f_{yd}$	Deck characteristic strength
$f_{yk}$	Steel characteristic strength
z	Lever arm
$f_{ck}$	Concrete characteristic strength

$f_{ctm}$	The mean tensile strength
$A_c$	Concrete cross-sectional area
$M_{c}$	Moment capacity
$m_r$	Resistance moment
$m_d$	Design capacity
X or $k$	Random variables
$\nu_{Rd,c}$	Concrete shear
$\nu_{Ed}$	Applied shear
$u^{Lu}$	Column critical perimeter
$\nu_{Ed max}$	Maximum design shear stress
$v_{Ed}$	Applied shear value at support
$\beta_c$	Moment transfer factor
$V_{Rdc}$	Slab shear resistance
$V_{Pd}$ mar	Maximum concrete shear resistance
0	Steel ratio
$q_r$	Limit state
$\gamma_{con}$	Concrete density
l/d	Span to depth ratio
$\rho_{0}$	Reference steel ratio
	Compression reinforcement
$\mathcal{P}$ $\mathcal{T}_{a_{1}}$	Longitudinal shear
$\tau_u$ $\tau_u$ Dd	Design shear strength
$\tau_u, \pi u$ $\tau_u, Ph$	Characteristic Shear strength
$m_{u,R\kappa}$	Composite slab action moment
$m_{rad}$	Composite slab bending resistance
$\delta_{max}$	Composite slab maximum deflection
m	The slope
k	The Intercept
PSC	Partial Shear Connection
e	Centroid distance above the base
$e_n$	Plastic neutral axis length
w	Failure load
$v_t$	Support reaction
$A_p$	Decking sheet effective area
$d_p$	Decking sheet Centroid-al distance
$l_s$	Shear span length
$m_u$	Profiled deck Maximum moment
$\psi$	Shear connection factor
$\zeta$	Degree of shear connection
$\zeta_{test}$	Experiment $\zeta$
$\zeta_{dl}$	Design load
$l_o$	Overhang length
$N_{pa}$	Steel yield force
$h_t$	Overall deck thickness
$h_c$	Concrete depth

Nef	Concrete compressive force
$\gamma_{an}$	Partial safety factor for Deck
$m_{m} Dd$	Design bending resistance
$m_{p,na}$	Plastic moment of resistance
$m_{max}$	Moment of resistance of deck
$m_{\mu}$	Experimental maximum bending moment
t	Sheeting deck thickness
$\tilde{v}$	Stud shear resistance
Pra Elomo	Mean Secant modulus
$O_{m}$	Mean resistance
$\mathcal{Q}_m$	Experimental test load per span
	Failure Testing Load
PE	Proposed Estimate
Г Ш. т	Material fabrication factor
f.	Geometry and dimension factor
$\frac{n}{n}$	Professional judgement factor
$V_{\Omega}$	Mean resistance coefficient of variation
v Q Vm	$cov$ corresponding to $m_{\rm m}$ factor
	$cov$ corresponding to $f_m$ factor
$v_{\pi}$	$cov$ corresponding to $p_m$ factor
PDCS	Profiled Deck Composite Slab
Ω 0	Shear span length
l.	Load ratio
$f_1$	Load ratio factor
J l <sub>r</sub> D c	Probability of Failure
$P_J$	Deck characteristics
n c	The mean safety index
Pf.mean	The mean $l_{\pi}$ value
$\lambda + c_1$	Deflection enhancement factor
$\lambda_{aefl}$	Shear enhancement factor
OSED	One Short Edge Discontinuous
TAED	Two Adjacent Edge Discontinuous
OLED	One Long Edge Discontinuous
IP	Interior panel
Wa	weighted least square
Wi	Limit state weighted factor of the limit state
$m_{\beta}$ .	The mean value of $\beta_i(\gamma_i)$
$\delta_{\rho}^{\rho_{j}}$	The SD value of $\beta_i(\gamma_i)$
$p_j$	Shear ratio
$\beta$	Deflection safety index
Pdefl	Denotion barouy much

### CHAPTER 1

### INTRODUCTION

#### 1.1 Background

This chapter presents a general overview of contemporary problems related to different slabs, and it is divided in to six sections after a discussion of the deterministic approach in achieving safety and design economy. This is followed by section 1.2, which provides an account of the problem statement related to the current design and strength verification of reinforced concrete (RC) slab and profiled deck composite slab, respectively. Section 1.3 presents the formulated research hypothesis. The goals, scope and limitation of this study, as well as its research significance, are concisely presented under sections 1.4, 1.5 and 1.6, respectively. Finally, the general thesis structure layout is discussed in section 1.7.

The engineering settings for organised structural building from onset to completion requires the client who owns the finished product, the engineering team that handles and facilitates the herculean task of designing and construction using appropriate tools and machineries are all necessary in ensuring that the structural building performs adequately in discharging its general purpose for which it is intended for under specific condition safely. Similarly, achieving these noble feats should be economically effective as well; herein the cost benefit ratio should be minimal to the best possible option. Safety and economic considerations are no doubt the guiding principles when a professional engineer engages in the design and construction of a building. This to a significant extent stands to be the difference between professional engineers and quacks who operates under the guise of engineering personnel: Apart from making their living from such deceptive and potentially dangerous, no cost-saving value is added to the project even if should they succeed in providing services for their unsuspecting client.

Structural building mainly consist of several members, and slab generally constitutes more in terms of structural weight and volume compared to other members (Yardim et al., 2013). Structural slab is part of modern high-rise building construction of both private and public buildings. Slab construction can either be in the form of reinforced concrete slab or composite slab. The former is most commonly used with reinforced concrete buildings, while the latter is usually applicable in steel structured buildings. Generally, irrespective of their area of application, both types will performed the same functions in building, but the design principles and suitability test for strengths differs considerably. However, in general terms, both are designs are based on a deterministic principle.

Engaging design engineers for structural buildings construction ultimately leads economical designs with a low probability of failure. That is, the chance of the structures action values exceeding material-strength resistance. Action values are a function of the structural load type and its magnitude on the building, and the resistance is determined solely by the member stiffness. Intuitively, ultimate structural failure is unavoidable if the member stiffness is not suitable for the load task on the building, and the building response is deemed unsatisfactory in such a situation. For example, the use of methods such as yield line analysis as well as design based method have a tendency to grossly under-predict slab peak load (Siemaszko and Doliski, 1996; Hossain and Olufemi, 2005). Hence, the current deterministic approach attempt to provide safety by the application of conservative makeshift use of safety factors. These factors are applied to both the load and strength parameters through amplifying the former and reducing the latter. The reason for that is based on the deterministic hypothesis, where strength variables are assigned with known value assumed to be free from uncertainty influence. However, this assumption does not hold in most cases, and even if it does, certainly it comes at an additional cost. Those factors will not guarantee the required safety because of the absence of acceptable framework in dealing with inherent uncertainties. Thus, the assumption only succeeds in making the design overly conservative. However, this is not to say that the flaws associated with the deterministic method make it invalid; Hence, it is still required with rational design approach formulations. The application of the rational method on structural design is highly encouraging; previous studies (Low and Hao, 2001; Ferrand, 2005; Neves et al., 2006) on its use for slab design have shown it to be beneficial (Chul-Woo et al., 2007a; Marsh and Frangopol, 2008). However, little research addresses how to balance safety and design economy effectively with the use of this powerful rational approach.

Certainly, the goal of designing structures is to achieve a low probability of failure; i.e. low probability of realising action value higher than the resistance (Larsen, 1995). Structural building design is primarily based on codes and standards that are deemed satisfactory by engineering judgement and previous experience with similar structures. In other words, deterministic approaches that consider loadresistance factors, allowable stress and deflection, are based on professional experiences and examination of available data (Galambos et al., 1982). The aim of all design codes is presumably structural safety and economy of design, which is the heart of structural design. Hence, whether it is RC slab design or design strength verification of profiled deck composite slab (PDCS), the safety and economic consideration from all design stages applicable to the respective slab is highly essential not only in attaining the desired cost-benefit ratio but also for inwards research and development of the respective deck.

