

PROGRAMMING FOR REINFORCED  
CONCRETE DESIGN FOR TWO-WAY  
RESTRAINED SOLID SLAB TO  
EUROCODE 2

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PROGRAMMING FOR REINFORCED CONCRETE DESIGN FOR TWO-WAY  
RESTRAINED SOLID SLAB TO EUROCODE 2

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for the award of the degree of  
B.Eng (Hons.) Civil Engineering

Faculty of Civil Engineering and Earth Resources  
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JUNE 2015

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**Dedicated to my parents,  
for their unending support and love  
for me to become who I am today.**

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## **ABSTRACT**

In this research, a program is coded by using Microsoft Small Basic in order to carry out the calculations in reinforced concrete design for two-way restrained solid slab as according to Eurocode 2 standards. The aim and objectives of this research is to provide a faster and accurate way to solve reinforced concrete design tests and questions. Other than that, this also seek to provide a free alternative to students or lecturers with minimum system requirements that would work on any Windows operating system as compared to the more advanced yet expensive available software on the market. Coding of the program is done using Microsoft Small Basic, utilizing a simple BASIC programming language, one of the easiest programming to learn and use. Microsoft Small Basic does not require high-end computer specifications including the programs coded through it. Coding is giving instructions to a computer in a language it can understand with the correct syntax. The Program would require certain values to be inputted by the user before proceeding with calculations. Once the program is finished in its coding, its accuracy is then compared to manual calculations of provided questions. This research would act as an aid to users to carry out reinforced concrete design via a free and easy to use software for quick and precise answers.



## ABSTRAK

Dalam kandungan penyelidikan ini, satu perisian berkod dibina melalui penggunaan *Microsoft Small Basic* untuk menjalankan reka bentuk konkrit bertulang untuk papak dihalang dua hala atas standard *Eurocode 2*. Matlamat dan objektifs penyelidikan ini adalah untuk menyediakan satu cara yang pantas dan tepat untuk pengiraan reka bentuk konkrit bertulang dalam ujian dan soalan. Selain daripada itu, penyelidikan ini juga bertujuan untuk membuat perisian tersebut percuma untuk digunakan oleh para pelajar atau cikgu tanpa menggunakan spesifikasi computer yang melampau berbanding dengan perisian-perisian yang ada dalam pasaran. Pengekoden perisian tersebut menggunakan *Microsoft Small Basic* dan bahasa komputer *BASIC* yang disenangkan. Bahasa computer tersebut adalah antara paling senang untuk dipelajari dan digunakan. Pengekoden adalah cara untuk berkomunikasi dengan komputer dalam bahasa yang komputer boleh memahami dengan sintaks yang betul. Perisian tersebut akan memerlukan pengguna untuk menginputkan data sebelum pengiraan bermula. Setelah pengekoden perisian tersebut tamat, ketepatan perisian tersebut dibandingkan dengan pengiraan manual. Kajian ini akan bertindak sebagai bantuan kepada pengguna untuk menjalankan kerja mereka bentuk konkrit bertulang melalui perisian percuma dan mudah untuk digunakan untuk mendapatkan jawapan yang cepat dan tepat.

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## LIST OF SYMBOLS

%	Percent
mm	Millimeter
m <sup>2</sup>	Square meter
mm <sup>2</sup> /m	Square millimeter per unit meter
MPa	Mega Pascal
kN/mm <sup>2</sup>	Kilo newton per square millimeter
kN	Kilo newton
n	Total ultimate load per unit area
n <sub>ed</sub>	Design action
°C	Degree Celsius
G <sub>k</sub>	Characteristic Permanent Action
Q <sub>k</sub>	Characteristic Variable Action
L <sub>y</sub>	Length of longer span
L <sub>x</sub>	Length of shorter span
M <sub>sx</sub>	Maximum moment per unit width
b	Width of slab
d	Breadth of slab
z	Lever arm
h	Slab Thickness
d <sub>x</sub>	Effective depth
d <sub>y</sub>	Effective depth
β <sub>sx</sub>	Moment coefficient for short span
β <sub>sy</sub>	Moment coefficient for long span
β <sub>vx</sub>	Shear coefficient for short span
β <sub>sy</sub>	Shear coefficient for long span
C <sub>nom</sub>	Nominal Cover
φ <sub>bar</sub>	Diameter of reinforcement bar
A <sub>s,min</sub>	Minimum area of reinforcement
A <sub>x,max</sub>	Maximum area of reinforcement
A <sub>s,req</sub>	Required area of reinforcement
A <sub>s,prov</sub>	Provided area of reinforcement

$A_{sl}$	Area of tensile reinforcement that extends $\geq (l_{bd} + d)$ beyond the section considered
$b_w$	Smallest width of the section in tensile area
$f_{ctm}$	Mean values of the axial tensile strength of concrete
$f_{ck}$	Characteristic strength of concrete
$f_{yk}$	Characteristic strength of steel
$V_{sx}$	Design shear force
$V_{ed}$	Maximum shear force
$V_{rd,c}$	Design shear resistance without shear reinforcement
$V_{min}$	Minimum shear force
$S_{max,slabs}$	Maximum bar spacing for slabs



## LIST OF ABBREVIATIONS

UMP	University Malaysia Pahang
ACI	American Concrete Institute
BS	British Standards
MS	Malaysian Standards
EN	European Standards
RC	Reinforced Concrete
EC	Eurocode 2

## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 BACKGROUND**

From rapid development of buildings to astounding technological discoveries, the modern world is ever on the rise in progress. Countless technological wonders are explored and adapted to our everyday lives and much of these technology help in solving complicated situations. Much of these complicated situations come from basic calculations which in turn are derived and transformed into something much bigger and complex to solve even bigger problems. Software and Programs are utilized by computers to execute the most complicated tasks of lengthy calculations with precision and in a short amount of time giving more options to new projects in which calculating manually would use up too much time and waste resources. All of these software and programs would not have been made possible without the basics of programming and coding of said software.

Computer Programming is essentially a process that comes from an original formulation for computing problems that turns into an executable program in which it will carry out the written formula. For example you can program and code a simple calculator to carry out simple calculations. There are much software that assists in the creation of new software such as Microsoft Small Basic, Visual Basic and Java. These softwares utilize a programming language as a way of communicating with machines via given instructions. There are various programming languages available but the most used is Java which is abundantly used throughout the world in various platforms.

Since it is capable of quick calculations, the field of civil engineering is no stranger to sophisticated software in their line of work. Likewise for reinforced concrete designs which have many calculations to be calculated, benefits greatly from quick and precise calculations that specialized software can offer.

## **1.2 PROBLEM STATEMENT**

Carrying out manual calculations is very tedious and may take a long time to finish for us to get the answers that we want. With the current rapid development of our country today, having a system for carrying out the said calculations in a short amount of time is a

There are plenty of sophisticated software and programs designed for civil engineering purposes such as AutoCAD, Esteem and Orion available in the market. However, not many of such software are easily available to students for study purposes. Some require older Operating Systems that are outdated and have errors plus complications if they were to be run on newer generation of Operating Systems. Even universities and colleges may not be able to provide the latest versions of said software as they are very costly.

In order to provide an easier and cost-free way for students or anyone who has interest in reinforced concrete design, this research is to study programming and coding from which will in turn produce a simple interactive software that would carry out the calculations in reinforced concrete design and still adhere to given rules from Eurocode 2. The main structural element type in question would be two-way restrained slabs and its analysis of bending moment and shear force

## **1.3 AIM AND OBJECTIVES**

The main aim of this research is to successfully program and code using Microsoft Small Basic in order to calculate and analyze two-way restrained slabs for reinforced concrete design for all 9 cases of slab position

- To provide an easy interface for users to use and input values to the program which will carry out the calculations in a short amount of time
- To successfully allow the program to carry out calculations for the analysis of reinforced concrete design for two-way restrained slabs

#### 1.4 SCOPE OF RESEARCH

The following is a list of the scope covered by this research:

1. The programming and coding will utilize and only coded through Microsoft Small Basic
2. Only Two-Way Restrained Solid Slabs are to be used and includes all 9 cases of the slab position
3. To the test the accuracy of the program, values of the slab's properties are provided and manually calculated to be used to compare the results gained from that of the program's outputs to the example's answers.
4. Calculations and rules are based on Eurocode 2 of Two Way Restrained Solid Slab for Reinforced Concrete Design. Calculations will begin at Design Action to Bending Moment Analysis for Main Reinforcement to Shear Force Analysis and finally Crack Checking in which will be calculated by the program but not shown on the screen.
5. Deflection Checking and Detailing is not included in the scope
6. Bending Moment Coefficients and Shear Force Coefficients will solely be based on Table 3.14 and Table 3.15 of BS8110:Part1:1997. These tables are Table 3.1 and Table 3.2 in this research report. It will not consider any values between and outside of the ratio of  $L_y/L_x$  given in the tables nor are the values of the coefficients themselves.
7. The values to be inputted once the program is finished are to follow the given units:
  - a) Permanent Characteristic Action (unfactored and includes self-weight of slab),  $G_k$ :  $\text{kN/m}^2$
  - b) Variable Characteristic Action(unfactored),  $Q_k$  in  $\text{kN/m}^2$
  - c) Characteristic Strength of concrete,  $f_{ck}$ :  $\text{N/mm}^2$
  - d) Characteristic Strength of steel reinforcement,  $f_{yk}$ :  $\text{N/mm}^2$

- e) Long Span and Short Span of slab;  $L_y$  and  $L_x$  in mm
- f) Slab Thickness,  $h$  in mm
- g) Nominal cover,  $C_{nom}$  in mm
- h) Case
- i) Diameter of reinforcement bar,  $\phi_{bar}$ : mm
- j) Area of linkage(corresponding to the  $A_{s,prov}$  at the support whichever is highest),  $A_{sl}$  in  $mm^2/m$
- k) Mean tensile strength of concrete,  $f_{ctm}$  in MPa

## 1.5 RESEARCH SIGNIFICANCE

This research is for the purpose of saving time and shortening the lengthy processes in the analysis of two way restrained slabs for reinforced concrete design. With the program finished in its coding, it would be able to calculate and analyze the slab within mere seconds after the values are inputted correctly with accuracy and speed. The finished program would provide accurate results and can be run on any Windows Operating System requiring minimal computer specifications and without draining much of the computer's resources. In addition, the program can be easily use with an easy interface to interact with the users by simple inputting values into given boxes and pressing buttons on the interface to proceed, reset or exit the program. The program would also be considered free to use for academic purposes and would not require any sort of payment for its usage.

## 1.6 EXPECTED OUTCOME

Once the program is finished in its programming and coding, the program will:

1. Able to be executed with any computer that has Microsoft Small Basic installed and its requirements
2. Read inputs given such as Characteristic Actions, Characteristic Strength of concrete and steel, length and width of slab, nominal cover, slab thickness, and Slab Position Case.
3. Once inputs are correctly added, clicking "Calculate" button will begin the calculation process and analyze the Two-Way Restrained Slab.

4. Calculations will not be shown on-screen but it will give the answers on the screen for the following:
- a) Area of the slab,  $A$  in  $\text{mm}^2$
  - b) Design action,  $n$  in  $\text{kN/m}^2$
  - c) Ratio of  $L_y/L_x$
  - d) Case
  - e) Bending moment coefficients for short span  $\beta_{sx}$  and  $\beta_{sy}$
  - f) Bending moments:  $M_{sx1}$ ,  $M_{sx2}$ ,  $M_{sy1}$  and  $M_{sy2}$  in  $\text{kN/mm}^2$
  - g) Diameter of bar in mm
  - h)  $F_{ctm}$  in  $\text{kN/mm}^2$
  - i) Effective depths,  $d_x$  and  $d_y$  in mm
  - j) Minimum and maximum reinforcement area in  $\text{mm}^2$
  - k) Areas of reinforcements for long spans and short spans with their respective mid spans and support,  $A_s$  in  $\text{mm}^2/\text{m}$
  - l) Values of  $k$  and  $z$  for the calculation of area of reinforcement
  - m) Design shear forces:  $V_{sx1}$ ,  $V_{sx2}$ ,  $V_{sy1}$  and  $V_{sy2}$
  - n) Maximum shear force,  $V_{ed}$
  - o) Design Shear Resistance,  $V_{rd,c}$
  - p) Minimum Shear Force,  $V_{min}$
  - q) Maximum Bar Spacing for Main and Secondary Bars

## **CHAPTER 2**

### **LITERATURE REVIEW**

#### **2.1 INTRODUCTION**

This chapter will cover up the literature review done throughout this research on topics relevant to the research. Two major topics are discussed which are Reinforced Concrete and Software Programming. Reinforced Concrete covers short summaries of reinforced concrete, slabs, reinforced concrete and design standards whereas Software Programming covers up topics on Software and Programs, Software available for Civil Engineering, Software available for Reinforced Concrete Design, Software Architecture and Programming Languages.

#### **2.2 REINFORCED CONCRETE**

Concrete is a major construction material that has been used for millennia by countless civilizations with the oldest dated concrete in the regions of southern Syria and Northern Jordan around 6500 BC (Gromicko & Shephard, 2015). It is a stone like substance produced when prepared carefully through the combination of cement, sand, gravel and water. The shape and size of the finished concrete can be set during the mixture of the elements by putting the mixture into a mold of desired dimensions (Jamal, 2014). Its advantages lie in its high compressive strength which requires low maintenance and would last a very long time in comparison to timber and steel. However, its weakness lies in its low tensile strength. It may easily crack when enough stress is applied to it. Therefore, concrete are usually reinforced with various other materials that have high tensile strength and the most abundantly used is reinforcement steel bars. This is called Reinforced Concrete.

Reinforced Concrete utilizes the concrete's high compression strength with a material that has high tensile strength and ductility of steel. Often called 'rebar', reinforcement steel bars are widely used in the production of reinforced concrete for buildings. Steel reinforcement bars are usually round as round surface areas provide the most possible surface area to the surrounding concrete thus providing a better bond between the molecules with concrete (Gambhir, 2008). The concrete mixture would surround and interlock with the steel bars and upon hardening of the concrete, reinforced concrete is produced (Jamal, 2014).

The compressive strength of reinforced concrete is dependent on the hardened concrete whereas the tensile strength is dependent on the reinforcement steel bars (Gambhir, 2008).

The strength of hardened concrete is dependent on these following factors (Sinha, 2002):

1) Fineness and type of cement used

Certain types of cements have the ability for rapid hardening and have low heat such as Portland cement. The fineness of the cement influences rate of strength gain of concrete

2) Strength, shape, size, grading and surface texture of aggregate

The aggregate's physical properties influence the strength of concrete via molecular bonds. The grading of aggregate does not directly influence the strength of concrete but rather its workability.

3) Water to cement ratio

Coarse aggregate produces higher workability. Water/Cement ratio affects the strength of concrete via the equation A.

4) Aggregate to cement ratio

An increase in aggregate to cement ratio increases compressive strength of concrete given water to cement ratio is constant.



### 5) Temperature and Curing Time

The temperature during curing of concrete affects water loss via evaporation. During the hardening of the concrete, the concrete is required to be saturated to prevent loss of water and strength loss. Temperatures above 23 °C would increase initial strength gain but decrease after 2-3 days. Temperatures below 23 °C would have a continuous strength gain at a rate that decreases overtime.

### 6) Concrete Age

The strength of concrete increases with age of the concrete where it would the concrete would harden rapidly with its strength increasing rapidly and reaching up to 66% of the final strength in 7 days. The rate of strength gain decreases slowly after that and it would reach up to 90% at 28 days. The rate becomes very low and it would increase very slowly as compared to the first few days.

Reinforced concrete provides plenty of advantages to the users such as high compressive strength, high tensile strength, good fire and weather resistance, flexibility in molding them into countless shapes and sizes and low maintenance cost (Civil Today, 2014). However, it is not without its disadvantages such as the requirement of mixing, casting and curing; all of which would affect the concrete strength, the high cost of the forms to mold the concrete and the its tensile strength is one-tenth of its compressive strength (Jamal, 2014).

## 2.2.1 Slab

Slabs is one of the most widely used structural element as it forms the floors and roofs in order to support loads normal to the surface floor. The slabs maybe supported on tops of walls or on columns or even the beams (Sinha, 2002). It carries gravity loads normal to the slab's surface and then transfers the loads to the supports via flexure. The slabs can be simply supported or even continuously span over more than one supports (Yassin & Abdullah, 2012). Slabs that have their flexural loads transferred from the slab to the supports can be split into two categories; One-way Slab or Two-way Slab. They are dependent on the ratio of the longer span to the shorter span of the slab. One-

way slab requires the ratio to be greater than 2 whereas Two-way slab requires the ratio to be between 1 and 2 (Gambhir, 2008).

One way slabs is assumed when the predominant flexural mode is only in one direction. Rectangular slabs that are supported only on two sides opposite of each other by walls or beams where the loads are uniformly distributed along the direction that is parallel to the supports (Devadas, 2003)

When the ratio between the longer span and the shorter span increases, the curvatures and moments along the long span would gradually reduce. The slab loads would effectively increase in its transfer to the longer span's supports by bending in the short span's direction (Devadas, 2003). However, if the slab is square and is restrained similarly on all four sides, the load is distributed equally in both directions (Yassin & Abdullah, 2012).

