# INVESTIGATION OF DEFLECTION AND CRACKS IN REINFORCED CONCRETE SOLID SLABS AS A FUNCTION OF CONCRETE THICKNESS USING STAAD PRO AND TEKLA TEDDS


**BY**

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# CERTIFICATION

This is to certify that the research project on "INVESTIGATION OF DEFLECTION AND CRACKS IN REINFORCED CONCRETE SOLID SLABS AS A FUNCTION OF CONCRETE THICKNESS USING STAAD PRO AND TEKLA TEDDS" was carried out by Ezeh Anne Ihechi with registration number (NAU/2017224043) of the department of civil engineering in partial fulfilment of the requirement for the award of bachelor's degree in civil engineering, Nnamdi Azikiwe University, Awka under the close supervision of Engr. Dr. Odinaka Okonkwo of the Department of Civil Engineering, Nnamdi Azikiwe University, Awka. This work has never been submitted either in part or in full for any degree in any university.

______________________ ______________________

Ezeh Anne Ihechi Date
(Student)

# APPROVAL PAGE

This research thesis on "Investigation of Deflection and Cracks in Reinforced Concrete Solid Slabs as a function of concrete thickness using STAAD Pro and Tekla Tedds" was carried out by Ezeh Anne Ihechi with registration number (NAU/2017224043) has satisfied all the requirements of this university for the award of Bachelor's degree (B.Eng.) in Civil Engineering, Nnamdi Azikiwe University, Awka.

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# DEDICATION

To my dad, who called almost every day and convinced me that I could do it every time I wanted to give up and to my mum for your sacrifices through the years. You will always be my inspiration.

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# ABSTRACT

Since the late 19th century, reinforced concrete has been used in construction. The invention of this viable composite material brought about a revolution in structural and civil engineering at large. Massive structures that were previously deemed unsafe were built. However, despite its many advantages, reinforced concrete does have its weaknesses. The most important and of more consequence of these are deflection and cracking. This research aims to study the behaviour of solid slabs as related to cracking and deflection under varying design considerations. It was done by using STAAD Pro and Tekla Tedds; two engineering software, to carry out rigorous design calculations and generate models of the test slab. The varying parameters in this study are slab thickness, concrete grade, reinforcement size and reinforcement spacing. In the end, it was discovered that concrete grade had the least effect on deflection and cracking characteristics of solid slabs irrespective of slab thickness. The optimum conditions for each design parameter were also determined.

# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# LIST OF PLATES

# CHAPTER ONE

# INTRODUCTION

## 1.0 BACKGROUND OF THE STUDY

Concrete is a composite material consisting of hard particles known as aggregate (sand and gravel), water, and a binder material such as cement. This combination forms a mix that hardens into a durable material used for various construction works. This process of hardening is known as setting of concrete (Hooton, 2001). It is sometimes mixed with substances known as admixtures to modify the properties of concrete. Steel is often embedded into the combination producing a material that works together to resist forces. The result is known as reinforced concrete.

Whilst concrete has been used in construction dating back to Roman times, the use of reinforcements in concrete was first introduced in the 19th century by French industrialist Francois Coignet who used iron for reinforcement. In the 1880s, German civil engineer G.A Wayss used steel as reinforcement and the practice has continued to this day.

A widely known phrase among civil engineers is that "Concrete is high in compression and weak in tension." The addition of steel in concrete before it sets seeks to eliminate the problems that may come up because of the weakness of concrete in its tension zone. Non-reinforced concrete members are assumed to carry only small gravity loads or perform a noncritical, non-life-threatening or load-carrying function (Naaman, 2001). With reinforced concrete, complex structures capable of carrying heavy loads can be built.

Despite its versatility, concrete is susceptible to deformations such as deflections and cracks which are the focus of this study. According to the American Concrete Institute (ACI), deflection is the movement of a point on a structure or structural element, usually measured as a linear displacement or as successive displacements transverse to a reference line or axis.

The primary material parameters that influence concrete deflections are temperature, modulus of elasticity, shrinkage, modulus of rupture, and creep.

In structural design, deflection checks are carried out to ensure that concrete members like slabs and beams comply with the criteria stated in reinforced concrete design codes such as BS 8110, EC 2, and IS 456. These codes contain guidelines that must be followed to ensure that the deflection does not go beyond what is allowable for the specifics of that structure.

Cracks in concrete are unavoidable. However, it can be controlled just as deflection can be controlled and different design codes state their acceptable crack widths which will be discussed later in the study. It is important to note that excessive deflection leads to cracking. Hence, it is necessary to analyse the factors which may give rise to these situations and prevent failure in the future.

**1.1 STATEMENT OF THE PROBLEM**

Concrete is the most widely used material in the construction industry. Its ability to carry loads, especially when reinforced with steel cannot be understated. However, some problems arise in concrete as time goes on. These problems are analysed under the serviceability limit state method during design. This method ensures that the concrete displays satisfactory behaviour after service or working loads. The most notable of these checks are checks for deflection and cracking.

The effects of excessive deflection and cracking on concrete members are loss of aesthetic appeal, impaired functionality, and eventually failure which may or may not lead to the complete rupture of the member.

With the advent of technology and its integration into the civil engineering sector, models can be made to analyse structures and ensure that they can withstand different conditions. Computer simulation modelling helps engineers to understand and evaluate 'what-if' scenarios. This has helped to save the time, money and effort physical experimentations require. Various parameters can be easily imputed into software and results will be obtained for that scenario. Taking a cue from this, this study seeks to use **STAADPro**, a design software to obtain important values which will aid in making conclusions on the behaviour of concrete slabs under certain variable conditions which will be discussed later. This software utilises the '**Finite Element Analysis**' in the design of models. Finite element analysis is the process of using mathematical calculations, models and simulations to analyse, understand and predict the behaviour of an object, part, assembly, or structure under physical conditions. It is a numerical technique that cuts a structure into several pieces, elements or plates and reconnects them to form nodes. Engineers use this method to discover vulnerabilities in their design prototypes and many design software are equipped with this mode of analysis. The second software, **Tekla Tedds,** is primarily a calculation software used to quickly analyse structural elements and produce results. The two software will be combined to give the necessary values needed for this study.

Although cracking in concrete hasn't always been associated with thickness, it is important to note that deflection and cracking are two phenomena that go together. So, it would not be a complete fallacy to state that concrete thickness does also play a small role in cracking as well. This study seeks to test with the aid of a design and modelling software, STAAD Pro and Tekla Tedds, the role of concrete thickness along with other design parameters on deflections and cracks in concrete solid slabs.

## 1.2 AIMS AND OBJECTIVES

**Aim**: To investigate the effects of concrete thickness on deflection and cracking in reinforced concrete slabs using STAAD Pro and Tekla Tedds.

**Research Objectives**

i. To determine the effects of slab thickness on deflection and cracking

ii. To test the behaviour of the modelled slabs under different concrete grades and reinforcement spacing in relation to deflection and cracking.
iii. To model solid slabs using STAAD Pro and carry out the design and analysis on Tekla Tedds
iv. To present and analyse in graphical forms the results obtained to enable the determination of best conditions for each design parameter.

## 1.3 SIGNIFICANCE OF THE STUDY

Deflection and crack control are of utmost importance to structural design. As deflection is a defect that develops gradually over a period, real-time observation is nearly impossible. As a result of this, theoretical formulas and ideas have been developed to tackle deflection.

In today's technological world, design software has made it possible to carry out virtual experiments and observations using models. This study will test the effects of concrete thickness in conjunction with other factors on deflection and cracking characteristics of a slab. In this way, a conclusion as to the optimum conditions to minimise deflection and cracking in concrete slabs can be made.

## 1.4 SCOPE OF WORK

The following areas, tools and experiments will be studied and used for this research.

i. This research will only cover deflections and cracks in concrete solid slabs. Other types of slabs such as the flat slabs, waffle slabs and ribbed slabs will not be studied.
ii. While there are many design software, this research will rely on STAADPro Connect Edition and Tekla Tedds for analysis.
iii. The design codes used for analysis are BS 8110, BS 8007 and EN 1992 (Eurocode)

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 INTRODUCTION

Reinforced concrete is made up of two seemingly different materials which end up complementing each other. Concrete on its own is a durable material with great strength properties and good fire resistance. It is however weak in tension. Its complementary partner, steel, has good tensile properties, poor fire resistance and is great in both shear and compression.

When a concrete member is loaded, it bends, and one part is in compression and the other is in tension. The behaviour of different support conditions when loaded is shown below.

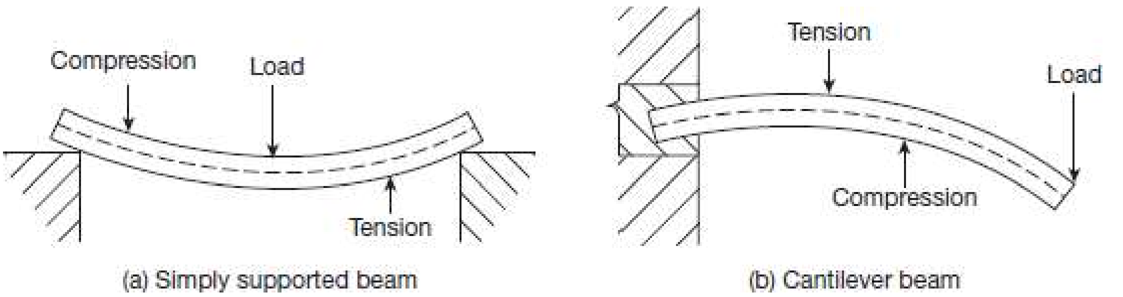


**Figure 2.1**: Bending behaviour of beams

Steel is placed in the tension parts of the beams to make up for concrete's weakness in tension. The method of combining these materials (concrete and steel) in the most economical way on one hand and safety on the other hand is referred to as reinforced concrete design (Oyenuga, 2018).

Every structure built today has been analysed and designed by professional civil engineers. This design ensures that the structure is safe for use and lasts as long as possible. The functional objectives which a reinforced concrete design must satisfy according to Oyenuga, 2018 are enumerated below.

i. Under the worst system of loading, the structure must be safe.
ii. Under the working load, the deformation of the structure must not impair appearance, durability and/or performance of the structure.
iii. The structure must be economical, that is, the factor of safety should not be too large to the extent that the cost of the structure becomes prohibitive with no additional significant advantage except for robustness.

Various design codes have been developed with formulas and guidelines to be followed for a stable structure. There is the British Standard Code, Eurocode, Indian Standard Code and so on. In Nigeria, the code adopted for design is the British Code commonly known as the BS code and more recently, the Eurocode. However, these codes all have similar directions/guidelines for design with differences in the factor of safety used for design, deflection check formulas, etc.

There are also different design methods used for design. The most common of these is the limit state method. The limit state design method is further divided into the ultimate limit state and the serviceability limit state. The serviceability limit state encompasses aspects such as deflection, cracking, vibration etc. The serviceability limit state is the focus of this research, but a short overview of the limit state method is given below.

## 2.2 THE LIMIT STATE DESIGN METHOD

There have been various design methods developed before the limit state method. As engineering evolves and more research is done, better approaches to design are made. The limit state design approach considers that the structure should sustain all loads and deformations liable to occur during its construction, perform adequately in normal use and be durable. This philosophy uses more than one safety factor attempting to provide adequate safety at ultimate loads as well as satisfactory serviceability performance at service loads, by considering all possible failure modes (Anwar and Najam, 2017). There are two criteria that the design of an individual member must fulfil under this condition.

i. The ultimate limit state: This is basically the design for the safety of a structure. The ultimate limit state represents the failure of the structure and its components usually when subjected to extreme values of actions or action effects (Paik & Thayamballi, 2009). In this state, the engineer ensures that the probability of failure is low. The ULS accounts for things such as; loss of equilibrium, rupture, progressive collapse, formation of plastic mechanism, instability, and fatigue.
ii. The serviceability limit state: this state ensures satisfactory behaviour of the structure after service/working loads. It is a criterion governing normal functional and operational use. The SLS covers aspects such as excessive deflection, excessive cracking, and undesirable vibration.

It should be noted that there are other limit states apart from the two mentioned above. However, these two happen to be the major ones and all other limit states can be classified under them.

The focus of this research will be on the serviceability limit state requirements as it covers deflection and cracking.

## 2.3 DEFLECTION

The serviceability limit state ensures that a structure fulfils its structural requirements without any form of impairment throughout its service life. There are various checks carried out during the serviceability limit state design but the most common and of more consequences to structures are deflection and cracking.

Deflection is simply the linear displacement of one point on a member transverse to a reference line or axis. It can also be described as deformation under load.

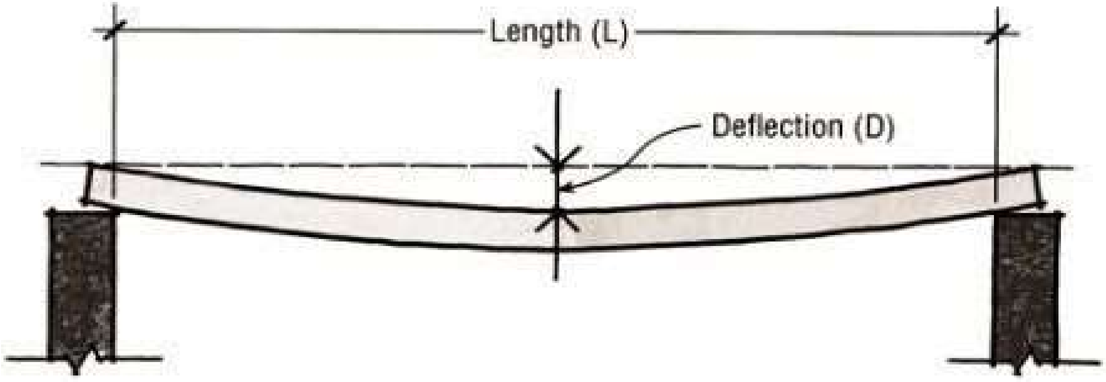


**Figure 2.2**: Deflection in beams

Deflection is bound to occur in concrete members such as beams and slabs. This is because loading will cause some form of deformation in the members. However, this deflection should not exceed a limit as described in various design codes. **Clause 7.4(1)P of EC 2** states that "the deformation of a member or structure shall not be such that it adversely affects the proper functioning or appearance." Excessive deflections may lead to sagging floors, and roofs that do not drain properly which will in turn damage partitions and finishes. It may also lead to cracking which is a major cause of concern for structures such as water tanks.

BS 8110 states that final deflections including the effects of creep and shrinkage should not be greater than;

i. Span/250
ii. span /500 or 20mm whichever is less.

Eurocode 2 gives the same guidelines for checking deflections. According to EC 2, total deflections should be limited to Span/250. To avoid damages to fixtures and fittings, the deflection will be limited to Span/500 to account for the part of deflection occurring after the application of finishes and partitions.

### 2.3.1 Theory of Deflection

Theoretically, the deflection of a concrete member is based on the elastic bending theory. Due to loads acting on a beam, it will be subjected to a bending moment. The deflection may be gotten from the curvature expression also known as the **differential equation of the elastic curve** thus;

$$M_x = \boldsymbol{EI}\ \frac{d^2y}{dx^2} \qquad (2.1)$$

Where $M_x$ = Bending moment and,

EI = Flexural rigidity of the member

Double integration of the above equation gives the deflection with the boundary conditions depending on the beam under consideration. The derivation of this equation is a fairly long process and of little concern to this study.

### 2.3.2 Factors affecting deflection.

The primary factors influencing deflection are as follows;

i. Tensile Strength: A slab will crack when the tensile stress in the extreme fibre is exceeded. With cracking comes deflection and higher tensile strength means a reduction in deflection. This can be done by increasing the compressive strength as tensile strength is inversely proportional to the square root of compressive strength.
ii. Elastic modulus: The elastic modulus of concrete is influenced by factors such as aggregates, workmanship and curing conditions. These factors in turn affect the deflection of concrete. For instance, use of poor-quality aggregates will lead to more deflection.
iii. Creep and Shrinkage: Creep is the time-dependent part of the strain resulting from stress. It can also be defined as the increase in strain under stress. Creep is affected by aggregates, mix proportions and age of loading. Creep increases deflection with time and is an important consideration in structural design.

iv. Boundary Conditions: A simply supported member will experience more deflection than a member that is restrained on all sides.

### 2.3.3 Calculation of Deflection

In checking deflection for concrete slabs, the shorter span is considered as it is the more critically loaded section. The most widely used method is done by checking the maximum limit of deflection based on the slab span.

In BS 8110, the basic span/effective depth ratio is obtained from **Table 3.9 of BS 8110-1:1997** (see table below).

**Table 2.1: Basic Span/Effective Depth Ratio According to BS 8110 (Oyenuga, 2011)**

| Support Condition | Rectangular Section | Flanged beam with $b_w/b \leq 0.3$ |
|---|---|---|
| Cantilever | 7 | 5.6 |
| Simply Supported | 20 | 16 |
| Continuous | 26 | 20.8 |

The values obtained are then modified by multiplying by factors for tension and compression reinforcements.

The modification for tension reinforcements is evaluated by the following expression;

$$MF_t = 0.55 + \frac{477 - F_s}{120(0.9 + M/bd^2)} \leq 2.0 \qquad (2.2)$$

Where M = Maximum moment at the centre of the span

$F_s$ = Service stress given by $2F_y \frac{Asreqd}{Asprov}$

Modification factor for compression reinforcements;

$$\mathrm{MF_c} = 1 + \frac{100\times \mathrm{Asprov}}{\mathrm{bd}} \Big/ \frac{3 + (100\times \mathrm{Asprov})}{\mathrm{bd}} \leq 2.0 \qquad (2.3)$$

The value gotten from the multiplication is called the allowable span/effective depth ratio. This value is compared with the actual span/effective depth ratio. For the deflection check to be considered okay, the actual span/effective depth ratio should be lesser than the allowable span/effective depth value.

The deflection check method for Eurocode 2 is basically the same thing, the only difference being the calculation for the allowable span/effective depth ratio. The details of this can be found in **Clause 7.4 of EC 5.**

**2.3.4 Deflection Control**

Deflection can be controlled during design by any of the following methods.

i. Increase in slab depth: This method is usually the first line of action for structural engineers as it has no adverse effect on the design. Stiffness of the structural element is a key factor affecting the deflection. This is because it indicates the ability of a slab to return to its normal form after deformation. Stiffness is given by EI/L where I is the moment of inertia ($bh^3/12$). An increase in h equates to an increase in stiffness. As stiffness increases, deflection decreases.

ii. Adjust the dead loads: A structure must be designed for the live loads applied to it therefore it cannot be tampered with in any situation. However, dead loads can be adjusted to control deflection. For instance, changing the materials used for internal partition walls and reducing the width of the walls will reduce the structure’s weight.

iii. Increase the area of reinforcements: Increasing the area of steel reduces the service stress which in turn increases the modification factor.

iv. Reduce the slab span: Reduction in span will reduce beam reinforcements and deflections. This is not an advisable method to use because it may require changes to the whole layout.

v. Use Prestressing.

## 2.4 CRACKING

According to the American Concrete Institute (ACI), cracking is the complete or incomplete separation of either concrete or masonry into two or more parts produced by breaking or fracturing. Concrete structures are bound to undergo some level of cracking. The job of the engineer is to limit the crack widths to an acceptable range and to ensure that these cracks do not cause failure to the structure. BS 8110 and Eurocode 2 states that crack width should be limited to 0.3mm.