Nowadays, structural mechanics puts more emphasis on the consideration of uncertainties that are inherent in structural design. Generally speaking the current deterministic design method is conservative, minimising the importance of the cost-benefit ratio while focusing. For example, the costlier and expensive laboratory procedure remains the only means for verifying PDCS capacity, and the use of analytical methods in RC slab design tend to grossly under-predict slab peak load capacity (Siemaszko and Doliski, 1996; Hossain and Olufemi, 2005). Importantly, design safety factors may contribute to over design, achieving a low probability of failure occasionally. Thus the effectiveness of any design or strength verification is largely dependent on balancing safety and economy of design.

Balancing safety and economical design is a strenuous task that requires accommodation of many diverging issues. For example, the RC slab design must capture the interest of not only flexural requirements, but also shear and deflection considerations at all design stages. Similarly, as it applies to PDCS, longitudinal shear capacity ultimately determines its performance appraisal and, interestingly, the current two methods for its strength appraisal are conflicting and vague. Slabs generally are among the biggest structural units contributing to the overall structural dead weight by more than 50% (Yardim et al., 2013), consequently requiring an appropriate solution that is capable of balancing both safety and economic considerations. This can be achieved through the use of a probabilistic framework.

The probabilistic measure is an undeviating framework that provides reassurance in treating inherent design uncertainties (Epaarachchi et al., 2002). It provides considerable help in reducing the high level of conservatism in the design models. Hence, in this study, probabilistic judgements will be applied to both reinforced concrete and composite slabs with a view to mitigating the high level of conservatisms of typical reinforced concrete slab design as well as alternate for costly PDCS laboratory strength tests.

### 1.2 Problem statements

Generally, slabs are a structural systems commonly used in residential buildings (both public and private) (Benavent-Climent et al., 2012; Semelawy et al., 2012). In most cases, slabs are either supported by columns directly (commonly known as flat slab, which is very easy to build), or by beam-column connections (Sahab et al., 2005b). In this thesis, slabs are classified in to two categories: i) RC slab, and ii) profiled deck composite slab. Conventionally, both are designed on a deterministic approach.

"Deterministic model has no stochastic element, where the entire input and output relation of the model are conclusively determined", Veritas (1992).

The load and resistance factor design and the allowable stress methods are good deterministic models, and both all based on professional experience (Ellingwood et al., 1980). However the major drawbacks of those methods hardly leads to the required safety level without compromising the design economy because of their limitations in taking care of gross errors (Gosling et al., 2013; Addis, 1990; Beal, 1979; Mortensen, 1983). These errors are clearly attributed to the inherent uncertainties associated with the materials properties, loads and dimension or those related to lack of quantitative knowledge about statistical properties (Diniz, 2008).

These limitations clearly tempers the hope of presenting safe and economical structure in every aspect (Jinxin et al., 2011).

Current deterministic based design outputs may yield to required safety measure, but bound by their limitations and the measures taken to address them, the design outputs are overly conservative. This conservatism was necessitated to accommodate variability, and this is done through increasing design loads with a subsequent reduction in materials strength properties. For example, the known empirical shear equations returns contentious values (Collins et al., 2008), and concrete shear strength is found to be underestimated (Lantsoght et al., 2015). Similarly, because of shear strength influencing parameters like shear span length, deck cross section, concrete depth, etc., development of a numerical PDCS strength determination approach is hampered. To mitigate this conservatism concern, this study proposes to solve it with the RC slab design enhancement and simplified strength verification for PDCS. Sections 1.2.1 and 1.2.2 provide more detailed overview of contemporary problems associated with the aforementioned slab types considered in this study.

## 1.2.1 Profiled deck composite slab (PDCS)

The use of profiled deck composite slab in the construction industry has many advantages, including its simple construction compared to other flooring systems. The profiled sheeting serves as shuttering by shouldering wet concrete during the construction stage, for example. This composite construction method gained popularity for eliminating time-consuming forms erection and their subsequent removal (Chen, 2003; Abbas et al., 2015). Another advantage of that construction system is the benefits derived from the decking sheet during service through performing the function of tensile reinforcement (Marimuthu et al., 2007; Degtyarev, 2012; Gholamhoseini et al., 2014; Abdullah et al., 2015). The composite action between the profiled sheeting deck and the hardened concrete (Figure 1.1) will come in to play with effective development of longitudinal shear at the steel-concrete interface. Several studies (Burnet and Oehlers, 2001; Chen, 2003; Tenhovuori and Leskel, 1998; Tsalkatidis and Avdelas, 2010; Abbas et al., 2015) show that the behaviour of profiled deck composite slab is affected by the bond failure between the decking sheet and the concrete. Abdullah et al. (2015) show that the most important shear bond strength influencing factor is the shear-span-to-effective-depth ratio, and this is a key factor in characterising PDCS shear capacity.

Metal deck embossing provides equivalent shear resistance characteristics for effective composite action between the sheeting deck and hardened concrete. However, a number of factors are known to affect the longitudinal shear capacity estimation for this composite construction system; section slenderness is one such example. Apart from known concerns that influences the PDCS shear bond capacity of profiled composite slab, the shear bond parameters are normally determined from



Figure 1.1: Typical profiled deck slab (a) Profiled deck composite slab construction (b) Embossing (c) Modelled profiled deck slab

the capital-intensive laboratory procedure. Such procedures includes the slopeintercept and the partial shear connection (PSC) methods, amongst others. In addition, research findings have shown a significant strength load variation (about 26%) as well as conflicting results in longitudinal estimation from those two methods (Hedaoo et al., 2012; Abdullah et al., 2015). The implication is that selection of the wrong longitudinal shear estimation method may lead to PDCS strength load underestimation.

Therefore, the capital-intensive, time-consuming PDCS strength test and its lon-

gitudinal shear capacity determination method became a major issue in strength characterisation. Existing schemes to mitigate the differences suggest the inclusion of the variables of concrete thickness and shear span considerations to the deficient method (Abdullah et al., 2015). However, the suggested working framework still lacks the alternate solution to the challenging and costly laboratory procedure required for the shear parameters. This necessitates the need for a framework that will improve on the longitudinal shear estimation variations from the two method and the development of a numerical PDCS strength determination function devoid of costly laboratory work. However, the finite element method is one of the widely used alternate numerical methods to the current costlier laboratory procedures for composite slab strength determination but some limitations make its results unsatisfactory. Hence, the main challenges in PDCS strength determination are longitudinal shear estimation method differences and the expensive laboratory procedure needed to estimate longitudinal shear. Therefore, the main challenges can be alleviated using a more rational-based numerical approach that will lead to the development of a numerical strength test within the framework of both longitudinal shear estimation methods. And, this numerical strength test will eliminate the laboratory procedure while improving the estimation differences.

#### 1.2.2 Reinforced concrete slab

RC slab is basically load and resistance factor design (LRFD), where the structural fitness is quantified beyond which it no longer satisfies the required design conditions. The LRFD approach is balanced to withstand all structural actions on the building that are likely to occur during its service life satisfying the principal requirement at both the ultimate and serviceability limit state condition. The method allows the use and application of resistance and load factors on the nominal resistance and load variables in order to prevent structural failure (Hsiao et al., 1990). In general, these factors are known as deterministic reliability measures.

Contemporary RC slab design codes are overly conservative because of load amplification and reduction in material strength (Neves et al., 2006). The use of such factors which are profoundly based on professional experiences and examination of available data (Galambos et al., 1982), may yield the required structural safety, but design economy is compromised (Behrouz and Varaee, 2011). Recent trends show the need for a transition towards more rational and probability-based design procedures, where discrete variables properties of both load and resistance parameters are taken in to considerations (Dolinski, 1982; Okasha and Aichouni, 2014). These measures address inherent design problems that necessitated the use of deterministic safety factors. Similar earlier study findings (Ravindra and Galambos, 1978; Galambos et al., 1982; Valdebenito et al., 2010; Vrouwenvelder, 1997) had shown the probabilistic method's potential for overcoming the deterministic method's drawbacks. Certainly, the use of a reliability approach in conjunction with the present deterministic RC slab design will aid to achieve the required safety and design economy.



