EXPERIMENTAL-NUMERICAL COMPARISONS OF TIMBER-CONCRETE COMPOSITE FLOORS TESTED UNDER SHORT-TERM LOADING

SHORT TERM RESEARCH GRANT

VOT 0773

UNIVERSITI TUN HUSSEIN ONN MALAYSIA

ABSTRACT

Timber or concrete floor is commonly used in construction of buildings and bridges. The advantage of timber and concrete such as the high tensile strength and high compressive strength respectively is used. Timber provides low structural load compared to concrete due to its low unit weight. Therefore the combination of concrete and timber for floor system is an alternative way to improve its structural performance of against tensile and compression stresses. Hence, development of timber–concrete composite (TCC) is crucial to reduce the use of cement in fully reinforcement concrete floor by replacing LVL timber as web and concrete as flange of the T-beam strip. Every single TCC beam is placed parallel to form floor strips. Since TCC floor system is comprised of two different materials which connected together thus the development of interlayer connection is required. Numerical method through finite element software to study the structural collapse behaviour of TCC floors is the interest of this paper. In this study, the TCC floor under short-term collapse load is modelled using FORTRAN 90 LANGUAGE to compare with the following relationship are of interest: load-deflection, load-horizontal slip and stress in section due to bending from the existing experimental results. Hence, the results are proven that modelling best present its reality if 10 connectors are used and friction between two combination layers is considered in modelling.

ABSTRAK

Kayu atau lantai konkrit biasanya digunakan dalam pembinaan bangunan-bangunan dan jambatan-jambatan. Kelebihan bagi kayu dan konkrit seperti kekuatan tegangan tinggi dan kekuatan mampatan tinggi, masing-masing adalah digunakan. Kayu menyediakan beban struktur rendah berbanding dengan kontrik disebabkan berat unit rendahnya. Lantarannya gabungan kayu dan konkrit untuk sistem lantai ialah satu cara alternatif untuk meningkatkan prestasi strukturnya menentang mampatan dan tegang menekankan. Maka, pembangunan recaman kayu–konkrit (TCC) adakah genting mengurangkan penggunaan simen dalam sepenuhnya lantai konkrit tetulang dengan menggantikan kayu LVL sebagai web dan konkrit sebagai bebibir jalur T-Rasuk. Setiap rasuk TCC diletakkan selari dengan membentuk jalur-jalur lantai. Sejak sistem lantai TCC diliputi dua bahan berbeza yang mana berhubung bersama maka pembangunan sambungan antara lapisan itu diperlukan. Kaedah berangka melalui perisian finite elemen untuk belajar tingkah laku keruntuhan struktur lantai TCC ini ialah kepentingan kertas ini. Dalam kajian ini, lantai TCC di bawah beban keruntuhan jangka pendek dimodelkan menggunakan FORTRAN 90 LANGUAGE membanding dengan hubungan berikut adalah daripada ingin: beban- pesongan, beban- gelinciran mengufuk dan tekanan dalam keratan disebabkan membengkok dari hasil eksperimen yang terwujud. Maka, keputusan adalah membuktikan bahawa peragaan itu yang paling baik realitinya jika 10 penyambung-penyambung digunakan dan geseran antara dua lapisan-lapisan gabungan dianggap dalam pemodelan.

CONTENTS

CHAPTER 1

INTRODUCTION

1.1 Introduction of Finite Element Modelling of Short term Collapse on Timber Concrete Composite (TCC) Floor

1.1.1 Timber Concrete Composite

The timber-concrete composite (TCC) system is a construction technique which has been common used in western country due to its strength and stiffness able upgrading of existing timber floors and short span bridges. By combination of concrete slab and timber, it is possible to exploit their best properties against natural loading on single material beam since the concrete is positioned as flange of T-shaped cross-section which is compression section while the timber is used in the tension region as web as well as connection system.

The presence of timber, due to its lower density in comparison with reinforced concrete, decreases the weight of this flooring system, implying several advantages if compared with traditional timber floor: higher efficiency in terms of load carried per self-weight; better seismic performance derived by less structural mass; and lower carbon footprint of the building when compared with concrete, due to the advantage of carbon stored in the timber. The advantages given by the concrete slab are: larger thermal mass and fire resistance; better acoustic separation; and good structural performance in seismic regions since the floor behaves as a rigid diaphragm (Deam B, 2007). The materials in TCC are effectively utilised in terms of strength performance where the timber web is mainly subjected to tension and bending, the concrete flange is mainly subjected to compression, and the connection system subjected to shear. A stiff and strong connection system is crucial in order to achieve a suitable bending strength and stiffness of the TCC. Hence, a minimum relative slip between the bottom fibre of the concrete slab and the top fibre of the timber beam, and a high composite efficiency are necessary to be achieved. (Yeoh D et al, 2008).

The connection system should preferably provide ductility within the TCC element, since both timber and concrete are naturally quite brittle (in tension and compression respectively. In contrast, the connection system needs to be inexpensive to manufacture and install in order to make TCC beams competitive with other construction systems.

1.1.2 Finite Element Modelling

Finite Element modelling is a numerical solution technique used to obtain approximate solution of a boundary value problem in engineering. It able to divide vertically and horizontally along the composite beam into small box either is triangle shape or square shape box. However, this research paper is going divide in square box size due to the most accuracy will obtain in result of deformation under loading over period.
A Finite Element (FE) program purposely developed for long-term and collapse analysis of timber-concrete composite beams. This paper is used to model the part of the short-term tests. The purpose of the numerical modelling was to calibrate the program on the experimental tests, which were performed over a limited period of time (...days), so as at a later stage to extend the results to the end of the service life (50 years) and to composite beams with different mechanical and geometrical properties.