There are two types of cracks namely; structural cracks and non-structural cracks.

- Structural cracks are caused by wrong design, faulty creation, or overloading. These cracks are formed by beams, slabs and columns and pose a danger to the safety of construction.
- Non-structural cracks are formed due to internal strength in concrete, temperature, corrosion of reinforcement, plastic shrinkage etc.

In design, the estimated crack width is calculated using a series of formulas given by the codes and compared to the acceptable standard given by the code. Cracks in concrete members can also be controlled by;

i. Limiting the maximum bar diameter according to Table 7.2 of Eurocode 2
ii. Limiting the maximum bar spacing according to table 7.3 of Eurocode 2 (BS 8110 also uses this method and details can be found in Clause 3.4.7 of the code).

## 2.5 SLABS

A slab is a part of a reinforced concrete structure which often is subjected to bending (tensile and compressive) but in rare cases such as in bridge deck is subjected to shear (Oyenuga, 2011). They are flat, plate elements used for floors and ceilings in buildings. Slabs are similar to beams except that;

- A width of 1m is generally assumed.
- The section is rectangular therefore, no flanges.
- Shear is not always considered unless where concentrated or live loads predominate, and the slab is thicker than 200mm

### 2.5.1 Types of Slabs

There are various types of slabs and the type chosen for construction depends on the use, architectural design and type of load to be carried. The most common types of slabs are;

i. Solid slabs
ii. Ribbed floor slabs
iii. Flat slab
iv. Waffle slab

### 2.5.2 Solid Slabs

These are the most used slabs especially in residential buildings and offices. They are used when the span does not exceed 6.0m. Common examples of cantilever slabs are cantilever, simply supported, continuous and one-way and two-way slabs. Slabs in buildings are generally designed as one way or two-way slabs depending on certain criteria.

#### 2.5.2.1 One-way Solid Slab

One-way slabs are supported by beams on two opposite sides to carry load in one direction. The main reinforcements for this slab are placed on the shorter span due to bending. The characteristic live/imposed load on this type of slab should not be greater than 5 $KN/m^2$.

Clause 5.3.1(5) of EN 1992-1-1:2004 gives the following criteria for a slab to be considered as one-way;

i. It possesses two free (unsupported) and sensibly parallel edges.
ii. It is the central part of a sensibly rectangular slab supported on four edges with a ratio of longer (Ly) to shorter span (Lx) greater than 2.

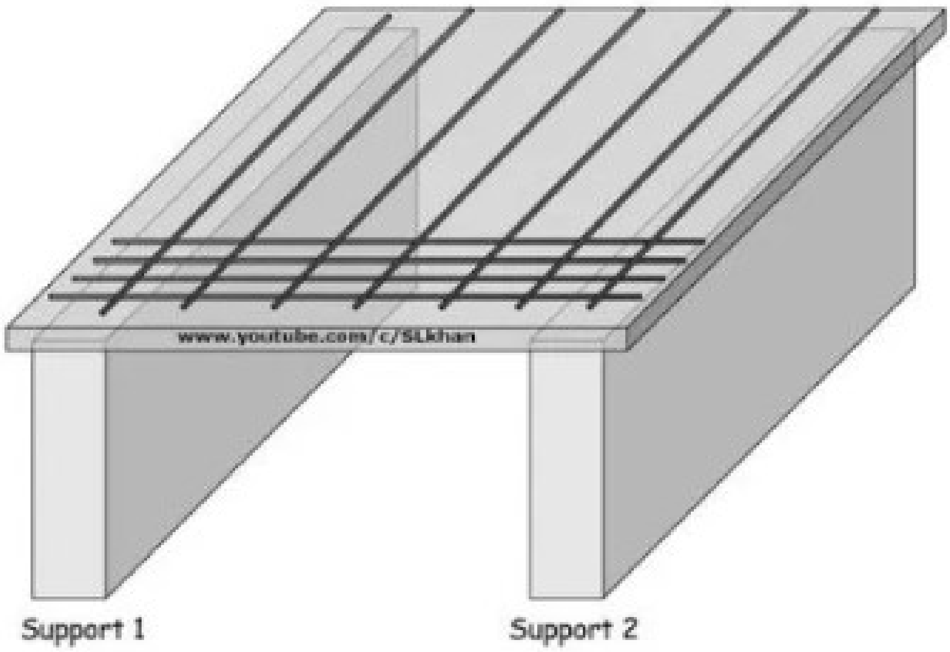


**Plate 2.1** One-way slab representation

### 2.5.2.2 Two-way Solid Slab

This is a slab with main reinforcements in both directions. It is supported on all four sides by beams and load is distributed to the supporting beams equally. It is also the type of slab where the ratio of the longer side to the shorter side is less than two.

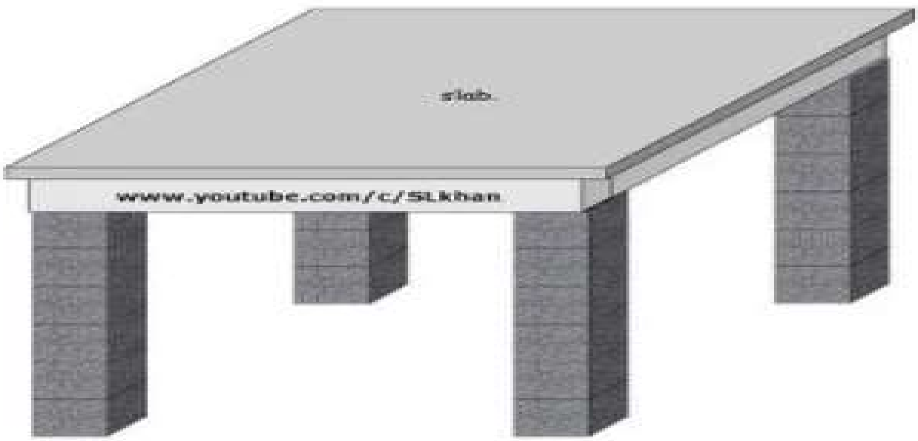


**Plate 2.2**: Two-way slab

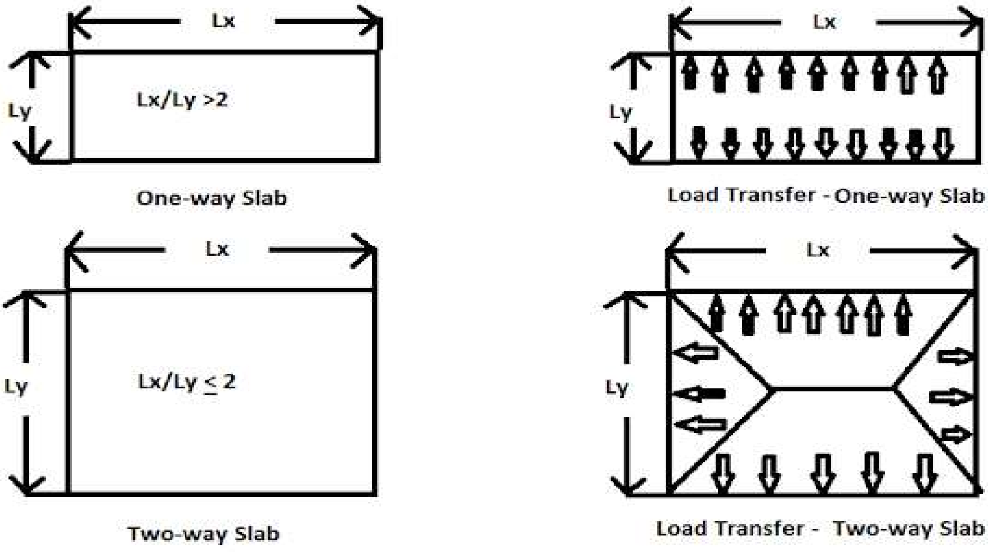


**Figure 2.3**: Load distribution in one-way and two-way slabs

### 2.5.3 Flat Slab

Flat slabs are reinforced concrete slabs supported directly by columns. There is generally uniform thickness throughout but is thicker (drops) around the vicinity of the columns. The columns are enlarged at the junction of the slab and column to form column heads. Drop panels are rectangular in shape and length and not less than one third of the panel length in that direction. They are used in conjunction with column heads to increase the shear strength of the slab. This type of slab can span up to 9m long.


**Plate 2.3:** Flat slabs

### 2.5.4 Ribbed Slabs

This is a type of slab where parts of the volume of the concrete are removed and filled with blocks or left hollow. It consists of small, reinforced concrete T beams that are connected with girders that are in turn carried by the building columns. It is particularly useful in long span construction of floors where the self-weight may become excessive.

**Plate 2.4**: A ribbed floor slab.

### 2.5.5 Waffle Slab

Waffle slabs can be described as two-way spanning solid slabs ribbed in two directions. This is an expensive type of slab to construct as slab thickness may be up to 500mm. They should only be used with large spans carrying heavy live loads of at least 5 $KN/m^2$. Due to the rigidity of waffle slabs, this form of structure is suggested for buildings like manufacturing plants and laboratories that require little vibration.

**Plate 2.5**: Waffle floor slab

## 2.6 CIVIL ENGINEERING DESIGN SOFTWARES: A BRIEF OVERVIEW AND HISTORY

Civil engineering design software is a group of computer programs used to execute the analysis, design and detailing for civil engineering projects. With the introduction of technology in various aspects of life, engineering was not left out. Gone are the days when engineers worked long hours on drafting boards and manual calculators to design a simple project. With the introduction of software, complex projects such as bridges, dams and high-rise structures can be designed in a matter of weeks if not days as long as the design information needed for these structures are present.

The term 'Computer Aided Design (CAD)' was introduced in the 1950s by Douglas T. Ross, a researcher at the Massachusetts Institute of Technology (MIT). He worked on projects that pioneered early CAD technology such as Automated Engineering Design. The first true CAD software was called SKETCHPAD and it was developed in 1963 by another MIT researcher, Ivan Sutherland. This software allowed the designer to interact graphically with the computer by drawing with a light pen on the computer's monitor. 1971 saw the introduction of ADAM (Automated Drafting and Machining), a CAD system developed by DR Patrick J. Hanretty. By mid 1970-1980, 3D CAD was introduced and although it wasn't widely used because it was an expensive tool back then it had begun to gain traction in the engineering industry.

In 1982, Autodesk was founded and subsequently AutoCAD, one of the more popular design software today was developed. The release of AutoCAD was revolutionary for the engineering design world and soon, other software followed. Today there are a range of design software for all engineering disciplines. In civil engineering, there are software catering to different specialisations. Some of these include;

i. AutoCAD (drafting, project management)
ii. STAAD Pro (structural analysis and design)
iii. ETABS (structural analysis and design)
iv. Bentley Road Network (highway design)
v. AutoCAD Civil 3D (3D modelling/highway design)
vi. Primavera 6 (project management)
vii. SAP2000 (geotechnical analysis)
viii. SAFE (geotechnical analysis)
ix. Hydra (design and model drainage systems)
x. Bentley Open Flows (water system analysis) e.t.c.

**2.6.1 STAAD Pro**

STAAD Pro stands for Structural Analysis and Design Program. It is a structural analysis and design program developed by Research Engineers International at Yorba Linda, California in 1997. Today it is owned by Bentley System Inc. The structure allows engineers to analyse and design structures of all sizes and forms with materials such as concrete, timber, steel and aluminium. The software has two editions offering the same tools and commands with a different interface. They are STAAD Pro V8i and STAAD Pro Connect Edition.

**2.6.1.1 Advantages of STAAD Pro**

i. Suitable for design of almost all kinds of materials.
ii. It adopts a faster technique for designing structures and no manual calculation is needed.
iii. It can be used for finite element model analysis of slabs, walls, and mats. The finite model analysis uses mathematical models to predict the behaviour of an object when exposed to real world stress. This is the basis of this research work.
iv. Improvements and corrections can be made quickly to any structure or section.
v. It can be used to design for any type of load such as dead loads, live loads, wind loads, seismic loads and so much more.
vi. The software has several building codes integrated so civil engineers can design based on the code of the region they reside in.
vii. Designs from AutoCAD can be imported to STAAD Pro
viii. It is easy to learn and beginner friendly.

**2.6.1.2 Limitations**

i. It is not suitable for costing materials and will not show the projected number of materials to be used.
ii. It is not suitable for brick/masonry work.
iii. One would need an adequate amount of civil engineering and structural design knowledge to use the software.

### 2.6.2 Tekla Tedds

Tekla Tedds is an easy-to-use software from Trimble Inc used to generate accurate results for engineering calculations. With Tekla, time spent on time consuming manual calculations can be cut down drastically with the assurance of error free results.

## 2.7 REVIEW OF RELATED WORKS

This section provides a brief review of academic works related to cracking and deflection control in slabs.

Agoes and Candra (2021) carried out experiments to analyse how crack widths are influenced by thickness in rigid pavements slabs. They tested three slabs of 100mm, 150mm and 200mm thickness respectively. Recordings and observations were made at 2 KN load applications until 180 KN. The graph of their findings is shown below;

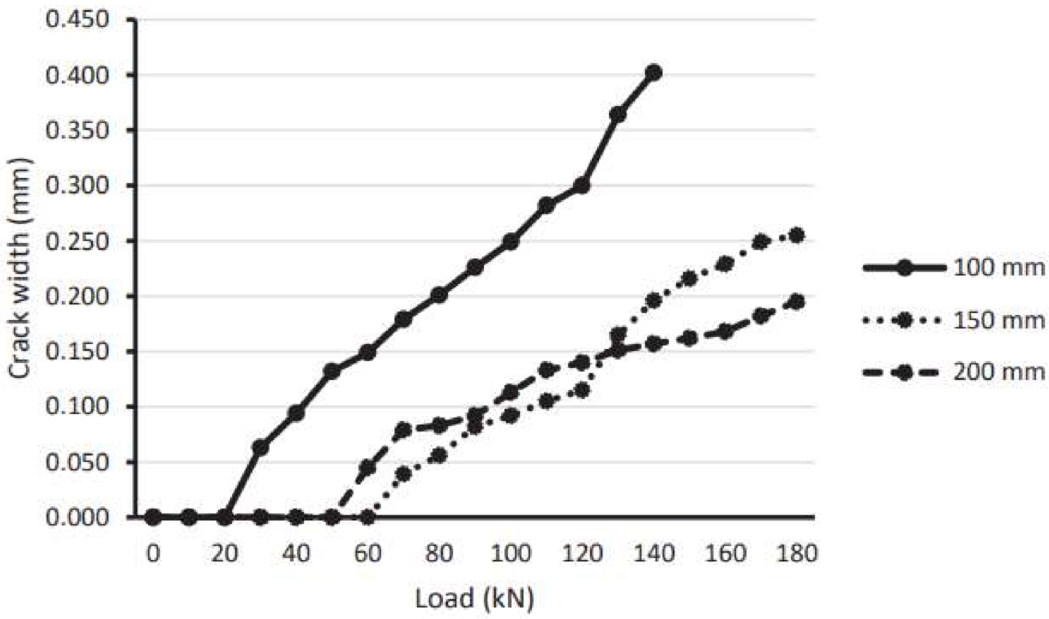


**Figure 2.4:** Variation of crack width with load (Agoes and Candra, 2021)

From the graph, the slab with the least thickness exceeded the allowable crack width as opposed to the other two that remained below 0.3mm even at the maximum load. Using this, they were able to decide that crack widths decrease with increase in thickness.

D'Antino and Pisani (2021) made an observation on the effect of concrete grade and deflection value. Different concrete grades were considered while doing calculations to test the effectiveness of the deflection check method proposed by Eurocode 2. According to them, low shrinkage and high concrete tensile strength relate to high concrete strength, which leads to small cracks and a reduction in the slab's deflection. The deflection of slabs made of concrete of various strength classes is typically not significantly different because of these opposing effects (reduction in cross-section height and high concrete characteristics).

While evaluating crack width in flexural RC beams, Bimalendu et al. (2021) observed that increasing the depth of the beam and the reinforcement diameter led to a decrease in crack width. This observation was made after calculating crack width using the formulas provided by various codes.

Piyasena et al (2004) researched the factors affecting crack width and spacing in reinforced concrete. The results of their research revealed that bar diameter, effective width of the bar per bar, concrete cover and effective spacing are the most significant parameters affecting crack width in beams.

Suh and McCullough (1994) also studied the factors affecting crack width this time in rigid pavements. In this study, the varying factors were; coarse aggregate type, slab temperature, season of placement and steel reinforcement. It was noted that using larger bars with the same amount of steel resulted in a slightly wider crack. However, the increase in crack width was small. It should be noted that this was determined experimentally. That is, the slab was constructed and the crack width was investigated using a microscope. It was then measured using a vernier calliper. It will be interesting to see the variation in an experimental result versus an analytical one.

The American Concrete Institute Report 435 (2000) indicated that increasing the section depth of a member reduces concrete tensile strength which in turn increases stiffness. In other words, deflection is reduced drastically.

Studies on deflection carried out by Gilbert (1985) and Gholamhoseini et al (2014) show that slabs with lesser thicknesses are susceptible to cracking and deflection than those with considerably more depth.

# CHAPTER THREE

# RESEARCH METHODOLOGY

## 3.1 INTRODUCTION

In this chapter, the variables involved, methods and steps used to carry out the research are discussed. A sample calculation to show how the deflection and crack width values are gotten are also done in this chapter and finally a short limitation to the study is discussed.

## 3.2 METHODOLOGY

In this section, the steps/processes taken to obtain results for this study are discussed. The aim of the research is to test how thickness of the slab element along with other varying parameters affect deflection and crack width values.

The parameters involved in this research are as follows;

i. Slab thickness: It is a well-known fact that the thickness of structural elements such as slabs and beams is a key factor in deflection control and evaluation. The objective is to test how varying other factors for different thickness affects deflection. Moreso, cracking is not usually considered as an important factor for crack control. By the end of this study, a relationship between the thickness of the element and crack width will be developed.

ii. Size and spacing of reinforcement: Decreasing the space between reinforcements leads to a subsequent increase in the area. It also leads to an increase in the amount of reinforcements. According to previous studies, a higher amount of reinforcements results to narrower crack widths. This is also another well-known method of controlling deflection. The same thing goes for cracking as Eurocode 2 recommends limiting the bar diameter and spacing to control cracking.

iii. Concrete Grade: The grade of concrete is a parameter not usually associated with cracking and deflection. Increasing the concrete compressive strength only slightly increases the elastic modulus. As a result, the changes in deflection and crack width values may be negligible.

### 3.2.1 Deflection Calculation

The following was involved in the analysis of the test slab;

i. The first floor slab plan of an office building was taken as a case study and a panel was chosen as the test slab. The floor plan is shown below. Panel 1 was taken as the test slab.