There are two types of two-way solid slabs which are simply supported slab and restrained slab. Simply supported slabs have its all four sides deflect about both axes under loads where its corners would lift and curl up from the support. This event causes torsional moments. Restrained slabs are dependent on the slabs edges whether they are continuous edges or fixed. There are a total of nine different support cases for two way slabs and can be found in Figure 3.4.1. Torsion reinforcement is required at discontinuous corners and needs to consist of both top and bottom mats with each having the reinforcement bars span in both directions. This reinforcement should extend from the edges at a minimum distance of  $L_x/5$  whereas the area in each four layers should be 75% of the area required of maximum mid-span moment. Torsional reinforcement is not needed when the edge is continuous in both directions (Yassin & Abdullah, 2012).

### **2.2.2 Other Types of Slab**

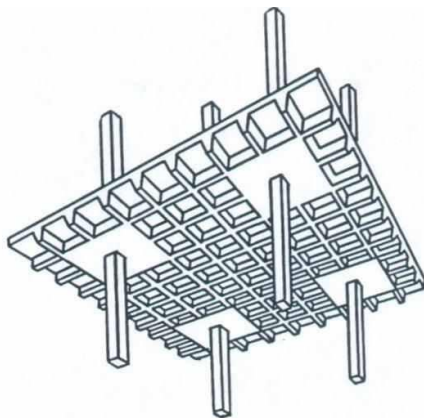
There are four other types of slabs which are Ribbed slabs, Waffle slabs, Flat slabs and Flat slabs with drop panel (Yassin & Abdullah, 2012). Ribbed slabs are slabs that are integrated with a series of closely spaced joists during casting. These joists are

then supported on a set of beams. The design of ribbed slabs is that it is a series of parallel T-beams which proves to be economical for medium spans that have very small to medium live loads.

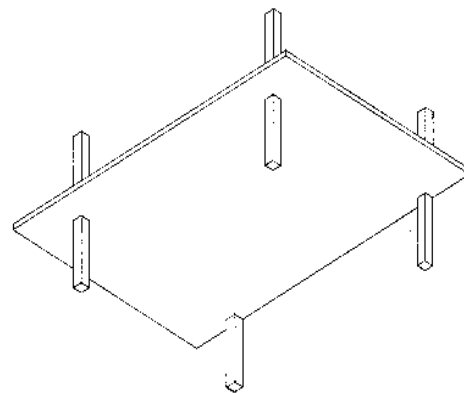
Waffle slabs are much like two-way slabs but it is reinforced by ribs in both directions. It is capable of carrying relatively heavier loads and can be of longer span compared to ribbed slabs.

Flat slabs are slabs of uniform thickness, reinforced in both directions and is supported directly by columns without beams.

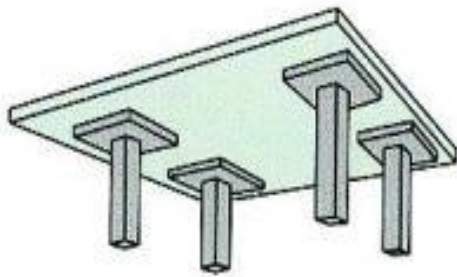
Flat slabs with drop panel are normal flat slabs with the addition that its column supports improved with drop panels. This would increase its shear strength and is capable of resisting stronger moments.



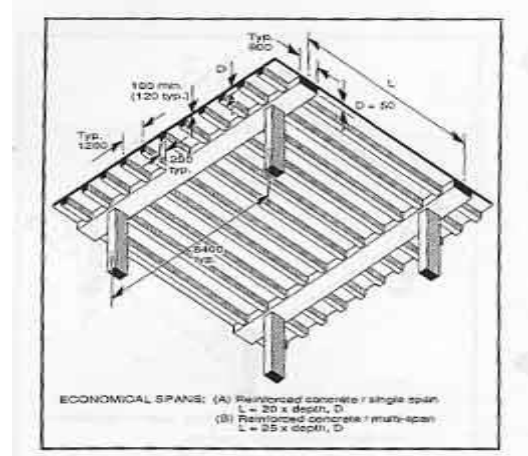
**Figure 2.2.1** Waffle Slab



**Figure 2.2.2** Flat Slab



**Figure 2.2.3 Flat Slab with Panels**



**Figure 2.2.4 Ribbed Slab**

### 2.2.3 Reinforced Concrete Design

The design of a structure can be regarded as the process of choosing materials and elements proper for the structure. Depending on the requirements of the structure, design methods can be split into two categories which are: Ultimate Limit State and Serviceability Limit State. Ultimate Limit State covers the strength and stability of the structure under maximum design load in which the structure is expected to withstand. This also means that no part of the structure should encounter failure such as cracking, collapsing or buckling. Serviceability Limit State covers conditions in which specified service requirements are no longer met (Yassin & Abdullah, 2012). Theoretically, the bending for reinforced is based on the assumptions from EN 1992:Cl 6.1 (2)P, which are:

- 1) The plane sections before bending must remain after the bending.  
This implies that the normal strains are distributed across the section is linear
- 2) The strain in bonded reinforcement, either tension or compression is the same throughout the surrounding concrete  
This assumption is necessary due to the fact that the concrete and reinforcement act together to carry loads

- 3) Concrete tensile strength is ignored  
Concrete tensile strength is roughly one tenth of the its compressive strength which is regarded as too small and can be neglected.
- 4) Stresses in the concrete and reinforcement is derivable from the strain by using the stress-strain curves for concrete and steel

Ultimately, reinforced concrete design to EC 2 has these following procedures; flexural design, shear design, deflection checking, cracking checking and detailing. Flexural design is based on bending moments acting on the structural element. It is the design of the specifications of the reinforcement steel bars such as diameter size and spacing to be used with concrete with regards to the loads. The plastic behavior of reinforced concrete at ultimate limit state affects how the moments are distributed in a structure. Plastic hinges that forms in the reinforced concrete requires large rotations with yielding of the tension reinforcement. Shear design is the design of reinforcement steel bars to link each other in order to resist shear forces. Shear forces is transmitted through crack member via a combination of other un-cracked concrete in zone of compression, dowelling action of the flexural reinforcement and aggregates that interlock across the cracks of tension. Deflection checking requires that the span of the structural element is not high enough to lead to excessive deflection such as sagging of floors, partitions being crushed, buckling and so on. Cracking checking is to limit the width of individual cracks for durability and corrosion protection (Yassin & Abdullah, 2012).

#### **2.2.4 Codes of Practices**

Codes of practices and design standards such as ACI, Eurocode and British Standards are sets of technical specifications that act as a control of important details of design and construction (Jamal, 2014). These codes of practices have the sole purpose to produce sound and safe structures in order to protect the public from inadequately designed structures and constructions. Below is some of the design standards used all over the world:

a) American Concrete Institute

The American Concrete Institute or ACI was founded in 1904 and acts as the leading authority and resource worldwide in the development and distribution of many design standards. Their main mission has always been the same which is to provide knowledge and information for the best use of concrete. ACI 318 Building Code Requirements for Structural Concrete is one of the most used design standards in America which is to provide minimum requirements for the design and construction of structural concrete under the requirements of a common code of building that is incorporated with it (ACI, 2015).

b) Eurocodes

Eurocodes are a set of technical rules that are consensus-agreed developed by the European Committee of Standardizations for the structural design of works regarding construction mainly used in the European Union. The standards are published separately where each member has a number of parts. By March 2010, the Eurocodes were considered mandatory for European public works.

## **2.3 SOFTWARE AND PROGRAM**

A software comprises the electronic instructions that govern the computer's functions (Kenneth & Baldauf, 2008). A program consists of sequences of instructions to a computer, where it is written to perform specified task on a computer (Ralph, 2003). Unlike a program where a program is developed by individuals for their own personal use, software is much more complex. It is meant for multiple users and therefore has a good interface, designed systematically, thoroughly tested and implemented carefully. Software is most often very complex and too large for one person to create and develop singlehandedly (Rajib, 2004). For example, given a software that records names and addresses in a database. The program and database is considered a part of the software but the database is not a program (Ben, 2010).

However, software and program are used interchangeably due to the fact that they refer to the same thing in daily usage. Program is included in software where all software is programs but not all programs are software (Ben, 2010).

### **2.3.1 Software Available for Civil Engineering**

Many software exists today are available to each discipline of civil engineering. The first spark in the implementation of software into the civil engineering field began when educational concerns for the future of civil engineering to enter the modern age. Rapid expansion of the civil engineering software with use and demands render draftsman useless. Manual drafting becomes eliminated due to the fact that even engineers can prepare and design the parameters into the software (Xeidakis & George, 1994).

Autodesk has been a staple in the civil engineering field as the creator of great civil engineering software used by countless engineers all over the world. This includes AutoCAD and Revit. AutoCAD capable of precise computer drafting of floor plans whereas Revit can create 3D models of buildings combined with phenomenal information system capable of quantity take-off and site planning.

### **2.3.2 Software Available For Reinforced Concrete Design**

There is plenty of software available on the market for civil engineering purposes created by various companies. Most of them do even more than just reinforced concrete design such as the 3D modeling Orion Structural Design Software. They can even be carried out in different standards and code of practice with simple commands such as the Orion SDS and CivilFEM integrated Ansys Software by Ansys Inc. The following are a list of available software that is capable of reinforced concrete design but not limited to:

- a) ADC by Oasys-Software is a software that is capable of analyzing and designing structural elements. These elements include piles, columns, beams, solid and ribbed slabs. They can be designed according to EC2, BS8110 and even Hong

Kong codes. Columns can be analyzed in their rectangular or circular forms, piles and circular piles are able to be analyzed for their axial loads and moments. Arrangements of reinforcements can be decided by the user to meet their requirements given by the software.

- b) Advanced Concrete by Autodesk is a software capable of the designing and detailing of concrete. It is also capable of modeling in 3-D with the various elements' properties able to be selected according to the users liking. Other than that, it is capable of modeling and detailing the reinforcements in the concrete for in-site concrete, precast concrete and special construction elements which extends its features but not limited to detail bars, create 3D reinforcements cages, and automatic optimization. It can also create paper drawings and has an in-built bill of materials program.
- c) Orion Structural Software is software capable of designing, modeling and analyzing multi-storey concrete building designs. Modeling can be done in 2-D and 3-D with integrated automatic analysis, design and drafting provided for the user. It can also automatically produce a bill of quantity, detailed calculations and structural layout plans among many others to allow easier and faster outputs for projects. It is capable of copying a finished floor to be repeated for subsequent floors which are great for buildings that have repetitive floors. Built for the experienced structural engineer specialized in reinforced concrete design, it offers great speed in its modeling, analysis and design.
- d) ConCrete+ by buildsoft is software made to analyze and design reinforce concrete. The software can also provide deformations which consider the effects of cracks and creep, internal forces and reinforcement requirements where they will be represented neatly in clear graphics.
- e) Excel by Microsoft is an electronic spreadsheet where it can organize data in tabular form and even perform mathematical calculations. It consists of rows and columns and for each cell and be made unique where you can insert an equation where it will calculate the said mathematical equation. Some



companies use Microsoft Excel for reinforced concrete design even data storing and other civil calculating purposes due to its simplicity and flexibility. The program is bundled with most Windows OS but is not available for Mac users. Although not originally designed to be as reinforced concrete design tool, the flexibility of the software allows users to produce the tool quite easily and quickly in forms of spreadsheets. However, most companies would not disclose their spreadsheets to avoid competition.

However, many of this sophisticated software have a great downside namely the price. The price for the software is very expensive with AutoCAD at USD 4,195.00 which in Malaysia would cost RM14403.53. ADC costs at £720.00; RM3876.98. ConCrete+ requires a subscription at 385€ every 6 months which is RM1633.66 every 6 months. Some software companies such as Orion do not disclose their prices as to avoid competition but admits that their product is very pricy. (All money converts are done by Google money converter in March 2015).

This is something of what a typical student studying civil engineering will not be able to afford and would really bring down a University's budget to have the latest versions of the design software available in their computer labs. The end product of this research would produce a software that is free and can be accessed easily by anyone for academic purposes.

### **2.3.3 Software Architecture**

A system is a collection of parts and sets of unified principles of purposes that together puts the parts into a unified whole for one purpose. A software system is a system that consists of parts that are mostly software element with unifying principles for a single purpose (Reekie & McAdmin, 2006). A software architecture is the set of structures needed to reason with a system which consists of software elements, a unifying connection and properties of both (Jones, 2013).

When building a software system, the process involves the designing of the architecture of the software. The architecture would describe the software system as one

whole object which then can be broken down into parts and tell how the parts come together for the design's purpose and meet a human need. It is the knowledge on how to design the architecture of the software system (Reeking & McAdmin, 2006).

In the words of Luke Hofmann (2003), "the initial version of a software architecture is a young child, whole and complete but immature". Over time and through continued use and multiple release cycles, the architecture matures and solidifies" In other words, once a software architecture is initially finished ergo the first version, it is considered complete but may still be unstable. Once it undergoes continued usage and is constantly updated and upgraded, it can be outfitted with newer features and become more stable. A software' architecture should evolve through its features and capabilities alongside constant care (Hoffmann, 2003). The first version of this research proposed program would fall in the same line. The software architecture should be developed according to 4 elements which are (Reekie & McAdmin, 2006):

- 1) Stakeholder's needs – anyone affected by the system or with interest in the software system
- 2) Requirements – the technical expression of the software system will do after being built
- 3) Architecture – complex set of responses and decisions
- 4) Contextual factors – factors affecting the 3 previous elements

The element of this research for its software architecture would be primarily built upon is the requirements or rather functional requirements which are as listed in the expected outcomes in Chapter 1. For a quick summary of it; the finished product would be a freeware that is capable of reinforced concrete design for two-way restrained slabs with a simple interface.

#### **2.3.4 Software Programming**

Programming is the ability to talk to a computer in a language it can understand and using grammar and syntax that it can follow and perform task for you (Hughes & Hughes, 2005). In simpler words; write some codes, computer interprets the codes and

carries out whatever the codes demand. Writing or programming software requires the designer to describe the processes and procedures as it involves authoring algorithms.

A successful program if it succeeds in what we tell it to do (Peter & Serif, 2004). A program does not nothing more than what the computer tells it to do such as accepting some type of input, manipulating said input and bring it out in another form that users find useful. Programming is nothing more than writing down lines of codes of step-by-step instructions telling it what to do. However, it requires precise instructions in order to work. A collection of instructions that instructs the computer is called a program. The instructions that are written in a specified programming language are known as source code (Wang, 2014).

### **2.3.5 Programming Languages**

A computer requires a form of language that it can understand in order to carry out our orders. This is what we call a programming language. Each language has their own structure and may different in their commands. A program is written according to the rules of the language (Regan, 2005).

Before 1940, the first programming language were simple codes and not used by modern computers. Rather they are used by other machineries such as Jacquard looms in 1801, a mechanical loom invented by Joseph Marie Jacquard (Regan, 2005). This was to simplify the manufacturing of textiles with complex patterns. Computing-wise it used punched cards to control the operations in sequence. Despite no computing at all happened but it was the first step in computing as it changed the pattern of loom's weave by changing the cards in a simple way. As time progressed, so did the computer and its programming languages (Hughes & Hughes, 2005). There is a wide array of programming languages available which includes Java, C++, BASIC, Atari BASIC, COBOL, FORTRAN, MATHEMATICA, Visual Basic among many others. A survey by Stephen Cass shows that the most popular programming language is Java, followed by C and C++ respectively.

Computers only understand one language and that is binary, a set of zeroes and ones. Writing a program in binary is capable of creating the fastest programs possible. However, there are three major disadvantages in doing so. First, any mistake made will outright prevent you from giving the computer the right instructions. Secondly, programs that are created using binary will not allow it to be run on other processors. Finally, binary takes a lot more time to write (Wang 2014).

With the creation of programming languages that is a formal constructed language that is designed to communicate with computers, it is much easier and faster to create programs in which the computers can use. All programming languages have building blocks in order to describe the data and to process them. Ultimately, two building blocks are defined and those are Syntax and Semantic.

Syntax is the programming language's surface form. The syntax of a programming language defines the possible combinations of symbols that correlate to form a syntactically correct program. It is the rules set and defined in a programming language in order to define the combination of said symbols and generally distinguished into three levels: Words that are how characters form tokens, Phrases that are how the grammar level works and Context that are what determines the objects and variables that refer to (Friedman et. al, 2001).

Semantics, the opposite of syntax, is the field in which concerns the mathematical study in a programming language. This is done through the process of evaluating the syntactically correct legal strings defined by the programming language in which would show the computations involved. Formal semantics prove aid in the writing of compilers to better understand how a program works using said programming language (Schwartz, 1967).

## **CHAPTER 3**

### **RESEARCH AND METHODOLOGY**

#### **3.1 INTRODUCTION**

This research will utilize Microsoft Small Basic for the coding of the program in order to carry out Reinforced Concrete Design of Two-Way Restrained Solid Slabs to Eurocode 2. The programming language used by Microsoft Small Basic is simplified Basic. There are 3 major procedures for the whole of this research which are;

- 1) Coding with Microsoft Small Basic to produce the program file
- 2) Use the program file to carry out reinforced concrete design for a two-way restrained solid slab of given values.
- 3) Compare the values obtained from program file to manual calculations as accuracy test

#### **3.2 MICROSOFT SMALL BASIC**

Microsoft Small Basic is a programming language and coding software utilizing a more simplified variant of the BASIC programming language for the purpose of teaching beginners. A smaller and more simplified version of Microsoft Visual Basic, this coding software provides a user-friendly interface and environment to the users with great functionality such as syntax detection, integrated code completion intelligence and in-editor documentation access. Based on the modern .NET Framework Platform, it draws inspiration from an early different version of BASIC programming language. It provides a simple working environment but comes with various features

granting beginners a concept of what professional programmers consider as Integrated Development Environment.