The finite element used to model the TCC is displayed in Fig. 1. It is constituted by a lower timber beam linked to an upper concrete flange by means of a continuous spring system. Such a spring system represents the connection by hypothesizing the connectors as smeared along the beam axis. Two layers of reinforcement may be placed inside the concrete slab. The timber and concrete cross sections are divided into horizontal and vertical fibres in order to consider different properties along the height and the width.(Fragiacomo M. and Ceccotti A,2006)

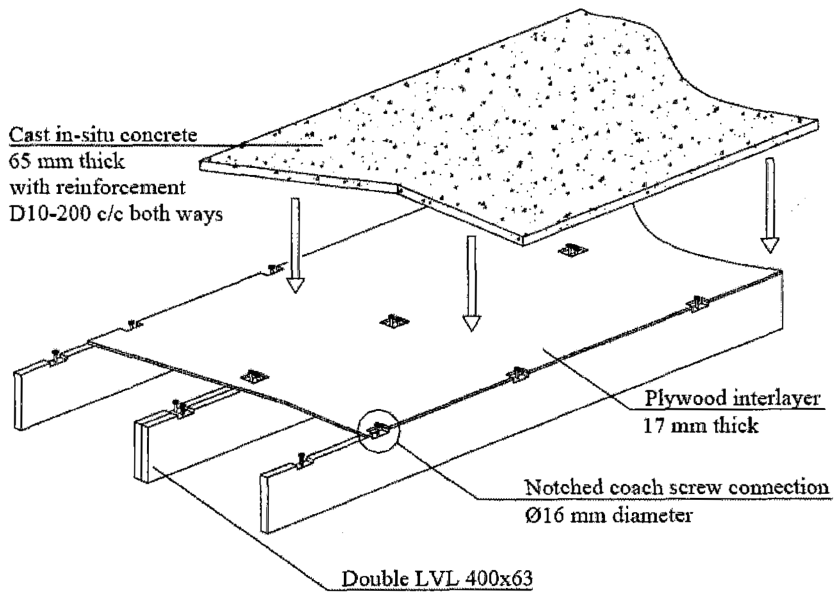


Figure 1 Proposed semi-prefabricated timber-concrete composite system

1.2 Problem statement

Generally, the development of timber concrete composite floors system is seen rarely used in Malaysia if compared to western country since we are more rely on conventional method by using reinforcement concrete floor system. Indeed, Timber Concrete Composite is widely benefit to building services with substitute RC T-shape beam in floor system due to its best properties as timber beam giving greater strength and stiffness (composite action), better resistance against earthquakes (rigid diaphragm), fewer vibration problems, better acoustic separation and better fire resistance. However the setup of TCC floor need higher work man skill and accuracy on connecting systems.

Recently little information is available and the application of this type of floor is problematical, because British standards are not yet available especially Malaysia Standard. In order to change this situation, but yet need spend a lot of money on experiment research and time consume due to it's vary connector system in design. Therefore computation modelling is developed by using finite element modelling method which is depend on 2 criteria of the material used as element type of geometrical properties and model type for the material behaviour. This is purposely bringing comparing to existing experiment measurement with numerical measurement in order to verify the accuracy of stress and strain relationship by numerical measurement on Timber Concrete Composite floors system without carry single experiment in future.

1.3 Project Objectives

The main aim in this research investigation is to compare the relationship of stress and strain by using numerical method to experiment method on Timber Concrete Composite with different connecting system under the deformation of load over time. The TCC floor is topping with narrow depth of concrete (with steel mesh) on the LVL timber beam if compare to normal concrete slab design then load until failure (short term collapse).

Towards achieving the above mentioned aim, the related objectives associated were identified as follows:

i. To plot the relationship of stress versus strain (short term failure) for each different connecting system
ii. To compared the result of numerical and experimental values through the plotted graph of force-deflection, shear force-relative slip, and load versus stress (short term failure)
iii. To verify the accuracy or validity of the numerical method on designing TCC floor system in different connecting system without need of carries experiment in future.

1.4 Scope of study

The study consists of finite element work is in term of FORTRAN LANGUAGE with need of geometrical properties and behaviour of material used. Therefore the scopes of work for this study are also need to review on the properties of concrete and timber from others researchers regarding to their methods in producing TCC floors. Hence, geometrical data in shape of rectangular as giving dimension of the material in term of length, width and height and in additional on behaviours of material like its young modulus is needed. They all crucial to be taking into account since the finite element software does not have any library data of any tested material regarding their limitation to failure. This valuable information was used as reference during conducting this research. In this research, the accuracy of numerical method on TCC floor was investigated in terms of non-linear finite element modelling which dividing grid in small boxes along the composite beam.

In conjunction of this, there was a test referred by the model validation of the timber concrete composite is push out test. The specimen was subjected to one-sided push out test under ambient laboratory conditions. The value of experiment result will then compared with this finite element modelling result.

1.5 Contribution of Study

This study takes numerical study to modelling the Timber Concrete Composite Floor systems with different connecting system. Analytical study will be carrying on developing the relationship of stress versus strain for TCC floor system.

CHAPTER 2

LITERATURE REVIEW

2.1 Finite element method approach

2.1.1 Definition of finite element method

A Finite Element (FE) program purposely developed for long-term and collapse (short term) analysis of timber-concrete composite beams. They are the methods for solving boundary value problems in which one divides the domain of the problem into little pieces or small region according shape. It is powerful tools that people can define the problem in according to its result of displacement and stress analysis.

There are generally two types of analysis that are used in industry: 2-D modelling, and 3-D modelling. While 2-D modelling conserves simplicity and allows the analysis to be run on a relatively normal computer, it tends to yield less accurate results. 3-D modelling, however, produces more accurate results while sacrificing the ability to run on all but the fastest computers effectively. Within each of these modelling schemes, the programmer can insert numerous algorithms (functions) which may make the system behave linearly or non-linearly. Linear systems are far less complex and generally do not take into account plastic deformation. Non-linear systems do account for plastic deformation, and many also are capable of testing a material all the way to fracture (Peter Widas, 1997).

2.1.2 Brief history of finite element method

Finite Element Analysis (FEA) was first developed in 1943 by R. Courant, who utilized the Ritz method of numerical analysis and minimization of variation calculus to obtain approximate solutions to vibration systems. Shortly thereafter, a paper published in 1956 by M. J. Turner, R. W. Clough, H. C. Martin, and L. J. Top established a broader definition of numerical analysis. The paper centered on the "stiffness and deflection of complex structures". (Peter Widas,1997).

