# SLENDERNESS STUDY OF COMPOSITE SLABS MODELED BY EXPLICIT DYNAMIC PROCEDURE

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# SLENDERNESS STUDY OF COMPOSITE SLABS MODELED BY EXPLICIT DYNAMIC PROCEDURE

YUSUF ABDINASIR MOHAMED

A project report submitted in partial fulfillment of the
requirements for the award of the degree of
Master of Engineering (Civil-Structure)

Faculty of Civil Engineering
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DECEMBER 2010

I declare that this project report entitled “*slenderness study of composite slabs modeled by explicit dynamic procedure*” is the result of my own research except as cited in the references. This project has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Dedicated to my beloved mother and father

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# ABSTRACT

Composite slabs are popular flooring systems in steel-framed buildings. They have a lot of advantages which make their use the most feasible option in many situations. Slenderness ratio (shear span/effective depth) has a dominant effect on composite slabs. It is not possible to test the whole range of slenderness for each deck profile because of limitation in time and cost. A good understanding of the slenderness effect makes prediction of the slab strength possible, and contribution to such understanding was the main aim of this study. A nonlinear finite element model was employed to predict the behavior of composite slabs. Steel-concrete interface was modeled with cohesive elements and a quasi-static solution was achieved through explicit dynamic analysis. Modeling procedure was improved to avoid unnecessary computational cost. The study then focused on examining the behavior of composite slabs with respect to variable slenderness. It is found that at slenderness ratio 7.0, the slab behavior changes between compact and slender. Finally, the study explored the use of shear bond-slenderness equation by plotting a linear regression line. The application of shear bond-slenderness equation enables the prediction of the shear-bond strength of any number of slabs utilizing the same profile from only two sets of test data. It was demonstrated that the shear bond stress varies linearly with the slab slenderness, with slender slabs exhibiting lower shear bond stress.

# ABSTRAK

Lantai komposit merupakan satu sistem lantai yang sering digunakan dalam pembinaan bangunan keluli. Terdapat banyak kelebihan mengunakan sistem lanatai komposit ini. Nisbah kelangsingan (jarak ricih/kedalaman berkesan) banyak memberi kesan terhadap lantai komposit. Keseluruhan nisbah kelangsingan tidak dapat diuji disebabkan masa dan kos ujian adalah terbatas. Tujuan kajian ini adalah untuk memahami dengan baik terhadap kesan kelangsingan lantai komposit dari segi kekuatannya. Kaedah unsur terhingga (nonlinear) telah digunakan untuk meramal kelakuan sesebuah lantai komposit. Permukaan keluli-konkrit dimodelkan dengan menggunakan cohesive elements dan penyelesaian quasi statik dengan menggunakan analisis explicit dynamic dilakukan. Prosedur pemodelan diperbaiki untuk mengelakan pengunaan kos pengkomputeran yang terlampau banyak. Kajian ini kemudianya tertumpu kepada ujian kelakuan lantai berkomposit terhadap kelangsingan. Ujian menunjukkan nisbah kelangsingan adalah 7.0 dimana kelakuan lantai komposit berubah antara jenis padat dan langsing. Kajian ini juga melihat penggunaan persamaan ikatan ricih dan kelangsingan dengan memplot graf regresi linear. Aplikasi persamaan kekuatan ricih dan kelangsingan membolehkan ramalan kelakuan ricih dan kekuatan ikatan sesebuah lantai komposit yang mepunyai profile yang sama dapat dilakukan dengan hanya menggunakan dua set data ujian. Ikatan tekanan ricih berkadar langsung dengan kelangsingan lantai, dimana kelangsingan lantai menunjukkan ikatan tekanan ricih yang rendah.

## TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# CHAPTER 1

# INTRODUCTION

## 1.1 Background of Study

Composite slab systems are common flooring systems in steel-framed buildings whereby concrete is placed on profiled steel decking which carries the construction loads and acts compositely upon hardening of concrete. The sheeting acts as the tensile reinforcement besides its other benefits. Light mesh reinforcement is normally placed in the concrete to account for temperature, shrinkage, cracks and fire. Shear connectors are used to develop composite action between the slab and the beam. The system has many advantages to offer including: high-speed erection due to un-propped construction, better quality control, lightweight and longer spans which all lead to overall economy of the system compared to conventional systems. On the other hand, some shortcomings can be highlighted such ah susceptibility to fire damage, damage caused by large local loads, and criticality of the steel-concrete bond [1-4].

The behavior of composite systems is complex and established methods for concrete and steel design are not applicable. The quest for developing established physical models has never stopped because the current design methods have some weaknesses including the lack of underlying mechanical models and dependency on costly and time-consuming full-scale bending tests. To overcome this, many attempts have been made so far to develop small-scale tests and numerical models which are in turn constantly evolving and improving.

Slenderness is a geometric property that has a paramount effect on load carrying capacity, shear bond strength and other properties of composite slabs. Hence, slab behavior with respect to variable slenderness must be understood properly so that wise decisions can be made at testing and design stages.

## 1.2 Problem Statement

Due to the apparent limitations of tests; development of reliable analytical models is desirable. These models can supplement available experimental data to increase efficiency and eliminate the need for too many tests. In the last two decades, few two-dimensional (2D) and three-dimensional (3D) Finite Element (FE) models have been proposed with successes and inherent limitations in each model. The FE model adopted in the current study is one of best models developed so far but has some deficiencies. These include the sensitivity to mesh refinement and reliance on trial-and-error procedure for obtaining some material parameters, both of which result in excessive analysis time and computer memory. It must be improved to make it more practical.

Some past researchers ignored the effect of slenderness in their numerical models or utilized constant behavioral properties for different slabs. However, slenderness is a geometric property that directly controls the behavior of composite slabs and hence must be understood so that wise decisions can be taken at testing and design stages. Slender slabs exhibit lower capacity and shear stress-slip property values but they do not undergo large variation in capacity when slenderness is change. However, any small change of slenderness in the compact region results in significant changes of load carrying capacity.

## 1.3 Research Aim and Objectives

The aim of this research was to study the effect of slenderness on the behavior of composite slabs and subsequently propose useful recommendations for the design, numerical simulation and testing of composite slabs. In order to achieve that aim, the following objectives were set out:

1. To build a 3D model of the composite slab using the commercial software ABAQUS/Explicit. Cohesive elements were used for representing the shear bond between concrete and steel deck, whereas 3D continuum elements were used for both steel and concrete. Concrete damaged plasticity material model was used for the concrete.

2. To perform non-linear explicit dynamic analysis for the developed model in order to achieve a computationally efficient quasi-static solution similar to the static lab testing of the slab. The weaknesses of this approach -which has been developed by a previous researcher [12] – are pointed out and some improvements suggested.

3. To carry out parametric study by changing span length and concrete thickness in order to study the slenderness effect.

## 1.4 Scope of Study

- A three-dimensional finite element model utilizing interface elements for shear bond between steel and concrete is performed which incorporates both geometric and material non-linearity.
- Profile deformations are not included in the FE model and no shear connectors are present.
- Taking benefit from the two-way symmetry, only quarter model is taken for the analysis.
- The FE models are built for 2” deep Gage 16 trapezoidal Vulcraft decks.
- For comparison purposes, the model adopts the small-scale setup used by Abdullah [9] in his experimental work. In this setup, one-rip wide simply supported slab is loaded by two-point loading.