One of the advantages of using Microsoft Small Basic as the coding program is ease of use and mastery. The simplistic linear coding of simplified 'Basic' programming language allows users to code fairly easily when compared to other sophisticated programming languages such as JAVA.

Another advantage is that Microsoft Small Basic is free to use. There's no fee for the use of Microsoft Small Basic. It can be downloaded and installed without any charge.

However, it does have its disadvantages. One of these disadvantages is that it cannot hold too many codes in a single file. When there are too many coding in one file, the coding program may undergo crashes or errors in which will auto-close the coding program.

Another disadvantage is that it requires the proper operating system and certain things to be installed. Only Windows operating systems will allow the program to be installed and work on and it will require .net Framework to be installed to work. Windows OS before Windows 7 needs to install .NET Framework 3.5 and its previous versions whereas Windows 8 and newer only require .NET Framework 4.

One more disadvantage of Microsoft Small Basic is that it can consume "Objects" but not produce them in a sense they are not object oriented programming thus limiting its coding to linear coding and not for complex programming.

### **3.3 CODING**

For this research, Microsoft Small Basic is used to create the software. It is a freeware with minimal system requirements and minimum difficulty to understand its usage. This is ideal for academic purposes for students, teachers and anyone who has

interest in programming. This advantage is the reason this research opted for this software. Sequencing is important in coding in Microsoft Small Basic as the computer will execute the codes based on the sequences of the codes.

### 3.3.1 Graphics Window

The first thing we must consider is having a working interface. In order to provide a working interface for the user to interact with program, first we must create a window. A window of 800x600 in size is produced using the following commands and codes where objects can be placed inside it where it can interact with the user.

```
GraphicsWindow.Width = 800
GraphicsWindow.Height = 600
```

To make things simple, certain keywords like 'Ly' and 'Lx' are used in order to name certain software elements or objects. For example, when we write 'Ly' followed by an equal sign '=' and subsequently by a value such as 2; Ly will have a value of 2 in the program and can be used when needed to simplify commands.

```
Ly = 2
```

Software elements and objects can be placed in the provided window. These objects need to be placed properly in order to not overlap each other to not disrupt the given information. The codes would require two variables. These variables are similar to x-y coordinate system. They need two values which are X and Y. X is the horizontal placement where the left most side is zero and increasing values will move it to the right. Y is the vertical placement where the top most side is zero and increases values will move it to the bottom. Some codes and commands would also require a third variable in which text can be or values can be attached to it. However, not all codes and commands require positioning variables.

The window can be cleared of existing texts and objects with the 'GraphicsWindow.Clear' command. All objects on the window are removed when the command 'GraphicsWindow.Clear' command is written.

`GraphicsWindow.Clear()`

### 3.3.2 Subroutines

Writing the same codes and lines repeatedly would not make any sense for repeated execution. A subroutine allows the program to jump to a specific group of codes and lines and execute them. This is done by separating the codes and place them in between the code 'Sub' and 'EndSub'. The program will only execute the subroutine if the subroutine's name is called in the coding. This is very useful in order to separate stages of the program such as in between equations and calculations. Addition equation is added between 'Sub Add' and 'EndSub'.

```
Sub Add
  z = x + y
EndSub
```

In this context, 'Add' is the name of the subroutine and it will only execute when it is called in the coding. The 'Add' subroutine will execute when the code below is written;

```
Add()
```

For this research, subroutines are primarily used in dividing the major processes of the program. The coding of the program would divide the major design segments in the reinforced concrete design of two-way restrained solid slabs into subroutines. Coding in Microsoft small basic would carry out from start to finish in an ascending number order. With the use of subroutines, one may code anywhere on the number order and the program would not carry out the subroutine until requested in the coding.

### 3.3.3 Draw Text

Texts are words or values that can be written by the designer and seen on the program by the users. They can give information to the users. The command is 'GraphicsWindow.DrawText(x,y,text)' in which it will write it in the window with the given coordinates. Text in this context must be enclosed with "", such as "Hello". This



will write the text with the word 'Hello'. Otherwise, if it is not enclosed, the program would write down whatever value or word Hello contained. If it does not contain anything, it will not run. The words 'Reinforced Concrete Design' is shown at the given coordinates on the graphics interface when the command below is written.

```
GraphicsWindow.DrawText(300,250,"Reinforced Concrete Design")
```

For this research, this command provide information to the user in the graphics interface window. With correct positioning, values can be shown to the user and what those values refer to can be told to the user in the graphics interface window. It helps in in telling the user what certain things are.

### 3.3.4 Add Text Box

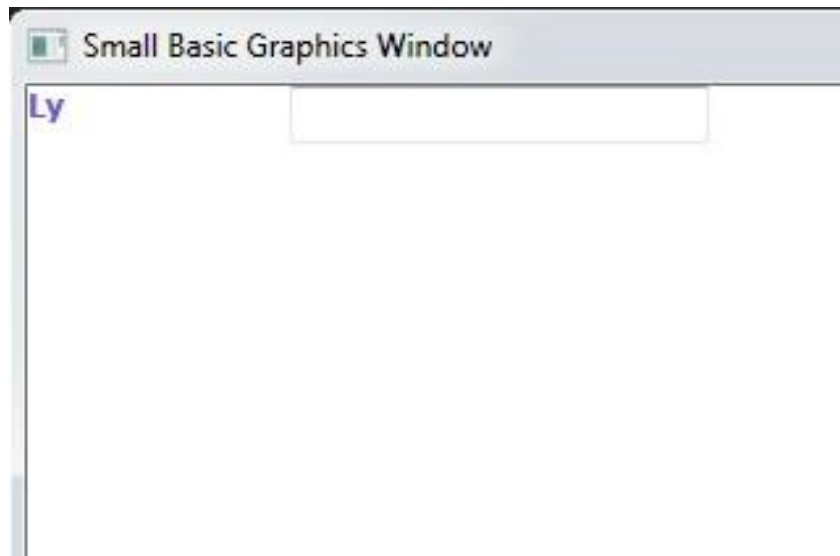
Textboxes are mediums for the user to insert words or values to the program. The command 'Controls.AddTextBox(x,y)' will place a textbox at the designated position of x and y. Two text boxes at the given coordinates are placed in the window when the following commands are written.

```
Ly = Controls.AddTextBox(100,0)
Lx = Controls.AddTextBox(100,50)
```

This will have two text boxes named Ly and Lx at their respective positions. Combining DrawText and AddTextBox corrently will allow the user to know where to input their values. The text Ly with a text box to the right of it is shown in the program when the following commands are written.

```
GraphicsWindow.DrawText(0,0,"Ly")
Ly = Controls.AddTextBox(100,0)
```

This will produce as follows when the program is executed, the text on the left and a textbox to the right.



**Figure 3.1:** Draw Text and Text Box

For this research, the textboxes are used to allow users to input certain values into the respective textboxes in which will then be read and used by the program to carry out mathematical calculations and other coding.

### 3.3.5 Reading Data

In order for the program to read whatever it is in the boxes, the command `Controls.GetTextBoxText(TextBox)` is used where `TextBox` is the name of the text box it will read. The values of `Ly` and `Lx` are read by the program when the following commands are written.

```
x1 = Controls.GetTextBoxText(Ly)
y1 = Controls.GetTextBoxText(Lx)
```

This will read the value of what is inputted in Text Box `Ly` and Text Box `Lx` and these values will be named `x1` and `y1` respectively in the program.

For this research, this command is primarily used in reading values inputted into the program and store them for use in the proceeding mathematical computations. For Case values, it will read the value and determine which subroutine the program will

carry out in order to use the values of coefficients for bending moment and shear force dependant on the slab position case..

### 3.3.6 Mathematical Computation

Microsoft Small Basic allows the coding to work like a calculator. Carrying out addition, subtraction, multiplication and division can be done by using + , - , \* and / respectively in between values. However, it would still need a keyword to be tied in with the results of the computation. Basic addition is executed with the following codes:

```
z = x1 + y1
```

To show the value in the window, we use the 'DrawText' command with the last variable we put z. The value of z is shown when the following command is written.

```
GraphicsWindow.DrawText(0,0,z)
```

Microsoft Small Basic can also use various mathematical computations through the Math command. It can power up values through Math.Power(x,y) where x and y in this context are the number and exponent respectively. The value of 2 is powered up to 2 with the following command.

```
z = Math.Power(2,2)
```

It can also be used to round up values to the nearest interger through Math.Round(x) where x in this context is the value. The value of X is rounded up with the following command.

```
Math.Round(x)
```

For this research, all calculations are handled through the mathematical computation commands of Microsoft Small Basic.

### 3.3.7 Add Button

Buttons are a type of clickable object in which when clicked, will perform whatever the codes the button is tied to. Buttons, when pressed by the user, allow the program to jump to certain subroutines coded in the program. The command is `Controls.Addbutton(z,x,y)` where `z` is the text on the Button, `x` and `y` are the horizontal and vertical position variables respectively. The command is preceded by a name for the Button and an equal sign. A button is shown with the name "Next" with the following command at the designated position.

```
Next = Controls.AddButton("Next",700,450)
```

For this research, the 4 primary buttons are added. The buttons are named 'Analyze', 'Next', 'Reset', and 'Exit Program'. Each button is coded to carry out certain actions when clicked on. The 'Analyze' button will proc the program to begin the calculations when the proper values are inputted into the program. The 'Next' button will move the program from subroutine to subroutine in a progressive way. The 'Reset' Button will reset all values and calculations, and place back the program to the starting interface. The "Exit Program" button will prompt a 'Thank you' message and close down the program.

### 3.3.8 If Statement

When there are branching events or choices, the If statement is used. The command is the code "If", followed by a condition, the code "Then", commands or codes executed should the condition is met and closed with `EndIf`. Example:

```
If I = 1 Then
    GraphicsWindow.DrawText(0,0,"Hello")
ElseIf I = 2 Then
    GraphicsWindow.DrawText(0,0,"Goodbye")
Else
    GraphicsWindow.DrawText(0,0,"Nothing")
EndIf
```

When the value of I is equal to 1 then the window will say Hello. If the value of I is equal to 2 then it will say Goodbye. With the “Else” command, any other values will have the window say Nothing.

For this research, the “If” command is used primarily to discern certain values that have limiting values such as the value of K in the calculation of required area of reinforcement,  $A_{s,req}$  with a limiting value of 0.167. This command is also used in order for the program to take values of short span and long span coefficients for bending moment and shear force design according to the ratio of  $l_y/l_x$  and the case of the slab position.

### 3.3.9 Summary of Coding

This section will summarize the codings done in Microsoft Small Basic. The actual coding for the entire program is not shared for this thesis. The following are the steps of the summarized coding of the program:

1. A graphics window is created to provide an interface for the user.
2. Subroutine ‘Start’ is coded with the following texts and their corresponding textboxes which corresponds to the values to be inputted by the user;
  - a)  $L_y$  in mm
  - b)  $L_x$  in mm
  - c) Slab Thickness, h in mm
  - d) Characteristic Permanent Action,  $G_k$  in  $\text{kN/m}^2$
  - e) Characteristic Variable Action,  $Q_k$  in  $\text{kN/m}^2$
  - f) Concrete Strength,  $F_{ck}$  in  $\text{N/mm}^2$
  - g) Steel Strength,  $F_{yk}$  in  $\text{N/mm}^2$
  - h) Nominal Cover,  $C_{nom}$  in mm
  - i) Case
  - j)  $F_{ctm}$  in MPa
  - k) Bar diameter in mm
3. Three buttons are added named ‘Analyse’, ‘Reset’ and ‘Exit Program’ with each are tied to separate subroutines.

4. Subroutine 'Reset' is coded to clear the graphics window of existing objects and restart the problem. This code is repeated for all subroutines.
5. Subroutine 'Exit Program' is coded to close the program. This code is repeated for all subroutines.
6. Subroutine 'Level1' is coded to read the above inputs and calculate  $\text{Area}(L_y * L_x)$ ,  $\text{Ratio}(L_y/L_x)$  and Design Action,  $n$  when the 'Analyse' button is clicked
7. 'Analyse' button is coded to be replaced with 'Next' button.
8. Subroutine Level2Case1 is coded and tied to 'Next' button in which will choose the values of Bending Moment coefficients based on the coefficients table via 'If' commands with the conditions tied to the value of Ratio.
9. The Next Button is recoded to execute subroutine 'level3'. This new 'Next' button is named 'Next1' in the coding.
10. Step 8 and 9 is repeated 8 times to compensate for all 9 cases of slab positions their subroutine names will be Level2Case2, Level2Case3, and so forth.
11. Subroutine 'Level3' is coded to read the previous coefficients, calculate the maximum moments per unit width, effective depths, minimum and maximum area of reinforcements and show these values on the interface
12. The 'Next' Button is recoded to execute subroutine level4 and named Next2. This step is repeated for every subsequent level subroutines and be renamed in increasing order.
13. Subroutine 'Level4' is coded to calculate the coefficient  $k$  and  $z$ , and area of reinforcements for both short span and long span and their respective mid-span and support reinforcements
14. Subroutine 'Level4' is also coded requesting the value of  $A_{sl}$  to be inputted at the bottom of the interface.
15. Subroutine 'Level5Case1' is coded and tied to 'Next' button in which will choose the values of Shear Force Coefficients based on the coefficients table via 'If' commands with the conditions tied to the value of Ratio.
16. The Next Button is recoded to execute subroutine 'Level6'.
17. Step 15 to 16 is repeated 8 times to compensate for all 9 cases of slab positions their subroutine names will be Level5Case2, Level5Case3, and so forth.

18. Subroutine 'Level6' is coded to calculate design shear forces and set to choose the highest amongst the four values is the final design shear force, calculate the shear force resistance and minimum shear force.
19. Subroutine 'Level6' is coded to show on the interface the previous values alongside coefficients  $k$  and  $\phi_{ro}$ , maximum bar spacing for main bars and secondary bars.

### **3.4 REINFORCED CONCRETE DESIGN CALCULATIONS AND FORMULAS**

This section will highlight all the major Reinforced Concrete Design calculations for two-way restrained slabs that is covered by the scope of this research. These are also the calculations that are carried out by the program. The calculations are carried out in sequential order. Note that deflection checking is not included in this research.

#### **3.4.1 Assumptions**

The following lists the assumptions made for this research. The program abides to these assumptions/rules. Certain assumptions require the values to be inputted correctly and will cause the program to fail otherwise.:

- 1) Values for  $L_y$  and  $L_x$  must produce the ratio  $L_y / L_x$  for any values of 1, 1.1, 1.2, 1.3, 1.4, 1.5, 1.75 and 2.
- 2) Minimum width of tension zone,  $b$  is 1000mm
- 3) Concrete Tensile Strength,  $f_{ck}$  is dependant on the value of  $f_{ck}$  and can be taken from Appendix A
- 4) Unit weight of reinforced concrete is fixed at  $25\text{kN/m}^3$
- 5) All flexural reinforcements only require compression reinforcements (  $K = K_{bal}$  ) and not does consider any tension reinforcements
- 6) Values of coefficients of long span and short for bending moment (Table 3.1) and shear force design (Table 3.2) must only come from their respective tables as in accordance to Eurocode 2

- 7) The Case Text Box requires a numerical value from 1 to 9. The following numbering corresponds to the Slab Position Case (Figure 3.1);
- a) Case 1 – Interior Panels
  - b) Case 2 – One Short Edge Discontinuous
  - c) Case 3 – One Long Edge Discontinuous
  - d) Case 4 – Two Adjacent Edges Discontinuous
  - e) Case 5 – Two Short Edges Discontinuous
  - f) Case 6 – Two Long Edges Discontinuous
  - g) Case 7 – Three Edges Discontinuous ( One Long Edge Continuous )
  - h) Case 8 – Three Edges Discontinuous ( One Short Edge Continuous )
  - i) Case 9 – Four Edges Discontinuous



**Table 3.1** Bending Moment Coefficients

(Source: Table 3.14 BS8110:Part 1:1997)