Figure 1.2: (a) Typical concrete slab (b) Flat slab type (c) Reinforcement layout

Structural reliability based studies on reinforced concrete slab are well documented, and considerable efforts has gone in to establishing an acceptable referral safety

benchmark for probabilistic design. The referral safety benchmarks for a wide range of loadings or different slab types with distinct ends conditions are known. A significant contributions towards balancing design safety and design economy may have been possible if the optimisation had more reliability-based inputs (Sahab et al., 2005a), and little evidence is documented. Furthermore, RC slab deck optimisation will no doubt have an influence on shear and deformation capacity requirements. Hence, there is need for ensuring sufficient shear capacity (Lantsoght et al., 2015). This action will definitely safeguard the high susceptibility to progressive failure (Jinrong et al., 2013). Presently, concrete shear capacity is a cause of concern structural concrete design as such several attempts were made to create new models through empirical studies (Ju et al., 2015; Lantsoght et al., 2015; Antonio et al., 2013; Shehata and Regan, 1989). These attempts built on previous developments, and several proposals have been presented (Hewitt and Batchelor, 1975; Kinnunen and Nylander, 1960). It is important to note that many empirical equations are known to predict shear performance contentiously (Collins et al., 2008), and this may not be unconnected to uncertainties in input and output design variables.

Secondly, the increasing concern for serviceability requirement checks cannot be overemphasised (Ellingwood et al., 1986). The literature has shown that service-ability condition results in structural defects rather than flexural failure (Daniel, 2014; Stewart, 1996b), and serviceability requirements using probabilistic models have been presented (Holicky, 1998; Leicester, 1993; Stewart and Rosowsky, 1998). Stewart (1996a,b) presented serviceability study results related to American and Australian design standards, but such results for European standards are quite limited (Daniel, 2014). In addition, there are known safety-value inconsistencies under different load configurations using traditional deflection limits. Notwithstanding, the simplified deflection check method  $(\frac{l}{d})$  is allowed by the code without necessarily calculating the traditional deflection check requirement to the European structural standard.

Therefore, in balancing both safety and design economy of a building must look inwards to the issues of concrete shear capacity improvement and the development of a probabilistic code for the simplified deflection check method. These are issues that must be addressed along with structural optimisation of RC slab performance. Existing schemes for RC slab optimisation mainly focus on the flexural capacity requirement, but the need for both shear and deflection capacity enhancement from the optimisation process has not been extensively investigated. This also warrants an acceptable framework to improve both ultimate- and serviceability-limit state performance in terms of optimised RC slab sections, and improvements in concrete shear and deflection requirement capacities.

## 1.3 Research hypothesis

The corner stone of meaningful research is the formulation of a research hypothesis. This study has one hypothesis: Reliability plus a deterministic approach will lead to the reduction of high level of design conservatism. Accordingly, the use of a rational-based method will provide the much needed departure.

## 1.4 Aim and Objectives

The aim of this research is to produce a operational mechanism that couples design safety and economy by means of a rational-based approach to reduce the high level of design conservatism that is a by-product of current profiled composite slab strength determination verification methods and the ultimate and serviceability limit state design conditions for RC slab under Eurocode requirements.

The specific objectives are:

- 1. To optimise RC slab flexural capacity while maintaining minimum flexural reinforcement requirements for the section.
- 2. To optimise concrete shear resistance capacity and propose method to improve Eurocode-compliant concrete-shear resistance technique in order to reduce underestimation problem.
- 3. To develop probabilistic output based framework for RC slab serviceability requirement using the simplified deflection l/d ratio.
- 4. To formulate longitudinal shear capacity safety benchmarks for profiled composite slab using both the slope-intercept and partial shear connection methods to replace existing inconsistent safety datum.
- 5. To develop an effective numerical model for profiled composite slab strength determination and validate through experimental validation testing.

## 1.5 Scope and limitation

This study scope involves the use of reinforced concrete slab design based on Eurocode-2 specifications with static load applications for both deterministic- and reliability-based design inputs. Predefined numerical examples are considered for typical cases of simply supported and continuous slab types. Importantly, only four typical continuous slab type are adopted, and all are subject to parametric sensitivity tests on span length variations, concrete strength class change and minimum reinforcement requirement considerations. Furthermore, profiled composite slab safety indices and subsequent development of PDCS strength determination are based on the use of slope-intercept and partial shear connection methods only. Statistical tests on the viability of this new approach using both methods are compared with experimental results. This study designed an experimental test consisting of only eight specimens: two each for the four shear span lengths.

This study is constrained in a number of ways. First, the experimental laboratory test is mainly for PDCS strength verification. This means that experimental testing is not conducted on optimised RC slab performance; rather, a rich data bank is made available for possible future study on this subject. Second, shearstud influence on PDCS longitudinal shear performance is not captured in this study. Finally, only the two major longitudinal shear estimation methods defined by Eurocode-4 provisions are considered.

### 1.6 Study significance

There are number of reasons why this research work is important. First, presently the simplest means for PDCS strength determination is through a complex and costly laboratory procedure. This limitation hampers the independent confirmation of deck strength parameters supplied by the manufacturer in most cases. Therefore, decking-material users are forced to rely on data provided by the producer. Apart from the difficulty of verifying the deck data authenticity, the methods used for defining deck safety parameters are conflicting, introducing an additional variable to the design and production process. Hence, this study approach will ensure the simplification of PDCS strength verification, which can be of great help to both deck-material manufacturers and product end-user. The development of a PDCS numerical strength test will lead to considerable cost savings by eliminating laboratory testing expenses.

Second, this study will produce a probabilistic PDCS longitudinal-shear safety benchmark for the two methods thus providing a solution to current safety data inconsistencies. Safety code developers will find this particularly useful for updating PDCS longitudinal shear codes. Furthermore, this study methodology will bridge the significant variations in strength capacity estimates derived from the two existing longitudinal-shear testing methods.

Third, this study will provide a much-needed to the scarce literature on reliability based assessments of profiled deck composite slab. In addition, it will serve as a useful reference for future research on profiled deck composite slab strength verification.

Finally, relating to RC slab optimisation assessment, this study outcomes can be to moment reduction factors, increasing the concrete shear resistance capacity, and the defining new probabilistic serviceability buffer limits for RC slab design.

## 1.7 Thesis Structure

The thesis is presented in five chapters, summarized as:

- Chapter 1 provides the general background of the problem statement, and the study's justification is explained herein. The aim of the research, as well as its objectives, significance, scope and limitations are also presented in this chapter.
- Chapter 2 presents a general review of structural slab design optimisation as it relates to ultimate- and serviceability-limit state violations. A concise review of existing shear and deflection requirements for RC slab design is also presented in this chapter. Similarly, the chapter presents a review of alternative strength determinations for profiled deck composite slab strength. Also in this chapter, in-depth critical review for closed form solutions to multi-fold integral.
- Chapter 3 explains this study's general methodology. Similarly, the respective limit-state formulations related to both slab types are presented, as are experimental set-up and verification test details for profiled deck composite slab.
- Chapter 4 provides an analysis of the reliability assessment of the optimised RC slab design at both the ultimate-limit state (ULS) and serviceability-limit state (SLS). A design case presenting simply supported slab and continuous slab responses to a variety of parametric indices is also found in this chapter. Moreover, discussion of a proposed adjustment to concrete shear resistance and deformation check for RC slab design are also presented herein. Similar results analysis for profiled composite slab are captured in this section. This includes a scholarly formulation of a PDCS strength determination method to replace the costly and time-consuming laboratory procedure. Using analytic statistics, the overall effectiveness of the proposed methodology was compared to available data from the literature. Finally, the chapter also presents and analyses computational variation of the two methods used to determine safety levels for longitudinal shear of profiled composite slab.
- Chapter 5 reports this study's general findings, conclusions and recommendations for use in future research on the application of this reliability concept. Ideally, it will reduce design conservatism brought about by constraint in existing strength verification methods for RC and and profiled deck composite slab.