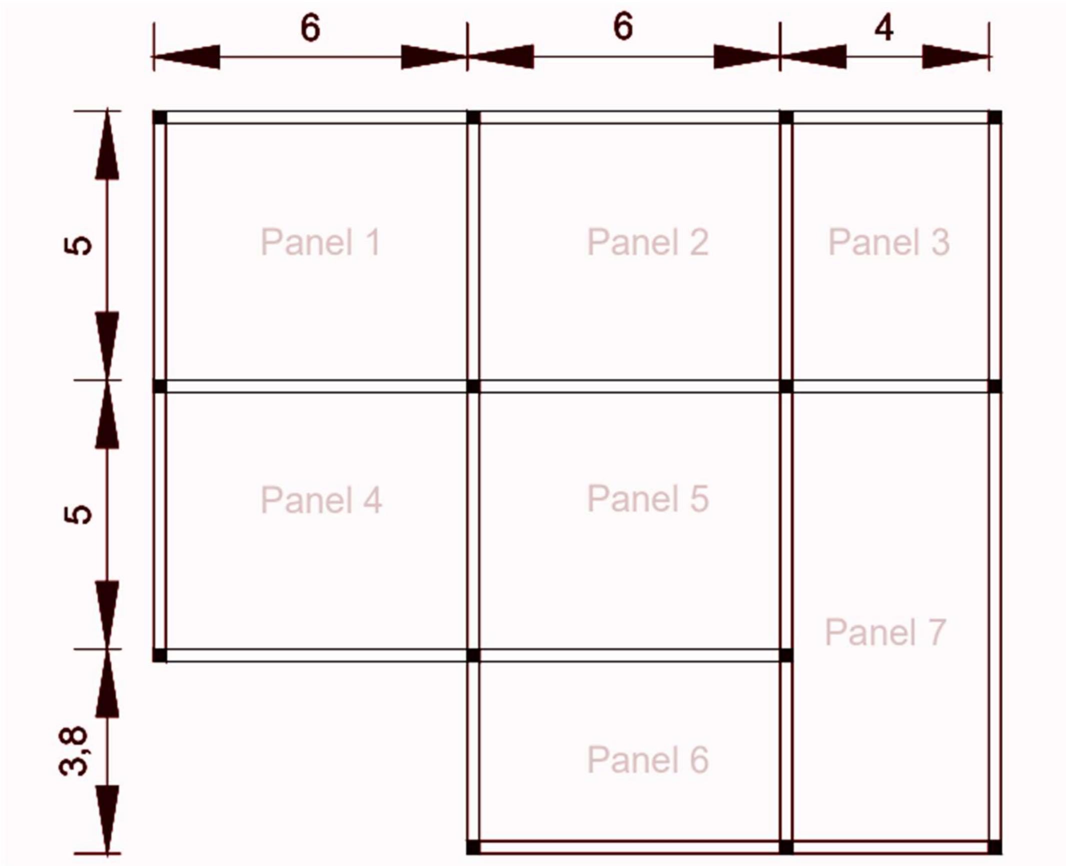


**Figure 3.1**: Floor plan of an office building.

ii. The slab was assumed to have three different thicknesses; 150mm, 175mm, and 200mm respectively.

iii. Dead load for each assumed thickness was calculated. The live load was taken from Table 10.5 (Oyenuga, 2018). This table is based on the BS 8110 and EC 1 recommendations.

iv. For each slab thickness, the deflection was calculated using Tekla Tedds. The mode in which the parameters varied are as follows;

   a. Spacing between bars; 150mm, 200mm, 250mm, 300mm.
   b. Size of reinforcement; 10mm, 12mm, 16mm
   c. Concrete grade; (15, 20, 25, 30, 35, 40, 45) $N/mm^2$

   The calculation was done entirely on Tekla Tedds software using EN 1992.

v. A graph of the results was plotted to aid analysis.

**Sample calculation.**

**RC slab design**

**In accordance with EN1992-1-1:2004 incorporating corrigendum January 2008 and the UK national annex**

Type of slab; Two way spanning with restrained edges

Overall slab depth; $h = 150$ mm

Shorter effective span of panel; $l_x = 5000$ mm

Longer effective span of panel; $l_y = 6000$ mm

Support conditions; Two adjacent edges discontinuous

Top outer layer of reinforcement; Short span direction

Bottom outer layer of reinforcement; Short span direction

**Loading**

Characteristic permanent action; $G_k = \mathbf{7.5}$ $kN/m^2$

Characteristic variable action; $Q_k = \mathbf{3.0}$ $kN/m^2$

Partial factor for permanent action; $\gamma_G = \mathbf{1.35}$

Partial factor for variable action; $\gamma_Q = \mathbf{1.50}$

Quasi-permanent value of variable action; $y_2$ = **0.30**

Design ultimate load; $q = \gamma_G G_k + g_Q \times Q_k$ = **14.6** kN/m$^2$

Quasi-permanent load; $q_{SLS} = 1.0 \times G_k + y_2 \times Q_k$ = **8.4** kN/m$^2$

**Concrete properties**

Concrete strength class; C12/15

Characteristic cylinder strength; $f_{ck}$ = **12** N/mm$^2$

Partial factor (Table 2.1N); $\gamma_C$ = **1.50**

Compressive strength factor (cl. 3.1.6); $\alpha_{cc}$ = **0.85**

Design compressive strength (cl. 3.1.6); $f_{cd}$ = **6.8** N/mm$^2$

Mean axial tensile strength (Table 3.1); $f_{ctm} = 0.30$ N/mm$^2$ $\times (f_{ck} / 1$ N/mm$^2)^{2/3}$ = **1.6** N/mm$^2$

Maximum aggregate size; $d_g$ = **20** mm

**Reinforcement properties**

Characteristic yield strength; $f_{yk}$ = **500** N/mm$^2$

Partial factor (Table 2.1N); $\gamma_S$ = **1.15**

Design yield strength (fig. 3.8); $f_{yd} = f_{yk} / \gamma_S$ = **434.8** N/mm$^2$

**Concrete cover to reinforcement**

Nominal cover to outer top reinforcement; $c_{nom\_t}$ = **30** mm

Nominal cover to outer bottom reinforcement; $c_{nom\_b}$ = **30** mm

Fire resistance period to top of slab; $R_{top}$ = **60** min

Fire resistance period to bottom of slab; $R_{btm}$ = **60** min

Axial distance to top reinforcement (Table 5.8); $a_{fi\_t}$ = **10** mm

Axial distance to bottom reinforcement (Table 5.8); $a_{fi\_b}$ = **10** mm

Min. top cover requirement with regard to bond; $c_{min,b\_t}$ = **12** mm

Min. btm cover requirement with regard to bond; $c_{min,b\_b}$ = **10** mm

Reinforcement fabrication; **Not subject to QA system**

Cover allowance for deviation; $Dc_{dev}$ = **10** mm

Min. required nominal cover to top reinft; $c_{nom\_t\_min}$ = **22.0** mm

Min. required nominal cover to bottom reinft; $c_{nom\_b\_min}$ = **20.0** mm

PASS - There is sufficient cover to the top reinforcement

PASS - There is sufficient cover to the bottom reinforcement

**Reinforcement design at midspan in short span direction (cl.6.1)**

Bending moment coefficient; $\beta_{sx\_p}$ = **0.0470**

Design bending moment; $M_{x\_p} = \beta_{sx\_p} \times q \times l_x^2$ = **17.2** kNm/m

Reinforcement provided; 10 mm dia. bars at 150 mm centres

Area provided; $A_{sx\_p}$ = 524 mm$^2$/m

Effective depth to tension reinforcement; $d_{x\_p} = h - c_{nom\_b} - \Phi_{x\_p} / 2$ = **115.0** mm

K factor; $K = M_{x\_p} / (b \times d_{x\_p}^2 \times f_{ck})$ = **0.108**

Redistribution ratio; $\delta = 1.0$

K' factor; $K' = 0.598 \times d - 0.18 \times d^2 - 0.21$ = **0.208**

K < K' - Compression reinforcement is not required

Lever arm; $z = \min(0.95 \times d_{x\_p}, d_{x\_p}/2 \times (1 + \sqrt{(1 - 3.53 \times K)}))$ = **102.7** mm

Area of reinforcement required for bending; $A_{sx\_p\_m} = M_{x\_p} / (f_{yd} \times z)$ = **385** mm$^2$/m

Minimum area of reinforcement required; $A_{sx\_p\_min} = \max(0.26 \times (f_{ctm}/f_{yk}) \times b \times d_{x\_p}, 0.0013 ´ b ´ d_{x\_p})$ = **149** mm$^2$/m

Area of reinforcement required; $A_{sx\_p\_req} = \max(A_{sx\_p\_m}, A_{sx\_p\_min})$ = **385** mm$^2$/m

PASS - Area of reinforcement provided exceeds area required

**Check reinforcement spacing**

Reinforcement service stress; $\sigma_{sx\_p} = (f_{yk} / gs) \times \min((A_{sx\_p\_m}/A_{sx\_p}), 1.0) \times q_{SLS} / q$ = **183.6** N/mm$^2$

Maximum allowable spacing (Table 7.3N); $s_{max\_x\_p}$ = **271** mm

Actual bar spacing; $s_{x\_p}$ = **150** mm

PASS - The reinforcement spacing is acceptable

**Reinforcement design at midspan in long span direction (cl.6.1)**

Bending moment coefficient; $b_{sy\_p}$ = **0.0340**

Design bending moment; $M_{y\_p} = b_{sy\_p} \times q \times l_x^2$ = **12.4** kNm/m

Reinforcement provided; 10 mm dia. bars at 200 mm centres

Area provided; $A_{sy\_p}$ = 393 mm$^2$/m

Effective depth to tension reinforcement; $d_{y\_p} = h - c_{nom\_b} - \Phi_{x\_p} - \Phi_{y\_p} / 2$ = **105.0** mm

K factor; $K = M_{y\_p} / (b \times d_{y\_p}^2 \times f_{ck})$ = **0.094**

Redistribution ratio; $\delta = 1.0$

K’ factor; $K' = 0.598 \times d - 0.18 \times d^2 - 0.21$ = **0.208**

K < K' - Compression reinforcement is not required

Lever arm;

$z = \min(0.95 \times d_{y\_p}, d_{y\_p}/2 \times (1 + \sqrt{(1 - 3.53 \times K)}))$ = **95.4** mm

Area of reinforcement required for bending; $A_{sy\_p\_m} = M_{y\_p} / (f_{yd} \times z)$ = **300** mm$^2$/m

Minimum area of reinforcement required; $A_{sy\_p\_min} = \max(0.26 \times (f_{ctm}/f_{yk}) \times b \times d_{y\_p}, 0.0013 \times b \times d_{y\_p})$ = **137** mm$^2$/m

Area of reinforcement required; $A_{sy\_p\_req} = \max(A_{sy\_p\_m}, A_{sy\_p\_min})$ = **300** mm$^2$/m

PASS - Area of reinforcement provided exceeds area required

**Check reinforcement spacing**

Reinforcement service stress;

$\sigma_{sy\_p} = (f_{yk} / \gamma_S) \sqrt{\min((A_{sy\_p\_m}/A_{sy\_p}), 1.0)} \times q_{SLS} / q$ = **190.5** N/mm$^2$

Maximum allowable spacing (Table 7.3N); $s_{max\_y\_p}$ = **262** mm

Actual bar spacing; $s_{y\_p}$ = **200** mm

PASS - The reinforcement spacing is acceptable

**Reinforcement design at continuous support in short span direction (cl.6.1)**

Bending moment coefficient; $\beta_{sx\_n}$ = **0.0630**

Design bending moment; $M_{x\_n} = \beta_{sx\_n} \times q \times l_x^2$ = **23.0** kNm/m

Reinforcement provided; 12 mm dia. bars at 175 mm centres

Area provided; $A_{sx\_n}$ = 646 $mm^2/m$

Effective depth to tension reinforcement; $d_{x\_n} = h - c_{nom\_t} - f_{x\_n} / 2 = \mathbf{114.0}$ mm

K factor; $K = M_{x\_n} / (b \times d_{x\_n}^2 \times f_{ck}) = \mathbf{0.148}$

Redistribution ratio; $\delta = 1.0$

K' factor; $K' = 0.598 \times d - 0.18 \times d^2 - 0.21 = \mathbf{0.208}$

K < K' - Compression reinforcement is not required

Lever arm; $z = \min(0.95 \times d_{x\_n}, d_{x\_n}/2 \times (1 + \sqrt{(1 - 3.53 \times K)})) = \mathbf{96.4}$ mm

Area of reinforcement required for bending; $A_{sx\_n\_m} = M_{x\_n} / (f_{yd} \times z) = \mathbf{549}$ $mm^2/m$

Minimum area of reinforcement required;

$A_{sx\_n\_min} = \max(0.26 \times (f_{ctm}/f_{yk}) \times b \times d_{x\_n}, 0.0013 \times b \times d_{x\_n}) = \mathbf{148}$ $mm^2/m$

Area of reinforcement required; $A_{sx\_n\_req} = \max(A_{sx\_n\_m}, A_{sx\_n\_min}) = \mathbf{549}$ $mm^2/m$

PASS - Area of reinforcement provided exceeds area required

**Check reinforcement spacing**

Reinforcement service stress;

$\sigma_{sx\_n} = (f_{yk} / \gamma_S) \times \min((A_{sx\_n\_m}/A_{sx\_n}), 1.0) \times q_{SLS} / q = \mathbf{212.3}$ $N/mm^2$

Maximum allowable spacing (Table 7.3N); $s_{max\_x\_n} = \mathbf{235}$ mm

Actual bar spacing; $s_{x\_n} = \mathbf{175}$ mm

PASS - The reinforcement spacing is acceptable

**Reinforcement design at continuous support in long span direction (cl.6.1)**

Bending moment coefficient; $\beta_{sy\_n} = \mathbf{0.0450}$

Design bending moment; $M_{y\_n} = \beta_{sy\_n} \times q \times l_x^2 = \mathbf{16.5}$ kNm/m

Reinforcement provided; 12 mm dia. bars at 200 mm centres

Area provided; $A_{sy\_n}$ = 565 $mm^2/m$

Effective depth to tension reinforcement; $d_{y\_n} = h - c_{nom\_t} - \Phi_{x\_n} - \Phi_{y\_n} / 2 = \mathbf{102.0}$ m

K factor; $K = M_{y\_n} / (b \times d_{y\_n}^2 \times f_{ck}) = \mathbf{0.132}$

Redistribution ratio; $\delta = 1.0$

K' factor; $K' = 0.598 \times d - 0.18 \times d^2 - 0.21 = \mathbf{0.208}$

K < K' - Compression reinforcement is not required

Lever arm; $z = \min(0.95 \times d_{y\_n}, d_{y\_n}/2 \times (1 + \sqrt{(1 - 3.53 \times K)})) = \mathbf{88.3}$ mm

Area of reinforcement required for bending; $A_{sy\_n\_m} = M_{y\_n} / (f_{yd} \times z) = \mathbf{429}$ mm$^2$/m

Minimum area of reinforcement required;

$A_{sy\_n\_min} = \max(0.26 \times (f_{ctm}/f_{yk}) \times b \times d_{y\_n}, 0.0013bd_{y\_n}) = \mathbf{133}$ mm$^2$/m

Area of reinforcement required; $A_{sy\_n\_req} = \max(A_{sy\_n\_m}, A_{sy\_n\_min}) = \mathbf{429}$ mm$^2$/m

PASS - Area of reinforcement provided exceeds area required

**Check reinforcement spacing**

Reinforcement service stress;

$\sigma_{sy\_n} = (f_{yk} / \gamma_S) \times \min((A_{sy\_n\_m}/A_{sy\_n}), 1.0) \times q_{SLS} / q = \mathbf{189.3}$ N/mm$^2$

Maximum allowable spacing (Table 7.3N); $s_{max\_y\_n} = \mathbf{263}$ mm

Actual bar spacing; $s_{y\_n} = \mathbf{200}$ mm

PASS - The reinforcement spacing is acceptable

**Shear capacity check at short span continuous support**

Shear force; $V_{x\_n} = q \times l_x / 2 + M_{x\_n} / l_x = \mathbf{41.2}$ kN/m

Effective depth factor (cl. 6.2.2); $k = \min(2.0, 1 + (200 \text{ mm} / d_{x\_n})^{0.5}) = \mathbf{2.000}$

Reinforcement ratio; $\rho = \min(0.02, A_{sx\_n} / (b \times d_{x\_n})) = \mathbf{0.0057}$

Minimum shear resistance (Exp. 6.3N);

$V_{Rd,c\_min} = 0.035 \text{ N/mm}^2 \times k^{1.5} \times (f_{ck} / 1 \text{ N/mm}^2)^{0.5} \times b \times d_{x\_n}$

$V_{Rd,c\_min} = \mathbf{39.1}$ kN/m

Shear resistance constant (cl. 6.2.2); $C_{Rd,c} = 0.18 \text{ N/mm}^2 / \gamma_C = \mathbf{0.12}$ N/mm$^2$

Shear resistance (Exp. 6.2a);

$V_{Rd,c\_x\_n} = \max(V_{Rd,c\_min}, C_{Rd,c} \times k \times (100 \times \rho \times (f_{ck} / 1 \text{ N/mm}^2))^{0.333} \times b \times d_{x\_n}) = \mathbf{51.8}$ kN/m

PASS - Shear capacity is adequate

**Shear capacity check at long span continuous support**

Shear force; $V_{y\_n} = q \times l_x / 2 + M_{y\_n} / l_y = \mathbf{39.3}$ kN/m

Effective depth factor (cl. 6.2.2); $k = \min(2.0, 1 + (200\ mm / d_{y\_n})^{0.5}) = \mathbf{2.000}$

Reinforcement ratio; $\rho_l = \min(0.02, A_{sy\_n} / (b \times d_{y\_n})) = \mathbf{0.0055}$

Minimum shear resistance (Exp. 6.3N); $V_{Rd,c\_min} = 0.035\ N/mm^2 \times k^{1.5} \times (f_{ck} / 1\ N/mm^2)^{0.5} \times b \times d_{y\_n}$

$V_{Rd,c\_min} = \mathbf{35.0}$ kN/m

Shear resistance constant (cl. 6.2.2); $C_{Rd,c} = 0.18\ N/mm^2 / g_C = \mathbf{0.12}\ N/mm^2$

Shear resistance (Exp. 6.2a);

$V_{Rd,c\_y\_n} = \max(V_{Rd,c\_min}, C_{Rd,c} \times k \times (100 \times \rho_l \times (f_{ck} / 1\ N/mm^2))^{0.333} \times b \times d_{y\_n}) = \mathbf{46.0}$ kN/m

PASS - Shear capacity is adequate

**Shear capacity check at short span discontinuous support**

Shear force; $V_{x\_d} = q \times l_x / 2 = \mathbf{36.6}$ kN/m;

Reinforcement provided; **10 mm dia. bars at 200 mm centres**

Area provided; $A_{sx\_d} = \mathbf{393}\ mm^2/m$

Effective depth; $d_{x\_d} = h - c_{nom\_b} - f_{x\_d} / 2 =$ ;**115.0** mm

Effective depth factor; $k = \min(2.0, 1 + (200\ mm / d_{x\_d})^{0.5}) = \mathbf{2.000}$

Reinforcement ratio; $\rho_l = \min(0.02, A_{sx\_d} / (b \times d_{x\_d})) = \mathbf{0.0034}$

Minimum shear resistance; $V_{Rd,c\_min} = 0.035\ N/mm^2 \times k^{1.5} \times (f_{ck} / 1\ N/mm^2)^{0.5} bd_{x\_d}$

$V_{Rd,c\_min} = \mathbf{39.4}$ kN/m

Shear resistance constant (cl. 6.2.2); $C_{Rd,c} = 0.18\ N/mm^2 / \gamma_C = \mathbf{0.12}\ N/mm^2$

Shear resistance;

$V_{Rd,c\_x\_d} = \max(V_{Rd,c\_min}, C_{Rd,c} \times k \times (100 \times \rho_l \times (f_{ck}/1\ N/mm^2))^{0.333} bd_{x\_d}) = \mathbf{44.1}$ kN/m