By the early 70's, FEA was limited to expensive mainframe computers generally owned by the aeronautics, automotive, defence, and nuclear industries. Since the rapid decline in the cost of computers and the phenomenal increase in computing power, FEA has been developed to an incredible precision. Present day supercomputers are now able to produce accurate results for all kinds of parameters. (Peter Widas, 1997).

Brief History

1.	1950s	Structural analysis
2.	1965	A. M. Winslow
3.	1969	P. P. Silvester (waveguide analysis)
4.	1974	K. K. Mei (unimoment method for scattering and antenna analysis)
5.	1982	S. P. Marin (combined with boundary integral equations for scattering analysis)
6.	1980	J. C. Nedelec (vector elements)
7.	1985 -	Extensive developments for EM problems
8.	1983	P. P. Silvester & R. L. Ferrari, *Finite Elements for Electrical Engineers*, 1st ed.
9.	1993	J. Jin, *The Finite Element Method in Electromagnetics*, 1st ed.

Figure 2.1 Brief History of FEM

2.1.2 Finite element modelling

The problem is modelling as beam as linear analysis, consisting of discrete number of element, each having a uniform cross section. The purpose of the numerical modelling was to calibrate the program on the experimental tests, which were performed over a limited period of 28 days, so as at a later stage to extend the results to the end of the service life (50 years) and to composite beams with different mechanical and geometrical properties. (Yeoh D, 2007)

2.1.2.1 First applications

One of the first applications of timber-concrete composite floor systems in Europe is to be found in the early 20th century. VAN DER LINDEN (1999) mentioned a patent of Mueller (1922) in which a system of nails and steel braces formed the connection between a concrete slab and the timber. Schaub from Switzerland patented a composite system in 1939, which consisted of a timber girder and a concrete slab and used Z- or I-sections as connectors (BLASS, 1995).

This early development was mainly caused by a deficiency of steel during and after the world wars. In the United States, Australia and the Scandinavian countries, the main focus was, and still is, more targeted on the application of composite systems for bridges, in which case the concrete slab simultaneously acts as a shelter for the wood from the solar irradiation and from the rain. Less than 5 years ago the Vihantasalmi bridge, which incorporates timber-concrete composite, was built in Finland. This is one of the biggest wood bridges ever built on a main road with a total length of 182 m. It is an impressive argument for the effective application of the timber-concrete composite construction.

Benitez (2000) stated that the developing of a composite system using steel connectors between timber and concrete was carried out around 1930 at the University of Oregon, USA. The first major growth occurred after composite design and construction were introduced into "The American Association of State Highway Officials Specifications" in 1944 (Cook, 1976). The connection was performed through triangular steel plates, which were put between thin timber beams. In Australia, the first major composite system was built on a highway bridge in the 1950s on the Pacific Highway in New South Wales over the Maria River (Benitez, 2000).

2.1.2.2 Application of Timber Concrete Composite

The state-of-the-art literature review on timber concrete composite is found in Yeoh et al (2011c). Timber concrete composite had invented to benefit the existing or non-existing building floor structure system. TCC cover with concrete slab on a timber cross section beam is proof that giving highest durability than the traditional reinforcement floor system due its combination of high compressive strength of concrete on top and the high tensile strength on bottom of a floor system as shown as figure 2.2.

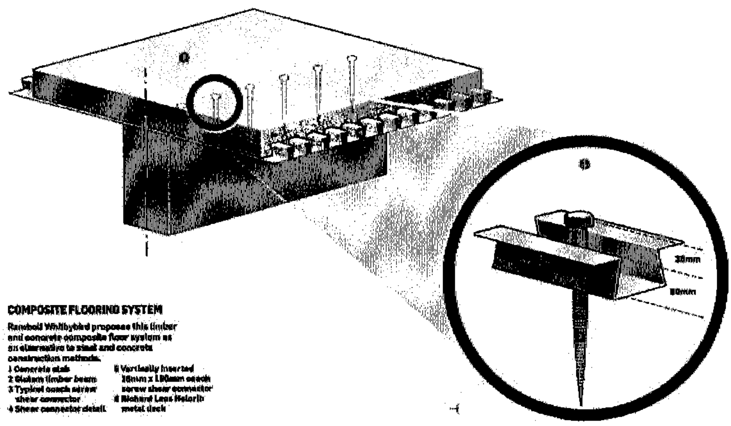


Figure 2.2 Timber Concrete Composite

In additional the TCC is able for refurbish the existing wooden floor system which is undergoes degradation of timber structure by enhancing its stability and strength. However the TCC system is also applicable to apply as a new floor system in new building due to its best performance of fire resistance, better acoustic separation and good structural performance in seismic regions (Deam B, 2007). TCC even is use as new bridge systems which enable reduce the use of asphalt concrete or steel but without affect on its strength of bridge as shown in figure 2.3.

Figure 2.3 TCC Bridge Systems (Professor Rautenstrauch ,2009)

In year 2009, an effort of engineer Ramboll Whitbybird has been researching and developing a timber and concrete composite scheme that enables large open-plan buildings to be constructed with a timber frame as shown as in figure 2.4.

Figure 2.4 TCC floor systems building in Mossbourne Community Academy in Hackney, east London

However, in Malaysia there is still reliable on concrete and steel based structure instead of using timber-concrete composite as an alternative method in construct floor system even Malaysia is sitting on Tropicana region which is rich in hard wood production.

2.2 Previous research and development of TCC

2.2.1 Research with different connector

From the earliest century till now there is a lot of design focus on connecting system for TCC. The attention in this section is focused on the development of different kinds of connectors.

Deam B. (2007) describes that the results of an experimental programme that investigated the suitability of a range of connectors to transfer shear between a concrete slab and a laminated veneer lumber (LVL) beam. Then the best mechanical performance is found that using concrete plug reinforced with a screw, particularly the rectangular plug. Such a system can be used for cost-effective composite floor systems due to its efficient cost-to-capacity ratio, which reduces the number of connectors needed along the beam axis to achieve the composite action.