#### BIBLIOGRAPHY

- Abbas, H. S., Bakar, S. A., Ahmadi, M. and Haron, Z. 2015. Experimental studies on corrugated steel-concrete composite slab. *GRAEVINAR* 67 (3): 225–233. Doi: 10.14256/JCE.1112.2014.
- Abdinasir, Y., Abdullah, R. and Mustaffa, M. 2012. Modelling of shear bond with cohesive element and slenderness study of composite slabs. In Proceedings of Joint Conference of the 8th Asia Pacific Structural Engineering Construction Conference (APSEC) and 1st International Conference on Civil Engineering Conference (ICCER), 208216. APSEC-ICCER-2012.
- Abdullah, R., Kueh, A. B. H., Ibrahim, I. S. and Easterling, W. S. 2015. Characterization of shear bond stress for design of composite slabs using an improved partial shear connection method. *Journal of Civil Engineering and Management* 21 (6): 720–732. 10.3846/13923730.2014.893919.
- Abdullah, R. and Samuel Easterling, W. 2009. New evaluation and modeling procedure for horizontal shear bond in composite slabs. *Journal of Constructional Steel Research* 65 (4): 891–899. Http://dx.doi.org/10.1016/j.jcsr.2008.10.009.
- Addis, W. 1990, Structural engineering: The nature of theory and design, Ellis Horwood London.
- Adrzej, S. N., Anna, M. R. and Ewa, K. S. 2012. Revised statistical resistance model for reinforced concrete structural component. ACI 284: 1–16. Doi:10.14359/51683801.
- Albrecht, U. 2002. Design of flat slabs for punching European and North American practices. *Cement and Concrete Composites* 24 (6): 531–538.
- Allaix, D. L. and Carbone, V. I. 2011. An improvement of the response surface method. *Structural safety* 33 (2): 165–172. Http://dx.doi.org/10.1016/j.strusafe.2011.02.001.
- An, L. 1993. Load Bearing Capacity and Behaviour of Composite Slabs with Profiled Steel Sheet. PhD thesis, Chalmers University of Technology. Http://publications.lib.chalmers.se/publication/1378-load-bearing-capacityand-behaviour-of-composite-slabs-with-profiled-steel-sheet.
- Andrade, V. 2004. Standardized composite slab systems for building constructions. Journal of Constructional Steel Research 60: 493 – 524. Doi:10.1016/S0143-974X(03)00126-3.
- Antonio, G., Alberto, M. and Zila, R. 2013. Experimental behaviour of fibre reinforced concrete bridge decks subjected to punching shear. *Composites Part B: Engineering* 45. 10.1016/j.compositesb.2012.09.044.

- Ayyub, B. M., Assakkaf, I. I. and Atua, K. 2000. Reliability-Based Load and Resistance Factor Design (LRFD) of Hull Girders for Surface Ships. *Naval Engineers Journal* 112 (4): 279–296. 10.1111/j.1559-3584.2000.tb03337.x.
- Bailey, C. G. 2001. Membrane action of unrestrained lightly reinforced concrete slabs at large displacements. *Engineering Structures* 23 (5): 470–483.
- Bakht, B. and Mufti, A. A. 1996. FRC deck slabs without tensile reinforcement. Concrete International 18 (2): 50–55.
- Balomenos, G., Polak, M. and Pandey, M. 2014. Reliability Analysis of a Reinforced Concrete Slab-Column Connection without Shear Reinforcement, 835– 846. ASCE.
- Beal, A. 1979. What's wrong with load factor design. *ICE Virtual Library* 66: 595–604. ISBN:1753-7789.
- Behrouz, A.-N. and Varaee, H. 2011. Minimum cost design of concrete slabs using particle swarm optimization with time varying acceleration coefficients. World Applied Sciences Journal 13 (12): 2484–2494. Http://www.idosi.org/wasj/wasj13(12)/11.pdf.
- Benavent-Climent, A., Zamora-Snchez, D. and Gil-Villaverde, J. F. 2012. Experimental study on the effective width of flat slab structures under dynamic seismic loading. *Engineering Structures* 40: 361–370.
- Bojorquez, J. and Ruiz, S. E. 2014. An Efficient Approach to Obtain Optimal Load Factors for Structural Design. *The Scientific World Journal* 2014: 9. 10.1155/2014/456826.
- Bond, A. J., Harison, T., Brooker, O., Harris, A. J., Moss, R. M., Narayanan, R. S. and Webster, R. 2006. *How to design concrete using Eurocode 2*. Blackwater, Camberly, Surrey, GU 17 9AB: Cement and concrete industry publication (CCIP-006), price group p.
- Bucher, C. G. and Bourgund, U. 1990. A fast and efficient response surface approach for structural reliability problems. *Structural safety* 7 (1): 57–66.
- Burnet, M. J. and Oehlers, D. J. 2001. Rib shear connectors in composite profiled slabs. *Journal of Constructional Steel Research* 57 (12): 1267–1287. Http://dx.doi.org/10.1016/S0143-974X(01)00038-4.
- Chen, S. 2003. Load carrying capacity of composite slabs with various end constraints. *Journal of Constructional Steel Research* 59: 385 403. Doi:10.1016/S0143-974X(02)00034-2.
- Chul-Woo, K., Mitsuo, K. and Young-Rog, K. 2007a. Impact coefficient of reinforced concrete slab on a steel girder bridge. *Engineering Structures* 29. 10.1016/j.engstruct.2006.05.021.

- Chul-Woo, K., Mitsuo, K. and Young-Rog, K. 2007b. Impact coefficient of reinforced concrete slab on a steel girder bridge. *Engineering Structures* 29. 10.1016/j.engstruct.2006.05.021.
- CIBD. 2014, Building Materials Price, http://www.cibd.gov.my/.
- Cifuentes, H. and Medina, F. 2013. Experimental study on shear bond behavior of composite slabs according to Eurocode 4. *Journal of Constructional Steel Research* 82 (0): 99–110. Http://dx.doi.org/10.1016/j.jcsr.2012.12.009.
- Clarke, L. and Cope, R. 1984. *Concrete Slabs: Analysis and design*. Elservier Applied Science Publishers, iSBN: 0853342547.
- Collins, M. P., Bentz, E. C., Sherwood, E. G. and Xie, L. 2008, An adequate theory for the shear strength of reinforced concrete structures.
- Crisinel, M. and Marimon, F. 2004. A new simplified method for the design of composite slabs. *Journal of Constructional Steel Research* 60: 481 – 491. Doi:10.1016/S0143-974X(03)00125-1.
- Daniel, H. 2014. Design for serviceability: A probabilistic approach. Ph.d thesis, Lund University. ISSN: 0349-4969.
- Degtyarev, V. 2012. Reliability-Based Evaluation of U.S. Design Provisions for Composite Steel Deck in Construction Stage. *Journal of Structural Engineering* 138 (3): 308–317. Doi:10.1061/(ASCE)ST.1943-541X.0000437.
- Der Kiureghian, A. and Dakessian, T. 1998. Multiple design points in first and second-order reliability. *Structural safety* 20 (1): 37–49. Http://dx.doi.org/10.1016/S0167-4730(97)00026-X.
- Dhanesh, P. 2003. Reliability-based optimization for multidisciplinary system design. Dissertation, University of Notre Dame.
- Diniz, S. 2008, Structural Reliability: Rational Tools for Design Code Development, doi:10.1061/41016(314)78.
- Dirk, G., Robby, C. and Luc, T. 2013. Experimental investigation of the loaddisplacement behaviour under catenary action in a restrained reinforced concrete slab strip. *Engineering Structures* 49. 10.1016/j.engstruct.2012.12.045.
- Ditlevsen, O. and Madsen, H. 2005, Structural Reliability Methods, http://www.mek.dtu.dk/staff/od/books.htm.
- Dolinski, K. 1982. First-order second-moment approximation in reliability of structural systems: Critical review and alternative approach. *Structural safety* 1 (3): 211–231. Http://dx.doi.org/10.1016/0167-4730(82)90027-3.
- El-Dardiry, E. and Ji, T. 2006. Modelling of the dynamic behaviour of profiled composite floors. *Engineering Structures* 28 (4): 567–579. Http://dx.doi.org/10.1016/j.engstruct.2005.09.012.