PASS - Shear capacity is adequate (0.828)

**Shear capacity check at long span discontinuous support**

Shear force; $V_{y\_d} = ql_x / 2 = \mathbf{36.6}$ kN/m;

Reinforcement provided; **10 mm dia. bars at 200 mm centres**

Area provided; $A_{sy\_d} = \mathbf{393}\ mm^2/m$

Effective depth; $d_{y_d} = h - c_{nom_b} - \Phi_{x_p} - \Phi_{y_d} / 2 = \mathbf{105.0}$mm

Effective depth factor; $k = \min(2.0, 1 + (200\ mm / d_{y\_d})^{0.5}) = \mathbf{2.000}$

Reinforcement ratio; $\rho_l = \min(0.02, A_{sy\_d} / (b \times d_{y\_d})) = \mathbf{0.0037}$

Minimum shear resistance;

$V_{Rd,c\_min} = 0.035\ N/mm^2 \times k^{1.5} \times (f_{ck} / 1\ N/mm^2)^{0.5} \times b \times d_{y\_d}$

$V_{Rd,c\_min} =$ **36.0** kN/m

Shear resistance constant (cl. 6.2.2); $C_{Rd,c} = 0.18\ N/mm^2 / \gamma_C =$ **0.12** $N/mm^2$

Shear resistance;

$V_{Rd,c\_y\_d} = \max(V_{Rd,c\_min}, C_{Rd,c} \times k \times (100 \times \rho_l \times (f_{ck}/1\ N/mm^2))^{0.333} \times b \times d_{y\_d}) =$ **41.5** kN/m

PASS - Shear capacity is adequate (0.880)

**Basic span-to-depth deflection ratio check (cl. 7.4.2)**

Reference reinforcement ratio; $\rho_0 = (f_{ck} / 1\ N/mm^2)^{0.5} / 1000 = \mathbf{0.0035}$

Required tension reinforcement ratio;

$\rho = \max(0.0035, A_{sx\_p\_req} / (b \times d_{x\_p})) = \mathbf{0.0035}$

Required compression reinforcement ratio; $\rho' = A_{scx\_p\_req} / (b \times d_{x\_p}) = \mathbf{0.0000}$

Stuctural system factor (Table 7.4N); $K_d = \mathbf{1.3}$

Basic limit span-to-depth ratio (Exp. 7.16);

$ratio_{lim\_x\_bas} = K_d\ [11 + 1.5(f_{ck}/1\ N/mm^2)^{0.5} r_0/(r-r') + (f_{ck}/1\ N/mm^2)^{0.5}((r'/r_0)^{0.5})/12] = \mathbf{20.99}$

Mod span-to-depth ratio limit;

$ratio_{lim\_x} = \min(40 \times K_d, \min(1.5, (500\ N/mm^2 / f_{yk}) \times (A_{sx\_p} / A_{sx\_p\_m})) \times ratio_{lim\_x\_bas}) = \mathbf{28.55}$

Actual span-to-eff. depth ratio; $ratio_{act\_x} = l_x / d_{x\_p} = \mathbf{43.48}$

FAIL - Limit span-to-effective depth ratio is exceeded

The results of subsequent calculations are summarised in tables in chapter four.

### 3.2.2 Crack Width Calculation

The following steps were taken in the calculation of crack width;

i. The same slab used for the deflection analysis was used.

ii. The slab was modelled on STAADPro CONNECT Edition and analysed to get the serviceability state moments for each thickness.

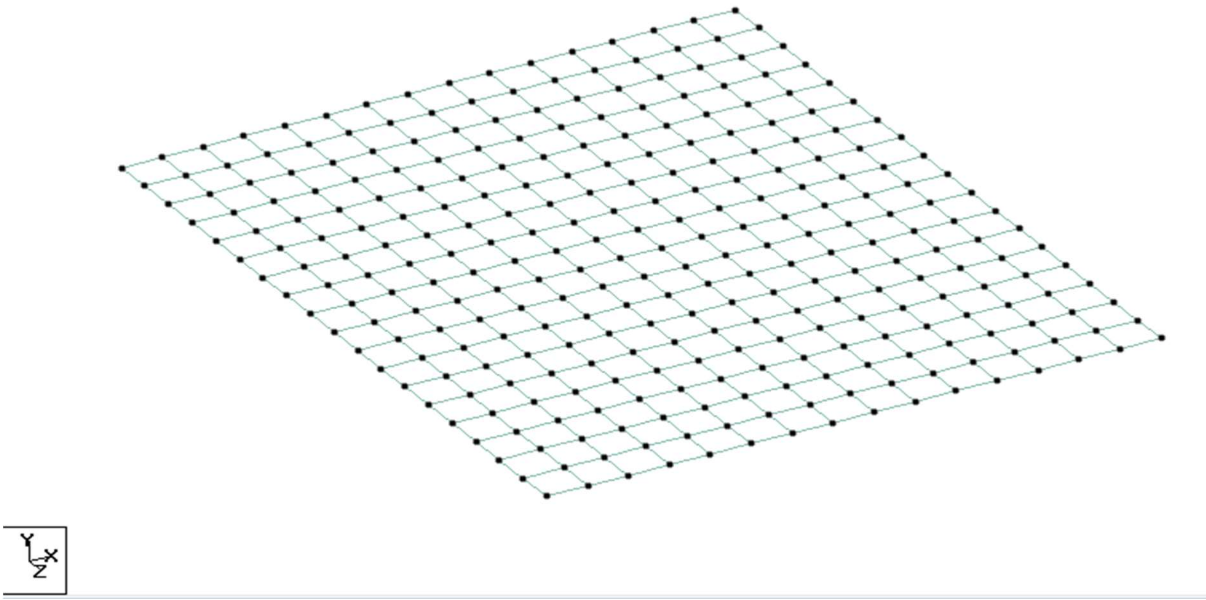

**Plate 3.1**: Meshing the slab/plate element. Meshing is a technique used in design software to divide an element into smaller squares/plates to make the analysis more accurate.

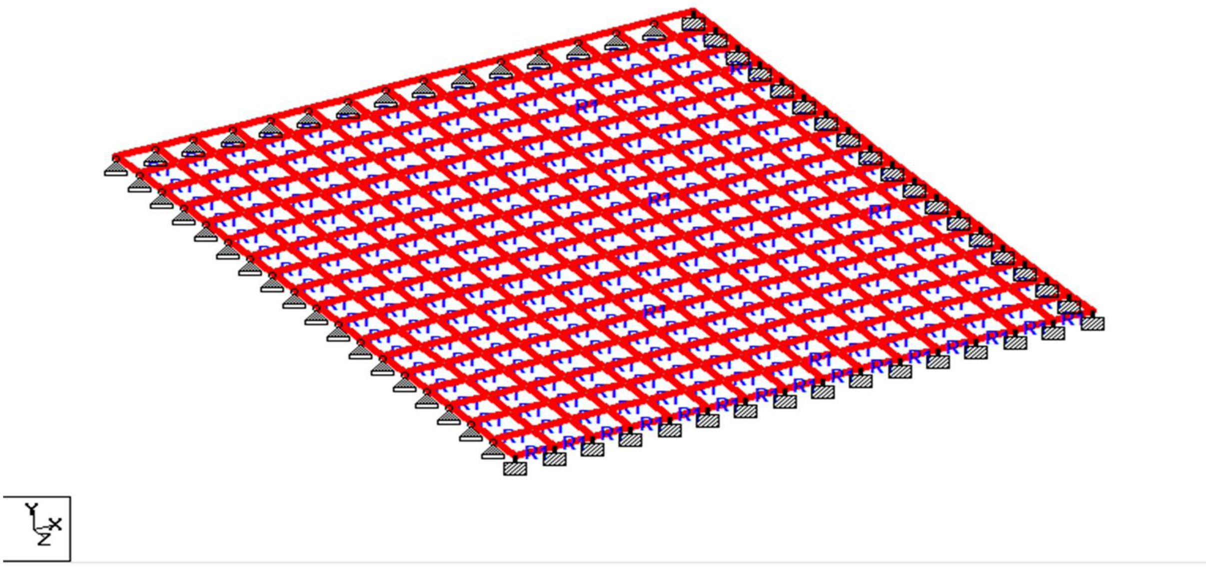

**Plate 3.2**: Adding the properties of the slab (Thickness and support conditions)

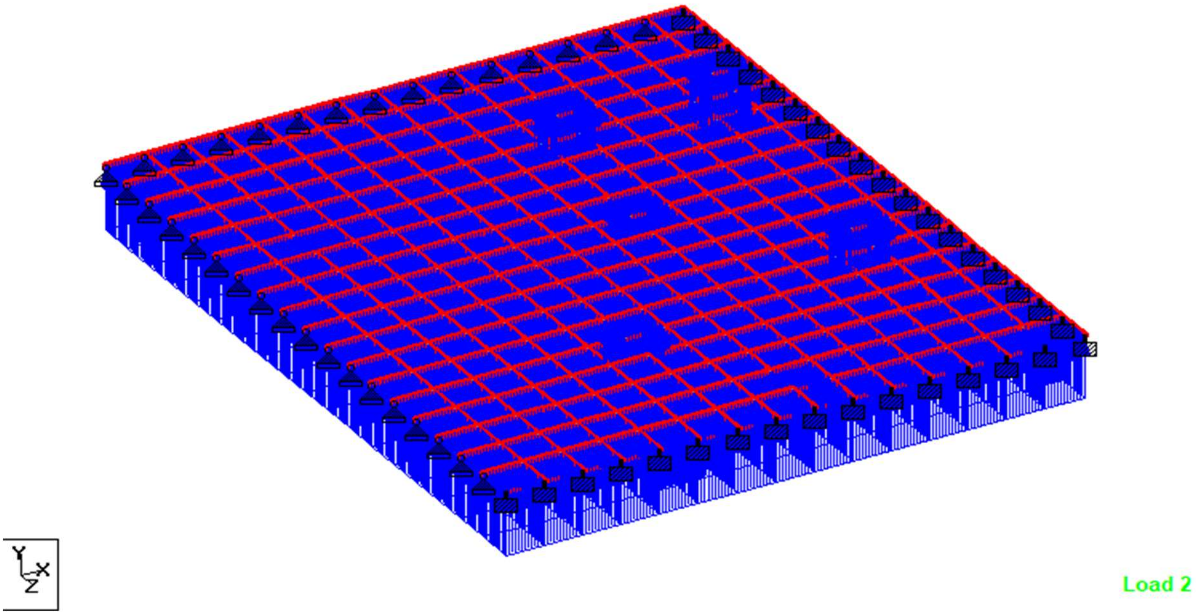


**Plate 3.3**: The slab element after loading

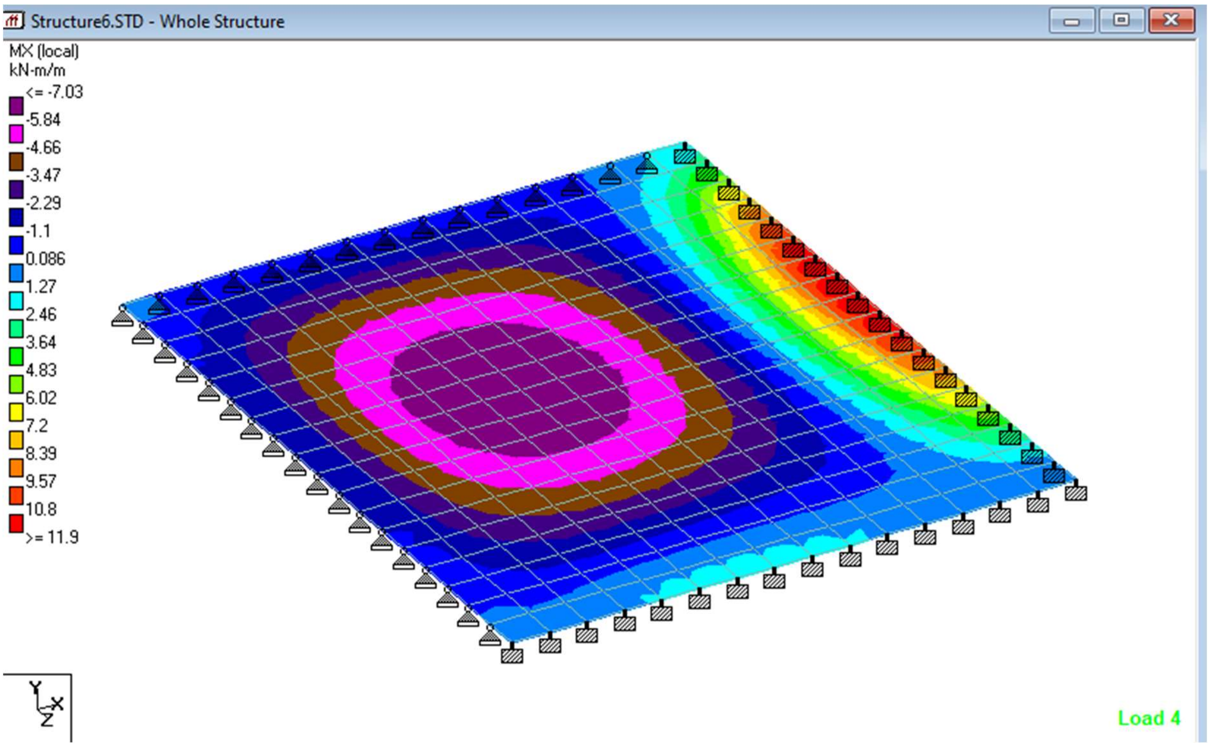


**Plate 3.5**: Plate stress diagram. This diagram depicts the bending moments on the slab.

iii. The bending moment from STAADPro was taken to Tekla to perform the crack width calculations.

iv. The calculation was carried out in the same way as the deflection calculations. The varying parameters are:

a. Spacing between bars; 150mm, 200mm, 250mm, 300mm.

b. Size of reinforcement; 10mm, 12mm, 16mm

c. Concrete grade; (15, 20, 25, 30, 35, 40, 45) $N/mm^2$

v. A graph of the results was plotted to aid in the analysis.

A sample calculation is shown below:

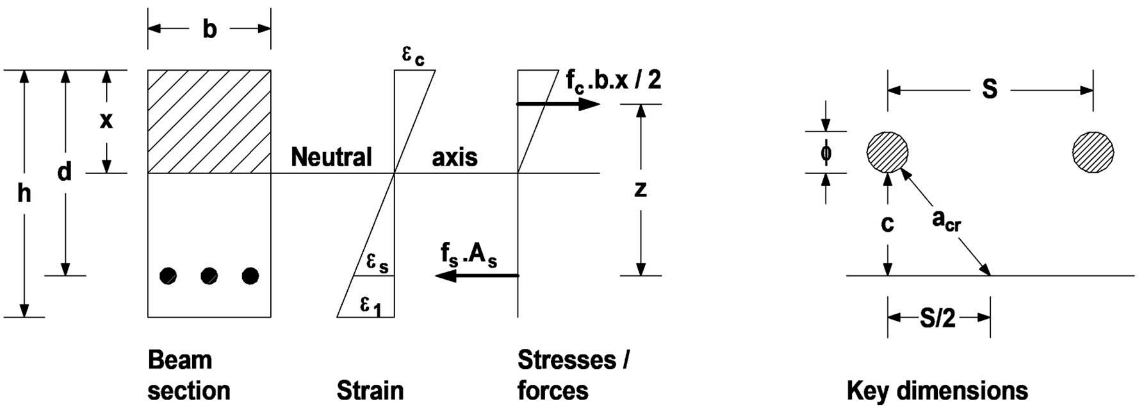


**Figure 3.2**: Beam Section

**Crack width calculation to BS 8110:Part 2:1985**

**TEDDS calculation version 1.0.02**

**Beam details**

Section width; b = **1000** mm

Section depth; h = **150** mm

Applied serviceability limit state moment; $M_s$ = **11.9** kNm

**Material details**

Characteristic strength of concrete; $f_{cu}$ = **15** $N/mm^2$

Characteristic strength of reinforcement; $f_y$ = **500** N/mm$^2$

Modulus of elasticity of the concrete; $E_c$ = (20kN/mm$^2$ + 200 ′ $f_{cu}$) / 2 = **11.5** kN/mm$^2$

Modulus of elasticity of reinforcement; $E_s$ = 200 kN/mm$^2$

**Reinforcement details**

Area of tension reinforcement provided; $A_s$ = **523** mm$^2$

Diameter of tension reinforcement bars; f = **10** mm

Maximum spacing of tension reinforcement bars; S = **150.0** mm

Minimum cover to tension reinforcement bars; $c_{min}$ = **30** mm

**Calculate design surface crack width**

Effective depth of tension reinforcement; $d = h - c_{min} - \Phi/2$ = **115.0** mm

Modular ratio; $m = E_s / E_c$ = **17.391**

$n = A_s / (b \times d)$ = **0.005**

Depth to neutral axis;

x = (- m ′ n + Ö((m ′ n)$^2$ + 2 ′ m ′ n)) ′ d = **37.5** mm

Lever arm; $z = d - x / 3$ = **102.5** mm

Reinforcement stress; $f_s = M_s / (A_s \times z)$ = **222.012** N/mm$^2$

Concrete stress; $f_c = f_s \times A_s / (0.5 \times b \times x)$ = **6.186** N/mm$^2$

Strain at soffit of beam; $e_1 = (f_s / E_s) \times (h - x) / (d - x)$ = **0.001612**

Strain due to stiffening of concrete between cracks; $e_2$ = 1N/mm$^2$ $\times b \times (h - x)^2 / [3 \times E_s \times A_s \times (d - x)]$ = **0.000520**

Average strain at soffit of beam; $e_m = e_1 - e_2$ = **0.001091**

Library item – Crack width calculation 1

Distance of crack to surface of nearest tension bar; $a_{cr} = \sqrt{(S / 2)^2 + (h - d)^2} - \Phi/2$ = **77.8** mm

**Design surface crack width;**

$w = 3 \times a_{cr} \times e_m / (1 + 2 \times (a_{cr} - c_{min}) / (h - x))$ = **0.138** mm

The calculation above is the output from the Tekla Tedds software. Since the calculations for all the parameters are the same, the results are summarised in tables in chapter four.

## 3.3 LIMITATIONS OF THE RESEARCH METHODOLOGY

Creep and shrinkage are two unavoidable factors that affect deflection and cracking in concrete. However, it is usually ignored by civil engineers when making serviceability state calculations except in special cases such as long span slabs and cantilevers.

Concrete shrinkage is the change in length per unit length expressed as a percentage. Creep is the long-term deformation of a structure under load. Shrinkage reduces volume thereby causing tensile strain in the concrete, ultimately leading to cracks. Excessive crack-width and deflection affect the durability and strength of the concrete. Creep reduces the modulus of elasticity of the concrete, causing a reduction of strength and an increase in deflection.

The equations used for calculations in this study are termed the ‘deemed-to-satisfy’ methods because they are believed to take care of the effects of creep and shrinkage in concrete.

There are equations derived by other researchers and software such as Atena 2D that incorporate the effects of creep and shrinkage for serviceability calculations. These equations are quite complex and difficult to understand at this level so this research will make do with the approved methods of calculations from the British Standard Code and Eurocode 2.

# CHAPTER FOUR

# RESULTS AND ANALYSIS

## 4.2 INTRODUCTION

This chapter presents the results of the analysis. It also analyses the results and compares it to what has been discovered by other researchers.