Seibold E (2004) stated that a good understanding of the mechanics of shear connections between LVL and concrete can be constructed through this project with different connector system in timber concrete composite. The result showed that the most desirable characteristics for the shear connection were found to be stiffness and strength, but post-elastic deformation capacity is also desirable in order to avoid brittle failure.

Yeoh et al (2011a) has found that the length of the notch significantly enhances the strength performance of the connection while a lag screw improves the slip modulus at ultimate limit state, the post-peak behavior, and enables a more ductile failure to take place.

2.2.2 Short term loading behaviour studies

Quite a number of short-term collapse tests have been performed to date on TCC floor beams. Collapse tests are important to quantify the actual composite action of the system, the load bearing capacity and the failure mechanisms. There is in general a close relationship between the collapse load and the failure mechanism, and the type of connection system.

Yeoh D et al (2008 and 2011b) attempted experimental-numerical comparisons in terms of mid span deflection for selected outdoor TCC beams under unconditioned environment (daily temperature and relative humidity) were monitored for a period of 28 days and then compared with a purposely developed numerical model.

Fragiacomo et al. (2004) said that a nonlinear analysis to failure is carried out, the applied load is incrementally increased and at each step the solution is sought through an iterative procedure based on the modified secant stiffness method.

Yeoh D et al (2010 and 2011b) attempted short-term collapse tests were conducted mid span laminated veneer lumber (LVL)-concrete composite floor T-beams. Several variables such as connection types, concrete type, and design level corresponding to number of connections were investigated. This research found that no significant difference was found in the short-term performance among beams with different shrinkage properties of concrete. However, the strength of concrete is important especially in notch-connected beams since the concrete within the notches provides the shear transfer between the LVL and the concrete slab.

Ceccotti et al (2007) stated that double 6 m span glulam T-beam, with 18 corrugated rebars glued to each beam with epoxy resin. Beam was twice loaded and unloaded prior to 4-point bending collapse test after a 5-year long-term monitoring. By result showed that collapse load was 2P = 500 kN with a 33.2 mm and 2.47 mm of maximum deflection and end slip, respectively

Deam et al (2008) had tested with four 6 m long full-scale TCC beams with LVL joists and lag screw connection tested in 4-point bending. Then there are two specimens is prestressed with unbounded draped tendons and straight tendons, respectively, and one specimen non-prestressed.

Lukaszewska et al (2009a) had done five 4.8 m span full-scale TCC floors of triple T-section glulam joists tested to failure in 4-point bending. The concrete slab of specimens was prefabricated off-site with mounted connectors. Three specimens had lag screws surrounded by steel pipes embedded in the concrete whilst two specimens had metal plates nailed to the glulam joists.

2.3 Finite element for TCC work

Timber-concrete composite is widely applied in reality especially western country like London and Australia. Its benefit of structural performance for floor system had encouraged the occupant or owner to reduce the reliable on reinforcement concrete beam and floor. In actually, TCC not only use as refurbish work on existing timber floor to enhance its stiffness and durability then it also able apply as new floor system and girder bridge instead of using RC floor. It helps reduce the content of concrete over all the structure which is also benefit the occupant or user by risking of carbon dioxide release from concrete.

Ramboll Whitbybird (2009) stated that timber has been used mainly for residential buildings traditionally. But in the past four years, structural engineer Ramboll Whitbybird has been researching and developing a timber and concrete composite scheme that enables large open-plan buildings to be constructed with a timber frame. The system locks concrete floors to timber beams using shear studs. Ramboll Whitbybird developed the timber and concrete composite floor construction in collaboration with Cambridge University's engineering department. After a year of desk study, it carried out a full-scale load test consisting of a 130mm concrete slab cast on a metal deck, connected to a 550mm whitewood glulam beam with a standard shear stud 16mm in diameter and 130mm long. Through various trials, the firm discovered that inclining the shear studs towards the direction of the support gave a much stronger result.

CHAPTER 3

METHODOLOGY

3.1 Identify software

Finite element method is a numerical analysis technique to obtain approximate solutions to a wide variety of engineering problems. Among the variety of finite element analysis package, FORTRAN 90 version is being use for this study to make a comparison of FE modeling and experiment result.

3.1.1 What is FORTRAN?

FORTRAN is a general-purpose programming language mainly intended for mathematical computations in engineering. It is an acronym for formula translator first-ever high-level programming language, using the first compiler ever developed initially developed by a team of programmers at IBM lead by John Backus, and first published in 1957.

FORTRAN is the dominant programming language used in engineering applications and the most enduring computer programming language in history. From previous time till now, experts have predicted the extinction of FORTRAN, and these predictions have always unsuccessful. One of the main reasons it has endured as software inertia and other reliable software translation is very difficult and expensive.

3.1.2 History of FORTRAN

FORTRAN 90 is major revision where released as an ANSI standard in 1992 free-form source input, modules, recursive procedures, derived/abstract data types, dynamic memory allocation, pointers, case construct, and so on. It had giving out inline comments, identifiers up to 31 characters in length, new and it also able enhanced intrinsic procedures in system.