- Ellingwood, B., Allen, D., Elnimeiri, M., Galambos, T. V., Iyengar, H., Robertson, L. E., Stockbridge, J. and Turkstra, C. J. 1986. Structural Serviceability: A Critical Appraisal and Research Needs. *Journal of Structural Engineering* 112 (12): 2646–2664.
- Ellingwood, B. and Galambos, T. V. 1982. Probability-based criteria for structural design. *Structural safety* 1 (1): 15–26.
- Ellingwood, B., Galambos, T. V., MacGregor, J. G. and Cornell, C. A. 1980, Development of a probability based load criteria for American National Standard Committee A58, Special Publication No. 577, National Bureau of Standards.
- EN, B. 1992, 1-1: 2004 Eurocode 2: Design of concrete structures.
- Epaarachchi, D., Stewart, M. and Rosowsky, D. 2002. Structural Reliability of Multistory Buildings during Construction. *Journal of Structural Engineering* 128 (2): 205–213. Doi:10.1061/(asce)0733-9445(2002)128:2(205).
- Estee, M. E. 2010. *Deflection of Reinforced Concrete Flat Slab*. Msc, The Stellenbosch University.
- Eurocode, C. 1994, 4: Design of composite steel and concrete structures. Part1.1: General rules and rules for building (PrEN 1994-1-1:2003).
- Faravelli, L. 1989. Response-surface approach for reliability analysis. Journal of Engineering Mechanics 115 (12): 2763–2781.
- Ferrand, D. 2005. *Reliability analysis of a Reinforced Concrete Deck Slab supported on Steel Girders*. Ph.d, University of Michigan. Civil Engineering Department.
- Fiessler, B., Neumann, H.-J. and Rackwitz, R. 1979. QUADRATIC LIMIT STATES IN STRUCTURAL RELIABILITY. ASCE J Eng Mech Div 105 (4): 661–676. Http://www.scopus.com/inward/record.url?eid=2-s2.0-0018503596partnerID=40md5=68f0a8451ba9af46f7719b390af9a6fb.
- Freudenthal, A. M. 1947. The safety of structures. Transactions of the American Society of Civil Engineers 112 (1): 125–159.
- Freudenthal, A. M. 1956. Safety and the probability of structural failure, , vol. 121, 1337–1397. ASCE.
- Freudenthal, A. M., Garrelts, J. M. and Shinozuka, M. 1964. The analysis of structural safety. *Journal of Structural Engineering*, ASCE 92 (ST1): 267–325.
- Galambos, T. and Ellingwood, B. 1986. Serviceability Limit States: Deflection. Journal of Structural Engineering 112 (1): 67–84. Doi:10.1061/(ASCE)0733-9445(1986)112:1(67).
- Galambos, T., Ellingwood, B., MacGregor, J. and Cornell, C. 1982. Probability Based Design Load criteria in Load factors and Load combination. *Journal of Structural Division, ASCE* 108 (1): 959–975.

- Galambos, T., Gould, P., RavIndra, M., Suryoutomo, H. and Crist, R. 1973. Structural Deflections-A Literature and State-ofthe-Art Survey. National Bureau of Standards, Building Science Series 47.
- Ganesh, G. M., Upadhyay, A. and Kaushik, S. K. 2005. Simplified Design of Composite Slabs Using Slip Block Test. *Journal of Advanced Concrete Technology* 3 (3): 403–412. Doi: 10.3151/jact.3.403.
- Gayton, N., Mohamed, A., Sorensen, J. D., Pendola, M. and Lemaire, M. 2004. Calibration methods for reliability-based design codes. *Structural Safety* 26 (1): 91–121. Http://dx.doi.org/10.1016/S0167-4730(03)00024-9.
- Gesund, H. 1981. Limit design of slabs for concentrated loads. *Journal of the Structural Division* 107 (9): 1839–1856.
- Gholamhoseini, A., Gilbert, R. I., Bradford, М. Α. and Chang, Ζ. Т. 2014. Longitudinal shear stress and bondslip relationships composite concrete slabs. Engineering Structures 69 (0): 37 - 48.inHttp://dx.doi.org/10.1016/j.engstruct.2014.03.008.
- Gilbert, R. I. 1988. Time effects in concrete structures. *Developments in civil engineering* 23.
- Gollwitzer, S., Abdo, T. and Rackwitz, R. 1988. First Order Reliability Method, FORM Manual. *RCP Gmbh, Nymphenburger Str* 134.
- Gosling, P. D., Bridgens, B. N. and Zhang, L. 2013. Adoption of a reliability approach for membrane structure analysis. *Structural Safety* 40. 10.1016/j.strusafe.2012.09.002.
- Guan, X. L. and Melchers, R. E. 2001. Effect of response surface parameter variation on structural reliability estimates. *Structural safety* 23 (4): 429–444. Http://dx.doi.org/10.1016/S0167-4730(02)00013-9.
- Guandalini, S., Burdet, O. L. and Muttoni, A. 2009. Punching Tests of Slabs with Low Reinforcement Ratios. *ACI structural journal* 106 (1): 87–95. ¡Go to ISI¿://WOS:000262291800010.
- Gupta, S. and Manohar, C. S. 2004. An improved response surface method for the determination of failure probability and importance measures. *Structural safety* 26 (2): 123–139. Http://dx.doi.org/10.1016/S0167-4730(03)00021-3.
- Hedaoo, N., Gupta, L. and Ronghe, G. 2012. Design of composite slabs with profiled steel decking: a comparison between experimental and analytical studies. *International Journal of Advanced Structural Engineering* 4 (1): 1. Doi:10.1186/2008-6695-3-1.
- Hewitt, B. E. and Batchelor, B. d. 1975. Punching shear strength of restrained slabs. *Journal of the Structural Division* 101 (11548).

- Hohenbichler, M., Gollwitzer, S., Kruse, W. and Rackwitz, R. 1987. New light on first- and second-order reliability methods. *Structural safety* 4 (4): 267–284. Http://dx.doi.org/10.1016/0167-4730(87)90002-6.
- Holicky, M. 1998. Fuzziness of performance requirements in reliability analysis. In Proceedings of ICOSSAR'97, the 7th International Conference on Structural Safety and Reliability, 333. Taylor Francis US.
- Dunne, K. Holmes, Ν., and O'Donnell, J. 2014. Longitudinal shear of composite slabs containing crumb rubber in resistance concrete toppings. Construction and Building Materials 55(0): 365 - 378.Http://dx.doi.org/10.1016/j.conbuildmat.2014.01.046.
- Honfi, D., Mrtensson, A. and Thelandersson, S. 2012. Reliability of beams according to Eurocodes in serviceability limit state. *Engineering Structures* 35 (0): 48–54. Http://dx.doi.org/10.1016/j.engstruct.2011.11.003.
- Hossain, K. M. A. and Olufemi, O. O. 2005. Design optimization of simply supported concrete slabs by finite element modelling. *Structural and Multidisciplinary Optimization* 30. 10.1007/s00158-004-0470-4.
- Hossain, N. and Stewart, M. 2001. Probabilistic Models of Damaging Deflections for Floor Elements. *Journal of performance of constructed facilities* 15 (4): 135–140. 10.1061/(asce)0887-3828(2001)15:4(135).
- Hossain, T. R. and Vollum, R. L. 2002. Prediction of slab deflections and validation against Cardington data. In *PROCEEDINGS OF THE INSTITUTION* OF CIVIL ENGINEERS-STRUCTURES AND BUILDINGS, 235–248. ICE.
- Hsiao, L., Yu, W. and Galambos, T. 1990. AISI LRFD Method for ColdFormed Steel Structural Members. *Journal of Structural Engineering* 116 (2): 500–517. 10.1061/(asce)0733-9445(1990)116:2(500).
- Hyo-Nam, C., Hyun-Ho, C., Jung-Ho, K. and Young-Min, C. 2004. An experience of practical reliability-based safety assessment and capacity rating. *KSCE Journal of Civil Engineering* 8. 10.1007/BF02829082.
- James, H. H., Bakar, B. H. A., Ayad, A. A.-R. and Jayaprakash, J. 2010. Dynamic response simulation for reinforced concrete slabs. *Simulation Modelling Practice and Theory* 18. 10.1016/j.simpat.2010.01.011.
- Jamshidi, A., Koduru, S. and Driver, R. 2014. Reliability Analysis of Shear Tab Connections under Progressive Collapse Scenario, 2151–2161. ASCE, doi:10.1061/9780784413357.189.
- JCSS. 2000, Probabilistic Model code, part 1 Basis of Design working material, http://www.jcss.ethz.ch/.2001.