## 4.2 DEFLECTION RESULTS

The analysis was carried out on the same slab with different thicknesses. The general information for the concrete slabs are as follows;

1. Slab type design: Two-way slab
2. Support condition: Two adjacent edges are discontinuous
3. Slab dimensions: ly = 6m, lx = 5m
4. Characteristic strength of reinforcement, $F_{yk}$: 500N/mm$^2$
5. Concrete cover: 30mm

**N.B:** The deflection values shown on the tables are the calculated allowable span/depth ratio (Allowable l/d).

**Slab A**

Slab thickness; H = 150mm

Dead load; Gk = 7.5KN/m$^2$

Live load: Qk = 3KN/m$^2$

**Table 4.1: Allowable Span/Depth for H = 150mm**

| Size of Reinforcements (mm) | | 10 Actual l/d = 43.48 | | | | 12 Actual l/d = 43.86 | | | | 16 Actual l/d = 44.64 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Spacing of Reinforcements (mm) | | | | | | | | | | | |
| **S/N** | **Concrete Grade ($N/mm^2$)** | **150** | **200** | **250** | **300** | **150** | **200** | **250** | **300** | **150** | **200** | **250** | **300** |
| 1 | 15 | 28.55 | 21.41 | 17.13 | 14.27 | 31.48 | 30.49 | 24.39 | 20.33 | 31.32 | 31.32 | 31.32 | 31.32 |
| 2 | 20 | 33.88 | 25.41 | 20.33 | 16.94 | 36.17 | 36.17 | 28.97 | 24.14 | 36.17 | 36.17 | 36.17 | 36.17 |
| 3 | 25 | 40.29 | 30.22 | 24.17 | 20.15 | 42.25 | 42.25 | 34.47 | 28.72 | 42.25 | 42.25 | 42.25 | 42.25 |
| 4 | 30 | 49.30 | 36.98 | 29.58 | 24.65 | 51.10 | 51.10 | 42.23 | 35.19 | 51.10 | 51.10 | 51.10 | 51.10 |
| 5 | 35 | 52.00 | 41.21 | 32.96 | 27.47 | 52.00 | 52.00 | 47.06 | 39.21 | 52.00 | 52.00 | 52.00 | 52.00 |
| 6 | 40 | 52.00 | 47.23 | 37.79 | 31.49 | 52.00 | 52.00 | 52.00 | 44.95 | 52.00 | 52.00 | 52.00 | 52.00 |
| 7 | 45 | 52.00 | 52.00 | 41.61 | 34.67 | 52.00 | 52.00 | 52.00 | 49.50 | 52.00 | 52.00 | 52.00 | 52.00 |

**Slab B**

Slab thickness; H = 175mm

Dead load; Gk = $8KN/m^2$

Live load; Qk = $3KN/m^2$

**Table 4.2: Allowable Span/Depth for H = 175mm**

| Size of Reinforcements (mm) | | 10 Actual l/d = 35.71 | | | | 12 Actual l/d = 35.97 | | | | 16 Actual l/d = 36.50 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Spacing of Reinforcements (mm) | | | | | | | | | | | |
| **S/N** | **Concrete Grade ($N/mm^2$)** | **150** | **200** | **250** | **300** | **150** | **200** | **250** | **300** | **150** | **200** | **250** | **300** |
| 1 | 15 | 31.48 | 27.17 | 21.74 | 18.11 | 31.48 | 31.48 | 31.04 | 25.87 | 31.48 | 31.48 | 31.48 | 31.48 |
| 2 | 20 | 36.17 | 31.83 | 25.47 | 21.22 | 36.17 | 36.17 | 36.17 | 30.22 | 36.17 | 36.17 | 36.17 | 36.17 |
| 3 | 25 | 42.25 | 35.58 | 28.46 | 23.72 | 42.25 | 42.25 | 40.69 | 33.91 | 42.25 | 42.25 | 42.25 | 42.25 |
| 4 | 30 | 51.10 | 43.03 | 34.42 | 28.69 | 51.10 | 51.10 | 49.21 | 41.01 | 51.10 | 51.10 | 51.10 | 51.10 |
| 5 | 35 | 52.00 | 47.95 | 38.36 | 31.97 | 52.00 | 52.00 | 52.00 | 45.70 | 52.00 | 52.00 | 52.00 | 52.00 |
| 6 | 40 | 52.00 | 52.00 | 43.97 | 36.64 | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 |
| 7 | 45 | 52.00 | 52.00 | 48.82 | 40.35 | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 |

**Slab C**

Slab thickness; H = 175mm

Dead load; Gk = $8.5/m^2$

Live load; Qk = $3KN/m^2$

**Table 4.3: Allowable Span/Depth for H = 200mm**

| Size of Reinforcements (mm) | | 10 Actual l/d = 30.30 | | | | 12 Actual l/d = 30.49 | | | | 16 Actual l/d = 30.86 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Spacing of Reinforcements (mm) | | | | | | | | | | | |
| **S/N** | **Concrete Grade ($N/mm^2$)** | **150** | **200** | **250** | **300** | **150** | **200** | **250** | **300** | **150** | **200** | **250** | **300** |
| 1 | 15 | 31.48 | 31.48 | 26.15 | 21.79 | 31.48 | 31.48 | 31.48 | 31.19 | 31.48 | 31.48 | 31.48 | 31.48 |
| 2 | 20 | 36.17 | 36.17 | 30.04 | 25.04 | 36,17 | 36.17 | 36.17 | 35.83 | 36.17 | 36.17 | 36.17 | 36.17 |
| 3 | 25 | 42.25 | 40.16 | 32.13 | 26.77 | 42.25 | 42.25 | 42.25 | 38.32 | 42.25 | 42.25 | 42.25 | 42.25 |
| 4 | 30 | 51.10 | 48.57 | 38.86 | 32.38 | 51.10 | 51.10 | 51.10 | 46.34 | 51.10 | 51.10 | 51.10 | 51.10 |
| 5 | 35 | 52.00 | 52.00 | 43.30 | 36.08 | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 |
| 6 | 40 | 52.00 | 52.00 | 49.63 | 41.36 | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 |
| 7 | 45 | 52.00 | 52.00 | 52.00 | 45.55 | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 | 52.00 |

### 4.2.1 Analysis

The results of the analysis are visualised on the graphs below.

### 4.2.2 Effects of concrete grade and thickness

To analyse the results, a graph of allowable l/d against concrete grade for 10mm bars was plotted. The 10mm bars were chosen because it showed more variations in the values of deflections (as related to concrete grade).

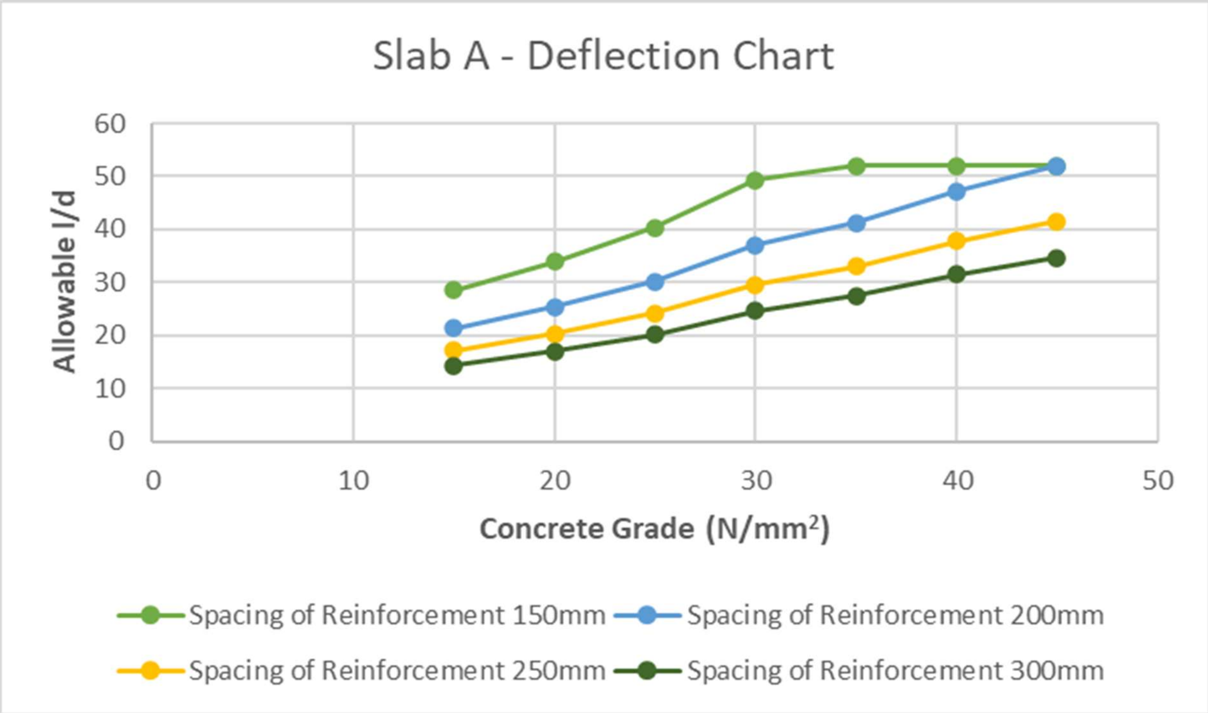


**Figure 4.1**: Deflection chart for slab A, H = 150mm

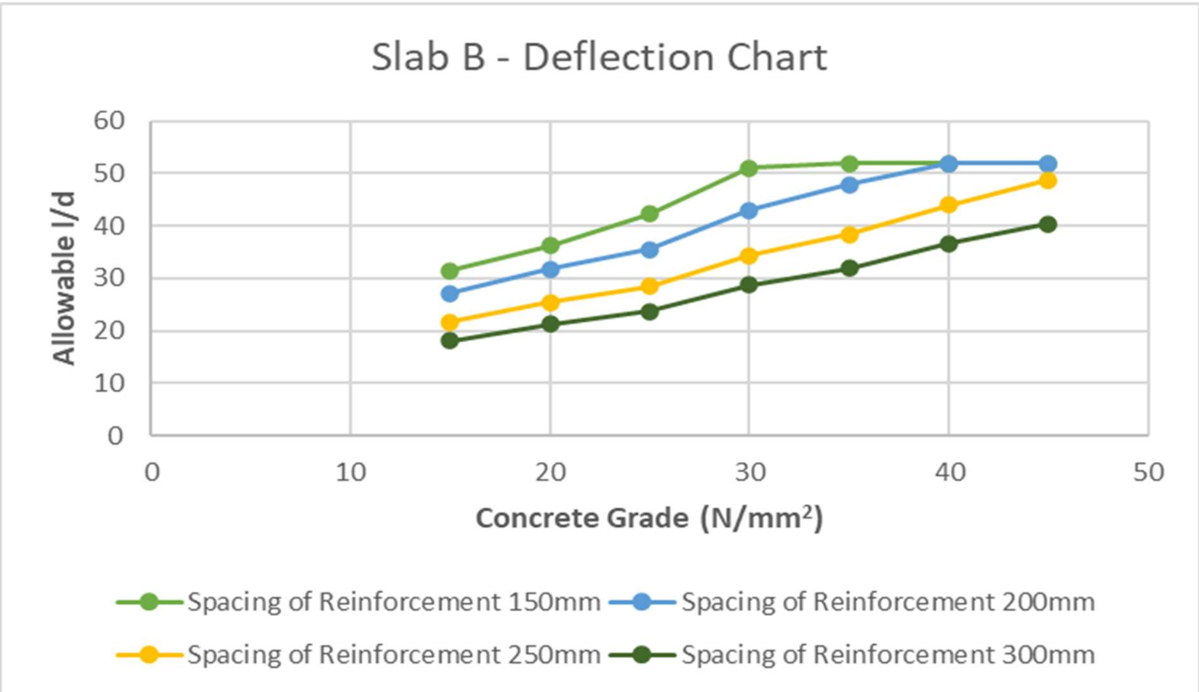


**Figure 4.2**: Deflection chart for slab B, H=175mm

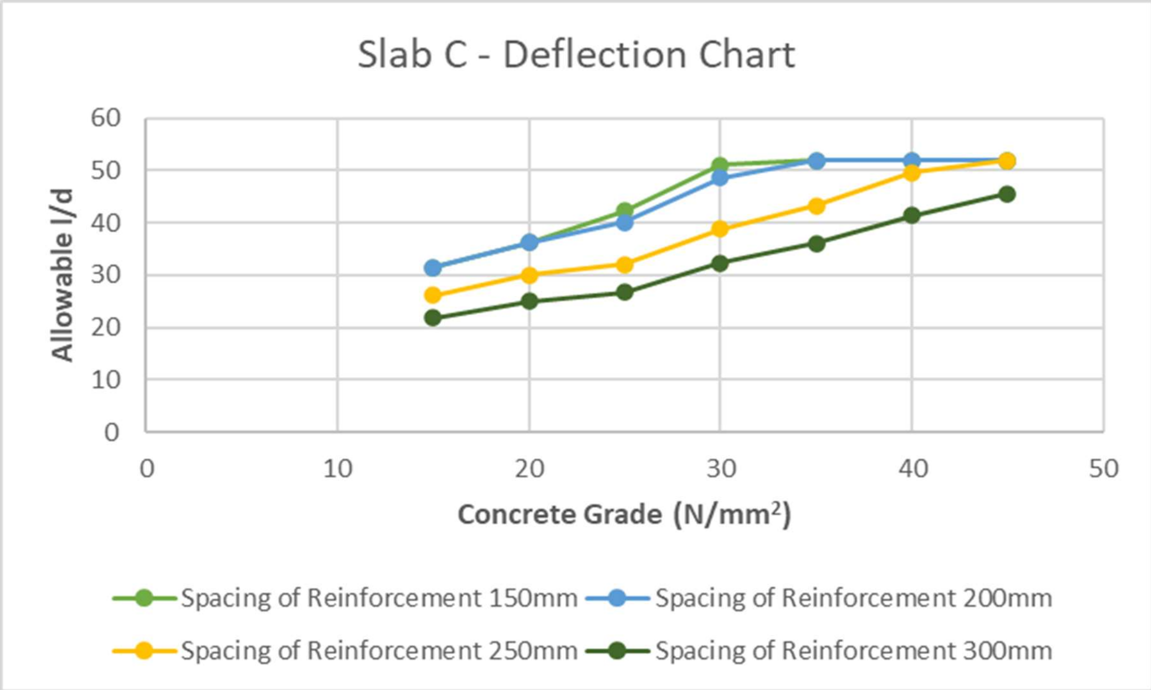


**Figure 4.3**: Deflection chart for slab C. H=200mm

In figure 4.1 and table 4.1, there is a significant increase in the value of the allowable l/d when the concrete grade is changed from 15 to 20. As the compressive strength of the concrete is increased, the change in the values is less significant. Putting it as a percentage, there is a 19% increase in the deflection value which goes down to an average of 11% as the compressive strength is increased. For this slab too, the design fails the deflection check at concrete grade 15, 20 and 25.

The same trend continues in the 175mm slab. However, when comparing the deflection value for both slabs at the same concrete grade, there is an average increase of 13%. In slab B, deflection failure occurs at concrete grade 15.

For slab C, the values tend to become more stable (especially with lesser spacing) and the change negligible. The percentage difference between the 175mm and 200mm slab is 12% (approximately). Deflection failure wasn't prominent in this slab as it was for the other two. While there were deflection failures, it was primarily due to increasing reinforcement spacing.

### 4.2.3 Effects of thickness and reinforcement (size and spacing)

To analyse the results for these parameters properly, the values for concrete grade 15 was used because the results showed greater variance.