3.2 Methodology Flow Chart

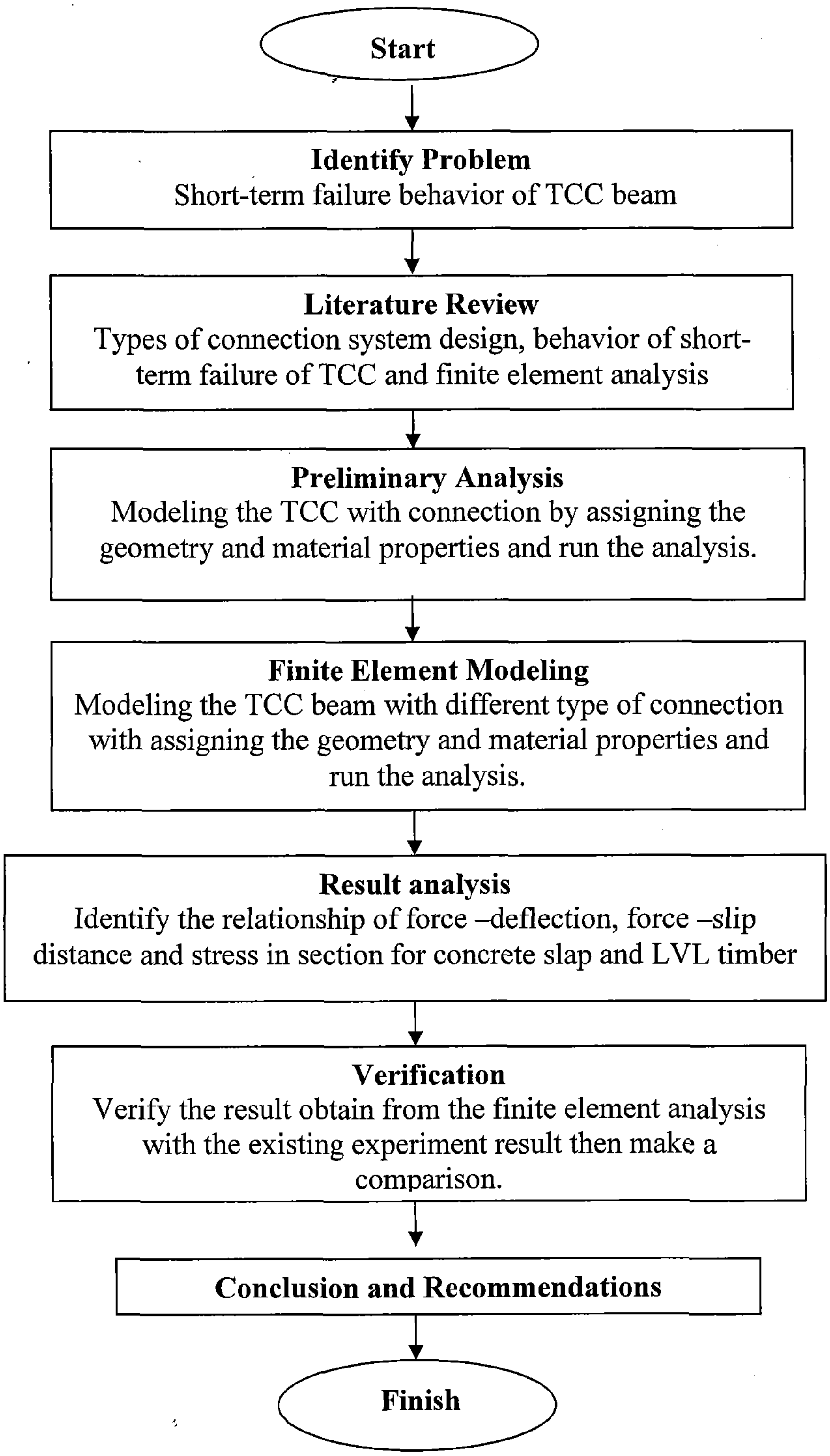


Figure 3.1: Methodology Flow Chart

3.3 Finite Element Analysis Model

The uniaxial FE model is made from two parallel beams, the concrete slab and the timber beam, connected at their interface with a continuous spring system which models the connection system and account for its flexibility. In this study, a T-beam timber-concrete composite (TCC) where connecting each other was modelled and verified. The section of the TCC beam that studied is shown in Figure 3.2 where the size of the flange is 65mm concrete with long 600mm and size of web is 63mm width with 400 mm depth. The total length of the T-beam is 8m for each section.

In this study, flange and web of TCC beam has been divided into vertical and horizontal equally regions as shown as figure 3.3. It is usual needed in software analysis to achieve more efficiency on detecting creep movement once virtually load had been apply at distance 1/3 of the total length from the both end of span as showed as figure 3.4 by using numerical analysis.

The same model as shown in Figure 3.5, 3.6 and 3.7 was then with some modification with different connecting system. There are 2 samples with connecting 25 x 150 NCS16 but different number of connecting along the span and another sample with connecting 30-60degree TRINCS16 as shown as figure 3.8.