Type of panel and location	Short span coefficients, $\beta_{sx}$								Long span coefficients, $\beta_{sy}$ for all values of $l_y/l_x$	
	Values of $l_y/l_x$									
	1	1.1	1.2	1.3	1.4	1.5	1.75	2		
Interior Panels / Four edges continuous										
Negative Moments at continuous edge	0.031	0.037	0.042	0.046	0.050	0.053	0.059	0.063	0.032	
Positive Moment at Mid-span	0.024	0.028	0.032	0.035	0.037	0.040	0.044	0.048	0.024	
One Short edge discontinuous										
Negative Moments at continuous edge	0.039	0.044	0.048	0.052	0.055	0.058	0.063	0.067	0.037	
Positive Moment at Mid-span	0.029	0.033	0.036	0.039	0.041	0.043	0.047	0.050	0.028	
One long edge discontinuous										
Negative Moments at continuous edge	0.039	0.049	0.056	0.062	0.068	0.073	0.082	0.089	0.037	
Positive Moment at Mid-span	0.030	0.036	0.042	0.047	0.051	0.055	0.062	0.067	0.026	
Two adjacent edge discontinuous										
Negative Moments at continuous edge	0.047	0.056	0.063	0.069	0.074	0.078	0.087	0.093	0.045	
Positive Moment at Mid-span	0.036	0.042	0.047	0.051	0.055	0.059	0.065	0.070	0.034	
Two short edges discontinuous										
Negative Moments at continuous edge	0.046	0.050	0.054	0.057	0.060	0.062	0.067	0.070	-	
Positive Moment at Mid-span	0.034	0.038	0.040	0.043	0.045	0.047	0.050	0.053	0.034	
Two long edges discontinuous										
Negative Moments at continuous edge	-	-	-	-	-	-	-	-	0.045	
Positive Moment at Mid-span	0.034	0.046	0.056	0.065	0.072	0.078	0.091	0.100	0.034	
Three edges discontinuous (one long edge discontinuous)										
Negative Moments at continuous edge	0.057	0.065	0.071	0.076	0.081	0.084	0.092	0.098	-	
Positive Moment at Mid-span	0.043	0.048	0.053	0.057	0.060	0.063	0.069	0.074	0.044	
Three edges discontinuous (one short edge discontinuous)										
Negative Moments at continuous edge	-	-	-	-	-	-	-	-	0.058	
Positive Moment at Mid-span	0.042	0.054	0.063	0.071	0.078	0.084	0.096	0.105	0.044	
Four edges discontinuous										
Positive moment at mid-span	0.055	0.065	0.074	0.081	0.087	0.092	0.103	0.110	0.056	

**Table 3.2** Shear Force Coefficients

(Source: Table 3.15 BS8110:Part 1:1997)

Type of panel and moments considered	Short span coefficients, $\beta_{vx}$								Long span coefficients, $\beta_{vy}$ for all values of $l_y/l_x$	
	Values of $l_y/l_x$									
	1	1.1	1.2	1.3	1.4	1.5	1.75	2		
Interior Panels / Four edges discontinuous										
Continuous Edge	0.33	0.36	0.39	0.41	0.43	0.45	0.48	0.50	0.33	
One Short edge discontinuous										
Continuous Edge	0.36	0.39	0.42	0.44	0.45	0.47	0.50	0.52	0.36	
Discontinuous Edge	-	-	-	-	-	-	-	-	0.24	
One long edge discontinuous										
Continuous Edge	0.36	0.40	0.44	0.47	0.49	0.51	0.55	0.59	0.36	
Discontinuous Edge	0.24	0.27	0.29	0.31	0.32	0.34	0.36	0.38	-	
Two adjacent edge discontinuous										
Continuous Edge	0.40	0.44	0.47	0.50	0.52	0.54	0.57	0.59	0.40	
Discontinuous Edge	0.26	0.29	0.31	0.33	0.34	0.35	0.38	0.38	0.26	
Two short edges discontinuous										
Continuous Edge	0.40	0.43	0.45	0.47	0.48	0.49	0.52	0.54	-	
Discontinuous Edge	-	-	-	-	-	-	-	-	0.26	
Two long edges discontinuous										
Continuous Edge	-	-	-	-	-	-	-	-	0.40	
Discontinuous Edge	0.26	0.30	0.33	0.36	0.38	0.40	0.44	0.47	-	
Three edges discontinuous (one long edge discontinuous)										
Continuous Edge	0.45	0.48	0.51	0.53	0.55	0.57	0.60	0.63	-	
Discontinuous Edge	0.30	0.32	0.34	0.35	0.36	0.37	0.39	0.41	0.29	
Three edges discontinuous (one short edge discontinuous)										
Continuous Edge	-	-	-	-	-	-	-	-	0.45	
Discontinuous Edge	0.29	0.33	0.36	0.38	0.40	0.42	0.45	0.48	0.30	
Four edges discontinuous										
Discontinuous Edge	0.33	0.36	0.39	0.41	0.43	0.45	0.48	0.50	0.33	

	lx			
ly	4	2	4	8
	3	1	3	6
	4	2	4	8
	7	5	7	9

**Figure 3.2:** Classification of restrained two-way slab

### 3.4.2 Actions

Actions are loading that is applied to the slab. Permanent Action can also be named dead load is any permanent loading that is applied to the slab such as the selfweight of the slab , beams and other loadings that is going to be fixed to the slab. Variable Action is any additional loading that is applied to slab that is not permanent. Design Action is the design value for all the actions that are to be considered in which will be used to design the reinforcement of the slab itself.

- 1) Slab Selfweight is the weight of the slab multiplied by the thickness of the slab in  $\text{kN/mm}^2$
- 2) Characteristic Permanent Action in  $\text{kN/mm}^2$ ,  $G_k = G_k$  (without self-weight) + Slab Selfweight; where the second  $G_k$  in this equation represents the value to be inputted in the program.
- 3) Characteristic Variable Action in  $\text{kN/mm}^2$ ,  $Q_k$
- 4) Design Action,  $n = 1.35G_k + 1.5Q_k$  (Eq. 1 )

### 3.4.3 Bending Moment and Main Reinforcement Analysis

The calculations for flexural reinforcement follow a similar procedure to that in use in beam design for designing rectangular sections. However, slabs mostly does not require additional compression reinforcement.

- 1) Ratio of  $L_y / L_x$  (Eq. 2 )
- 2) The maximum Moments per unit width in  $\text{kN/mm}^2$ ;
  - a) Short Span Mid Span,  $M_{sx1} = \beta_{sx1} n L_x^2$  (Eq. 3 )
  - b) Short Span Support,  $M_{sx2} = \beta_{sx2} n L_x^2$  (Eq. 4 )
  - c) Long Span Mid Span,  $M_{sy1} = \beta_{sy1} n L_x^2$  (Eq. 5 )
  - d) Long Span Support,  $M_{sy2} = \beta_{sy2} n L_x^2$  (Eq. 6 )
- 3) Effective depth in mm;
  - a) Short Span Effective Depth ;  $d_x = h - C_{nom} - 0.5\phi_{bar}$  (Eq. 7 )
  - b) Long Span Effective Depth;  $d_y = h - C_{nom} - 1.5\phi_{bar}$  (Eq. 8 )

4) Minimum and Maximum Reinforcement Area in  $\text{mm}^2/\text{m}$ ;

The minimum area of reinforcement bars correspond to the steel reinforcement in the bottom of the slab for each edge strip. The maximum area of reinforcement bars correspond to the highest area of reinforcement bars that the slab may have. Any higher would cause the bars to show outside the slab and may cause structural failure to the slab. The value of  $f_{ctm}$  can be taken from Appendix A and is dependent of the value of  $f_{ck}$ .

a) Minimum Reinforcement Area (Secondary Reinforcement Bars);

$$A_{s,\min} = 0.26 \left( \frac{f_{ctm}}{f_{yk}} \right) bd \geq 0.0013bd \quad (\text{Eq. 9})$$

Where  $d$  is  $d_x$

b) Maximum Reinforcement Area in  $\text{mm}^2/\text{m}$  ;

$$A_{s,\max} = 0.04 A_c \quad (\text{Eq. 10})$$

$$\text{Where } A_c = bh \quad (\text{Eq. 11})$$

$h$  = slab thickness

5) Flexural Reinforcement Design for Short Span and Long Span and their respective Mid-span and Support;

Flexural Reinforcement Design corresponds to the finding of the area required for the reinforcement bars in a slab based on the design action. This series of calculation is repeated 4 times for both long span and short span of the slab and their respective mid-spans and supports.

a) First Equation:

$$K = M \frac{bd^2}{f_{ck}} \leq 0.167 (K_{bal}) \quad (\text{Eq. 12})$$

Where  $d = d_x$  for Short Span,  $d = d_y$  for Long Span,

$b$  is 1000 mm as in one meter span of slab,

$M$  is;

- 1) Value of  $M_{sx1}$  is used for Short Span Mid span
- 2) Value of  $M_{sx2}$  is used for Short Span Support
- 3) Value of  $M_{sy1}$  is used for Long Span Mid span
- 4) Value of  $M_{sy2}$  is used for Long Span Support

b) Second Equation:

$$z = d \left[ 0.5 + \sqrt{0.25 - \left( \frac{K}{1.134} \right)} \right] \leq 0.95d \quad (\text{Eq. 13})$$

c) Third Equation

$$A_{s,req} = \frac{M}{0.87f_{yk}z} \quad (\text{Eq. 14})$$

Where;  $A_{s,min} \leq A_{s,req} \leq A_{s,max}$

Then, we need to provide a sufficient area of reinforcement bars which must be bigger than the required area of reinforcement. The area of reinforcement bars is dependent on the diameter size of the reinforcement bars and the spacing between each bar per 1000 mm span length. Table 3.4.1 shows the area provided for given bar sizes and spacing.

**Table 3.3:** Sectional area per meter width for various bar spacing ( $\text{mm}^2/\text{m}$ )

(Source: Reinforced Concrete Design to Eurocode 2 by Yassin M.S. Appendix B)

Bar Size	Spacing of bars									
(mm)	50	75	100	125	150	175	200	225	250	300
6	566	377	283	226	189	162	141	126	113	94
8	1005	670	503	402	335	287	251	223	201	168
10	1571	1047	786	628	524	449	393	349	314	262
12	2262	1508	1131	905	754	646	566	503	452	377
16	4022	2681	2011	1609	1341	1149	1005	894	804	670
20	6284	4189	3142	2514	2095	1795	1571	1396	1257	1047
25	9819	6546	4909	3928	3273	2805	2455	2182	1964	1636
32	16087	10725	8044	6435	5362	4596	4022	3575	3217	2681
40	25136	16757	12568	10054	8379	7182	6284	5586	5027	4189

### 3.4.4 Shear Force Design

Shear stresses in slabs are subjugated to loads that are uniformly distributed are considered very small. It is only necessary to ensure that the design ultimate shear,  $V_{ed}$  to be less than the shear strength of the unreinforced section,  $V_{rd,c}$ . The design shear forces of the slab or the loads on beams in which supports the slabs can be evaluated below.

a) Design Shear Forces,  $V$  in kN/m where the highest  $V$  is chosen as the design ultimate shear,  $V_{ed}$ :

$$1) \quad \text{Short Span Mid Span, } V_{sx1} = \beta_{vx1} n L_x \quad (\text{Eq. 15})$$

$$2) \quad \text{Short Span Support, } V_{sx2} = \beta_{vx2} n L_x \quad (\text{Eq. 16})$$

$$3) \quad \text{Long Span Mid Span, } V_{sy1} = \beta_{vy2} n L_x \quad (\text{Eq. 17})$$

$$4) \quad \text{Long Span Support, } V_{sy2} = \beta_{vy2} n L_x \quad (\text{Eq. 18})$$

- b) Design Shear Resistance in kN/m,  $V_{Rd,c}$ ;

$$V_{Rd,c} = [0.12k\sqrt[3]{(100p_1f_{ck})}]bd \quad (\text{Eq. 19})$$

$$\text{Where } k = 1 + \sqrt{\left(\frac{200}{d_x}\right)} \leq 2.0 \quad (\text{Eq. 20})$$

$$p_1 = A_{sl} \frac{b}{d} \leq 0.02 \quad (\text{Eq. 21})$$

$$d = d_x$$

- c) Minimum Shear Force in kN/m,  $V_{min}$ ;

$$V_{min} = [0.035 k^{\frac{3}{2}} f_{ck}^{1/2}]bd \quad (\text{Eq. 22})$$

$$\text{Where } d = d_x$$

### 3.4.5 Cracking Checking

Cracking checking for slabs requires the slab thickness,  $h$  to not be greater than 200mm. Additionally, it requires that the maximum bar spacing for main and secondary reinforcement bars to be less than or equal to 400 mm for main bars and less than or equal to 450 mm for secondary bars.

- a) Minimum thickness:  $h < 200 \text{ mm}$
- b) Maximum main bar spacing:  $S_{max,slabs} = 3h \leq 400\text{mm}$
- c) Maximum secondary bar spacing:  $S_{max,slabs} = 3.5h \leq 450\text{mm}$



## **CHAPTER 4**

### **RESULTS AND DISCUSSIONS**

#### **4.1 INTRODUCTION**

This chapter covers all the results obtained from this research. The program is finished and chapter 4.2 covers the manual on how to use the finished program. Chapter 4.3 contains the accuracy test in which hold the values to be tested by the program and to be proven by manual calculations. Chapter 4.4 covers one example of the manual calculation. Chapter 4.5 covers all the results from manual calculations. Chapter 4.6 covers all the results from the program. Chapter 4.7 covers the comparison of data between the results of manual calculations and program results. Chapter 4.8 covers the discussions of the results obtained and other important factors.

#### **4.2 PROGRAM MANUAL OF OPERATIONS**

This section will cover the standard procedures on how to use the finished program:

1. Open sb.exe to immediately open the program.
2. OR open sb.sb to open the program via Microsoft Small Basic interface and press F5/Run once it is finished loading.
3. The first interface will show up requiring values to be inserted into the respective boxes (Figure 4.1).
4. Insert the values in the respective boxes
5. Click on the 'Analyze' button once all boxes are filled in with the correct values (Figure 4.2)

6. Next interface will show the values for Area, Design Action and Ratio (Figure 4.3).
7. Click on Next to proceed to an empty interface. Click on 'Next' to proceed (Figure 4.4).
8. Next interface will show the calculated values as in the picture below (Figure 4.5).
9. Click on 'Next' to proceed to show the calculated values as in the picture below (Figure 4.6).
10. Insert the values for  $A_{sl}$  in the bottom part of the window interface (Figure 4.7).
11. Click on 'Next' to proceed to an empty interface. Click on 'Next' to proceed (Figure 4.8).
12. The last interface will show the calculated values as in the picture below (Figure 4.2.9).

All interfaces will contain the 'Reset' and 'Exit Program' buttons at the bottom right of the window interface. 'Reset' will clear all values and bring the program to the first interface. 'Exit Program' will prompt a 'Thank You' message and then by clicking OK, will close the program. If it's opened through the Run function in Microsoft Small Basic, it will close the program and return to the Small Basic coding interface.

Small Basic Graphics Window

Ly(mm)	<input type="text"/>	Fctm(N/mm <sup>2</sup> )	<input type="text"/>
Lx(mm)	<input type="text"/>	Bar Diamater(mm)	<input type="text"/>
Slab Thickness(mm)	<input type="text"/>		
Permanent, Gk(kN/m <sup>2</sup> )	<input type="text"/>		
Variable, Qk(kN/m <sup>2</sup> )	<input type="text"/>		
Concrete strength, Fck(N/mm <sup>2</sup> )	<input type="text"/>		
Steel strength, Fyk(N/mm <sup>2</sup> )	<input type="text"/>		
Nominal Cover(mm)	<input type="text"/>		
Case	<input type="text"/>		

Analyse  
Reset  
Exit Program

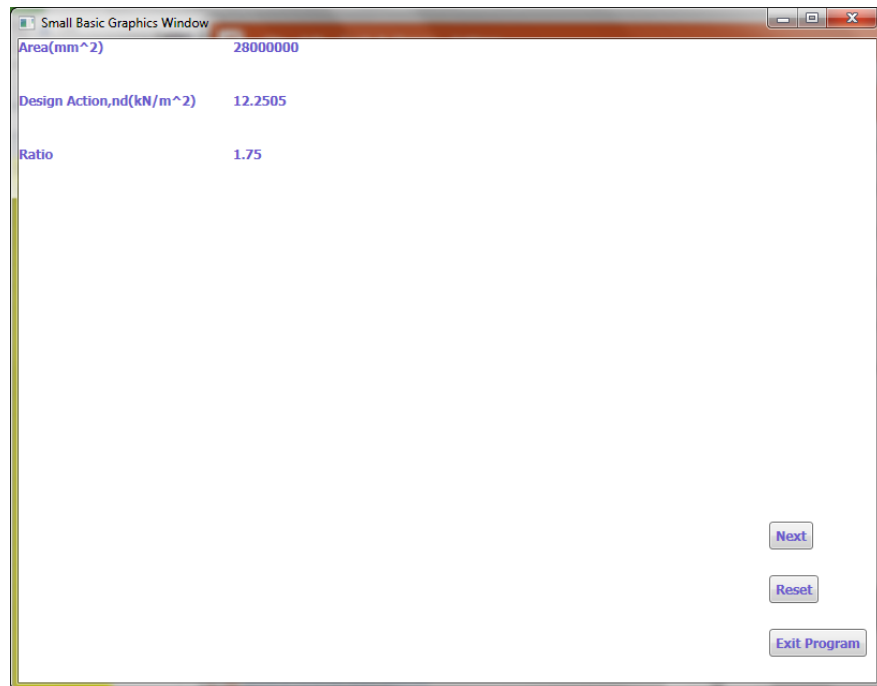
**Figure 4.1:** First Interface

Small Basic Graphics Window

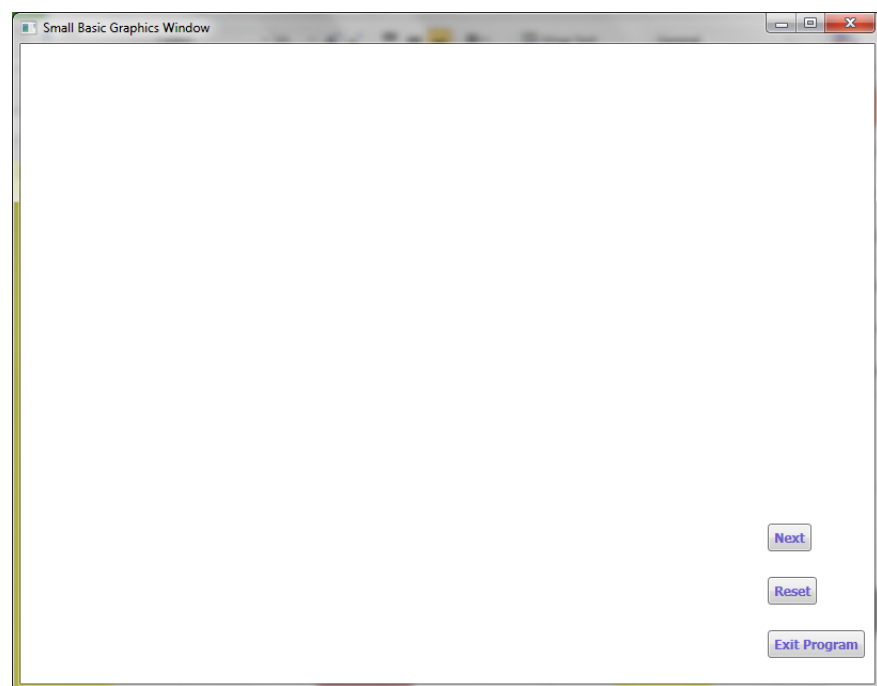
Ly(mm)	7000	Fctm(N/mm <sup>2</sup> )	2.6
Lx(mm)	4000	Bar Diamater(mm)	10
Slab Thickness(mm)	125		
Permanent, Gk(kN/m <sup>2</sup> )	4.63		
Variable, Qk(kN/m <sup>2</sup> )	4		
Concrete strength, Fck(N/mm <sup>2</sup> )	25		
Steel strength, Fyk(N/mm <sup>2</sup> )	500		
Nominal Cover(mm)	25		
Case	4		