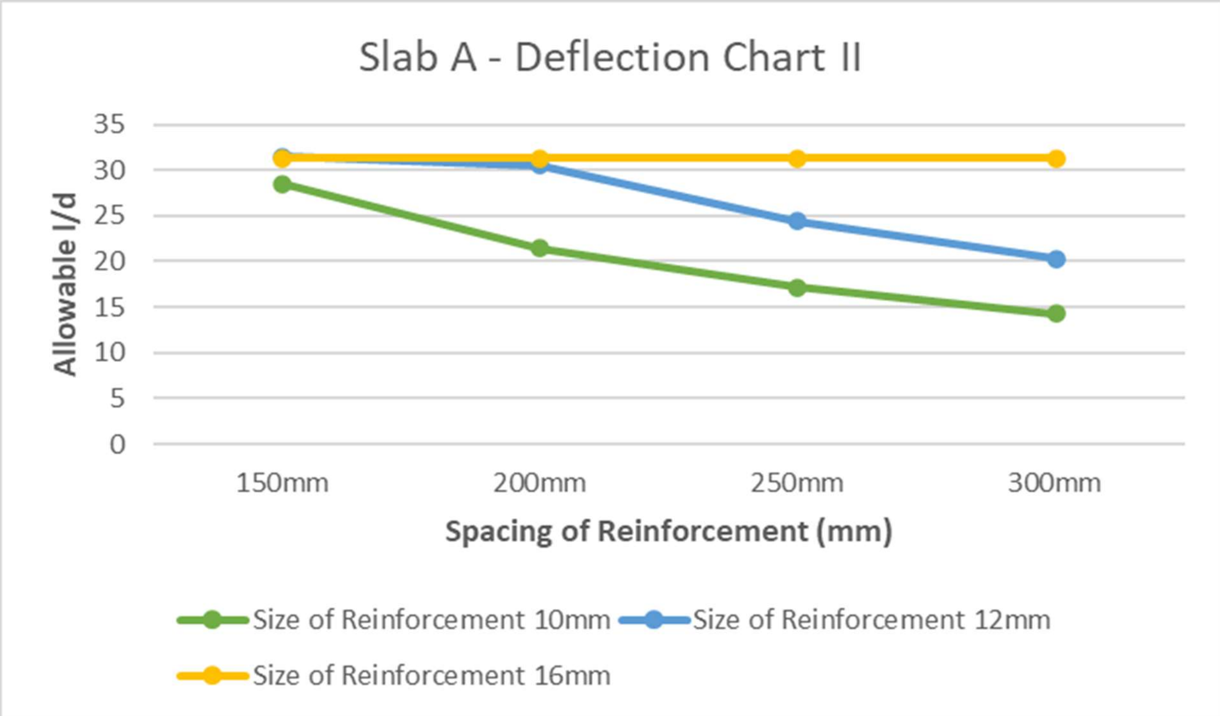


**Figure 4.4**: Deflection chart II for 150mm slab

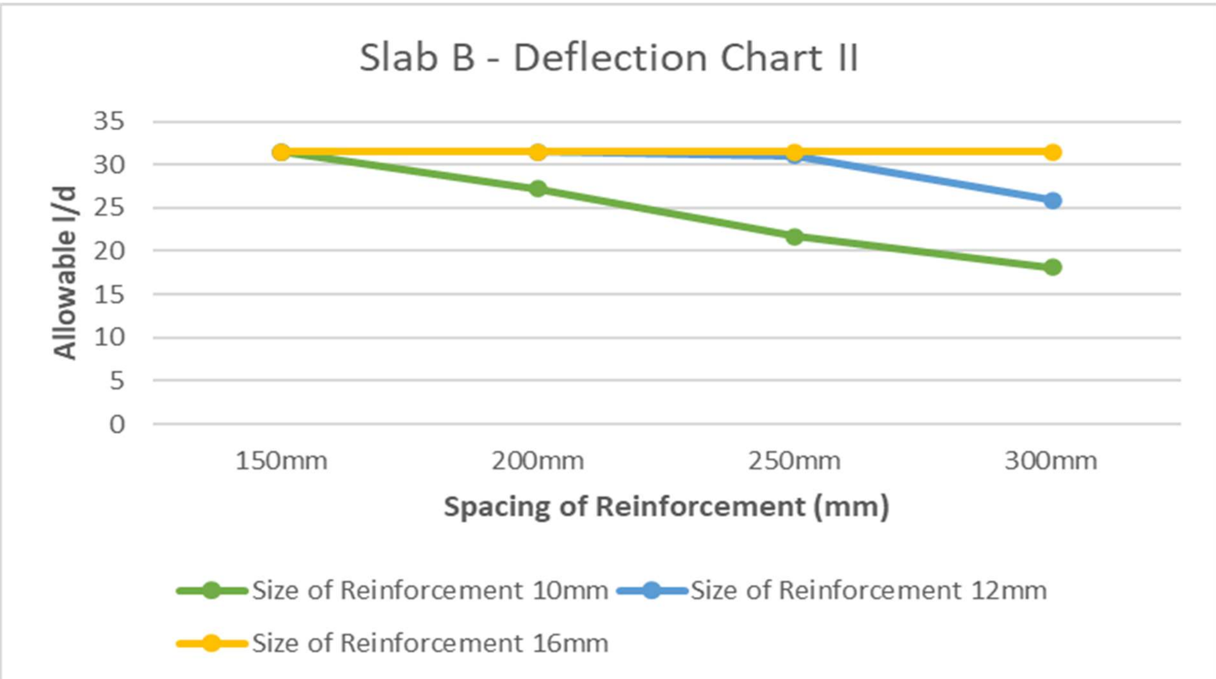


**Figure 4.5**: Deflection chart II for 175mm slab

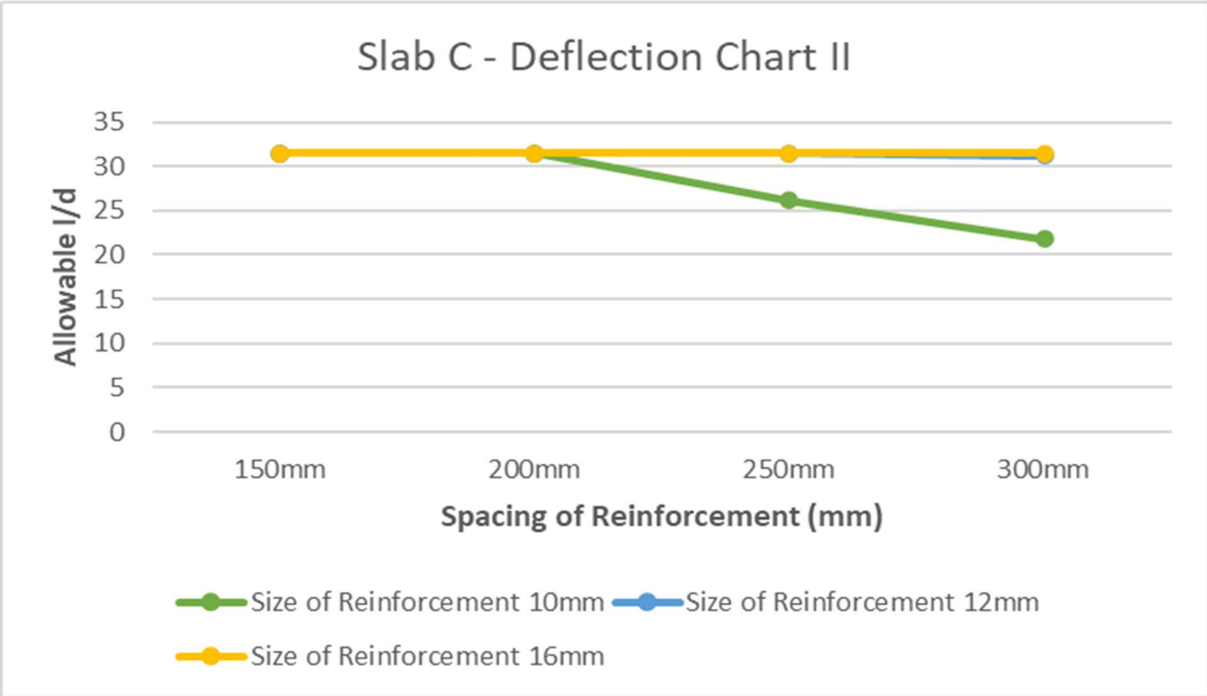


**Figure 4.6**: Deflection chart II for 200mm slab

The behaviour of all three slabs as regards bar spacing and size are the same. As is seen from the graph, increasing the spacing between bars leads to an equivalent decrease in the allowable span/depth ratio. In other words, the likelihood of failing the deflection check increases. On the other hand, increasing the size of the bars leads to an increment in the value of the results. The deflection value also tends to be more stable/constant as the bar size increases.

**4.3 CRACK WIDTH RESULTS**

The same design information used to design the slab and check for deflection was used to analyse the slab and get the bending moments before calculating the crack width. The results are presented below.

**Slab A**

Slab thickness; H = 150mm

Bending Moment; Ms = 11.9KN/m

**Table 4.4: Crack Width Values in mm for H = 150mm**

| **Spacing of Reinforcements (mm)** | | **10** | | | | **12** | | | | **16** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Spacing of Reinforcements (mm)** | | | | | | | | | | | |
| **S/N** | **Concrete Grade (N/mm²)** | **150** | **200** | **250** | **300** | **150** | **200** | **250** | **300** | **150** | **200** | **250** | **300** |
| 1 | 15 | 0.138 | 0.188 | 0.240 | 0.292 | 0.103 | 0.140 | 0.178 | 0.215 | 0.067 | 0.089 | 0.113 | 0.136 |
| 2 | 20 | 0.137 | 0.187 | 0.239 | 0.291 | 0.102 | 0.139 | 0.177 | 0.214 | 0.067 | 0.089 | 0.112 | 0135 |
| 3 | 25 | 0.136 | 0.186 | 0.238 | 0.290 | 0.102 | 0.138 | 0.176 | 0.214 | 0.066 | 0.088 | 0.111 | 0.134 |
| 4 | 30 | 0.135 | 0.185 | 0.237 | 0.289 | 0.101 | 0.138 | 0.175 | 0.213 | 0.066 | 0.088 | 0.111 | 0.134 |
| 5 | 35 | 0.135 | 0.185 | 0.236 | 0.288 | 0.100 | 0.137 | 0.174 | 0.212 | 0.065 | 0.087 | 0.110 | 0.133 |
| 6 | 40 | 0.134 | 0.184 | 0.235 | 0.287 | 0.100 | 0.136 | 0.174 | 0.211 | 0.065 | 0.087 | 0.110 | 0.133 |
| 7 | 45 | 0.134 | 0.183 | 0.235 | 0.286 | 0.100 | 0.136 | 0.173 | 0.211 | 0.064 | 0.086 | 0.109 | 0.132 |

**Slab B**

Slab thickness; H = 175mm

Bending Moment; Ms = 11.8KN/m

**Table 4.5: Table 4.4: Crack Width Values in mm for H = 175mm**

| Spacing of Reinforcements (mm) | | 10 | | | | 12 | | | | 16 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Spacing of Reinforcements (mm) | | | | | | | | | | | |
| **S/N** | **Concrete Grade ($N/mm^2$)** | **150** | **200** | **250** | **300** | **150** | **200** | **250** | **300** | **150** | **200** | **250** | **300** |
| 1 | 15 | 0.087 | 0.119 | 0.151 | 0.184 | 0.066 | 0.090 | 0.114 | 0.138 | 0.044 | 0.059 | 0.074 | 0.090 |
| 2 | 20 | 0.086 | 0.118 | 0.150 | 0.182 | 0.066 | 0.089 | 0.113 | 0.137 | 0.044 | 0.058 | 0.074 | 0.089 |
| 3 | 25 | 0.086 | 0.117 | 0.149 | 0.181 | 0.065 | 0.089 | 0.113 | 0.136 | 0.043 | 0.058 | 0.073 | 0.088 |
| 4 | 30 | 0.085 | 0.116 | 0.148 | 0.180 | 0.065 | 0.088 | 0.112 | 0.136 | 0.043 | 0.057 | 0.073 | 0.088 |
| 5 | 35 | 0.084 | 0.115 | 0.147 | 0.179 | 0.064 | 0.087 | 0.111 | 0.135 | 0.043 | 0.057 | 0.072 | 0.087 |
| 6 | 40 | 0.084 | 0.115 | 0.147 | 0.178 | 0.064 | 0.087 | 0.110 | 0.134 | 0.042 | 0.057 | 0.072 | 0.087 |
| 7 | 45 | 0.083 | 0.114 | 0.146 | 0.177 | 0.063 | 0.086 | 0.110 | 0.133 | 0.042 | 0.056 | 0.071 | 0.086 |

**Slab C**

Slab thickness; H = 200mm

Bending Moment; Ms = 11.6KN/m

**Table 4.6: Table 4.4: Crack Width Values in mm for H = 200mm**

| Spacing of Reinforcements (mm) | | 10 | | | | 12 | | | | 16 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Spacing of Reinforcements (mm) | | | | | | | | | | | |
| **S/N** | **Concrete Grade (N/mm²)** | **150** | **200** | **250** | **300** | **150** | **200** | **250** | **300** | **150** | **200** | **250** | **300** |
| 1 | 15 | 0.047 | 0.062 | 0.077 | 0.091 | 0.038 | 0.050 | 0.062 | 0.073 | 0.027 | 0.036 | 0.044 | 0.052 |
| 2 | 20 | 0.046 | 0.061 | 0.075 | 0.089 | 0.037 | 0.049 | 0.061 | 0.072 | 0.027 | 0.035 | 0.043 | 0.051 |
| 3 | 25 | 0.046 | 0.060 | 0.074 | 0.088 | 0.037 | 0.049 | 0.060 | 0.071 | 0.026 | 0.035 | 0.043 | 0.051 |
| 4 | 30 | 0.045 | 0.059 | 0.073 | 0.087 | 0.036 | 0.048 | 0.059 | 0.070 | 0.026 | 0.034 | 0.042 | 0.050 |
| 5 | 35 | 0.044 | 0.059 | 0.072 | 0.086 | 0.036 | 0.047 | 0.059 | 0.069 | 0.026 | 0.034 | 0.042 | 0.049 |
| 6 | 40 | 0.044 | 0.058 | 0.071 | 0.085 | 0.035 | 0.047 | 0.058 | 0.680 | 0.025 | 0.033 | 0.041 | 0.049 |
| 7 | 45 | 0.043 | 0.057 | 0.071 | 0.084 | 0.035 | 0.046 | 0.057 | 0.068 | 0.025 | 0,033 | 0.041 | 0.048 |

### 4.3.1 Analysis

The results from the calculations are analysed under two headings: effects of concrete grade and steel reinforcements in slabs of different thickness.

### 4.3.2 Effects of concrete grade and thickness

The crack width values based on change in concrete grade for 10mm bars was plotted. They can be seen below.

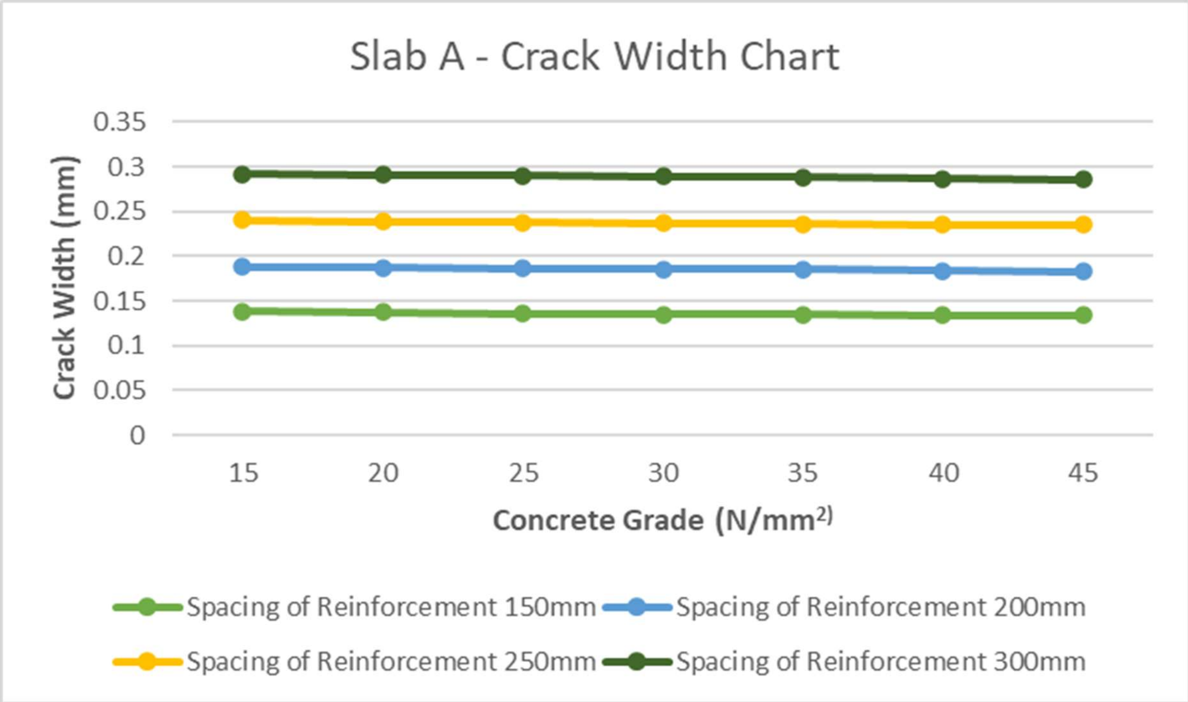


**Figure 4.7:** Crack width values for slab A, H=150mm

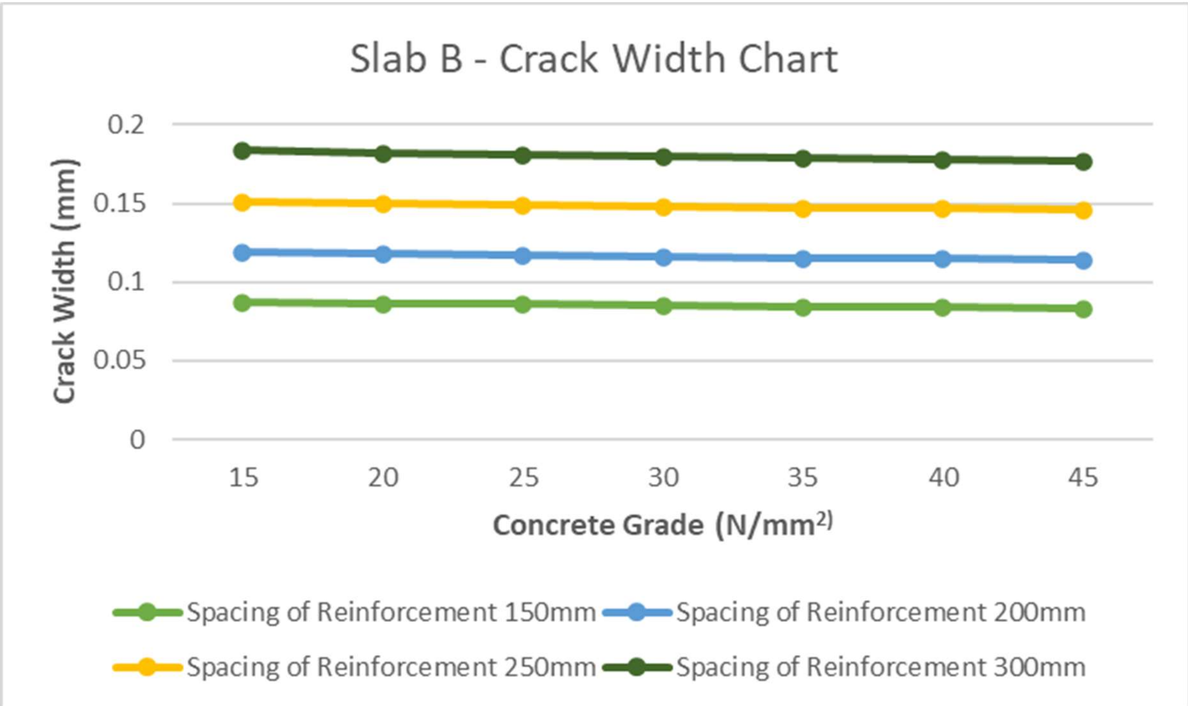


**Figure 4.8:** Crack width values for slab B, H=175mm

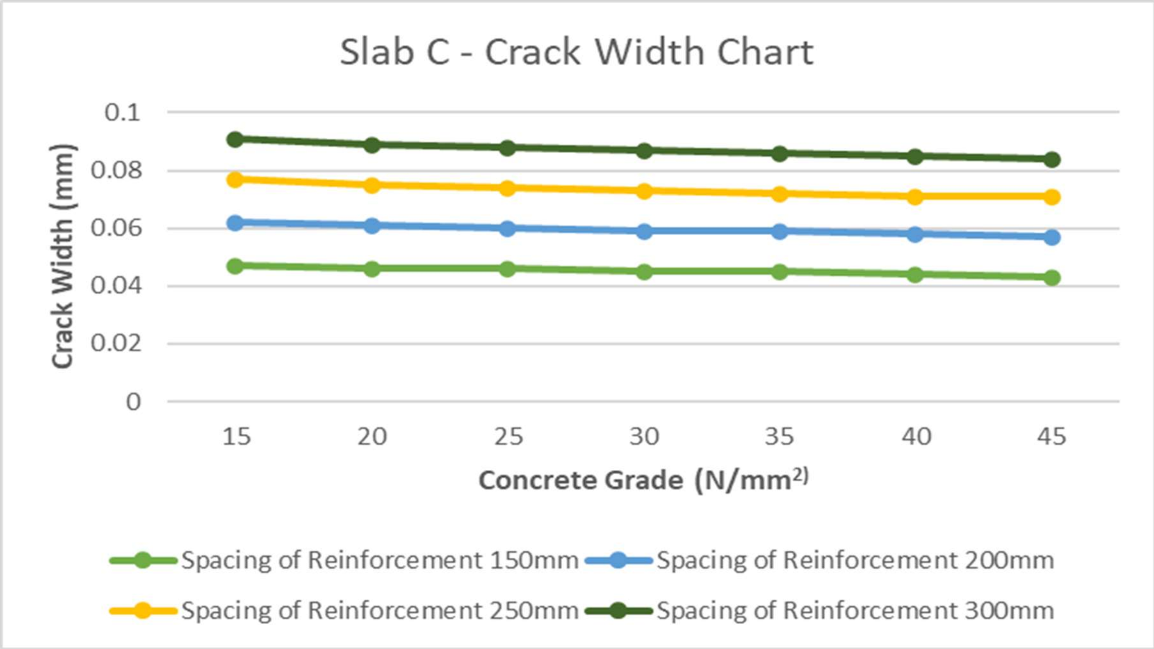


**Figure 4.9**: Crack width values for slab C, H=200mm

It can be seen from both the graph and the table of values that the crack width only decreases slightly when the compressive strength of the concrete is increased. The percentage increase ranges from 0 to 0.8%., an almost constant value. These results agree with the study done by D'Antino T, Pisani M.A. (2021) i.e that concrete grade has little effect on the value of deflection and crack width.