## 1.5 Report Organization

This project report consists of five chapters. After this introductory chapter, the literature is briefly reviewed in chapter 2. A general discussion of composite construction aspects is followed by summarizing the state-of-the-art of finite element modeling of composite slabs, past research on the slenderness effect and the usage of explicit dynamic algorithm for achieving quasi-static solutions. Chapter 3 summarizes the research methodology adopted. Among the topics discussed are the finite element choices made, extraction of material properties from the literature and the analysis control. Chapter 4 presents and discusses the results of the current study. This includes the effect of mesh and web strength variation, energy control and studying the slenderness effect on composite slab behavior. Finally, chapter 5 is devoted to the conclusions drawn and suggestions for further improvements.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Composite Construction

Composite Construction is the generic term given to a building system which consists of concrete placed over profiled steel sheeting which is in turn supported on beams as shown in Fig 2.1. The sheeting acts as the tensile reinforcement for the slab beside other advantages. However, light mesh reinforcement is placed in the concrete to account for temperature, shrinkage, crack and fire. Shear connectors are normally used to develop composite action between the slab and the beam.

The overall construction system has many advantages to offer when compared with the conventional systems. High speed of construction is achieved primarily through the un-propped beams and slabs. Moreover, high quality control is achieved and the whole operation is less susceptible to tolerance problems [1, 2]. On the other hand, some shortcomings of this system can be highlighted such ah susceptibility to fire damage, damage caused by large local loads, and criticality of the steel-concrete bond. In the design stage, liquid ponding and edge deformation must be accounted for [3].

