UNIVERSITI PUTRA MALAYSIA

A MODIFIED STRENGTH CAPACITY FOR COMPOSITE SLAB USING RELIABILITY APPROACH

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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

DEDICATIONS

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

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

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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, λ_{defl} and shear resistance, λ_{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 $l/6$ and $l/8$, 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 λ_{prop} factor of 2.0, and a similar λ_{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
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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, λ_{defl} dan rintangan ricih, λ_{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 λ_{prop} sebanyak 2.0, dan nilai λ_{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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I am always grateful to have been blessed with good friends and colleagues with whom I shared both personal and academic experience. I am highly appreciative for every shared moment of laugh and sadness.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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λ_i	Eigen value of the covariance matrix
t_i	Eigen vectors of the covariance matrix
μ	The mean
δ	The variance
PDF	Probability Density Function
CDF	Cumulative Density Function
$\|J\|$	Jacobian
α	Sensitivity factor
SLS	Serviceability-limit state
ULS	Ultimate-limit state
Q_k	Variable load
G_k	Dead load
l	Span length
F	Design load
γ_g	Partial safety factor for G_k
γ_q	Partial safety factor for Q_k
C_{norm}	Normal concrete cover
ΔC_{dev}	Normal concrete cover deviation
a	Minimum concrete cover
ϕ_{link}	Link diameter
ϕ_{bar}	Flexural bar diameter
l_y	Long span length
l_x	Short span length
R.E.I.	Resistance, Separation and Insulation
h	Slab depth
β_{sx}	Slab boundary condition along l_x
β_{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
ε_{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
ν_{Ed}	Applied shear
u	Column critical perimeter
$\nu_{Ed,max}$	Maximum design shear stress
v_{Ed}	Applied shear value at support
β_c	Moment transfer factor
$\nu_{Rd,c}$	Slab shear resistance
$\nu_{Rd,max}$	Maximum concrete shear resistance
ρ	Steel ratio
g_x	Limit state
γ_{con}	Concrete density
l/d	Span to depth ratio
ρ_o	Reference steel ratio
$\rho^{'}$	Compression reinforcement
τ_u	Longitudinal shear
$\tau_{u,Rd}$	Design shear strength
$\tau_{u,Rk}$	Characteristic Shear strength
m_{sd}	Composite slab action moment
m_{rd}	Composite slab bending resistance
δ_{max}	Composite slab maximum deflection
m	The slope
k	The Intercept
PSC	Partial Shear Connection
e	Centroid distance above the base
e_p	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
ψ	Shear connection factor
ζ	Degree of shear connection
ζ_{test}	Experiment ζ
ζ_{dl}	Design load
l_o	Overhang length
N_{pa}	Steel yield force
h_t	Overall deck thickness
h_c	Concrete depth

N_{cf}	Concrete compressive force
γ_{ap}	Partial safety factor for Deck
$m_{p,Rd}$	Design bending resistance
m_{pr}	Plastic moment of resistance
m_{pa}	Moment of resistance of deck
m_{test}	Experimental maximum bending moment
t	Sheeting deck thickness
p_{rd}	Stud shear resistance
E_{cm}	Mean Secant modulus
Q_m	Mean resistance
Q_n	Experimental test load per span
FTL	Failure Testing Load
PE.	Proposed Estimate
m_n	Material fabrication factor
f_n	Geometry and dimension factor
p_n	Professional judgement factor
V_Q	Mean resistance coefficient of variation
v_m	*cov* corresponding to m_n factor
v_f	*cov* corresponding to f_n factor
v_p	*cov* corresponding to p_n factor
PDCS	Profiled Deck Composite Slab
α	Shear span length
l_r	Load ratio
f_{l_r}	Load ratio factor
p_f	Probability of Failure
ϖ	Deck characteristics
$p_{f.mean}$	The mean safety index
$l_{r.mean}$	The mean l_r value
λ_{defl}	Deflection enhancement factor
λ_{prop}	Shear enhancement factor
OSED	One Short Edge Discontinuous
TAED	Two Adjacent Edge Discontinuous
OLED	One Long Edge Discontinuous
IP	Interior panel
W_γ	weighted least square
W_j	Limit state weighted factor of the limit state
m_{β_j}	The mean value of $\beta_j(\gamma_i)$
δ_{β_j}	The *SD* value of $\beta_j(\gamma_i)$
tau_r	Shear ratio
β_{defl}	Deflection safety index

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 load-resistance 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