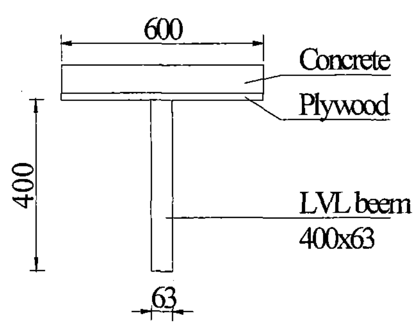


Figure 3.2 Section of the TCC beam

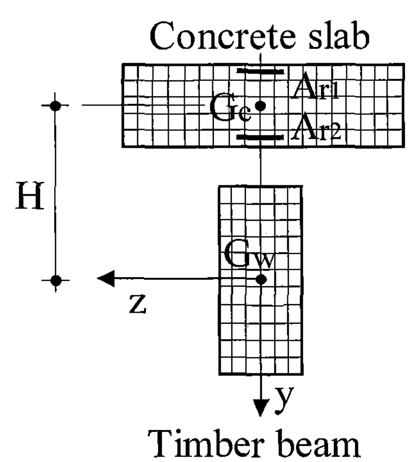


Figure 3.3 Finite element

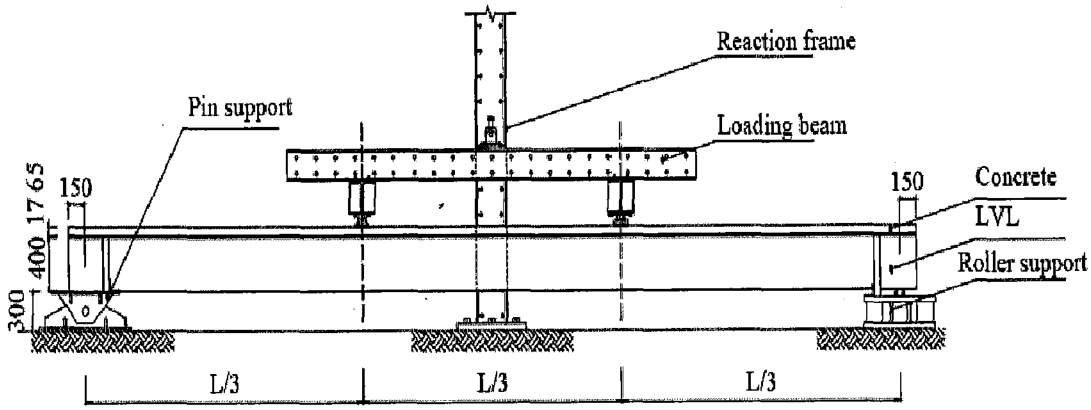


Figure 3.4 Loading at distance L/3 from the both end of span

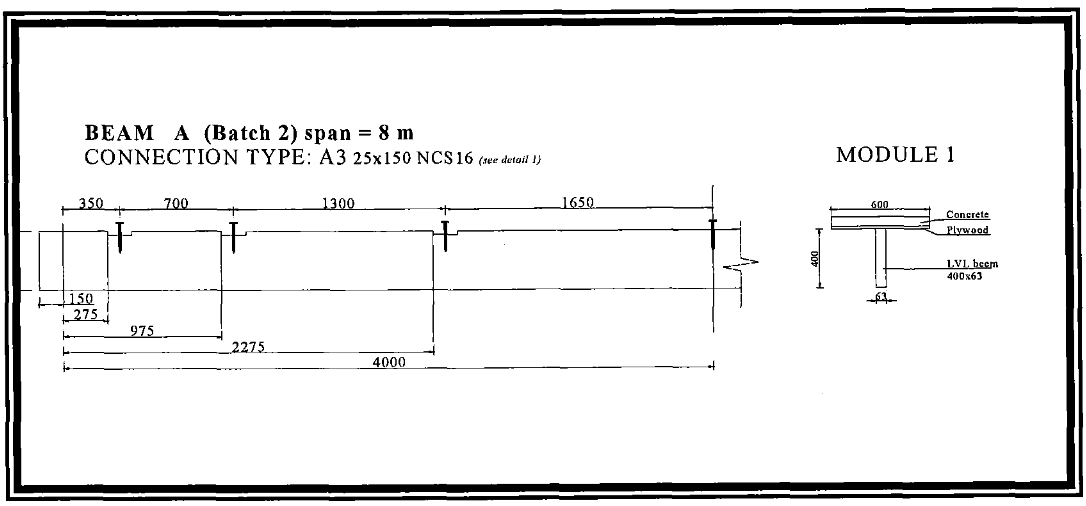


Figure 3.5 Section of the TCC beam A with connection A3

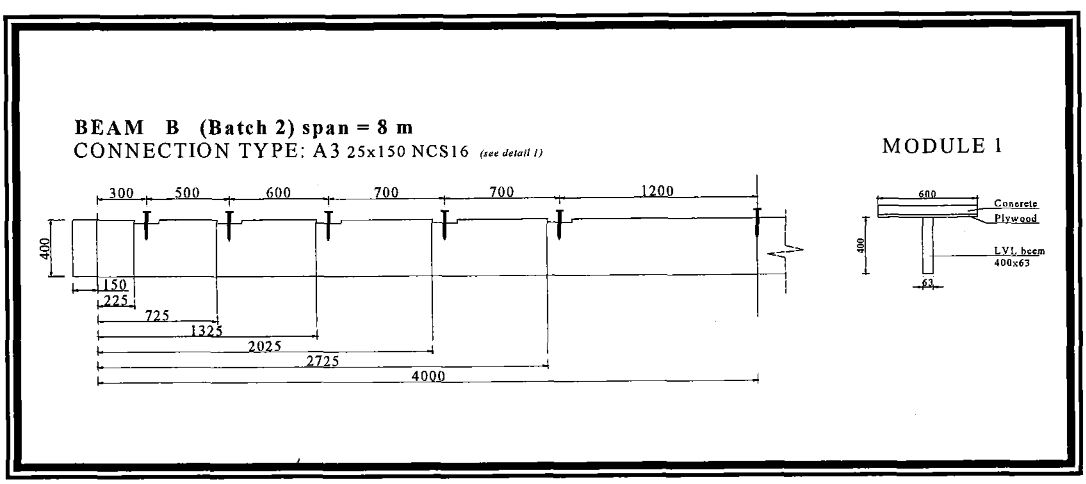


Figure 3.6 Section of the TCC beam B with connection A3 (narrow spacing)

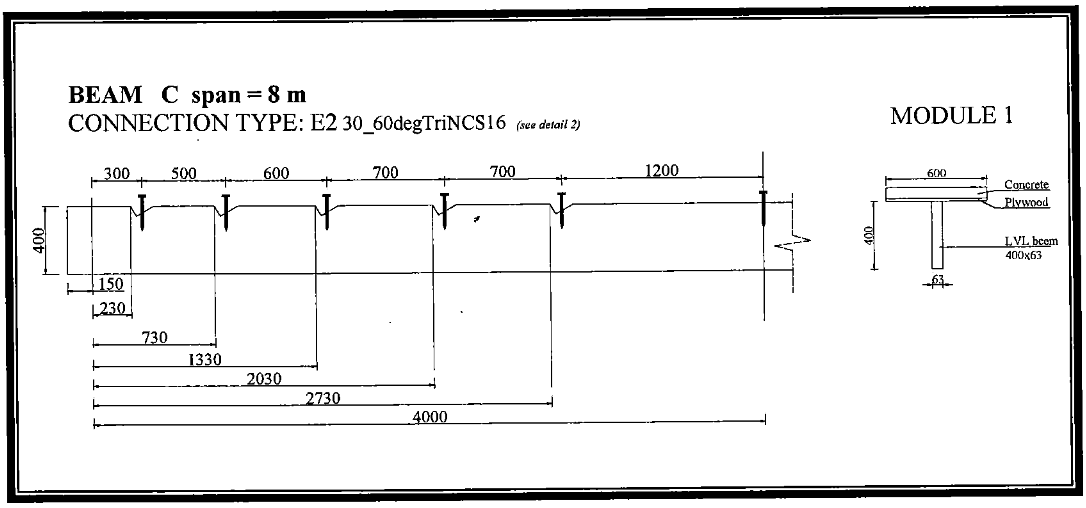
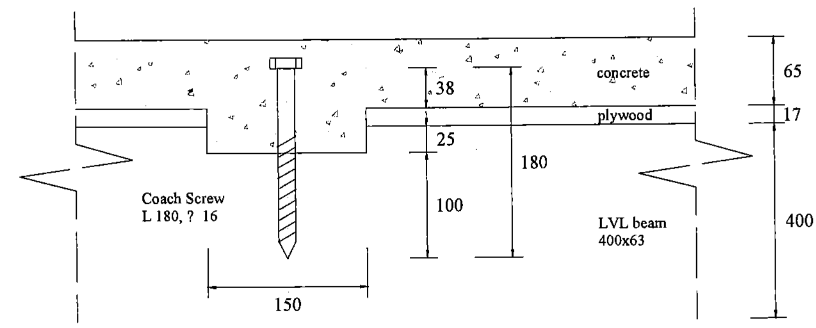