Analyse  
Reset  
Exit Program

**Figure 4.2:** First Interface; Data Inputted



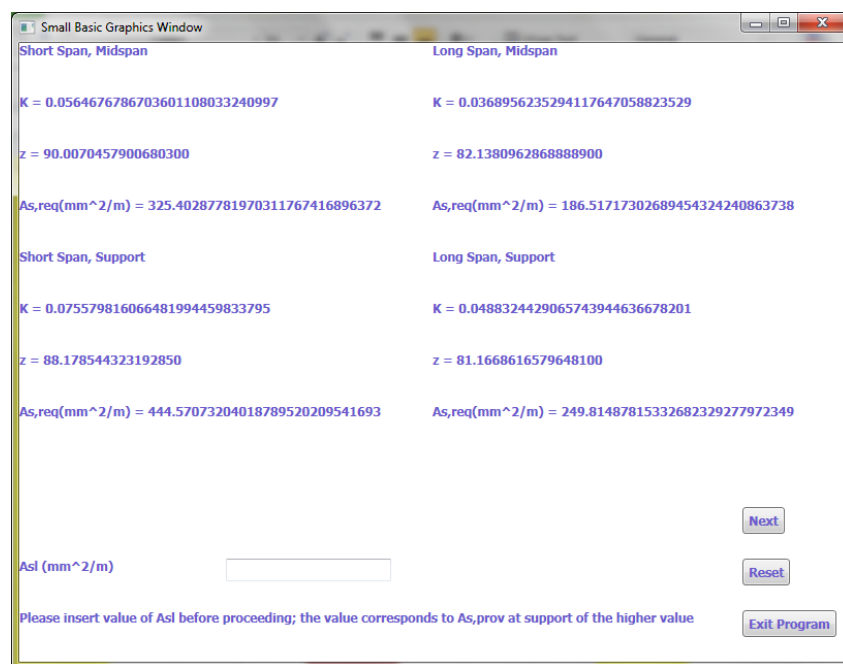
**Figure 4.3:** Second Interface



**Figure 4.4:** Third Interface



**Figure 4.5:** Fourth Interface



**Figure 4.6:** Fifth Interface

Small Basic Graphics Window

Short Span, Midspan	Long Span, Midspan
$K = 0.0564676786703601108033240997$	$K = 0.0368956235294117647058823529$
$z = 90.0070457900680300$	$z = 82.1380962868888900$
$A_{s,req}(mm^2/m) = 325.40287781970311767416896372$	$A_{s,req}(mm^2/m) = 186.51717302689454324240863738$
Short Span, Support	Long Span, Support
$K = 0.075579816066481994459833795$	$K = 0.0488324429065743944636678201$
$z = 88.178544323192850$	$z = 81.1668616579648100$
$A_{s,req}(mm^2/m) = 444.57073204018789520209541693$	$A_{s,req}(mm^2/m) = 249.81487815332682329277972349$

Asl (mm<sup>2</sup>/m)

Please insert value of Asl before proceeding; the value corresponds to As,prov at support of the higher value

Next  
Reset  
Exit Program

**Figure 4.7:** Fifth Interface; Inputting  $A_{sl}$  Value

Small Basic Graphics Window

Next  
Reset  
Exit Program

**Figure 4.8:** Sixth Interface



**Figure 4.9:** Seventh Interface

### 4.3 ACCURACY TEST

In order to test the accuracy of the program, below are the values used to be inputted into the program. These values will also be used for manual calculations which will then be compared to the values calculated by the program. 9 set of values are provided and each set of values correspond the test number.

**Table 4.1:** Accuracy Test Values

	TEST	TEST	TEST	TEST	TEST	TEST	TEST	TEST	TEST
	1	2	3	4	5	6	7	8	9
Ly	7000	8000	5000	4400	4800	5200	5600	6000	7000
Lx	4000	4000	5000	4000	4000	4000	4000	4000	4000
Ratio	1.75	2	1	1.1	1.2	1.3	1.4	1.5	1.75
Case	4	3	2	1	5	6	7	8	9
Cnom	25	25	30	25	30	25	25	25	25
slab h	125	150	150	125	150	125	125	125	125
Dbar	10	12	12	10	12	10	10	12	12
Fck	25	25	30	35	25	25	30	30	25
Fyk	500	500	500	500	500	500	500	500	500
Gk	4.63	4.13	5.75	4.63	5.75	4.63	5.63	4.63	4.63
Qk	4	3.5	3.5	4	3.5	4	4	4	3.5
K	1.3	1.3	1.3	1.5	1.3	1.3	1.3	1.3	1
Fctm	2.6	2.6	2.9	3.2	2.6	2.6	2.9	2.9	2.6

### 4.4 MANUAL CALCULATIONS

This section will cover an example of the manual calculations for reinforce concrete design of two-way restrained solid slab to Eurocode 2. The example considers the set of values given by Test 1. For this research, manual calculations will only consider 3 effective decimal points.



#### 4.4.1 Actions

- 1) Characteristic permanent action,  $G_k = 4.630$
- 2) Characteristic variable action,  $Q_k = 4.000$
- 3) Design action,  $n = 1.35g_k + 1.5Q_k = 12.251$

#### 4.4.2 Bending Moments

- 1)  $L_y/l_x = 700/4000 = 1.75 < 2.0$  Two-way Slab;

Slab has two adjacent edges discontinuous therefore it is Case 4, below are the values of coefficients for bending moments for long-span and short-span.

$$\beta_{sx1} = 0.065$$

$$\beta_{sx2} = 0.087$$

$$\beta_{sy1} = 0.034$$

$$\beta_{sy2} = 0.045$$

- 2) Short Span Mid Span,  $M_{sx1} = \beta_{sx1} n L_x^2$   
 $= 0.065 \times 12.251 \times 4.0^2 = 12.741 \text{ kNm}^2$
- 3) Short Span Support,  $M_{sx2} = \beta_{sx2} n L_x^2$   
 $= 0.087 \times 12.251 \times 4.0^2 = 17.053 \text{ kNm}^2$
- 4) Long Span Mid Span,  $M_{sy1} = \beta_{sy1} n L_x^2$   
 $= 0.034 \times 12.251 \times 4.0^2 = 6.665 \text{ kNm}^2$
- 5) Long Span Support,  $M_{sy2} = \beta_{sy2} n L_x^2$   
 $= 0.045 \times 12.251 \times 4.0^2 = 8.821 \text{ kNm}^2$

#### 4.4.3 Effective Depths

Effective depth in mm;

- 1) Short Span Effective Depth ;  $d_x = h - C_{nom} - 0.5\phi_{bar}$   
 $= 125 - 25 - (10/2) = 95.0 \text{ mm}$
- 2) Long Span Effective Depth;  $d_y = h - C_{nom} - 1.5\phi_{bar}$   
 $= 125 - 25 - 1.5(10) = 85.0 \text{ mm}$

#### 4.4.4 Minimum and Maximum Reinforcement Area

The Minimum and Maximum Reinforcement Area in  $\text{mm}^2/\text{m}$ :

- 1) Minimum Reinforcement Area (Secondary Reinforcement Bars):

$$\begin{aligned}
 A_{s,min} &= 0.26 \left( \frac{f_{ctm}}{f_{yk}} \right) bd \geq 0.0013bd \\
 &= 0.26 ( 2.6 / 500 ) = 0.00135bd \geq 0.0013bd \\
 &= 0.00135 ( 1000 \times 95 ) = 128.25 \text{ mm}^2/\text{m}
 \end{aligned}$$

- 2) Maximum Reinforcement Area in  $\text{mm}^2/\text{m}$  :

$$\begin{aligned}
 A_{s,max} &= 0.04 A_c \\
 &= 0.04 \times 1000 \times 125 = 5000 \text{ mm}^2/\text{m}
 \end{aligned}$$

#### 4.4.5 Flexural Reinforcement Design

- 1) Short Span

a) At Mid-span,

$$M_{sx1} = 12.741 \text{ kNm/m}$$

$$\begin{aligned}
 K &= \frac{M}{bd^2 f_{ck}} \leq 0.167 (K_{bal}) \\
 &= \frac{12.741 \times 10^6}{1000 \times 95^2 \times 25} \\
 &= 0.0565 \leq 0.167 \\
 &= 0.0565
 \end{aligned}$$

$$\begin{aligned}
z &= d \left[ 0.5 + \sqrt{0.25 - \left( \frac{K}{1.134} \right)} \right] \leq 0.95d \\
&= d \left[ 0.5 + \sqrt{0.25 - \left( \frac{0.0565}{1.134} \right)} \right] \\
&= 0.948d \leq 0.95d \\
&= 0.948d
\end{aligned}$$

$$\begin{aligned}
A_{s,req} &= \frac{M}{0.87 f_{yk} z} \\
&= \frac{12.741 \times 10^6}{0.87 \times 500 \times 0.95 \times 95} \\
&= 324.539 \text{ mm}^2/\text{m}
\end{aligned}$$

b) At Support,

$$M_{sx2} = 17.053 \text{ kNm/m}$$

$$\begin{aligned}
K &= \frac{M}{bd^2 f_{ck}} \leq 0.167 (K_{bal}) \\
&= \frac{17.053 \times 10^6}{1000 \times 95^2 \times 25} \\
&= 0.0756 \leq 0.167 \\
&= 0.0756
\end{aligned}$$

$$\begin{aligned}
z &= d \left[ 0.5 + \sqrt{0.25 - \left( \frac{K}{1.134} \right)} \right] \leq 0.95d \\
&= d \left[ 0.5 + \sqrt{0.25 - \left( \frac{0.0756}{1.134} \right)} \right] \\
&= 0.928d \leq 0.95d \\
&= 0.928d
\end{aligned}$$

$$\begin{aligned}
A_{s,req} &= \frac{M}{0.87 f_{yk} z} \\
&= \frac{17.053 \times 10^6}{0.87 \times 500 \times 0.928 \times 95} \\
&= 444.672 \text{ mm}^2/\text{m}
\end{aligned}$$

From table 3.4.1, we choose 10mm diameter of bar at a spacing of 175mm per unit 1m width;

$$A_{s,prov} = H10- 175 \text{ at } 449 \text{ mm}^2/\text{m}$$

2) Long Span

a) At Mid-span,

$$M_{sy1} = 6.664 \text{ kNm/m}$$

$$\begin{aligned} K &= \frac{M}{bd^2 f_{ck}} \leq 0.167 (K_{bal}) \\ &= \frac{6.664 \times 10^6}{1000 \times 85^2 \times 25} \\ &= 0.0369 \leq 0.167 \\ &= 0.0369 \end{aligned}$$

$$\begin{aligned} z &= d \left[ 0.5 + \sqrt{0.25 - \left( \frac{K}{1.134} \right)} \right] \leq 0.95d \\ &= d \left[ 0.5 + \sqrt{0.25 - \left( \frac{0.0369}{1.134} \right)} \right] \\ &= 0.967d \leq 0.95d \\ &= 0.95d \end{aligned}$$

$$\begin{aligned} A_{s,req} &= \frac{M}{0.87 f_{yk} z} \\ &= \frac{6.664 \times 10^6}{0.87 \times 500 \times 0.95 \times 85} \\ &= 189.716 \text{ mm}^2/\text{m} \end{aligned}$$

b) At Support,

$$M_{sy2} = 8.821 \text{ kNm/m}$$

$$\begin{aligned} K &= \frac{M}{bd^2 f_{ck}} \leq 0.167 (K_{bal}) \\ &= \frac{8.821 \times 10^6}{1000 \times 85^2 \times 25} \\ &= 0.0488 \leq 0.167 \\ &= 0.0488 \end{aligned}$$

$$\begin{aligned}
z &= d \left[ 0.5 + \sqrt{0.25 - \left( \frac{K}{1.134} \right)} \right] \leq 0.95d \\
&= d \left[ 0.5 + \sqrt{0.25 - \left( \frac{0.0488}{1.134} \right)} \right] \\
&= 0.955d > 0.95d ; \text{therefore use } 0.95d \\
&= 0.95d
\end{aligned}$$

$$\begin{aligned}
A_{s, \text{req}} &= \frac{M}{0.87 f_{yk} z} \\
&= \frac{8.821 \times 10^6}{0.87 \times 500 \times 0.95 \times 85} \\
&= 251.123 \text{ mm}^2/\text{m}
\end{aligned}$$

#### 4.4.6 Design Shear Forces

Shear Forces in kN/m where the highest V is chosen as the Design Shear Force,  $V_{ed}$ ;

- 1) Short Span Mid Span,  $V_{sx1} = \beta_{vx1} n L_x$   
 $= 0.57 \times 12.251 \times 4 = 27.932 \text{ kN/m}$
- 2) Short Span Support,  $V_{sx2} = \beta_{vx2} n L_x$   
 $= 0.38 \times 12.251 \times 4 = 18.622 \text{ kN/m}$
- 3) Long Span Mid Span,  $V_{sy1} = \beta_{vy2} n L_x$   
 $= 0.40 \times 12.251 \times 4 = 19.602 \text{ kN/m}$
- 4) Long Span Support,  $V_{sy2} = \beta_{vy2} n L_x$   
 $= 0.26 \times 12.251 \times 4 = 12.741 \text{ kN/m}$

Shear force is at its highest at short span's support, therefore the chosen design shear force,  $V_{ed} = 27.932 \text{ kN/m}$ .

#### 4.4.7 Design Shear Resistance

The Design Shear Resistance is in kN/m and below is the calculation for it:

$$V_{Rd,c} = \left[ 0.12k^3 \sqrt{(100p_1 f_{ck})} \right] bd$$

$$\text{Where } k = 1 + \sqrt{\left(\frac{200}{d_x}\right)} \leq 2.0$$

$$= 1 + \sqrt{\left(\frac{200}{95}\right)}$$

$$= 2.4 > 2.0; \text{ hence use } 2.0$$

$$= 2.0$$

$$p_1 = \frac{A_{sl}}{bd} \leq 0.02$$

$$= \frac{449}{1000 \times 95}$$

$$= 0.00473 < 0.02; \text{ hence use } 0.00473$$

$$= 0.00473$$

$$V_{Rd,c} = \left[ 0.12k^3 \sqrt{(100p_1 f_{ck})} \right] bd$$

$$= \left[ 0.12 \times 2 \times \sqrt{(100 \times (0.00473)(25))} \right] \times (1000)(95)$$

$$= 51.944 \text{ kN/m}$$

#### 4.4.8 Minimum Shear Force

The Minimum Shear Force is in kN/m and below is the calculation for it:

$$V_{min} = \left[ 0.035 k^{\frac{3}{2}} f_{ck}^{1/2} \right] bd$$

$$= \left[ (0.035) \times (2)^{\frac{3}{2}} \times (25)^{\frac{1}{2}} \right] \times (1000)(95)$$

$$= 47.023 \text{ kN/m}$$

$V_{min} > V_{ed}$ ; hence  $V_{min}$  will be used instead

$V_{rdc} > V_{min}$ , hence Shear force design satisfactory.