### 4.3.3 Effects of steel reinforcements (bar size and spacing) and thickness

The crack width values for concrete grade 15 were visualised on graphs to aid further analysis.

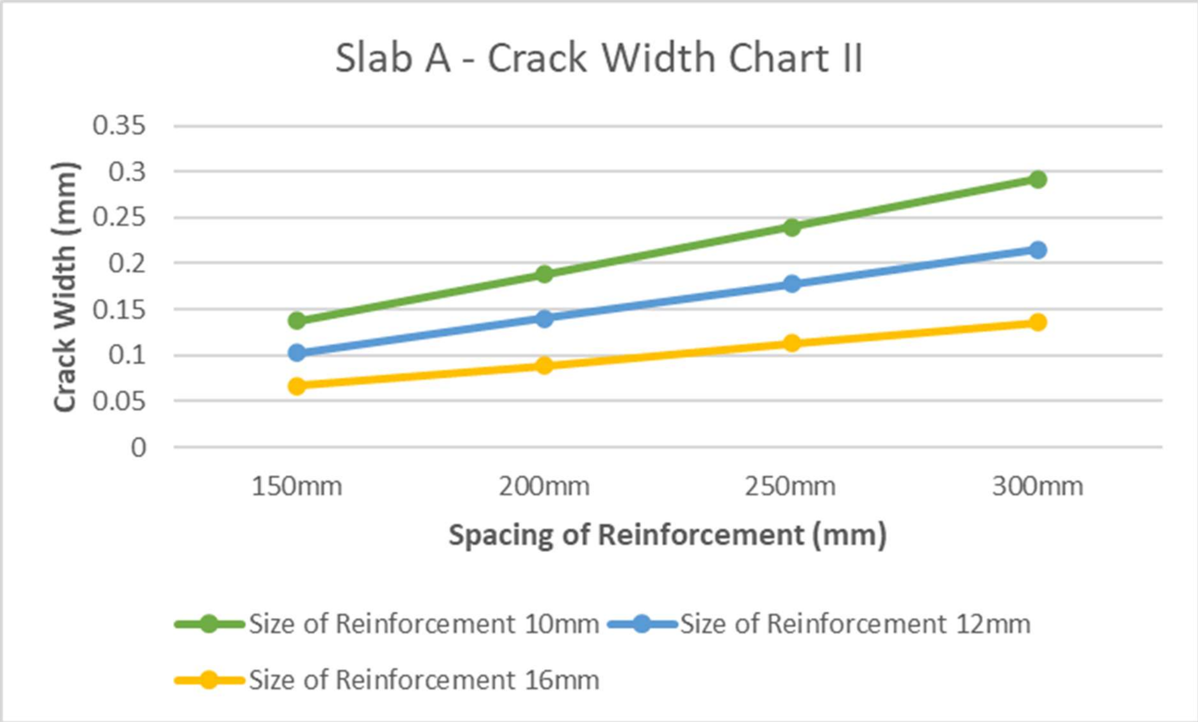


**Figure 4.10**: Crack width values (11) for slab A, H=150mm

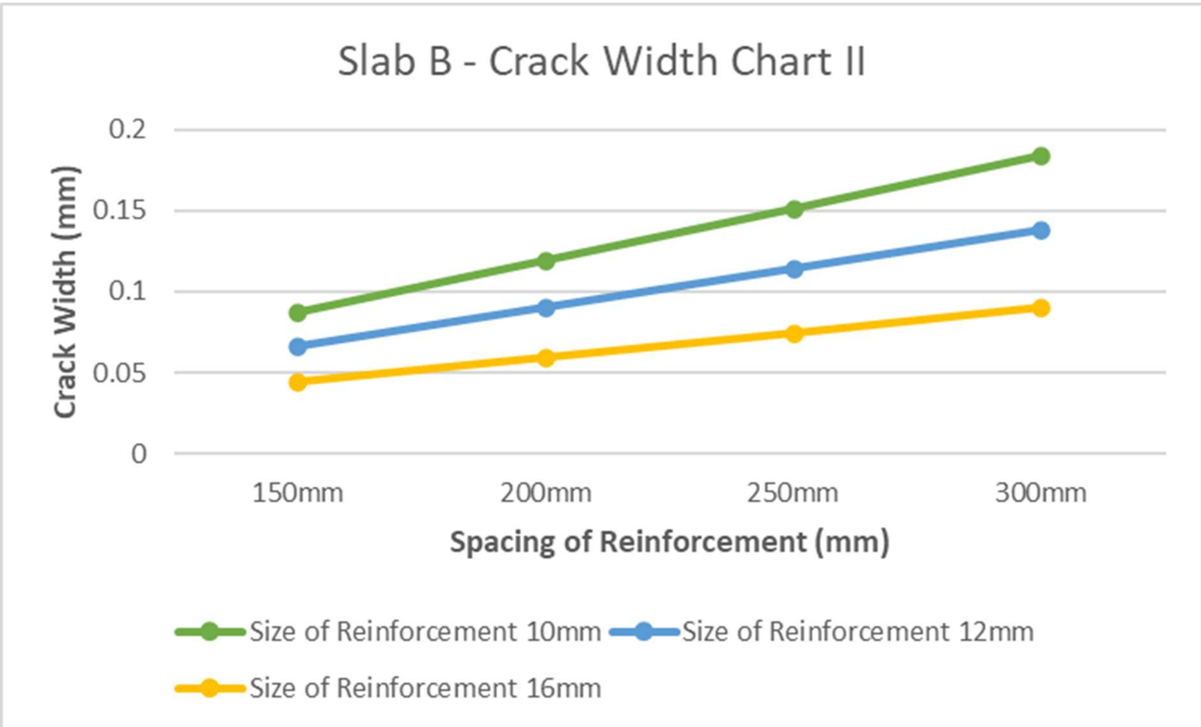


**Figure 4.11**: Crack width values (11) for slab B, H=175mm

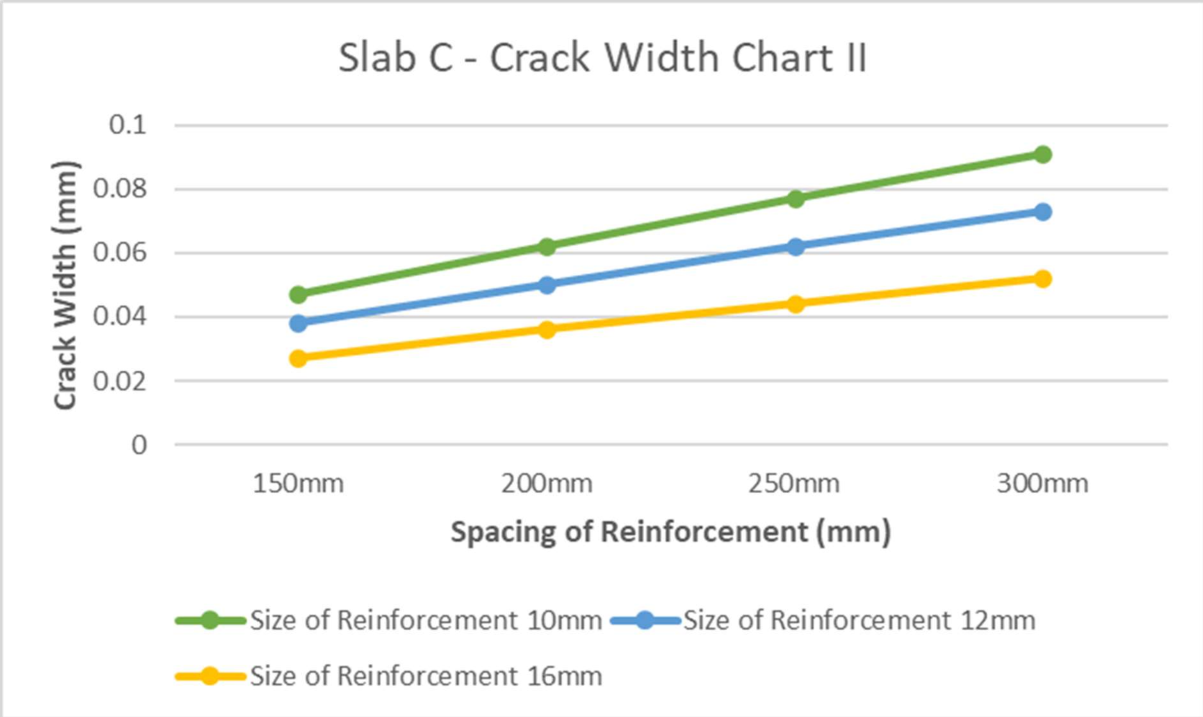


**Figure 4.12:** Crack width values (II) for slab C, H=200mm

Like is seen on the graph, the crack width becomes wider as the spacing between bars increases and becomes narrower as the diameter of the bar increases. In slab A, as the bar spacing goes from 150mm to 200mm, from 200mm to 250mm and 250mm to 300mm, the crack width also increases by 36%, 27% and 21% respectively. The crack width decreases by 34% and 54% as the bar size increases from 10mm to 12mm and from 12mm to 16mm respectively.

In slabs B and C, the percentage increase and decrease in crack width are roughly the same. Although, the cracks get narrower with increasing thickness. The result of this research agrees with the work of previous authors on related topics i.e. bar size and spacing (amount of reinforcement) play a notable role in crack width in concrete.

# CHAPTER FIVE

# CONCLUSION AND RECOMMENDATION

## 5.1 CONCLUSION

Research has been carried out to investigate the effects of concrete thickness on deflection and cracking in concrete slabs under varying design conditions. The following conclusions were made from the analysis of the results;

1. Thickness of the concrete element: As the thickness increases, the allowable span/depth ratio increases. That is, the slab is less likely to fail deflection check at higher thickness. For cracking, as the concrete thickness increases, the crack width becomes smaller. However, from the analysis it was observed that thickness affects crack width more than it does for deflection. Average increase in allowable span/depth for different slabs was 13%. For the crack width, there was an average of 41% change in the values as the thickness was changed. Higher thickness of the slab also resulted in stable values for deflection and crack width despite changing parameters.
2. Effects of concrete grade on deflection and crack width characteristics: after analysing the results, it was found that concrete grade plays a much more significant role on deflection than it does on cracking. As is seen in chapter four, concrete grade caused an average of 17% increase in the allowable span/depth values. However, in the evaluation of the crack width, the maximum change brought upon by change in the compressive strength of concrete was just 0.8%. It was also found that the design failed the deflection checks at concrete grades 15, 20 and 25. However, the higher the depth of the slab, the propensity for failure decreased.

3. Effects of bar size on crack and deflection values: Larger bars resulted in more acceptable values for both crack width and deflection. For deflection, larger bars resulted in stable deflection values despite the bar spacing.
4. Effects of bar spacing on crack and deflection: Increasing the spacing between bars was found to make slabs more susceptible to deflection and result in wider crack widths.

## 5.2 RECOMMENDATION

Based on the findings above, it is recommended that;

1. To aid in both deflection and crack control, a minimum of 12mm bars and at most 250mm spacing should be provided for slabs.
2. For residential buildings, a concrete grade of 25 and 30 can be used since the compressive strength has little effect on serviceability issues such as deflection and cracking. However, if a slab of 150mm thickness is chosen, the concrete grade used should not be less than $30N/mm^2$. This is because lower concrete grades were found to be more susceptible to deflection in slabs of this thickness. The slab is also less likely to fail serviceability checks at higher concrete grades.
3. As discussed in chapter three under limitations of the study, the effects of creep and shrinkage are not considered in the equations and formulas used for calculations. However, it is a well-known fact that these properties of concrete contribute to deflection and cracking in concrete slabs. It is recommended that this topic be expanded to include the effects of creep and shrinkage in the calculations. In this way, more accurate deductions can be made on the behaviour of reinforced concrete slabs with respect to deflection and cracking.

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## APPENDIX

## (Calculation Summary)

## TEST 1

## RC slab design in accordance with EN1992-1-1:2004 incorporating corrigendum January 2008 and the UK national annex

Tedds calculation version 1.0.18

### Design summary

| Description | Unit | Provided | Required | Utilisation | Result |
|---|---|---|---|---|---|
| **Short span** | | | | | |
| Reinf. at midspan | $mm^2/m$ | 524 | 385 | 0.735 | PASS |
| Bar spacing at midspan | mm | 150 | 271 | 0.554 | PASS |
| Reinf. at support | $mm^2/m$ | 565 | 549 | 0.972 | PASS |
| Bar spacing at support | mm | 200 | 197 | 1.017 | FAIL |
| Shear at cont. supp | kN/m | 49.6 | 41.2 | 0.831 | PASS |
| Shear at discont. supp | kN/m | 44.1 | 36.6 | 0.828 | PASS |
| Deflection ratio | | 43.48 | 28.55 | 1.523 | FAIL |
| **Long span** | | | | | |
| Reinf. at midspan | $mm^2/m$ | 393 | 300 | 0.763 | PASS |
| Bar spacing at midspan | mm | 200 | 262 | 0.764 | PASS |
| Reinf. at support | $mm^2/m$ | 565 | 429 | 0.758 | PASS |
| Bar spacing at support | mm | 200 | 263 | 0.759 | PASS |
| Shear at cont. supp | kN/m | 46.0 | 39.3 | 0.854 | PASS |
| Shear at discont. supp | kN/m | 41.5 | 36.6 | 0.880 | PASS |
| **Cover** | | | | | |
| Min cover top | mm | 30 | 22 | 0.733 | PASS |
| Min cover bottom | mm | 30 | 20 | 0.667 | PASS |

## ; TEST 1.1

## RC slab design in accordance with EN1992-1-1:2004 incorporating corrigendum January 2008 and the UK national annex

Tedds calculation version 1.0.18

### Design summary

| Description | Unit | Provided | Required | Utilisation | Result |
|---|---|---|---|---|---|
| **Short span** | | | | | |
| Reinf. at midspan | $mm^2/m$ | 393 | 385 | 0.980 | PASS |
| Bar spacing at midspan | mm | 200 | 194 | 1.031 | FAIL |
| Reinf. at support | $mm^2/m$ | 565 | 549 | 0.972 | PASS |
| Bar spacing at support | mm | 200 | 197 | 1.017 | FAIL |
| Shear at cont. supp | kN/m | 49.6 | 41.2 | 0.831 | PASS |
| Shear at discont. supp | kN/m | 44.1 | 36.6 | 0.828 | PASS |
| Deflection ratio | | 43.48 | 21.41 | 2.031 | FAIL |
| **Long span** | | | | | |
| Reinf. at midspan | $mm^2/m$ | 393 | 300 | 0.763 | PASS |
| Bar spacing at midspan | mm | 200 | 262 | 0.764 | PASS |
| Reinf. at support | $mm^2/m$ | 565 | 429 | 0.758 | PASS |
| Bar spacing at support | mm | 200 | 263 | 0.759 | PASS |
| Shear at cont. supp | kN/m | 46.0 | 39.3 | 0.854 | PASS |
| Shear at discont. supp | kN/m | 41.5 | 36.6 | 0.880 | PASS |
| **Cover** | | | | | |
| Min cover top | mm | 30 | 22 | 0.733 | PASS |
| Min cover bottom | mm | 30 | 20 | 0.667 | PASS |

## ; TEST 1.2

## RC slab design in accordance with EN1992-1-1:2004 incorporating corrigendum January 2008 and the UK national annex

Tedds calculation version 1.0.18

## Design summary

| Description | Unit | Provided | Required | Utilisation | Result |
|---|---|---|---|---|---|
| **Short span** | | | | | |
| Reinf. at midspan | mm²/m | 314 | 385 | 1.225 | FAIL |
| Bar spacing at midspan | mm | 250 | 188 | 1.331 | FAIL |
| Reinf. at support | mm²/m | 565 | 549 | 0.972 | PASS |
| Bar spacing at support | mm | 200 | 197 | 1.017 | FAIL |
| Shear at cont. supp | kN/m | 49.6 | 41.2 | 0.831 | PASS |
| Shear at discont. supp | kN/m | 44.1 | 36.6 | 0.828 | PASS |
| Deflection ratio | | 43.48 | 17.13 | 2.538 | FAIL |
| **Long span** | | | | | |
| Reinf. at midspan | mm²/m | 393 | 300 | 0.763 | PASS |
| Bar spacing at midspan | mm | 200 | 262 | 0.764 | PASS |
| Reinf. at support | mm²/m | 565 | 429 | 0.758 | PASS |
| Bar spacing at support | mm | 200 | 263 | 0.759 | PASS |
| Shear at cont. supp | kN/m | 46.0 | 39.3 | 0.854 | PASS |
| Shear at discont. supp | kN/m | 41.5 | 36.6 | 0.880 | PASS |
| **Cover** | | | | | |
| Min cover top | mm | 30 | 22 | 0.733 | PASS |
| Min cover bottom | mm | 30 | 20 | 0.667 | PASS |

## ; TEST 1.3

### RC slab design in accordance with EN1992-1-1:2004 incorporating corrigendum January 2008 and the UK national annex

Tedds calculation version 1.0.18

## Design summary

| Description | Unit | Provided | Required | Utilisation | Result |
|---|---|---|---|---|---|
| **Short span** | | | | | |
| Reinf. at midspan | mm²/m | 262 | 385 | 1.470 | FAIL |
| Bar spacing at midspan | mm | 300 | 188 | 1.597 | FAIL |
| Reinf. at support | mm²/m | 565 | 549 | 0.972 | PASS |
| Bar spacing at support | mm | 200 | 197 | 1.017 | FAIL |
| Shear at cont. supp | kN/m | 49.6 | 41.2 | 0.831 | PASS |
| Shear at discont. supp | kN/m | 44.1 | 36.6 | 0.828 | PASS |
| Deflection ratio | | 43.48 | 14.27 | 3.046 | FAIL |
| **Long span** | | | | | |
| Reinf. at midspan | mm²/m | 393 | 300 | 0.763 | PASS |
| Bar spacing at midspan | mm | 200 | 262 | 0.764 | PASS |
| Reinf. at support | mm²/m | 565 | 429 | 0.758 | PASS |
| Bar spacing at support | mm | 200 | 263 | 0.759 | PASS |
| Shear at cont. supp | kN/m | 46.0 | 39.3 | 0.854 | PASS |
| Shear at discont. supp | kN/m | 41.5 | 36.6 | 0.880 | PASS |
| **Cover** | | | | | |
| Min cover top | mm | 30 | 22 | 0.733 | PASS |
| Min cover bottom | mm | 30 | 20 | 0.667 | PASS |

## ; TEST 2

### RC slab design in accordance with EN1992-1-1:2004 incorporating corrigendum January 2008 and the UK national annex

Tedds calculation version 1.0.18

## Design summary

| Description | Unit | Provided | Required | Utilisation | Result |
|---|---|---|---|---|---|
| **Short span** | | | | | |
| Reinf. at midspan | mm²/m | 524 | 373 | 0.712 | PASS |
| Bar spacing at midspan | mm | 150 | 278 | 0.540 | PASS |
| Reinf. at support | mm²/m | 565 | 522 | 0.923 | PASS |
| Bar spacing at support | mm | 200 | 212 | 0.944 | PASS |

| Description | Unit | Provided | Required | Utilisation | Result |
|---|---|---|---|---|---|
| Shear at cont. supp | kN/m | 54.5 | 41.2 | 0.755 | PASS |
| Shear at discont. supp | kN/m | 48.6 | 36.6 | 0.753 | PASS |
| Deflection ratio | | 43.48 | 33.88 | 1.283 | FAIL |
| **Long span** | | | | | |
| Reinf. at midspan | mm$^2$/m | 393 | 292 | 0.743 | PASS |
| Bar spacing at midspan | mm | 200 | 268 | 0.746 | PASS |
| Reinf. at support | mm$^2$/m | 565 | 411 | 0.726 | PASS |
| Bar spacing at support | mm | 200 | 273 | 0.732 | PASS |
| Shear at cont. supp | kN/m | 50.6 | 39.3 | 0.776 | PASS |
| Shear at discont. supp | kN/m | 45.7 | 36.6 | 0.800 | PASS |
| **Cover** | | | | | |
| Min cover top | mm | 30 | 22 | 0.733 | PASS |
| Min cover bottom | mm | 30 | 20 | 0.667 | PASS |