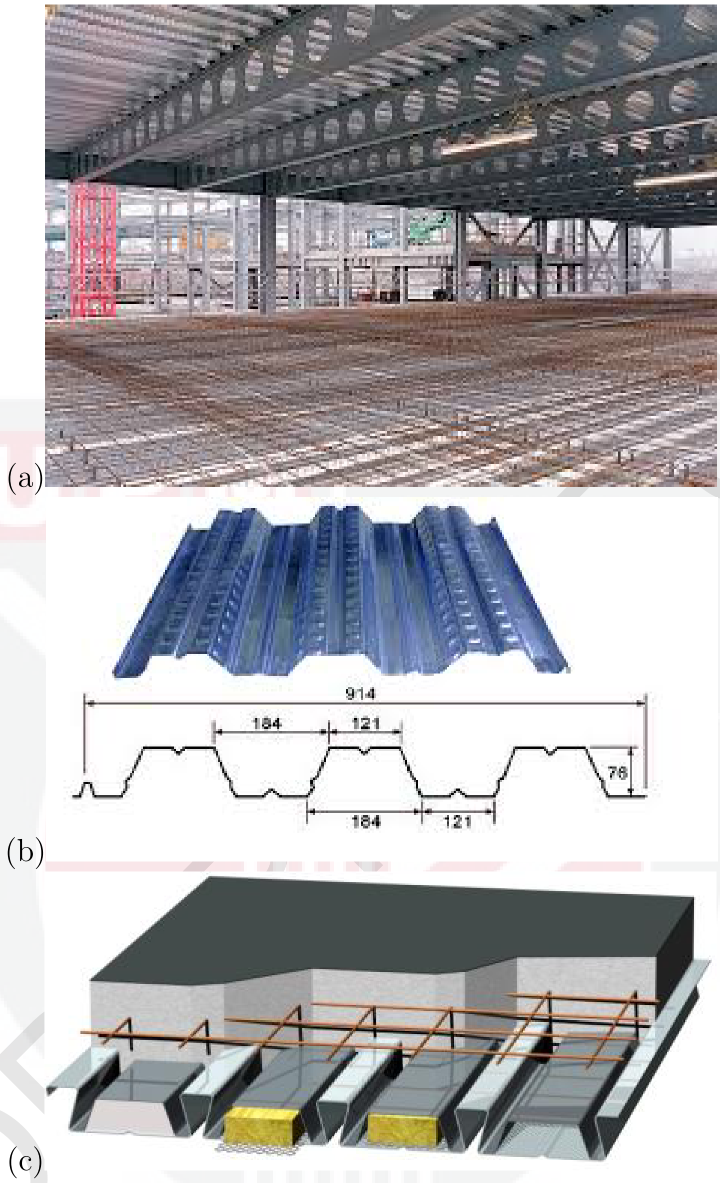


Figure 1.1: Typical profiled deck slab (a) Profiled deck composite slab construction (b) Embossing (c) Modelled profiled deck slab

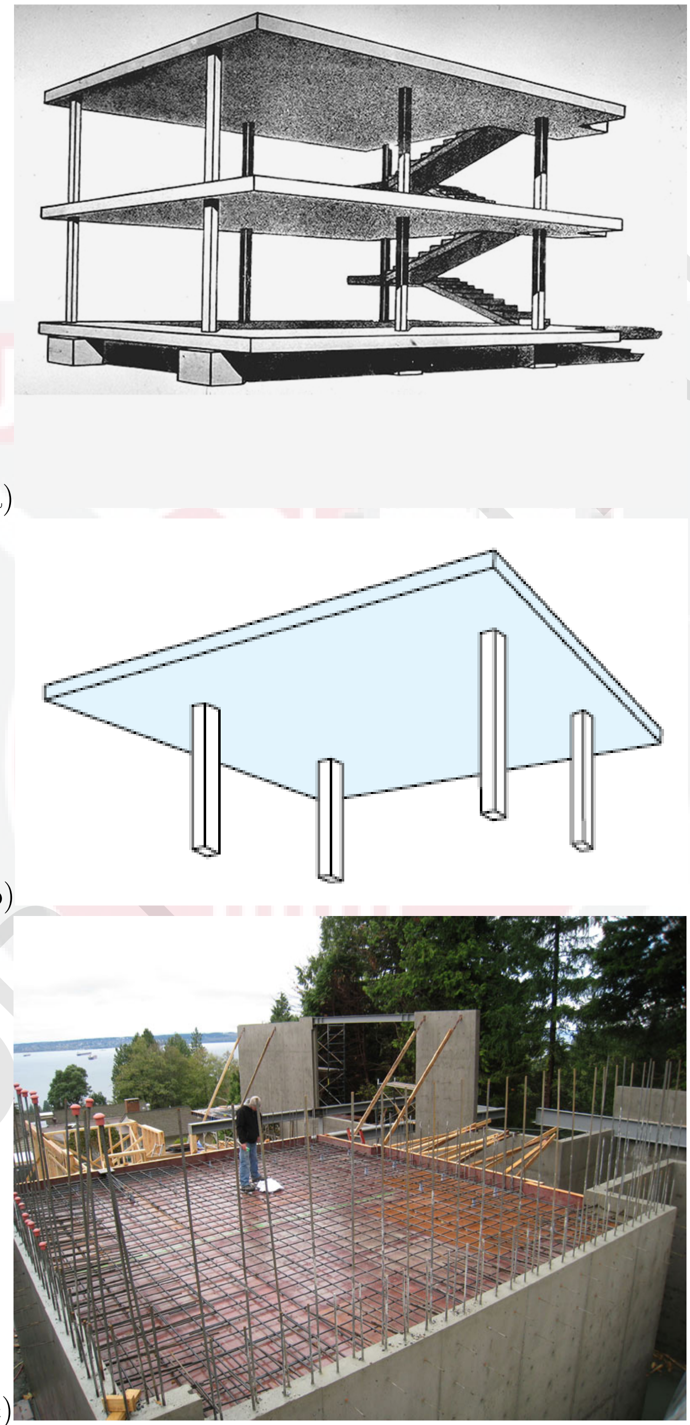
the capital-intensive laboratory procedure. Such procedures includes the slope-intercept and the partial shear connection (PSC) methods, amongst others. In addition, research findings have shown a significant strength load variation (about 26%) as well as conflicting results in longitudinal estimation 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 longitudinal 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.



(a)

(b)

(c)

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 serviceability 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 value for flat slabs. However, findings are not available on this simplified 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, shear-stud 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.

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LIST OF PUBLICATIONS

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