#### 4.4.9 Cracking Checking

The thickness of the slab is 125 mm which is smaller than the maximum of 200 mm hence satisfying the requirements of maximum thickness of slab. Both main and secondary bar spacing satisfy cracking checking.

a) Main bar spacing

$$\begin{aligned} S_{\max, \text{slabs}} &= 3h \leq 400 \text{ mm} \\ &= 3(125) \\ &= 375 \text{ mm} \leq 400 \text{ mm} \end{aligned}$$

b) Secondary bar spacing

$$\begin{aligned} S_{\max, \text{slabs}} &= 3.5h \leq 450 \text{ mm} \\ &= 3.5(125) \\ &= 437.5 \text{ mm} \leq 450 \text{ mm} \end{aligned}$$

#### 4.5 RESULTS FOR MANUAL CALCULATIONS

This section will cover all the values manually calculated for the reinforced concrete design of two-way restrained slabs to Eurocode 2 from the given test values in Chapter 4.3. Table 4.2 consists of the values of the coefficients of short span  $\beta_{sx}$  and long span  $\beta_{sy}$  which are dimensionless, area of the slab in  $\text{m}^2$ , design action  $n$  in  $\text{kN/mm}^2$  and design bending moments  $M_{sx1}$ ,  $M_{sx2}$ ,  $M_{sy1}$  and  $M_{sy2}$  in  $\text{kNm/m}$ .

**Table 4.2:** Manual Results: Area, Design Action and Design Bending Moments

	<b>T1</b>	<b>T2</b>	<b>T3</b>	<b>T4</b>	<b>T5</b>	<b>T6</b>	<b>T7</b>	<b>T8</b>	<b>T9</b>
<b>Area</b>	28	32	25	17.6	19.2	20.8	22.4	24	28
<b>n</b>	12.25	10.82	13.013	12.25	13.01	12.251	13.60	12.25	11.501
	1	6		1	3		1	1	
<b>M<sub>sx1</sub></b>	12.74	11.60	9.434	5.488	8.328	12.741	13.05	16.46	18.953
	1	5					6	5	
<b>M<sub>sx2</sub></b>	17.05	15.41	12.687	7.252	11.24	-	17.62	-	18.953
	3	6			3		6		
<b>M<sub>sy1</sub></b>	6.664	4.850	9.109	4.704	7.079	6.664	9.575	8.624	10.304
<b>M<sub>sy2</sub></b>	8.821	6.409	12.037	6.272	-	8.820	-	11.36 8	10.304

Table 4.3 consists of values for effective depths  $d_x$  and  $d_y$  in mm, minimum area of reinforcement and maximum area of reinforcement both in  $\text{mm}^2/\text{m}$ .

**Table 4.3:** Manual Results: Effective Depths, Minimum and Maximum Area of Reinforcements

	<b>T1</b>	<b>T2</b>	<b>T3</b>	<b>T4</b>	<b>T5</b>	<b>T6</b>	<b>T7</b>	<b>T8</b>	<b>T9</b>
<b>d<sub>x</sub></b>	95	119	114	95	114	95	95	94	94
<b>d<sub>y</sub></b>	85	107	102	85	102	85	85	82	82
<b>A<sub>s,min</sub></b>	127	160.65	172.14	157.7	153.9	128.25	143.45	141.94	126.9
<b>A<sub>s,max</sub></b>	5000	6000	6000	5000	6000	5000	5000	5000	5000



Table 4.4 to 4.7 consists of the values of the coefficient  $k$  and  $z$ , and the required area of reinforcement for short-span mid-span, short-span support, long-span mid-span and long-span support respectively.

**Table 4.4:** Manual Results: Short Span Mid-span Flexural Design

	<b>T1</b>	<b>T2</b>	<b>T3</b>	<b>T4</b>	<b>T5</b>	<b>T6</b>	<b>T7</b>	<b>T8</b>	<b>T9</b>
$k$	0.0565	0.0328	0.0242	0.0243	0.0214	0.0565	0.0482	0.0621	0.0858
$z$	90.250	113.05 0	108.30 0	90.250	108.30 0	90.004	90.774	88.535	86.249
$A_{s,req}$	324.53 9	235.98 6	200.25 3	139.79 0	176.77 6	325.42 6	330.64 3	427.52 1	505.16 7

**Table 4.5:** Manual Results: Short-span Support Flexural Design

	<b>T1</b>	<b>T2</b>	<b>T3</b>	<b>T4</b>	<b>T5</b>	<b>T6</b>	<b>T7</b>	<b>T8</b>	<b>T9</b>
$k$	0.0756	0.0435	0.0325	0.0321	0.0288	-	0.0651	-	0.0858
$z$	88.179	113.05 0	108.30 0	90.250	108.30 0	90.250	89.191	89.300	86.249
$A_{s,req}$	444.67 2	313.48 1	269.30 3	184.72 3	238.65 2	-	454.30 1	-	505.16 7

**Table 4.6:** Manual Results: Long-span Mid-Span Flexural Design

	<b>T1</b>	<b>T2</b>	<b>T3</b>	<b>T4</b>	<b>T5</b>	<b>T6</b>	<b>T7</b>	<b>T8</b>	<b>T9</b>
$k$	0.0369	0.0169	0.0292	0.0260	0.0227	0.0369	0.0442	0.0428	0.0613
$z$	85.000	101.65 0	96.900	80.750	96.900	80.750	80.750	78.779	77.298
$A_{s,req}$	189.71 6	109.68 4	216.10 1	133.91 7	167.94 2	189.71 6	272.58 8	254.49 7	306.44 2

**Table 4.7:** Manual Results: Long-Span Support Flexural Design

	<b>T1</b>	<b>T2</b>	<b>T3</b>	<b>T4</b>	<b>T5</b>	<b>T6</b>	<b>T7</b>	<b>T8</b>	<b>T9</b>
$k$	0.0488	0.0224	0.0386	0.0347	0.0000	0.0488	0.0000	0.0564	0.0613
$z$	80.750	101.65 0	96.900	80.750	96.900	80.750	80.750	77.696	77.298
$A_{s,req}$	251.12 3	144.94 2	285.56 5	178.55 6	-	251.09 4	-	336.35 4	306.44 2

Table 4.8 consists of the values of  $A_{sl}$  in  $\text{mm}^2/\text{m}$  and the design shear forces in  $\text{kN/m}$ . This is the value of a chosen area of reinforcement bars with defined diameter and spacing between each bar based on the required area of reinforcement at the support at either span of which is larger in value. Table 4.9 consists of the values of the maximum shear force,  $V_{ed}$ , design shear resistance  $V_{rdc}$  and the minimum shear force,  $V_{min}$ .

**Table 4.8:** Manual Results:  $A_{sl}$  and Shear Force Design

	<b>T1</b>	<b>T2</b>	<b>T3</b>	<b>T4</b>	<b>T5</b>	<b>T6</b>	<b>T7</b>	<b>T8</b>	<b>T9</b>
$A_{sl}$	449.00	377.00	377.00	262.00	377.00	262.00	524.00	377.00	566.00
$V_{sx1}$	27.90	16.45	-	17.64	-	17.64	19.58	20.58	22.08
$V_{sx2}$	18.60	25.54	23.42	17.64	23.42	-	29.92	-	22.08
$V_{sy1}$	19.60	-	15.61	16.17	13.53	-	15.77	14.70	15.18
$V_{sy2}$	12.70	15.58	24.72	16.17	-	19.60	-	22.05	15.18

**Table 4.9:** Manual Results:  $V_{rdc}$  and  $V_{min}$ 

	<b>T1</b>	<b>T2</b>	<b>T3</b>	<b>T4</b>	<b>T5</b>	<b>T6</b>	<b>T7</b>	<b>T8</b>	<b>T9</b>
$V_{ed}$	29.92	25.54	24.72	17.64	23.42	19.60	29.92	22.05	22.08
$k$	2	2	2	2	2	2	2	2	2
$p_l$	0.005	0.003	0.003	0.002	0.003	0.002	0.055	0.004	0.006
$V_{rd,c}$	51.94	56.94	58.79	48.55	55.34	43.40	58.11	51.69	55.70
$V_{min}$	47.02	58.90	61.81	55.63	56.42	47.02	51.51	50.96	46.52

Table 4.10 consists of the values for maximum bar spacing for both main and secondary reinforcements bars  $S_{max,slabs}$  needed for deflection checking.

**Table 4.10:** Manual Results: Maximum Bar Spacing

	<b>T1</b>	<b>T2</b>	<b>T3</b>	<b>T4</b>	<b>T5</b>	<b>T6</b>	<b>T7</b>	<b>T8</b>	<b>T9</b>
<b>Main Bar Spacing</b>	375	400	400	375	400	375	375	375	375
<b>Secondary Bar Spacing</b>	437.5	450	450	437.5	450	437.5	437.5	437.5	437.5

#### 4.6 RESULTS FOR PROGRAM

Table 4.11 consists of the values of the coefficients of short span  $\beta_{sx}$  and long span  $\beta_{sy}$  which are dimensionless, area of the slab in  $m^2$ , design action,  $n$  in  $kN/mm^2$  and design bending moments  $M_{sx1}$ ,  $M_{sx2}$ ,  $M_{sy1}$  and  $M_{sy2}$  in  $kNm/m$ .

**Table 4.11:** Program Results: Area, Design Action and Design Bending Moments

	<b>T1</b>	<b>T2</b>	<b>T3</b>	<b>T4</b>	<b>T5</b>	<b>T6</b>	<b>T7</b>	<b>T8</b>	<b>T9</b>
<b>Area</b>	28	32	25	17.6	19.2	20.8	22.4	24	28
<b><math>n_{ed}</math></b>	12.250 500	10.825 500	13.012 500	12.250 500	13.012 500	12.250 500	13.600 500	12.250 500	11.500 500
<b><math>M_{sx1}</math></b>	12.740 520	11.604 936	9.4340 63	5.4882 24	8.2380 00	12.740 520	13.056 480	16.464 672	18.952 824
<b><math>M_{sx2}</math></b>	17.052 696	15.415 512	12.687 188	7.2522 96	11.242 800	-	17.626 248	-	18.952 824
<b><math>M_{sy1}</math></b>	6.6642 72	4.8498 24	9.1087 50	4.7041 92	7.0788 00	6.6642 72	9.5747 52	8.6243 52	10.304 448
<b><math>M_{sy2}</math></b>	8.8203 60	6.4086 96	12.036 563	6.2722 56	-	8.8203 60	-	11.368 464	10.304 448

Table 4.12 consists of values for effective depths  $d_x$  and  $d_y$  in mm, minimum area of reinforcement and maximum area of reinforcement both in  $\text{mm}^2/\text{m}$ .

**Table 4.12:** Program Results: Effective Depths, Minimum and Maximum Area of Reinforcements

	<b>T1</b>	<b>T2</b>	<b>T3</b>	<b>T4</b>	<b>T5</b>	<b>T6</b>	<b>T7</b>	<b>T8</b>	<b>T9</b>
$d_x$	95	119	114	95	114	95	95	94	94
$d_y$	85	107	102	85	102	85	85	82	82
$A_{s,min}$	128.44 0000	160.88 8000	171.91 200	158.08 0000	154.12 8000	128.44 0000	143.26 0000	141.75 2000	127.08 8000
$A_{s,max}$	5000	6000	6000	5000	6000	5000	5000	5000	5000

Table 4.13 to 4.16 consists of the values of the coefficient  $k$  and  $z$ , and the required area of reinforcement for short-span mid-span, short-span support, long-span mid-span and long-span support respectively.

**Table 4.13:** Program Results: Short-Span Mid-Span Flexural Design

	<b>T1</b>	<b>T2</b>	<b>T3</b>	<b>T4</b>	<b>T5</b>	<b>T6</b>	<b>T7</b>	<b>T8</b>	<b>T9</b>
$k$	0.0564 68	0.0327 80	0.0241 97	0.0173 75	0.0256 33	0.0564 67	0.0482 24	0.0621 12	0.0857 98
$z$	90.250 000	113.05 0000	108.30 0000	90.250 000	108.30 0000	90.007 046	90.250 000	88.533 476	86.248 802
$A_{s,req}$	324.52 6889	235.98 4200	200.25 3924	139.79 6198	176.77 5878	325.40 2878	332.57 5031	427.51 9876	505.16 2960

**Table 4.14:** Program Results: Short-Span Support Flexural Design

	<b>T1</b>	<b>T2</b>	<b>T3</b>	<b>T4</b>	<b>T5</b>	<b>T6</b>	<b>T7</b>	<b>T8</b>	<b>T9</b>
$k$	0.075 569	0.043 543	0.032 541	0.022 959	0.034 604	-	0.065 102	-	0.085 798
$z$	88.17 8544	113.0 50000	108.3 00000	90.25 0000	108.3 00000	90.25 0000	89.19 0955	89.30 0000	86.24 8802
$A_{s,req}$	444.5 70732	313.0 50000	269.3 07002	184.7 30691	238.6 47435	-	454.3 07395	-	505.1 62960

**Table 4.15:** Program Results: Long-Span Mid-Span Flexural Design

	<b>T1</b>	<b>T2</b>	<b>T3</b>	<b>T4</b>	<b>T5</b>	<b>T6</b>	<b>T7</b>	<b>T8</b>	<b>T9</b>
$k$	0.036 896	0.016 944	0.029 183	0.018 603	0.027 216	0.036 896	0.044 174	0.042 754	0.061 300
$z$	80.75 0000	101.6 50000	96.90 0000	80.75 0000	96.90 0000	80.75 0000	81.54 8754	78.78 2161	77.29 7760
$A_{s,req}$	189.7 23412	109.6 84500	216.0 95513	133.9 22408	167.9 42000	189.7 23120	269.9 11225	251.6 57180	306.4 56073

**Table 4.16:** Program Results: Long-Span Support Flexural Design

	<b>T1</b>	<b>T2</b>	<b>T3</b>	<b>T4</b>	<b>T5</b>	<b>T6</b>	<b>T7</b>	<b>T8</b>	<b>T9</b>
<b><i>k</i></b>	0.0488 32	0.0223 9	0.0385 64	0.0248 04	0	0.04	0	0.0563 58	0.0613
<b><i>z</i></b>	80.75	101.65	96.9	80.75	102	80.75	85	77.699 18	77.297 76
<b><i>A<sub>s,req</sub></i></b>	251.10 45	144.94 18	285.54 48	178.56 31	0	251.10 45	0	336.35 36	306.45 61

Table 4.17 consists of the values of  $A_{sl}$  in  $\text{mm}^2/\text{m}$  and the design shear forces in  $\text{kN/m}$ . This is the value of a chosen area of reinforcement bars with defined diameter and spacing between each bar based on the required area of reinforcement at the support at either span of which is larger in value. Table 4.18 consists of the values of the maximum shear force  $V_{ed}$ , design shear resistance  $V_{rdc}$  and the minimum shear force  $V_{min}$ .

**Table 4.17:** Program Results:  $A_{sl}$  and Shear Force Design

	<b>T1</b>	<b>T2</b>	<b>T3</b>	<b>T4</b>	<b>T5</b>	<b>T6</b>	<b>T7</b>	<b>T8</b>	<b>T9</b>
<b><i>A<sub>sl</sub></i></b>	449	377	377	201	251	262	524	377	566
<b><i>V<sub>sx1</sub></i></b>	27.93 114	16.45 476	-	17.64 072	-	17.64 072	19.58 472	20.58 084	22.08 096
<b><i>V<sub>sx2</sub></i></b>	18.62 076	25.54 818	23.42 25	17.64 072	23.42 25	-	29.92 11	-	22.08 096
<b><i>V<sub>sy1</sub></i></b>	19.60 08	-	15.61 5	16.17 066	13.53 3	-	15.77 658	14.70 06	15.18 066
<b><i>V<sub>sy2</sub></i></b>	12.74 05	15.58 872	23.42 25	16.17 066	-	19.60 08	-	22.05 09	15.18 066

**Table 4.18:** Program Results:  $V_{rdc}$  and  $V_{min}$ 

	<b>T1</b>	<b>T2</b>	<b>T3</b>	<b>T4</b>	<b>T5</b>	<b>T6</b>	<b>T7</b>	<b>T8</b>	<b>T9</b>
$V_{ed}$	27.931 14	25.548 18	23.422 5	17.640 72	23.422 5	19.600 8	29.921 1	22.050 9	22.080 96
$k$	2	2	2	2	2	2	2	2	2
$pI$	0.0055 16	0.0031 7	0.0033 07	0.0027 58	0.0033 07	0.0027 58	0.0055 16	0.0040 11	0.0060 2
$V_{rd,c}$	51.930 49	56.929 36	58.789 8	48.545 62	55.323 32	43.406 14	58.100 23	51.695 25	55.703 43
$V_{min}$	47.022 6	58.901 995	61.812 814	55.637 892	56.427 121	47.022 601	51.510 678	50.968 461	46.527 626

Table 4.19 consists of the values for maximum bar spacing for both main and secondary reinforcements bars  $S_{max,slabs}$  needed for deflection checking

**Table 4.19:** Program Results: Maximum bar spacing

	<b>T1</b>	<b>T2</b>	<b>T3</b>	<b>T4</b>	<b>T5</b>	<b>T6</b>	<b>T7</b>	<b>T8</b>	<b>T9</b>
<b>Main Bar Spacing</b>	375	400	400	375	400	375	375	375	375
<b>Secondary Bar Spacing</b>	437.5	450	450	437.5	450	437.5	437.5	437.5	437.5

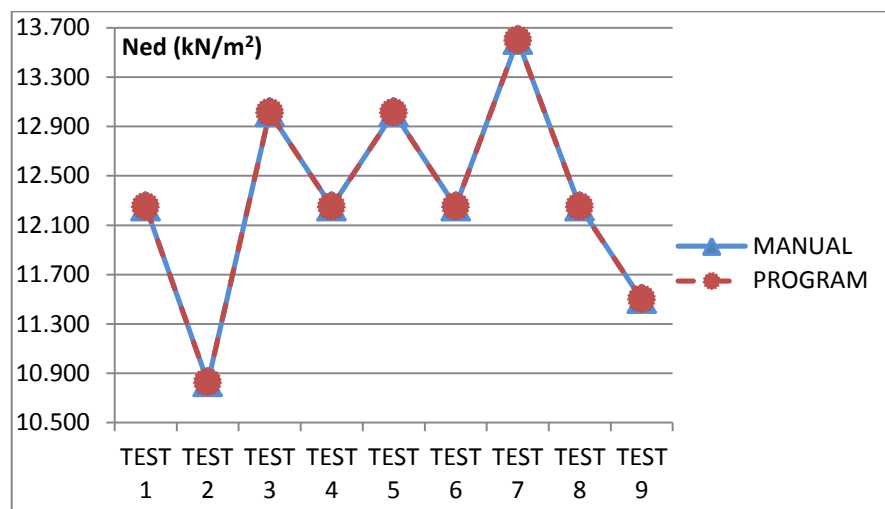


## 4.7 DATA ANALYSIS

### 4.7.1 Introduction

This section cover the comparison between the results achieved by the program and by manual calculation. Only certain values are compared to each other between manual calculations and program calculations and these values cover the primary or the end calculations of the reinforced concrete design segments for two-way restrained solid slabs. Most of the coefficients or mid-equation values are not shown but is available for checking as in Chapter 4.5 for manual calculation results and Chapter 4.6 for program results. These primary values are Design Action, Design Bending Moments, Required Area of Reinforcements, Design Shear Forces, Design Shear Resistance and Minimum Shear Force.