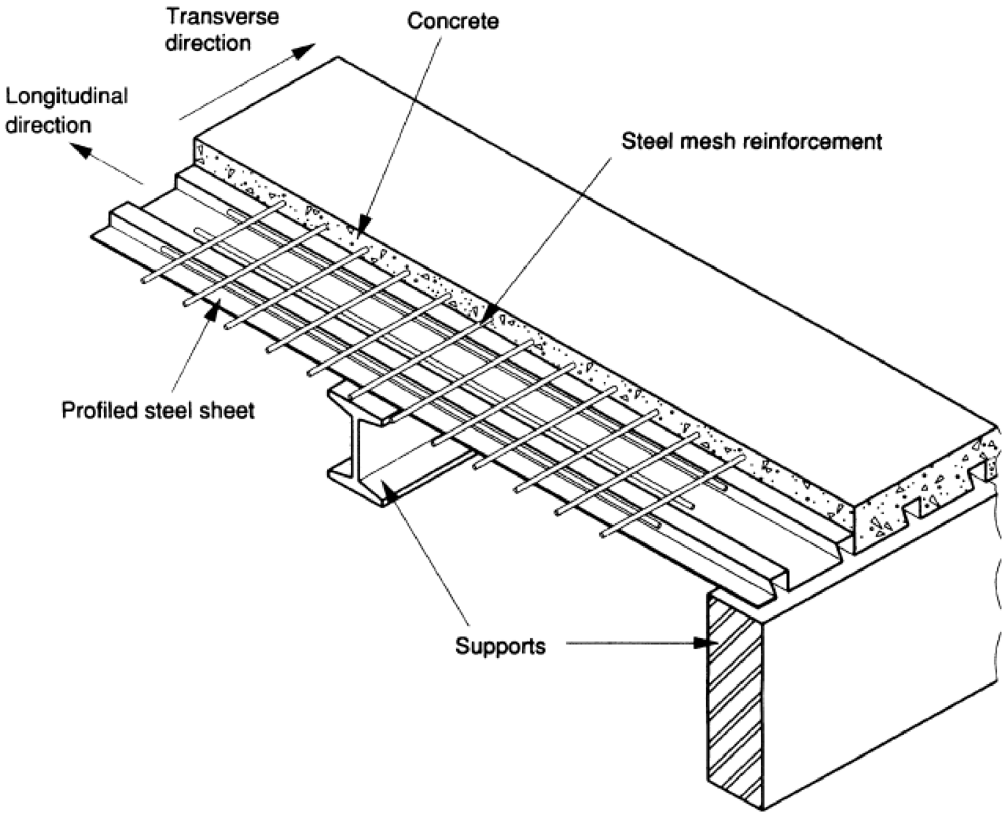


**Fig 2.1** Typical components of a composite construction system [4]

### 2.1.1 Composite Slabs

Composite slabs consist of concrete placed over profiled steel sheeting which acts compositely during service loading stage. In the construction stage, the decking supports construction loads and the weight of concrete before it gains sufficient strength. Normal slab spans range 2.7 to 3.6m between secondary beams if the system is un-propped but can be increased to 4m if props are used [2]. The overall slab depth range is 100-150mm depending on fire protection requirements. Both normal weight and lightweight concretes can be used, but lightweight concrete is preferred for its reduced self-weight and higher tensile strain capacity which helps reduce cracking. Concrete grades of 30 to 40 are normally specified and pumping is preferred as a method of placement [1, 2].

Composite slabs are usually designed as simply supported elements with no account taken of the continuity provided by the slab reinforcement at ultimate loads. They fail due to shear connection when end anchorage is not provided. This means that failure occurs by slip between the deck and the concrete before the plastic bending capacity of the slab is reached. The slippage between the concrete and the decking can be improved by the use of embossments or indentations in the web of the decking. Typical details of a composite slab are shown in Figure 2.2.

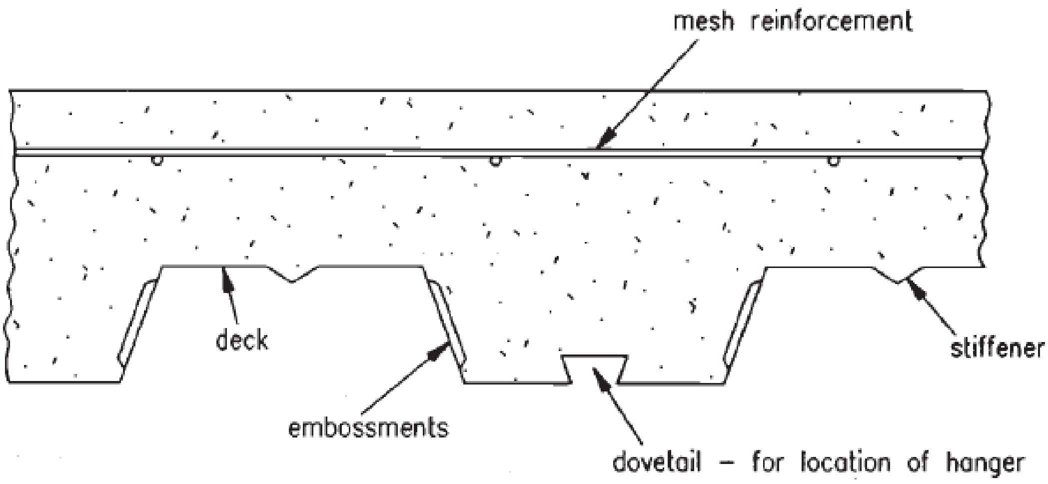


**Fig 2.2** Cross-section through a composite slab [2]

### 2.1.2 Profiled steel decking

There are two common types of profiled deck sheeting: Dovetailed (re-entrant) profiles and Trapezoidal profiles with web indentations. Common range for deck height is 38-80mm, trough spacing 150-300mm and a thickness of 0.8 to 1.5mm. The decking is normally galvanized to add a protection thickness of 0.02-0.04mm per face. The exposed bottom surface of the decking is usually painted with anti-corrosion paints to provide better protection. Grade S275 steel is normally used but for deeper, long-span profiles Grade S355 is preferred.