Figure 3.7 Section of the TCC beam C with connection E2

DETAIL 1
CONNECTION TYPE: A3 25x150 NCS16



DETAIL 2
CONNECTION TYPE: E2 30_60degTriNCS16

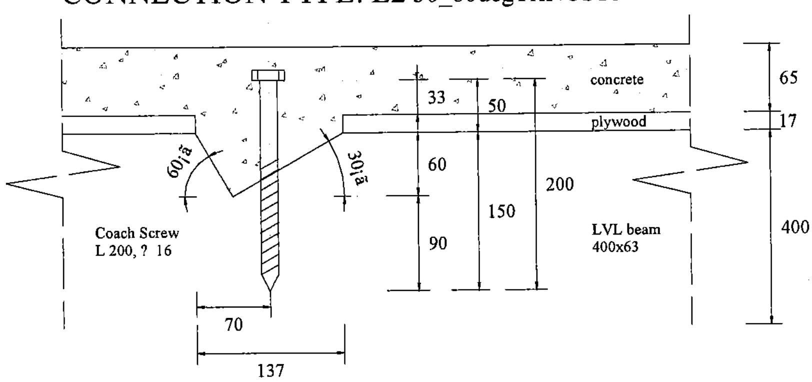


Figure 3.8 Detailing of connecting system

3.4 Finite Element Analysis Modelling

The procedures for TCC beam modelling that carried out are stated as below:

a. Creating model geometry

b. Meshing

c. Assign the geometry and material properties

d. Assign the boundary condition

e. Assigned the load applied

3.4.1 Model geometry

The section of the TCC beam shown in Figure 3.2 was modelled using finite element analysis package, Fortran 90 language, version Visual Fortran Professional 5.0A. The units used in the modelling were Newton and centimeter. In order to simplified the model's complexity, plywood which is place between the flange and web is been ignored. However, the type of connecting system between the web and flange is crucial been mention in FEM code.

3.4.2 Type of Elements

The Fortran 90 language is only applicable using line(1D), beam(2D) and brick solid(3D) element for solving engineering problems to be modelled compare to the other FE software since it is best in modelling plane and space frame structures. Beam element is a very versatile line-element; in general, it has six degrees of freedom at each node, which includes translations and rotations along the x, y, and z directions, respectively. Beam element is employed to simulate a slender structure that has a uniform cross section. The element is unsuitable for structures that have complex geometry, holes, and points of stress concentration. Therefore it is usually been used to modelling beam structures as uniform finite element divided.

3.4.3 Meshing

Meshing is a process to define a FE model in terms of geometric features which must be sub-divided into finite elements for solution as shown as Figure 3.4. Typically, there are two main types of meshing which is regular and irregular meshing. Regular meshing is used only on regular surface and volumes. Any elements shape may be selected for regular meshing. For irregular meshing, it can be used for both surface and volume. In this study, the regular meshing was used for both the flanges and webs of the TCC beam. The study is using mesh size and density which are optimal for the problem (to save computational time) and beam element types are appropriate for the analysis type performed (for accuracy). For a good mesh all elements must have a low aspect ratio with width /height which is roughly 2-4. Therefore, the concrete cross-section was divided into 20 layers, while the timber cross-section was divided into 80 horizontal layers and 20 vertical columns.

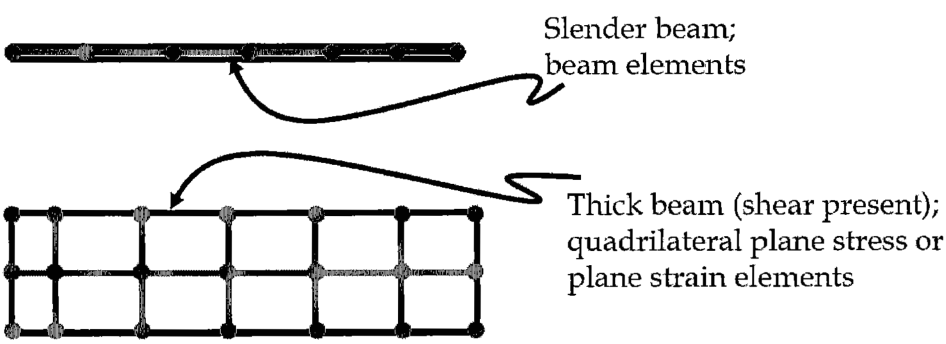


Figure 3.9 Meshing in quadrilateral region.

3.4.4 Material Properties

Most materials behave differently under different conditions. The connection system needs to provide the best possible compromise between structural efficiency and the cost of construction. For this purpose, a range of very different connection systems were tested to investigate their performance, in terms of stiffness, strength and ductility achievable. The tests were performed on small specimens comprising a concrete slab attached to the top of a short length of LVL. These were arranged so the connection was mainly subjected to shear. In actually, the field of numerical analysis and computer technology, modelling by the finite element method using software has become an alternative to used to study the structural behaviour of TCC floor with connecting system. Therefore the properties of the component materials (concrete, LVL and the connections) are described in the following sections will needed input in the analysis to model it.