- Jinrong, L., Ying, T. and Sarah, L. O. 2013. Vulnerability of Disproportionate Collapse in Older Flat Plate Buildings Subjected to Sudden Removal of a Bearing Column, 1151–1161. ASCE, doi:10.1061/9780784412848.245.
- Jinxin, G., Yanqing, Z. and Shi, H. 2011. Ultimate Bearing Capacity of Reinforced Concrete Slab Carrying Concentrated Load. *Journal of Engineering Mechanics* 137. Doi:10.1061/(asce)em.1943-7889.0000285.
- Johnson, R. P. 2004. Composite structures of steel and concrete. 2nd edn., vol. 1 Beams, slabs, columns and frames for building. Blackwell Publishing, London, iSBN: 0-632-02507-7.
- Ju, M., Park, C., Hwang, E. and Sim, J. 2015. Predictability evaluation of the existing punching shear formulas using failure test and probabilitybased approach. *KSCE Journal of Civil Engineering* 19 (5): 1420–1430. Http://dx.doi.org/10.1007/s12205-015-0040-x.
- Karamchandani, A. and Cornell, C. A. 1992. Sensitivity estimation within first and second order reliability methods. *Structural safety* 11 (2): 95–107. Http://dx.doi.org/10.1016/0167-4730(92)90002-5.
- Kim, B., Wright, H. D. and Cairns, R. 2001. The behaviour of through-deck welded shear connectors: an experimental and numerical study. *Journal of Constructional Steel Research* 57 (12): 1359–1380. Http://dx.doi.org/10.1016/S0143-974X(01)00037-2.
- Kim, S.-H. and Na, S.-W. 1997. Response surface method using vector projected sampling points. Structural safety 19(1): 3-19.Http://dx.doi.org/10.1016/S0167-4730(96)00037-9.
- Kinnunen, S. and Nylander, H. 1960. Punching of concrete slabs without shear reinforcement. Elander.
- Koduru, S. D. and Haukaas, T. 2010. Feasibility of FORM in finite element reliability analysis. *Structural safety* 32 (2): 145–153. Http://dx.doi.org/10.1016/j.strusafe.2009.10.001.
- Lam, D. and Qureshi, J. 2008, Prediction of longitudinal shear resistance of composite slabs with profile sheeting to Eurocode 4, http://eprints.whiterose.ac.uk/8480.
- Lantsoght, E., van der Veen, C. and Walraven, J. 2011. Experimental Study of Shear Capacity of Reinforced Concrete Slabs. In *Structures Congress 2011*, 152– 163. ASCE.
- Lantsoght, E. O. L., van der Veen, C., de Boer, A. and Walraven, J. 2015. Proposal for the extension of the Eurocode shear formula for oneway slabs under concentrated loads. *Engineering Structures* 95: 16–24. Http://dx.doi.org/10.1016/j.engstruct.2015.03.055.

- Larsen, H. J. 1995. *Limit state design and safety format*, Ch. A2. The Netherlands: Centrum hout.
- Leicester, R. H. 1993, Serviceability criteria for building codes, Tech. Rep. 1025-9104, IABSE REPORTS.
- Liu, J., Tian, Y. and Orton, S. 2013. Vulnerability of Disproportionate Collapse in Older Flat Plate Buildings Subjected to Sudden Removal of a Bearing Column, 2814–2823. ASCE, doi:10.1061/9780784412848.245.
- Liu, P.-L. and Der Kiureghian, A. 1991. Optimization algorithms for structural reliability. *Structural safety* 9 (3): 161–177. Http://dx.doi.org/10.1016/0167-4730(91)90041-7.
- Low, H. Y. and Hao, H. 2001. Reliability analysis of reinforced concrete slabs under explosive loading. *Structural Safety* 23 (2): 157–178. Http://dx.doi.org/10.1016/S0167-4730(01)00011-X.
- Low, H. Y. and Hao, H. 2002. Reliability analysis of direct shear and flexural failure modes of RC slabs under explosive loading. *Engineering Structures* 24 (2): 189– 198. Http://dx.doi.org/10.1016/S0141-0296(01)00087-6.
- Lysaght. 2011, BONDEK II structural decking system, www.bluescopelysaght.com.my.
- MacGregor, J. 1989. Problem from viewpoint of structural engineer. In Symposium on Limit States Design in Foundation Engineering, 1–16. ASCE.
- Marimuthu, V., Seetharaman, S., Arul Jayachandran, S., Chellappan, A., Bandyopadhyay, T. K. and Dutta, D. 2007. Experimental studies on composite deck slabs to determine the shear-bond characteristic values of the embossed profiled sheet. *Journal of Constructional Steel Research* 63 (6): 791–803. Http://dx.doi.org/10.1016/j.jcsr.2006.07.009.
- Mariukaitis, G., Jonaitis, B. and Valivonis, J. 2006. Analysis of deflections of composite slabs with profiled sheeting up to the ultimate moment. *Journal of Constructional Steel Research* 62 (8): 820–830. Http://dx.doi.org/10.1016/j.jcsr.2005.11.022.
- Marsh, P. S. and Frangopol, D. M. 2008. Reinforced concrete bridge deck reliability model incorporating temporal and spatial variations of probabilistic corrosion rate sensor data. *Reliability Engineering System Safety* 93 (3): 394–409. Http://dx.doi.org/10.1016/j.ress.2006.12.011.
- Martin, H. 2001, Reliability of timber structural systems, trusses and joists, Tech. Rep. Report TVBK-1022, Lund University.
- Melchers, R. E. 1999. Structural reliability analysis and prediction. Newyork: Wiley.