### 4.7.2 Design Action

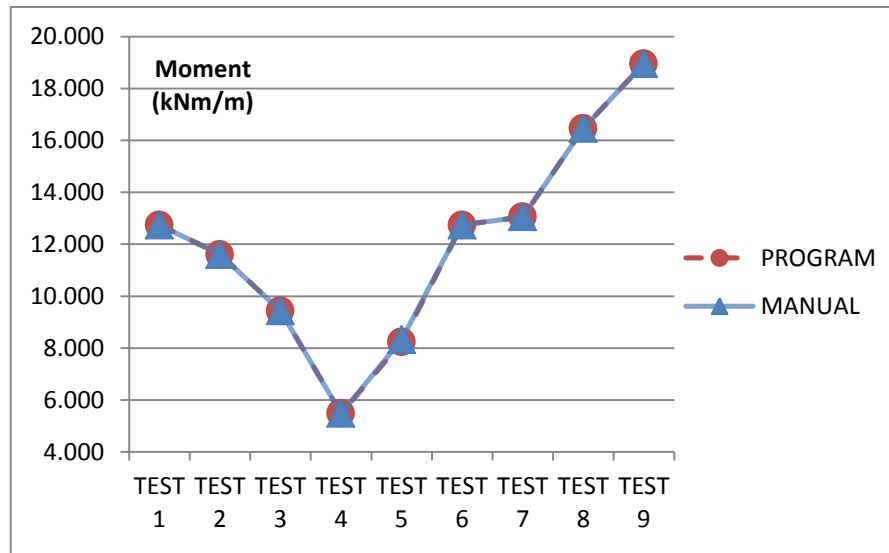


**Figure 4.10:** Design Action, n Graph

From Figure 4.10, all the values of the design action, n has a variation of 0.0005 kN/m<sup>2</sup> between the manual and program calculations across all 9 tests. The largest values are at 13.012500 kN/m<sup>2</sup> and 13.013 kN/m<sup>2</sup> in test 8 for program and manual

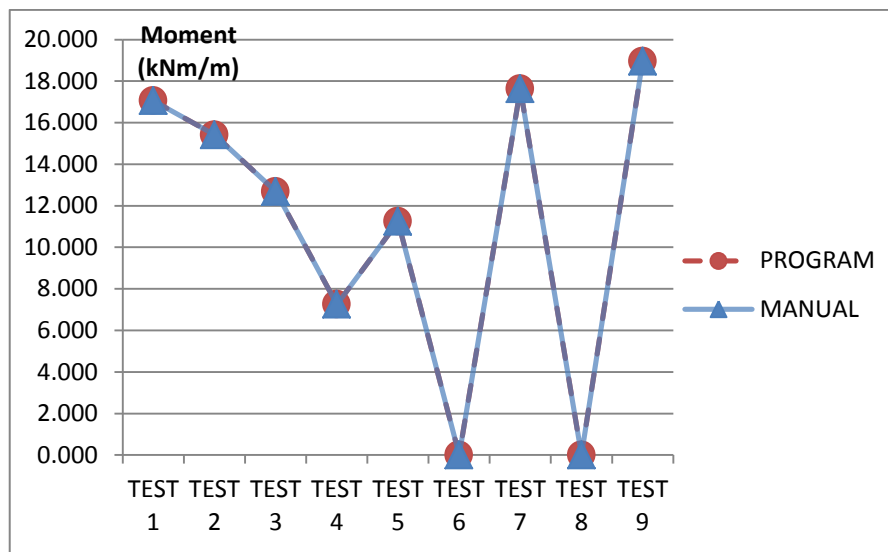
results respectively. The smallest values are at 10.825500 kN/m<sup>2</sup> and 10.826 kN/m<sup>2</sup> in Test 2 for program and manual results respectively.

#### 4.7.3 Design Moments



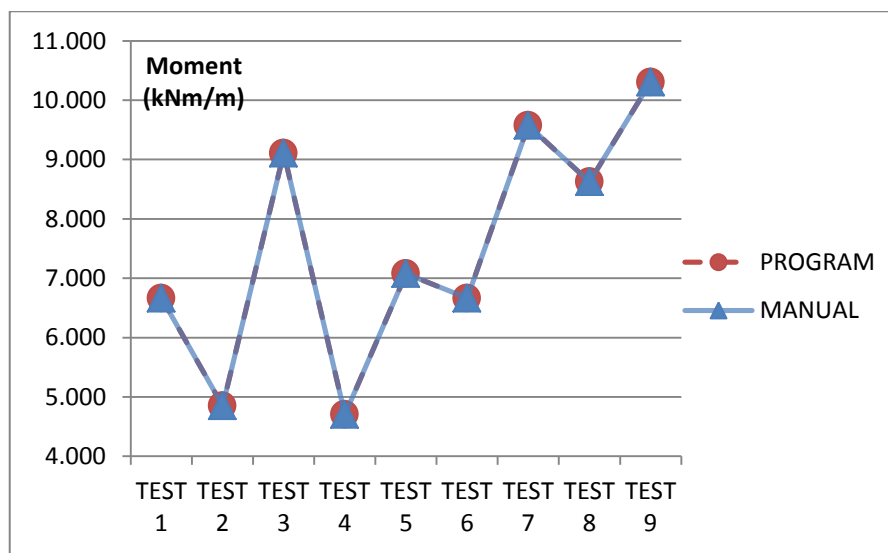
**Figure 4.11:** Bending Moment Design,  $M_{sx1}$  Graph

From Figure 4.7.2, the highest value difference of bending moment is 0.00048 kNm/m in test 1 and test 6. The highest values in the graph are at 18.952824 kNm/m for program and 18.953 kN/m for manual in test 9 whereas the smallest value is at 5.488224 kNm/m for program and 5.488 kNm/m for manual in test 4.



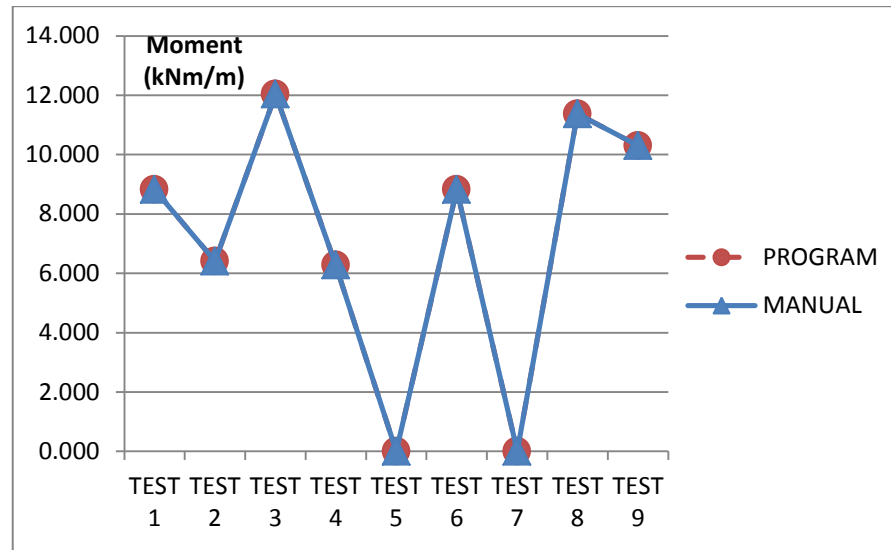
**Figure 4.12:** Bending Moment Design,  $M_{sx2}$  Graph

From Figure 4.12, the highest value difference of bending moment is 0.000488 kNm/m in test 2. The highest values in the graph are at 18.952824 kNm/m for program and 18.953 kNm/m for manual in test 9 whereas the smallest value is at zero for both program and manual is in test 6 and test 8.



**Figure 4.13:** Bending Moment Design,  $M_{sy1}$  Graph

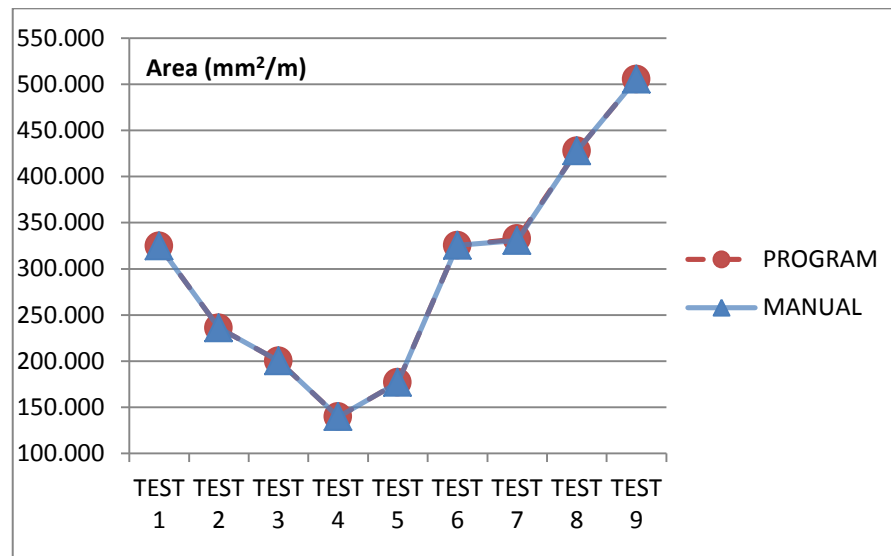
From Figure 4.14, the highest value difference of bending moment is at 0.000448 kNm/m in test 9. The highest values in the graph are at 10.304448 kNm/m for program and 10.304 kNm/m for manual in test 9 whereas the smallest values are at 4.704192 kNm/m for program and 4.704 kNm/m for manual in test 4.



**Figure 4.14:** Bending Moment Design,  $M_{sy2}$  Graph

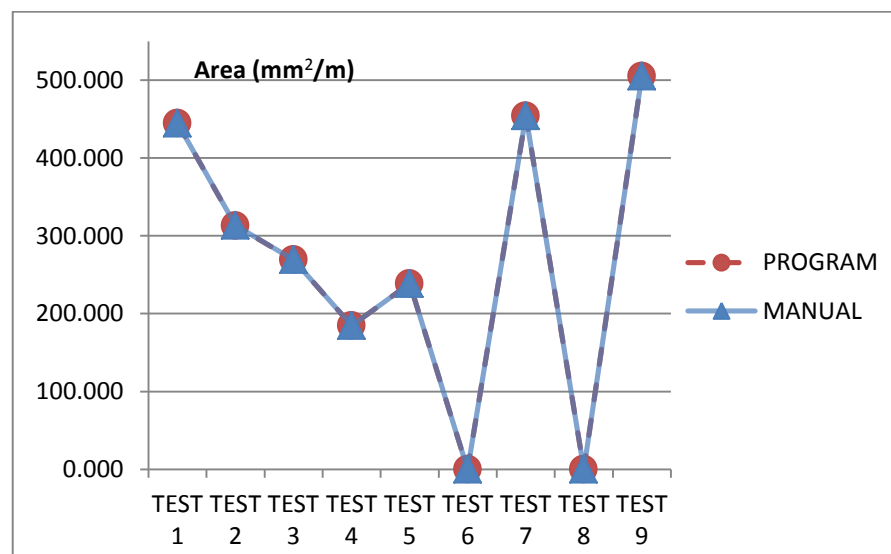
From Figure 4.14, the highest value difference of bending moment is at 0.000437 kNm/m in test 3. The highest values in the graph are at 12.0336563 kNm/m for program and 12.034 kNm/m for manual in test 3 whereas the smallest values are at zero for both program and manual in test 5 and test 7.

#### 4.7.4 Area of Reinforcements



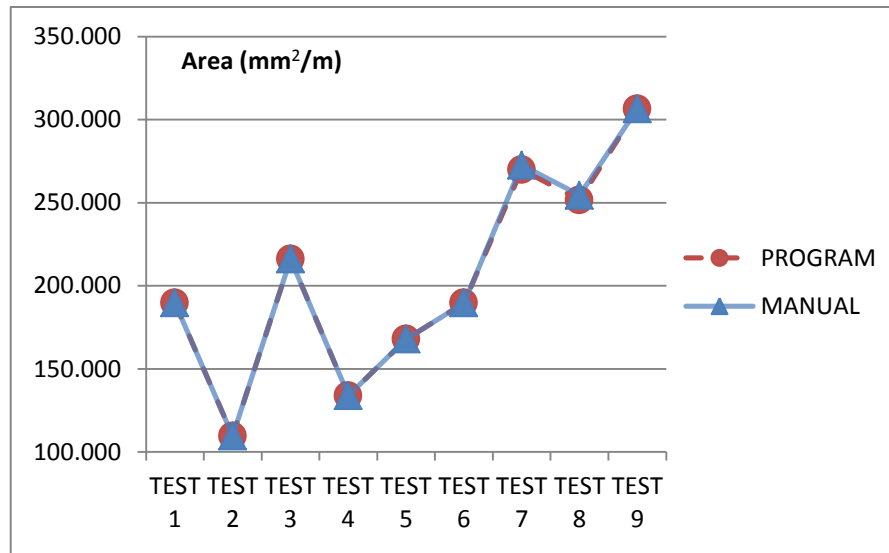
**Figure 4.15:** Required Area of Reinforcement for short-span mid-span Graph

From Figure 4.15, the highest value difference of area of reinforcement is at 1.9320231 mm<sup>2</sup>/m in test 7. The highest values in the graph are at 505.162960 mm<sup>2</sup>/m for program and 505.167 mm<sup>2</sup>/m for manual in test 9 whereas the smallest values are at 139.796198 mm<sup>2</sup>/m for program and 139.790 mm<sup>2</sup>/m for manual in test 4.



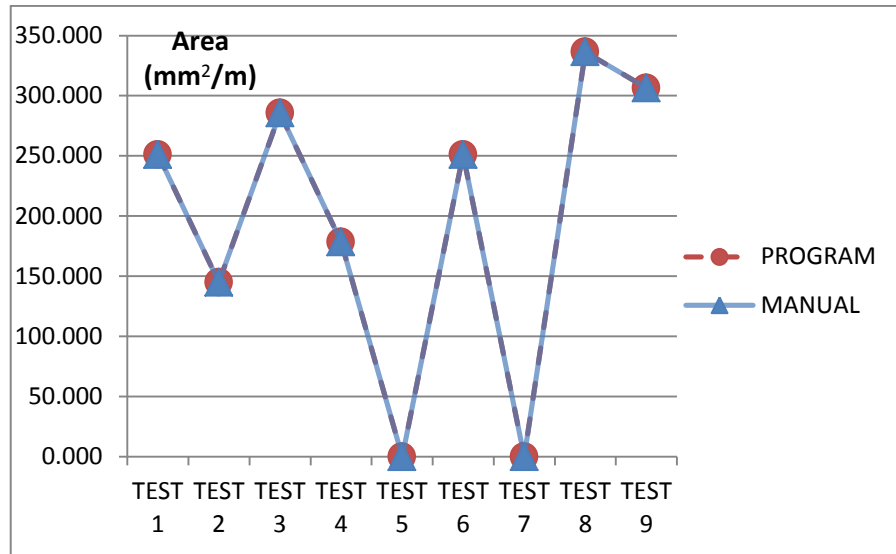
**Figure 4.16:** Required Area of Reinforcement for short-span support Graph

From Figure 4.16, the highest value difference of area of reinforcement is at 0.431 mm<sup>2</sup>/m inn test 2. The highest values in the graph are at 505.162960 mm<sup>2</sup>/m for program and 505.167 mm<sup>2</sup>/m for manual in test 9 whereas the smallest values are at zero for both program and manual in test 6 and test 8.