3.4.4.1 Concrete

Concrete a single batch of concrete was prepared with a tensile steel mesh to prevent cracking. A piece of T-10 mm diameter tensile steel mesh reinforcement was placed at mid-depth of the concrete Materials and Structures slab. Concrete (E= 33 GPa, f_{cm} = 46 MPa, f_{ctm} = 3.4 MPa) as measured from experimental tests or provided by the manufacturer were used.

3.4.4.2 Timber

The timber used in the tests was LVL, which is laminated from rotary peeled, parallel-arranged veneers graded for strength, staggered, lapped and glued with structural adhesive. The manufacturing process, which minimizes the size of the defects such as knots and randomizes and their location, leads to a product characterized by reduced variability and improved mechanical properties with respect to sawn timber. The properties of the LVL used for the specimens with The Young's modulus, E = 10.7 GPa, and the average density of the LVL is 603 kg/m^3.

3.4.5 Non-Linear Material Properties

Concrete or timber is a material that has brittle properties. It will occur collapsed when it is exceed the elastic limit so instead of behaviour like steel become plastic. However, the material linearity of concrete and timber has been taken consideration in the analysis of the study as non linear analysis though finite element method.

3.4.6 Boundary Conditions

As shown in Figure 3.10, both end of the TCC beam were fully restrained in x, y, z at the I – section as simply supported. The translation and rotation of the section in all of the direction were fixed.

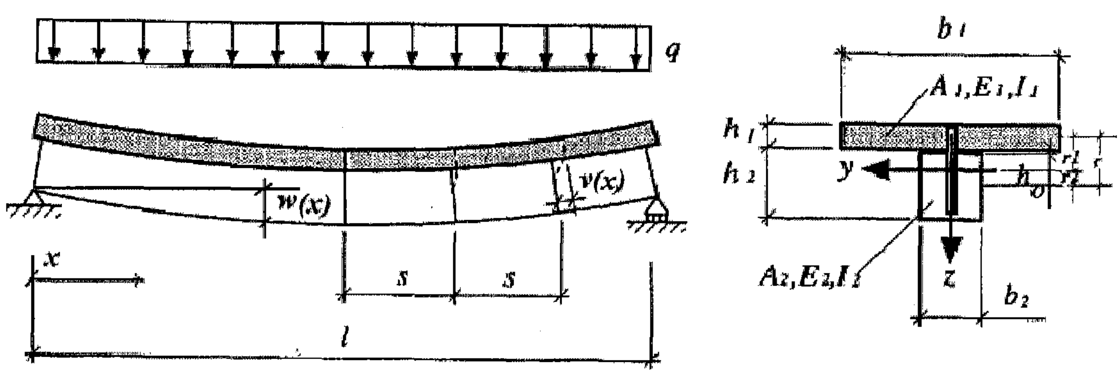


Figure 3.10 Simple support of TCC beam as semi-rigid connection (Ceccotti A., 2002)

REFERENCES

Benitez, M.F. (2000): *Development and Testing of Timber/Concrete Shear Connectors.* Proceedings of the World Conference on Timber Engineering 2000, Vancouver, BC, Canada, paper 8.3.2.

Blass, H.J., Goerlacher, R., Steck, G: *Holzbauwerke nach Eurocode 5:Bemessung and Baustoffe*. Original: Holzbauwerke STEP 1 Bemessung and Baustoffe. Fachverlag Holz, Duesseldorf, 1995.

Branson Mark, Heikes Ross and Dazlich Don (2009): Developing PowerPoint handouts to support meaningful learning. *FORTRAN 90 Seminar Spring 2009.* Retrieved August 10, 2010: from http://kiwi.atmos.colostate.edu/fortran/docs /fortran90-jan26.pdf.

Ceccotti, A., Fragiacomo, M., and Giordano, S. (2007). *Long-term and collapse tests on a timber-concrete composite beam with glued-in connection. RILEM, Mater. and Struct.*,40(1), 15-25.

Choi. T,Charles (2001).Developing PowerPoint handouts to support meaningful learning. *Introduction to the Finite Element Method*, Retrieved July 27, 2010, from: http://www.ee.isu.edu.tw/teacher/charles/fem/cem-fem-intro_Choi.pdf

Cook, J.P. (1976): *Composite Construction Methods. In: Journal of the Construction Division*, Proceedings of the American Society of Civil Engineers, Vol. 102, No. CO1, March 1976, pp 21 – 27.

Deam B.L, Fragiacomo M and Buchanan A (2007). *Connections for composite concrete slab and LVL flooring systems.* J Materials and Structures DOI 10.1617/s11527-007-9261-x

Deam, B.L., Fragiacomo, M., and Gross, L.S. (2008). *Experimental behavior of prestressed LVL-concrete composite beams.* J. Struct. Eng., 134(5), 801-809.

Fragiacomo, M., Amadio, C., and Macorini, L. (2004): *A finite element model for collapse and long-term analysis of steel-concrete composite beams.* J. Struct. Eng., 130_3_, 489–497.

Jin-Kyu Song1,a, Sun-Young Kim2,b, and Sang-Won Oh(2004): *The Compressive Stress-strain Relationship of Timber,* PH.D.thesis, Department of Architectural Engineering, Chonnam National University, Gwangju 500-757, South Korea.

Lukaszewska, E., Fragiacomo, M., and Johnsson, H. (2009a). "Laboratory tests and numerical analyses of prefabricated timber-concrete composite floors." *J. Struct. Eng.*, 136(1), 46-55.

M. Fragiacomo.(2003). *A Finite Element Model for Long-Term Analysis of Timber-Concrete Composite Beams.* Journal of Structural Engineering and Mechanics, Vol. 20, No. 2 (2005).

Ollgard, J. G., Slutter, R. G., and Fischer, J. W. ~1971!. ''Shear strength of stud connectors in lightweight and normal concrete.'' *AISC Eng. J.,* 8, 55–64.

Peter Widas (1997). Introduction to Finite Element Analysis. Retrieved August 4, 2010, from http://www.sv.vt.edu/classes/MSE2094_NoteBook/97ClassProj /num /widas/history.html.