- Melchers, R. E. and Ahammed, M. 2004. A fast approximate method for parameter sensitivity estimation in Monte Carlo structural reliability. *Computers Structures* 82 (1): 55–61. Http://dx.doi.org/10.1016/j.compstruc.2003.08.003.
- Mkelinen, P. and Sun, Y. 1999. The longitudinal shear behaviour of a new steel sheeting profile for composite floor slabs. *Journal of Constructional Steel Research* 49 (2): 117–128. Http://dx.doi.org/10.1016/S0143-974X(98)00211-9.
- Mohammed, B. S. 2010. Structural behavior and mk value of composite slab utilizing concrete containing crumb rubber. *Construction and Building Materials* 24 (7): 1214–1221. Http://dx.doi.org/10.1016/j.conbuildmat.2009.12.018.
- Mortensen, K. 1983, Is Limit State Design a Judgement Killer?, Tech. Rep. 8774510363, Danish Geoteknisk Institut.
- Moses, F. and Kinser, D. E. 1967. Analysis of structural reliability. *Journal of the Structural Division, American Society of Civil Engineers* 93: 147.
- Mostafaei, H., Vecchio, F., Gauvreau, P. and Semelawy, M. 2011. Punching Shear Behavior of Externally Prestressed Concrete Slabs. *Journal of Structural Engineering* 137 (1): 100–108.
- Muspratt, M. 1974. Stochastic methods for floor slab analysis. *Meccanica* Http://www.springerlink.com/index/Y4234X7832586WX7.pdf.
- Muttoni, A. 2008. Punching shear strength of reinforced concrete slabs without transverse reinforcement. ACI structural journal 105 (4): 440–450. ;Go to  $ISI_{\dot{c}}://WOS:000257181700006$ .
- Narayanan, R. S., Wilson, K. R. and Milne, R. J. W. 2000. Manual for the design of reinforced concrete building structures to EC2. Belgrade street london SWIX 8BH: Institution for the structural Engineers.
- Neves, R. A., Chateauneuf, A., Venturini, W. S. and Lemaire, M. 2006. Reliability analysis of reinforced concrete grids with nonlinear material behavior. *Reliability Engineering System Safety* 91 (6): 735–744. Http://dx.doi.org/10.1016/j.ress.2005.07.002.
- Nie, J., Ma, X. and Wen, L. 2015. Experimental and Numerical Investigation of Steel-Concrete Composite Waffle Slab Behavior. *Journal of Structural Engineering* 0 (0): 04015024. Doi:10.1061/(ASCE)ST.1943-541X.0001268.
- Okasha, N. and Aichouni, M. 2014. Proposed Structural Reliability-Based Approach for the Classification of Concrete Quality. *Journal of Materials in Civil Engineering* 0 (0): 04014169.
- Ong, K. C. G. and Mansurt, M. A. 1986. Shear-bond capacity of composite slabs made with profiled sheeting. *International Journal of Cement Composites and Lightweight Concrete* 8 (4): 231–237. Http://dx.doi.org/10.1016/0262-5075(86)90050-3.

- Park, R. and Gamble, W. 2000. Reinforced Concrete Slabs. Wiley, iSBN: 9780471348504.
- Phoon, K.-K. 1995. *Reliability-based design of foundations for transmission line structures*. PhD thesis, Cornell University.
- Pilakoutas, K. and Li, X. 2003. Alternative Shear Reinforcement for Reinforced Concrete Flat Slabs. Journal of Structural Engineering 129 (9): 1164–1172.
- Pinho Ramos, A., Lcio, V. J. G. and Regan, P. E. 2011. Punching of flat slabs with in-plane forces. *Engineering Structures* 33 (3): 894–902.
- Poh, K. W. and Attard, M. M. 1993. Calculating the load-deflection behaviour of simply-supported composite slabs with interface slip. *Engineering Structures* 15 (5): 359–367. Http://dx.doi.org/10.1016/0141-0296(93)90039-7.
- Porco, F., Uva, G., Sangirardi, M. and Casolo, S. 2013. About the Reliability of Punching Verifications in Reinforced Concrete Flat Slabs. Open Construction and Building Technology Journal 7: 74–87. DOI: 10.2174/1874836801307010074.
- Pugsley, A. 1955. Report on structural safety. *Structural Engineer* 33 (5): 141–149.
- Qian, K. and Li, B. 2013. Experimental Study of Drop-Panel Effects on Response of Reinforced Concrete Flat Slabs after Loss of Corner Column. ACI Structural Journal 110 (2).
- Rackwitz, R. 2001. Reliability analysisa review and some perspectives. *Structural safety* 23 (4): 365–395. Http://dx.doi.org/10.1016/S0167-4730(02)00009-7.
- Rajashekhar, M. R. and Ellingwood, B. R. 1993. A new look at the response surface approach for reliability analysis. *Structural safety* 12 (3): 205–220. Http://dx.doi.org/10.1016/0167-4730(93)90003-J.
- Rana, M. M., Uy, B. and Mirza, O. 2015. Experimental and numerical study of end anchorage in composite slabs. *Journal of Constructional Steel Research* 115: 372–386. Http://dx.doi.org/10.1016/j.jcsr.2015.08.039.
- Rashki, M., Miri, M. and Azhdary Moghaddam, M. 2012. A new efficient simulation method to approximate the probability of failure and most probable point. *Structural safety* 39 (0): 22–29. Http://dx.doi.org/10.1016/j.strusafe.2012.06.003.
- Ravindra, M. K. and Galambos, T. V. 1978. Load and resistance factor design for steel. Journal of the Structural Division 104 (9): 1337–1353.
- Rickard, A. and Markus, H. 2010. *Design of reinforced concrete with regard to explosions*. M.sc. thesis, Chalmers University of Technology.
- Rizk, E., Marzouk, H. and Hussein, A. 2011. Punching Shear of Thick Plates with and without Shear Reinforcement. ACI structural journal 108 (5): 581–591. ¡Go to ISI¿://WOS:000294198200007.

- Robert, K., Albin, K. and Thomas, K. 2013. Punching shear of RC flat slabs Review of analytical models for new and strengthening of existing slabs. *Engi*neering Structures 52. 10.1016/j.engstruct.2013.02.014.
- Roger, P. J. 2006. Models for the longitudinal shear resistance of composite slabs, and the use of none standard test data. American Society of Civil Engineers, doi:10.1061/40826(186)16.
- Rosowsky, D. and Fridley, K. 1997. Effect of Discrete Member Size on Reliability of Wood Beams. *Journal of Structural Engineering* 123 (6): 831–835. 10.1061/(asce)0733-9445(1997)123:6(831).
- Sahab, M. G., Ashour, A. F. and Toropov, V. V. 2005a. Cost optimisation of reinforced concrete flat slab buildings. *Engineering Structures* 27 (3): 313–322. Http://dx.doi.org/10.1016/j.engstruct.2004.10.002.
- Sahab, M. G., Ashour, A. F. and Toropov, V. V. 2005b. A hybrid genetic algorithm for reinforced concrete flat slab buildings. *Computers Structures* 83. Doi:10.1016/j.compstruc.2004.10.013.
- SAKO. 1999, Basis of design of structures proposals for modification of partial safety factors in Eurocodes, Joint committee of NKB and INSTA-B. NKB Committee and work reports, 1999:01 E.
- Schuller, G. I., Bucher, C. G., Bourgund, U. and Ouypornprasert, W. 1989. On efficient computational schemes to calculate structural failure probabilities. *Probabilistic Engineering Mechanics* 4 (1): 10–18. Http://dx.doi.org/10.1016/0266-8920(89)90003-9.
- Schuller, G. I. and Stix, R. 1987. A critical appraisal of methods to determine failure probabilities. *Structural safety* 4 (4): 293–309. Http://dx.doi.org/10.1016/0167-4730(87)90004-X.
- Schumacher, A., Lne, A. and Crisinel, M. 2002. Development of a New Design Approach for Composite Slabs, 322–333. American Society of Civil Engineers, doi:10.1061/40616(281)28.
- Semelawy, M. E., Nassef, A. O. and Damatty, A. A. E. 2012. Design of prestressed concrete flat slab using modern heuristic optimization techniques. *Expert Sys*tems with Applications 39. 10.1016/j.eswa.2011.11.093.
- Shehata, I. and Regan, P. 1989. Punching in R.C. Slabs. Journal of Structural Engineering 115 (7): 1726–1740.
- Shinozuka, M. 1983. Basic analysis of structural safety. *Journal of Structural Engineering* 109 (3): 721–740. Doi:10.1061/(ASCE)0733-9445(1983)109:3(721).
- Siemaszko, A. and Doliski, K. 1996. Limit state reliability optimization accounting for geometric effects. *Structural Optimization* 11. 10.1007/BF01376848.