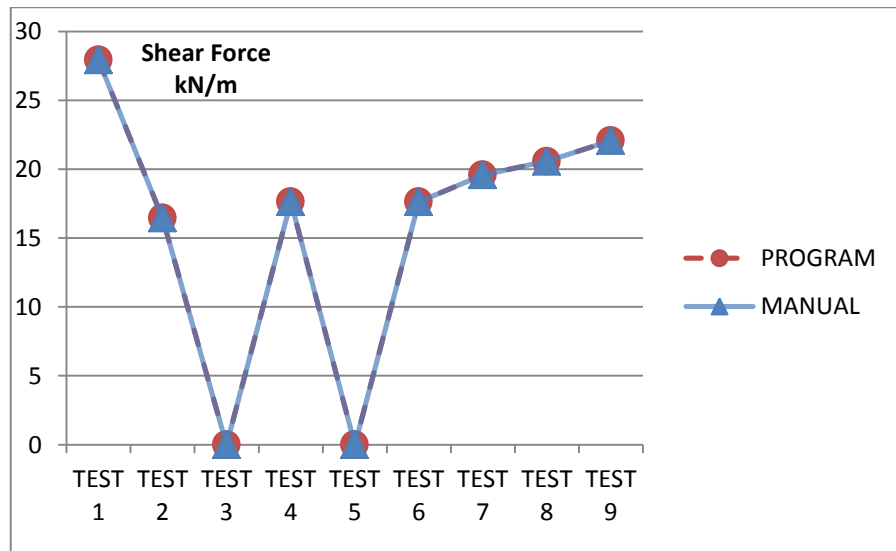
**Figure 4.17:** Required Area of Reinforcement for long-span mid-span Graph

From Figure 4.17, the highest value difference for area of reinforcement is at 2.83982 mm<sup>2</sup>/m in test 8. The highest values in the graph are at 306.456073 mm<sup>2</sup>/m for program and 306.442 mm<sup>2</sup>/m for manual in test 9 whereas the smallest values are at 109.6845 mm<sup>2</sup>/m for program and 109.684 mm<sup>2</sup>/m for manual in test 2.



**Figure 4.18:** Required Area of Reinforcement for long-span support Graph

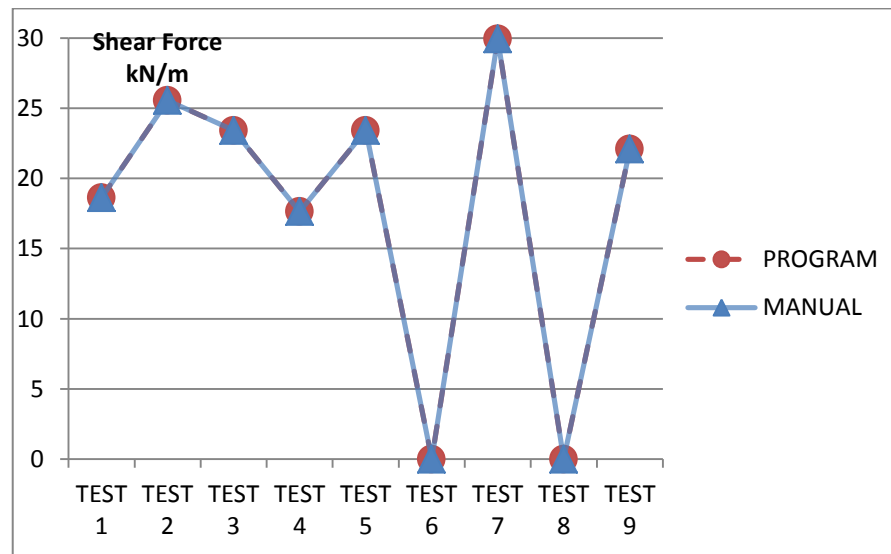
From Figure 4.18, the highest value difference for area of reinforcement is at 0.01848 mm<sup>2</sup>/m in test 1. The highest values in the graph are at 336.3536 mm<sup>2</sup>/m for program and 336.354 mm<sup>2</sup>/m for manual in test 8 whereas the smallest values are at zero for both program and manual in test 5 and test 7.



**Figure 4.19:** Shear Force Design,  $V_{sx1}$  Graph

From Figure 4.19, the highest value difference for shear force is at 0.00028 kN/m in test 4 and test 6. The highest values in the graph are at 27.93114 kN/m for program and 27.932 kN/m for manual in test whereas the smallest values are at zero for both program and manual at test 3 and test 5.

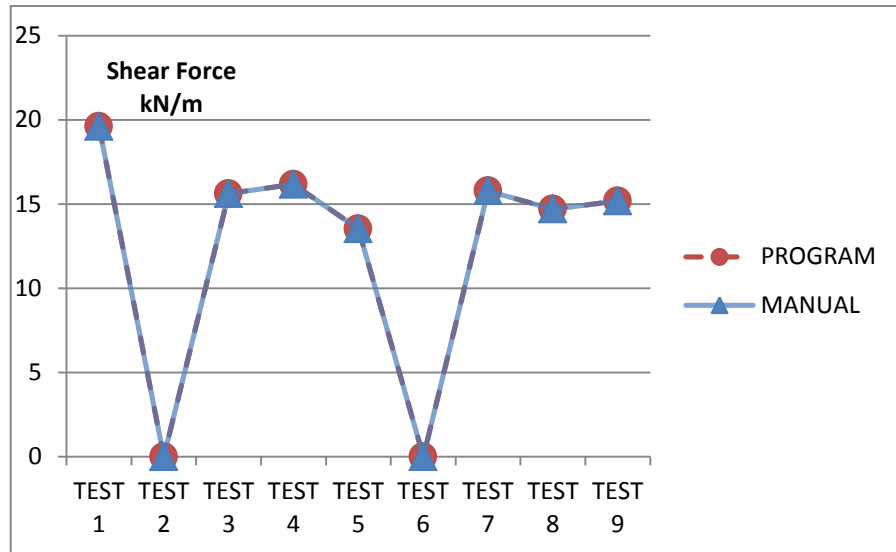
#### 4.7.5 Shear Force Design



**Figure 4.7.20:** Shear Force Design,  $V_{sx2}$  Graph

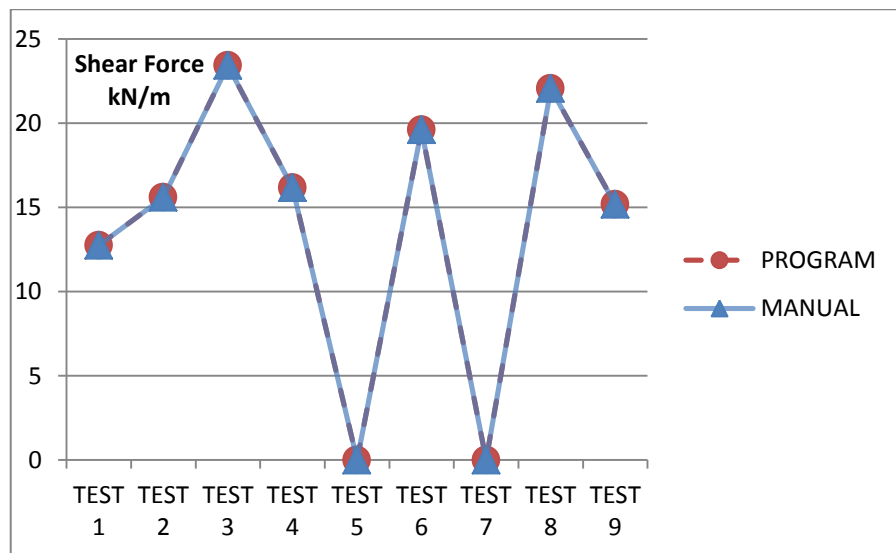
From Figure 4.20, the highest value difference for shear force is at 0.00082 kN/m in test 2. The highest values in the graph are at 29.9211 kN/m for program and 29.921 kN/m for manual in test 7 whereas the smallest values are at zero for both program and manual in test 6 and test 7.





**Graph 4.21:** Shear Force Design,  $V_{sy1}$  Graph

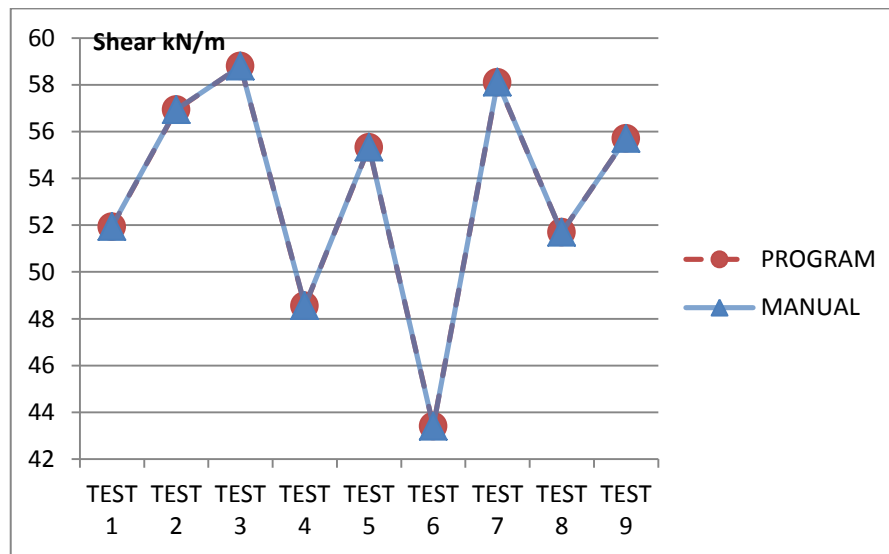
From Figure 4.21, the highest value difference for shear force is at 0.0012 kN/m in test 1. The highest values in the graph are at 19.6008 kN/m for program and 19.602 kN/m for manual in test 1 whereas the smallest values are at zero for both program and manual in test 2 and test 6.



**Figure 4.22:** Shear Force Design,  $V_{sy2}$  Graph

From Figure 4.22, the highest value difference of shear force is at 0.0005 kN/m in test 1 and test 3. The highest values in the graph are at 23.4225 kN/m for program and 23.423 kN/m for manual in test 3 whereas the smallest values are at zero for both manual and program in test 5 and test 7.

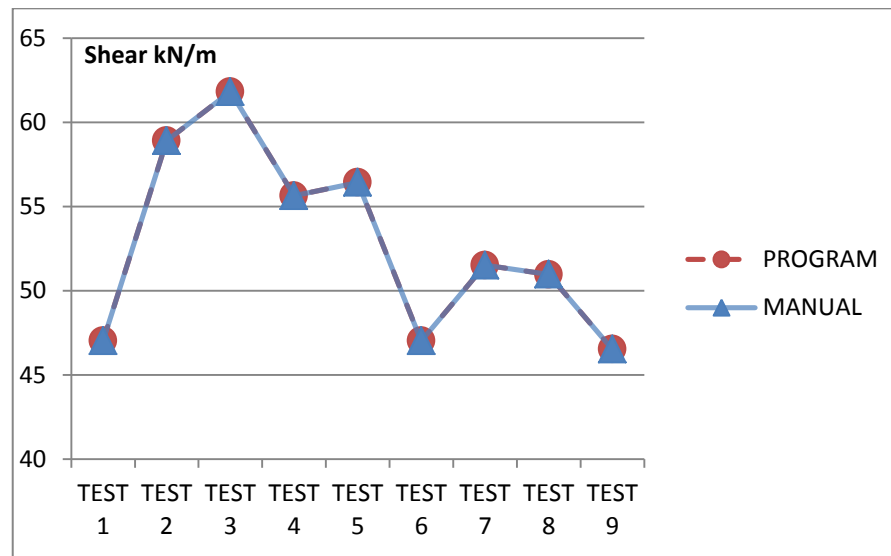
#### 4.7.6 Design Shear Resistance



**Figure 4.23:** Design Shear Resistance,  $V_{rd,c}$  Graph

From Figure 4.23, the highest value difference of shear force is at 0.01351 kN/m in test 1. The highest values in the graph are at 58.789803 kN/m for program and 58.780 kN/m for manual in test 3 whereas the smallest values are at 43.406144 kN/m for program and 43.406 kN/m for manual in test 6.

#### 4.7.7 Minimum Shear Force



**Figure 4.24:** Minimum Shear Force,  $V_{\min}$  Graph

From Figure 4.24, the highest value difference for shear force is at 0.0004 kN/m in test 1. The highest values in the graph are at 61.812814 kN/m for program and 61.813 for manual in test 3 whereas the smallest values are at 46.527626 kN/m for program and 46.528 kN/m for manual in test 9.

## 4.8 DISCUSSIONS

### 4.8.1 Program Accuracy

In this research, all results obtained through the program have very low deviation of values in comparison to the manual calculation. The cause of this small deviation lies in the manual calculations; where in this research the values are taken up to 3 effective decimal points while the program would take up all decimal values for calculations just like a calculator. The results from the program only show the values to 6 effective decimal points. The reason why this research does not consider more than 3 decimal points is to simplify manual calculations and save time.

The program results would have the better accuracy in the calculations as compared to manual calculations due to the fact it will store as many decimal values it can when given a large value with many decimal points and use them for succeeding calculations. The difference in values would be miniscule or non-existent if all decimal points are considered for manual calculations as the program already considers that.

#### **4.8.2 Deflection Checking**

In this research, the program does not cover deflection checking as in reinforced concrete design to Eurocode 2. The main reason for the absence of deflection checking in this research is due to the instability of the program file upon reaching a high number of coding in the file itself. The number of codes inside the program file is 1234 line of codes. The program file becomes less stable as more codes are inserted. This opens up risk of the coding program, Microsoft Small Basic, of crashing. Upon crashing, the coding program will prompt an error message and auto-closes in which will not save the progress during the coding of the program file. Upon reaching the deflection checking part of coding, the file would become so unstable that it may crash within a few seconds upon opening of the file. In order to preserve the stability of the program file, the coding of deflection checking is ultimately dropped.

#### **4.8.3 Detailing**

Much like deflection checking, the coding for the detailing part of reinforced concrete of the slab is ultimately dropped to preserve the stability of the program file. However this does not mean Microsoft Small Basic is incapable of carrying detailing. Microsoft Small Basic is capable of drawing images when coded properly. With the right commands in the coding, it can draw the detailing of reinforcements of the slab albeit in a simplified 2D form rather than a 3D model of the actual detailed reinforcement.

## **CHAPTER 5**

### **CONCLUSION AND RECOMMENDATIONS**

#### **5.1 INTRODUCTION**

The objectives of this research is to successfully program and code using Microsoft Small Basic in order to calculate and analyze two-way restrained slabs for reinforced concrete design for all 9 cases of slab position in accordance to EC 2. Through the program, it should be able to provide an easy interface for users to use and input values to the program which will carry out the calculations in a short amount of time. The program should also be able to successfully carry out calculations for the analysis of reinforced concrete design for two-way restrained slabs

#### **5.2 CONCLUSIONS**

Based on the results from Chapter 4, this research has been successfully conducted. A free alternative program was coded which can be used by any Windows Operating System that has the proper .net Framework version installed. It can carry out reinforced concrete design for two-way restrained solid slabs to Eurocode 2 in terms of design action analysis, bending moment and shear force analysis, reinforcement design and crack checking, all with great precision and in a short time. Despite the flaws of the coding program Microsoft Small Basic, it still able to deliver the functions of the program smoothly for up to 1000 lines of codes. However, only deflection checking and detailing that are ultimately aborted to preserve the program's structural integrity. However, Microsoft Small Basic is still capable of coding for both

### **5.3 RECOMMENDATIONS FOR FUTURE RESEARCH**

For this research, some recommendations have been identified in order to further progress this research and in order to improve what this research have done. The following fields are suggested to expand the present work by:

- 1) A better programming language that is non-linear in which it can carry out complex coding for a better structural integrity unlike Microsoft Small basis is unable to do such as javascript
- 2) A better programming software such as Microsoft Visual Basic or MathLab that allows object oriented approach in the design of the program that allows much better interactivity between the users and the program. These software should also be able to hold a program of more than 1000 lines of coding without crashing.

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# APPENDIX A

Strength classes for concrete														
$F_{ck}$ (MPa)	12	16	20	25	30	35	40	45	50	55	60	70	80	90
$F_{ck,cube}$ (MPa)	15	20	25	30	37	45	50	55	60	67	75	85	95	105
$F_{cm}$ (MPa)	20	24	28	33	38	43	48	53	58	63	68	78	88	98
$F_{ctm}$ (MPa)	1.6	1.9	2.2	2.6	2.9	3.2	3.5	3.8	4.1	4.2	4.4	4.6	4.8	5
$F_{ctk,0.05}$ (MPa)	1.1	1.3	1.5	1.8	2	2.2	2.5	2.7	2.9	3	3.1	3.2	3.4	3.5
$F_{ctk,0.95}$ (MPa)	2	2.5	2.9	3.3	3.8	4.2	4.6	4.9	5.3	5.5	5.7	6	6.3	6.6
$E_{cm}$ (MPa)	27	29	30	31	33	34	35	36	37	38	39	41	42	44
$\epsilon_{c1}$ (%)	1.8	1.9	2	2.1	2.2	2.25	2.3	2.4	2.45	2.5	2.6	2.7	2.8	2.8
$\epsilon_{cu1}$ (%)	3.5													
$\epsilon_{c2}$ (%)	2													
$\epsilon_{cu2}$ (%)	3.5													
$n$	2													
$\epsilon_{c3}$ (%)	1.75													
$\epsilon_{cu3}$ (%)	3.5													