Steel Decking has many benefits from both structural and construction perspectives. It adds value to construction projects by enhancing construction quality, cost and timing requirements. Some of the benefits are listed below [1, 2, 3]:

- During construction, it forms a working platform supporting workers and equipment and other construction loads.
- When concrete hardens, a composite action is achieved to resist imposed loading together
- It stabilizes the beams against lateral torsional buckling by acting as lateral restraint.
- It transfers in-plane loads by diaphragm action to the vertical bracing system or to the walls.
- It prevents concrete cracking through the distribution of shrinkage strains.
- It acts as transverse reinforcement to the composite beams.
- Installation of services is simple and openings can be easily made.
- Decking is manufactured to high-quality at factory and then is easily transported, handled and cut to length on site with minimum difficulty and tolerance problems.
- Shear connectors are welded to the supporting beam through the decking.

There is a third category of deck designs called deep profiles. The development in this regard was pioneered by Slimflor® with deck depths in the range of 210-225mm, deck thicknesses of 1.0-1.25mm, and overall slab depths of 280-310mm. In this system, a column section is used as a beam by adding a plate on its bottom flange and then the slab rests on the bottom flange making the beam embedded in the floor [2].

Deep floor systems have the benefit of reducing construction height and simplifying the services installation. Corus patented another innovated deep floor solution called Slimdek® which utilizes an asymmetric beam manufactured with a wider bottom flange. This later system is easier to construct because it eliminates the need for welding a bottom plate and associated difficulties as shown in Fig 2.3.

**Fig 2.3** Asymmetric beam in a Slimdek® Deep Profile developed by Corus [5]

### 2.1.3 Composite Beams

Composite beams are usually I beams which are designed to act compositely with the slab through the use of shear connectors. Their usual spans are 6 to 12m. The composite action increases stiffness and a saving of 30-50% steel weight can be achieved through the use of shallower depth beams. This has the benefit of reducing storey heights and permitting more room for services.

Composite beams are usually designed as a series of parallel T beams with wide flange, whereby the concrete flange is in compression and the steel beam is largely in tension. Bending capacity is evaluated on ‘plastic’ analysis principles, whereas serviceability performance is evaluated on elastic section analysis principles. S355 steel is often preferred for steel beams and they are designed to be un-propped [1].

### 2.1.4 Shear Connections

Appropriate form of shear connection must be chosen in order for the horizontal shear forces to be transferred at steel-concrete interface of composite slabs. There are many forms of shear connection which can be used independently or in combination. Whatever method is used, the shear-bond capacity must be determined through testing. Below are some of the common methods of profiled steel sheeting shear connection which are also shown in Figure 2.4 [4, 6]:

1) Mechanical interlock provided by deformations in the profile (embossments)
2) Frictional interlock in re-entrant/dovetailed profiles
3) End anchorage by through-deck welded studs or another type of local connection between the steel and concrete (only in combination with 1 or 2)
4) End anchorage by deformation of the ribs at the end of sheeting (only in combination with 2)

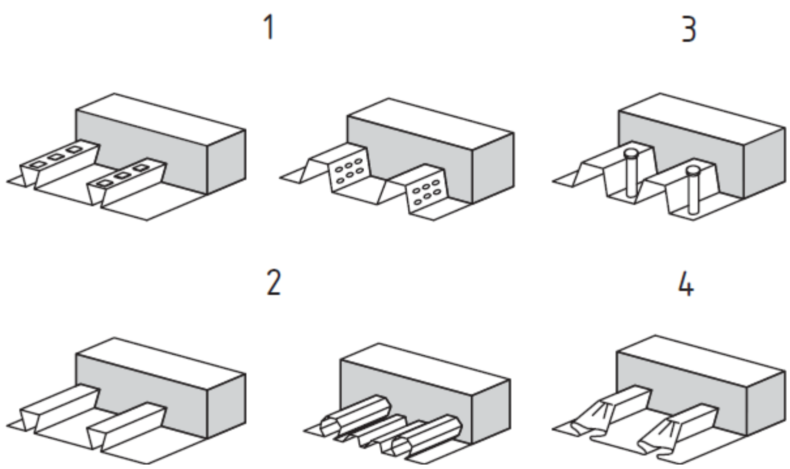


**Fig 2.4** Common forms of shear connection in composite slabs [6]