Stephen, H. 2008, Composite slab, 72e7e525dd76ebec43

- Stewart, M. 1996a. Serviceability Reliability Analysis of Reinforced Concrete Structures. Journal of Structural Engineering 122 (7): 794–803. 10.1061/(asce)0733-9445(1996)122:7(794).
- Stewart, M. G. 1996b. Optimization of serviceability load combinations for structural steel beam design. *Structural Safety* 18 (23): 225–238. Http://dx.doi.org/10.1016/0167-4730(96)00012-4.
- Stewart, M. G. and Rosowsky, D. V. 1998. Time-dependent reliability of deteriorating reinforced concrete bridge decks. *Structural safety* 20 (1): 91–109.
- Tahsin, R. H. and Md. Ruhul, A. 2007. Deflection estimation of two-way edgesupported slabs. *Journal of Civil Engineering (IEB)* 35 (1): 15.
- Tenhovuori, A. I. and Leskel, M. V. 1998. Longitudinal shear resistance of composite slabs. *Journal of Constructional Steel Research* 46 (13): 228. Http://dx.doi.org/10.1016/S0143-974X(98)00169-2.
- Theodorakopoulos, D. D. and Swamy, R. N. 2002. Ultimate punching shear strength analysis of slabcolumn connections. *Cement and Concrete Composites* 24 (6): 509–521.
- Thoft-Christensen, P. 1984, In Safety and reliability in Europe, In Safety and reliability in Europe, 82–99, Ispara Italy: ESRA, 82–99.
- Tich, M. 1994. First-order third-moment reliability method. Structural Safety 16 (3): 189–200. Http://dx.doi.org/10.1016/0167-4730(94)00021-H.
- Tolson, B., Maier, H. and Simpson, A. 2001. Water Distribution Network Reliability Estimation Using the First-Order Reliability Method, 1–10. ASCE, http://ascelibrary.org/doi/abs/10.1061/40569
- Tsalkatidis, T. and Avdelas, A. 2010. The unilateral contact problem in composite slabs: Experimental study and numerical treatment. *Journal of Constructional Steel Research* 66 (3): 480–486. Http://dx.doi.org/10.1016/j.jcsr.2009.10.012.
- Tzaros, K. A., Mistakidis, E. S. and Perdikaris, P. C. 2010. A numerical model based on nonconvexnonsmooth optimization for the simulation of bending tests on composite slabs with profiled steel sheeting. *Engineering Structures* 32 (3): 843–853. Http://dx.doi.org/10.1016/j.engstruct.2009.12.010.
- Unanwa, C. and Mahan, M. 2012. Statistical Analysis of Concrete Compressive Strengths for California Highway Bridges. *Journal of Performance of Constructed Facilities* 120921235615001. 10.1061/(asce)cf.1943-5509.0000404.
- Vaininas, P., alna, R. and akinis, D. 2015. Probability based design of punching shear resistance of column to slab connections. *Journal of Civil Engineering and Management* 21 (6): 804–812. 10.3846/13923730.2015.1043339.

- Val, D., Bljuger, F. and Yankelevsky, D. 1997. Reliability Assessment of Damaged RC Framed Structures. *Journal of Structural Engineering* 123 (7): 889–895. Doi:10.1061/(ASCE)0733-9445(1997)123:7(889).
- Valdebenito, M. A., Pradlwarter, H. J. and Schuller, G. I. 2010. The role of the design point for calculating failure probabilities in view of dimensionality and structural nonlinearities. *Structural Safety* 32. 10.1016/j.strusafe.2009.08.004.
- Vecchio, F. and Tang, K. 1990. Membrane action in reinforced concrete slabs. Canadian Journal of Civil Engineering 17 (5): 686–697.
- Veritas, D. N. 1992, DNV Classification notes No. 30.6: Structural Reliability analysis for Marine Structures.
- Vrouwenvelder, T. 1997. The JCSS probabilistic model code. *Structural safety* 19 (3): 245–251.
- Wang, Y., Sun, Y., Wang, L. and Chen, Y. 2008. Punching Shear Behavior of Reinforced Concrete Hollow Slab, 1–7. ASCE.
- Warner, R. F., Rangan, B., Hall, A. and Faulkes, K. 1998. Concrete structures. Pearson Australia, iSBN: 0582802474.
- Wen, Y. K. 1993. Reliability-based design under multiple loads. *Structural Safety* 13 (12): 3–19. Http://dx.doi.org/10.1016/0167-4730(93)90044-2.
- Wright, H. D., Evans, H. R. and Harding, P. W. 1987. The use of profiled steel sheeting in floor construction. *Journal of Constructional Steel Research* 7 (4): 279–295. Http://dx.doi.org/10.1016/0143-974X(87)90003-4.
- Xu, L. and Cheng, G. 2003. Discussion on: moment methods for structural reliability. *Structural safety* 25 (2): 193–199. Http://dx.doi.org/10.1016/S0167-4730(02)00056-5.
- Yardim, Y., Waleed, A. M. T., Jaafar, M. S. and Laseima, S. 2013. AAC-concrete light weight precast composite floor slab. *Construction and Building Materials* 40: 405–410. Http://dx.doi.org/10.1016/j.conbuildmat.2012.10.011.
- Ying Wei, L. and Moses, F. 1994. A sequential response surface method and its application in the reliability analysis of aircraft structural systems. *Structural safety* 16 (12): 39–46. Http://dx.doi.org/10.1016/0167-4730(94)00023-J.
- Zhang, L. 2010. *Reliability analysis of fabric structures*. Ph.d., Newcastle University.
- Zhao, Y. and Ono, T. 1999a. New Approximations for SORM: Part 1. Journal of Engineering Mechanics 125 (1): 79–85. Doi:10.1061/(ASCE)0733-9399(1999)125:1(79).

- Zhao, Y.-G. and Ono, T. 1999b. A general procedure for first/secondorder reliabilitymethod (FORM/SORM). *Structural safety* 21 (2): 95–112. Http://dx.doi.org/10.1016/S0167-4730(99)00008-9.
- Zheng, Y., Robinson, D., Taylor, S. and Cleland, D. 2009. Finite element investigation of the structural behaviour of deck slabs in composite bridges. *Engineering Structures* 31 (8): 1762–1776. Http://dx.doi.org/10.1016/j.engstruct.2009.02.047.



## LIST OF PUBLICATIONS

### Journals:

- Kachalla M., Izian Abd Karim, Nora Farah Abd. A. A., and Law T. H. 2015. Continuous RC Slab Flexural Limit State Optimisation from Slab Depth Consideration. *Int. J. of Applied Engr. Res.*, Vol 10(13), pp: 33430-33437, ISSN 0973-4562
- Kachalla, M. and Izian, A. K. 2015. Concrete Depth on Moment Capacity of Reinforced Concrete Slab: Safety Performance. *Research journal* of Applied Sciences, Engineering and Technology, 11(6): pp: 610– 616, ISSN.:2040-7459, eISSN.: 2040–7467
- Izian Abd Karim, Kachalla M., Nora Farah Abd. A. A., and Law T. H. 2015. Comparative Safety Performance Evaluation of Profiled Deck Composite Slab from the use of Slope-Intercept and Partial Shear Methods. World Academy of Science, Engr. and Techn. Int. J. of Civil, Environmental, Structural, Constr. And Arch. Engr. Vol 9(8), pp: 861–867, ISSN 0973-4562
- Izian Abd. Karim, **Kachalla Mohammed**, Nora Farah A. A. Aziz and Law Teik Hua. 2016. New Numerical Approach for Profiled Deck Composite Slab Strength Verification. *Engineering Structures (IF)* (Accepted for consideration)
- Kachalla Mohammed, Izian Abd. Karim, and Rasheed Abed Hammond. 2017 Composite Slab Strength Determination Approach through Reliability Analysis. *Journal of Building Engineering (IF)*, Vol 9, pp 1-9. http://dx.doi.org/10.1016/j.jobe.2016.11.002
- Kachalla Mohammed and Izian Abd. Karim. 2016 Profiled Deck Composite Slab Strength Verification. *Pertanika Journal of Scholarly Research Reviews*(Accepted for consideration)

**Conferences:** 

• Kachalla, M. and Izian, Abd K. 2014. Reliability analysis of simply supported reinforced concrete slab. In proceedings of the International Research Symposium on Engineering and Technology, Kuala Lumpur, Malaysia. pp: 221–235, ISBN: 978-986-5654-01-6

Izian Abd Karim and Kachalla Mohammed. 2016. Composite Slab numerical strength Test Method under *M-K* Approach, In proceeding of the IRES International conference, 16-17 July 2016 Langkawi, Malaysia, pp: 1–5, ISBN: 978-93-86083-34-0





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