## ; TEST 1.3

## RC slab design in accordance with EN1992-1-1:2004 incorporating corrigendum January 2008 and the UK national annex

Tedds calculation version 1.0.18

## Design summary

| Description | Unit | Provided | Required | Utilisation | Result |
|---|---|---|---|---|---|
| **Short span** | | | | | |
| Reinf. at midspan | mm$^2$/m | 393 | 373 | 0.949 | PASS |
| Bar spacing at midspan | mm | 200 | 204 | 0.981 | PASS |
| Reinf. at support | mm$^2$/m | 565 | 522 | 0.923 | PASS |
| Bar spacing at support | mm | 200 | 212 | 0.944 | PASS |
| Shear at cont. supp | kN/m | 54.5 | 41.2 | 0.755 | PASS |
| Shear at discont. supp | kN/m | 48.6 | 36.6 | 0.753 | PASS |
| Deflection ratio | | 43.48 | 25.41 | 1.711 | FAIL |
| **Long span** | | | | | |
| Reinf. at midspan | mm$^2$/m | 393 | 292 | 0.743 | PASS |
| Bar spacing at midspan | mm | 200 | 268 | 0.746 | PASS |
| Reinf. at support | mm$^2$/m | 565 | 411 | 0.726 | PASS |
| Bar spacing at support | mm | 200 | 273 | 0.732 | PASS |
| Shear at cont. supp | kN/m | 50.6 | 39.3 | 0.776 | PASS |
| Shear at discont. supp | kN/m | 45.7 | 36.6 | 0.800 | PASS |
| **Cover** | | | | | |
| Min cover top | mm | 30 | 22 | 0.733 | PASS |
| Min cover bottom | mm | 30 | 20 | 0.667 | PASS |

## ; TEST 1.3

## RC slab design in accordance with EN1992-1-1:2004 incorporating corrigendum January 2008 and the UK national annex

Tedds calculation version 1.0.18

## Design summary

| Description | Unit | Provided | Required | Utilisation | Result |
|---|---|---|---|---|---|
| **Short span** | | | | | |
| Reinf. at midspan | mm$^2$/m | 314 | 373 | 1.186 | FAIL |
| Bar spacing at midspan | mm | 250 | 188 | 1.331 | FAIL |
| Reinf. at support | mm$^2$/m | 565 | 522 | 0.923 | PASS |
| Bar spacing at support | mm | 200 | 212 | 0.944 | PASS |
| Shear at cont. supp | kN/m | 54.5 | 41.2 | 0.755 | PASS |
| Shear at discont. supp | kN/m | 48.6 | 36.6 | 0.753 | PASS |
| Deflection ratio | | 43.48 | 20.33 | 2.139 | FAIL |
| **Long span** | | | | | |
| Reinf. at midspan | mm$^2$/m | 393 | 292 | 0.743 | PASS |
| Bar spacing at midspan | mm | 200 | 268 | 0.746 | PASS |

| Description | Unit | Provided | Required | Utilisation | Result |
|---|---|---|---|---|---|
| Reinf. at support | mm$^2$/m | 565 | 411 | 0.726 | PASS |
| Bar spacing at support | mm | 200 | 273 | 0.732 | PASS |
| Shear at cont. supp | kN/m | 50.6 | 39.3 | 0.776 | PASS |
| Shear at discont. supp | kN/m | 45.7 | 36.6 | 0.800 | PASS |
| **Cover** | | | | | |
| Min cover top | mm | 30 | 22 | 0.733 | PASS |
| Min cover bottom | mm | 30 | 20 | 0.667 | PASS |

## ; TEST 1.3

## RC slab design in accordance with EN1992-1-1:2004 incorporating corrigendum January 2008 and the UK national annex

Tedds calculation version 1.0.18

## Design summary

| Description | Unit | Provided | Required | Utilisation | Result |
|---|---|---|---|---|---|
| **Short span** | | | | | |
| Reinf. at midspan | mm$^2$/m | 262 | 373 | 1.423 | FAIL |
| Bar spacing at midspan | mm | 300 | 188 | 1.597 | FAIL |
| Reinf. at support | mm$^2$/m | 565 | 522 | 0.923 | PASS |
| Bar spacing at support | mm | 200 | 212 | 0.944 | PASS |
| Shear at cont. supp | kN/m | 54.5 | 41.2 | 0.755 | PASS |
| Shear at discont. supp | kN/m | 48.6 | 36.6 | 0.753 | PASS |
| Deflection ratio | | 43.48 | 16.94 | 2.567 | FAIL |
| **Long span** | | | | | |
| Reinf. at midspan | mm$^2$/m | 393 | 292 | 0.743 | PASS |
| Bar spacing at midspan | mm | 200 | 268 | 0.746 | PASS |
| Reinf. at support | mm$^2$/m | 565 | 411 | 0.726 | PASS |
| Bar spacing at support | mm | 200 | 273 | 0.732 | PASS |
| Shear at cont. supp | kN/m | 50.6 | 39.3 | 0.776 | PASS |
| Shear at discont. supp | kN/m | 45.7 | 36.6 | 0.800 | PASS |
| **Cover** | | | | | |
| Min cover top | mm | 30 | 22 | 0.733 | PASS |
| Min cover bottom | mm | 30 | 20 | 0.667 | PASS |

## ; TEST 1.3

## RC slab design in accordance with EN1992-1-1:2004 incorporating corrigendum January 2008 and the UK national annex

Tedds calculation version 1.0.18

## Design summary

| Description | Unit | Provided | Required | Utilisation | Result |
|---|---|---|---|---|---|
| **Short span** | | | | | |
| Reinf. at midspan | mm$^2$/m | 377 | 315 | 0.834 | PASS |
| Bar spacing at midspan | mm | 300 | 236 | 1.270 | FAIL |
| Reinf. at support | mm$^2$/m | 565 | 431 | 0.762 | PASS |
| Bar spacing at support | mm | 200 | 259 | 0.772 | PASS |
| Shear at cont. supp | kN/m | 62.2 | 43.1 | 0.692 | PASS |
| Shear at discont. supp | kN/m | 55.4 | 38.3 | 0.690 | PASS |
| Deflection ratio | | 35.97 | 28.90 | 1.245 | FAIL |
| **Long span** | | | | | |
| Reinf. at midspan | mm$^2$/m | 393 | 246 | 0.626 | PASS |
| Bar spacing at midspan | mm | 200 | 300 | 0.667 | PASS |
| Reinf. at support | mm$^2$/m | 565 | 333 | 0.588 | PASS |
| Bar spacing at support | mm | 200 | 300 | 0.667 | PASS |
| Shear at cont. supp | kN/m | 58.6 | 41.1 | 0.702 | PASS |
| Shear at discont. supp | kN/m | 52.2 | 38.3 | 0.733 | PASS |
| **Cover** | | | | | |

| Description | Unit | Provided | Required | Utilisation | Result |
|---|---|---|---|---|---|
| Min cover top | mm | 30 | 22 | 0.733 | PASS |
| Min cover bottom | mm | 30 | 22 | 0.733 | PASS |

## ; TEST 1.3

**RC slab design in accordance with EN1992-1-1:2004 incorporating corrigendum January 2008 and the UK national annex**

Tedds calculation version 1.0.18

## Design summary

| Description | Unit | Provided | Required | Utilisation | Result |
|---|---|---|---|---|---|
| **Short span** | | | | | |
| Reinf. at midspan | mm$^2$/m | 452 | 315 | 0.695 | PASS |
| Bar spacing at midspan | mm | 250 | 280 | 0.892 | PASS |
| Reinf. at support | mm$^2$/m | 565 | 431 | 0.762 | PASS |
| Bar spacing at support | mm | 200 | 259 | 0.772 | PASS |
| Shear at cont. supp | kN/m | 62.2 | 43.1 | 0.692 | PASS |
| Shear at discont. supp | kN/m | 55.4 | 38.3 | 0.690 | PASS |
| Deflection ratio | | 35.97 | 34.68 | 1.037 | FAIL |
| **Long span** | | | | | |
| Reinf. at midspan | mm$^2$/m | 393 | 246 | 0.626 | PASS |
| Bar spacing at midspan | mm | 200 | 300 | 0.667 | PASS |
| Reinf. at support | mm$^2$/m | 565 | 333 | 0.588 | PASS |
| Bar spacing at support | mm | 200 | 300 | 0.667 | PASS |
| Shear at cont. supp | kN/m | 58.6 | 41.1 | 0.702 | PASS |
| Shear at discont. supp | kN/m | 52.2 | 38.3 | 0.733 | PASS |
| **Cover** | | | | | |
| Min cover top | mm | 30 | 22 | 0.733 | PASS |
| Min cover bottom | mm | 30 | 22 | 0.733 | PASS |

## ; TEST 1.3

**RC slab design in accordance with EN1992-1-1:2004 incorporating corrigendum January 2008 and the UK national annex**

Tedds calculation version 1.0.18

## Design summary

| Description | Unit | Provided | Required | Utilisation | Result |
|---|---|---|---|---|---|
| **Short span** | | | | | |
| Reinf. at midspan | mm$^2$/m | 565 | 315 | 0.556 | PASS |
| Bar spacing at midspan | mm | 200 | 300 | 0.667 | PASS |
| Reinf. at support | mm$^2$/m | 565 | 431 | 0.762 | PASS |
| Bar spacing at support | mm | 200 | 259 | 0.772 | PASS |
| Shear at cont. supp | kN/m | 62.2 | 43.1 | 0.692 | PASS |
| Shear at discont. supp | kN/m | 55.4 | 38.3 | 0.690 | PASS |
| Deflection ratio | | 35.97 | 36.17 | 0.995 | PASS |
| **Long span** | | | | | |
| Reinf. at midspan | mm$^2$/m | 393 | 246 | 0.626 | PASS |
| Bar spacing at midspan | mm | 200 | 300 | 0.667 | PASS |
| Reinf. at support | mm$^2$/m | 565 | 333 | 0.588 | PASS |
| Bar spacing at support | mm | 200 | 300 | 0.667 | PASS |
| Shear at cont. supp | kN/m | 58.6 | 41.1 | 0.702 | PASS |
| Shear at discont. supp | kN/m | 52.2 | 38.3 | 0.733 | PASS |
| **Cover** | | | | | |
| Min cover top | mm | 30 | 22 | 0.733 | PASS |
| Min cover bottom | mm | 30 | 22 | 0.733 | PASS |

## ; TEST 1.3

### RC slab design in accordance with EN1992-1-1:2004 incorporating corrigendum January 2008 and the UK national annex

Tedds calculation version 1.0.18

## Design summary

| Description | Unit | Provided | Required | Utilisation | Result |
|---|---|---|---|---|---|
| **Short span** | | | | | |
| Reinf. at midspan | $mm^2/m$ | 754 | 315 | 0.417 | PASS |
| Bar spacing at midspan | mm | 150 | 300 | 0.500 | PASS |
| Reinf. at support | $mm^2/m$ | 565 | 431 | 0.762 | PASS |
| Bar spacing at support | mm | 200 | 259 | 0.772 | PASS |
| Shear at cont. supp | kN/m | 62.2 | 43.1 | 0.692 | PASS |
| Shear at discont. supp | kN/m | 55.4 | 38.3 | 0.690 | PASS |
| Deflection ratio | | 35.97 | 36.17 | 0.995 | PASS |
| **Long span** | | | | | |
| Reinf. at midspan | $mm^2/m$ | 393 | 246 | 0.626 | PASS |
| Bar spacing at midspan | mm | 200 | 300 | 0.667 | PASS |
| Reinf. at support | $mm^2/m$ | 565 | 333 | 0.588 | PASS |
| Bar spacing at support | mm | 200 | 300 | 0.667 | PASS |
| Shear at cont. supp | kN/m | 58.6 | 41.1 | 0.702 | PASS |
| Shear at discont. supp | kN/m | 52.2 | 38.3 | 0.733 | PASS |
| **Cover** | | | | | |
| Min cover top | mm | 30 | 22 | 0.733 | PASS |
| Min cover bottom | mm | 30 | 22 | 0.733 | PASS |

## ; TEST 1.3

### RC slab design in accordance with EN1992-1-1:2004 incorporating corrigendum January 2008 and the UK national annex

Tedds calculation version 1.0.18

## Design summary

| Description | Unit | Provided | Required | Utilisation | Result |
|---|---|---|---|---|---|
| **Short span** | | | | | |
| Reinf. at midspan | $mm^2/m$ | 754 | 321 | 0.426 | PASS |
| Bar spacing at midspan | mm | 150 | 300 | 0.500 | PASS |
| Reinf. at support | $mm^2/m$ | 565 | 444 | 0.785 | PASS |
| Bar spacing at support | mm | 200 | 252 | 0.795 | PASS |
| Shear at cont. supp | kN/m | 56.6 | 43.1 | 0.761 | PASS |
| Shear at discont. supp | kN/m | 50.3 | 38.3 | 0.760 | PASS |
| Deflection ratio | | 35.97 | 31.48 | 1.143 | FAIL |
| **Long span** | | | | | |
| Reinf. at midspan | $mm^2/m$ | 393 | 249 | 0.635 | PASS |
| Bar spacing at midspan | mm | 200 | 299 | 0.668 | PASS |
| Reinf. at support | $mm^2/m$ | 565 | 341 | 0.603 | PASS |
| Bar spacing at support | mm | 200 | 300 | 0.667 | PASS |
| Shear at cont. supp | kN/m | 53.3 | 41.1 | 0.772 | PASS |
| Shear at discont. supp | kN/m | 47.4 | 38.3 | 0.807 | PASS |
| **Cover** | | | | | |
| Min cover top | mm | 30 | 22 | 0.733 | PASS |
| Min cover bottom | mm | 30 | 22 | 0.733 | PASS |

## ; TEST 1.3

### RC slab design in accordance with EN1992-1-1:2004 incorporating corrigendum January 2008 and the UK national annex

Tedds calculation version 1.0.18

## Design summary

| Description | Unit | Provided | Required | Utilisation | Result |
|---|---|---|---|---|---|
| **Short span** | | | | | |
| Reinf. at midspan | $mm^2/m$ | 452 | 321 | 0.710 | PASS |
| Bar spacing at midspan | mm | 250 | 276 | 0.907 | PASS |
| Reinf. at support | $mm^2/m$ | 565 | 444 | 0.785 | PASS |
| Bar spacing at support | mm | 200 | 252 | 0.795 | PASS |
| Shear at cont. supp | kN/m | 56.6 | 43.1 | 0.761 | PASS |
| Shear at discont. supp | kN/m | 50.3 | 38.3 | 0.760 | PASS |
| Deflection ratio | | 35.97 | 29.56 | 1.217 | FAIL |
| **Long span** | | | | | |
| Reinf. at midspan | $mm^2/m$ | 393 | 249 | 0.635 | PASS |
| Bar spacing at midspan | mm | 200 | 299 | 0.668 | PASS |
| Reinf. at support | $mm^2/m$ | 565 | 341 | 0.603 | PASS |
| Bar spacing at support | mm | 200 | 300 | 0.667 | PASS |
| Shear at cont. supp | kN/m | 53.3 | 41.1 | 0.772 | PASS |
| Shear at discont. supp | kN/m | 47.4 | 38.3 | 0.807 | PASS |
| **Cover** | | | | | |
| Min cover top | mm | 30 | 22 | 0.733 | PASS |
| Min cover bottom | mm | 30 | 22 | 0.733 | PASS |

## ; TEST 1.3

### RC slab design in accordance with EN1992-1-1:2004 incorporating corrigendum January 2008 and the UK national annex

Tedds calculation version 1.0.18

## Design summary

| Description | Unit | Provided | Required | Utilisation | Result |
|---|---|---|---|---|---|
| **Short span** | | | | | |
| Reinf. at midspan | $mm^2/m$ | 452 | 321 | 0.710 | PASS |
| Bar spacing at midspan | mm | 250 | 276 | 0.907 | PASS |
| Reinf. at support | $mm^2/m$ | 565 | 444 | 0.785 | PASS |
| Bar spacing at support | mm | 200 | 252 | 0.795 | PASS |
| Shear at cont. supp | kN/m | 56.6 | 43.1 | 0.761 | PASS |
| Shear at discont. supp | kN/m | 50.3 | 38.3 | 0.760 | PASS |
| Deflection ratio | | 35.97 | 29.56 | 1.217 | FAIL |
| **Long span** | | | | | |
| Reinf. at midspan | $mm^2/m$ | 393 | 249 | 0.635 | PASS |
| Bar spacing at midspan | mm | 200 | 299 | 0.668 | PASS |
| Reinf. at support | $mm^2/m$ | 565 | 341 | 0.603 | PASS |
| Bar spacing at support | mm | 200 | 300 | 0.667 | PASS |
| Shear at cont. supp | kN/m | 53.3 | 41.1 | 0.772 | PASS |
| Shear at discont. supp | kN/m | 47.4 | 38.3 | 0.807 | PASS |
| **Cover** | | | | | |
| Min cover top | mm | 30 | 22 | 0.733 | PASS |
| Min cover bottom | mm | 30 | 22 | 0.733 | PASS |

## ; TEST 1.3

### RC slab design in accordance with EN1992-1-1:2004 incorporating corrigendum January 2008 and the UK national annex

Tedds calculation version 1.0.18

## Design summary

| Description | Unit | Provided | Required | Utilisation | Result |
|---|---|---|---|---|---|
| **Short span** | | | | | |
| Reinf. at midspan | $mm^2/m$ | 377 | 321 | 0.852 | PASS |
| Bar spacing at midspan | mm | 300 | 231 | 1.301 | FAIL |
| Reinf. at support | $mm^2/m$ | 565 | 444 | 0.785 | PASS |
| Bar spacing at support | mm | 200 | 252 | 0.795 | PASS |

| Description | Unit | Provided | Required | Utilisation | Result |
|---|---|---|---|---|---|
| Shear at cont. supp | kN/m | 56.6 | 43.1 | 0.761 | PASS |
| Shear at discont. supp | kN/m | 50.3 | 38.3 | 0.760 | PASS |
| Deflection ratio | | 35.97 | 24.63 | 1.460 | FAIL |
| **Long span** | | | | | |
| Reinf. at midspan | $mm^2/m$ | 393 | 249 | 0.635 | PASS |
| Bar spacing at midspan | mm | 200 | 299 | 0.668 | PASS |
| Reinf. at support | $mm^2/m$ | 565 | 341 | 0.603 | PASS |
| Bar spacing at support | mm | 200 | 300 | 0.667 | PASS |
| Shear at cont. supp | kN/m | 53.3 | 41.1 | 0.772 | PASS |
| Shear at discont. supp | kN/m | 47.4 | 38.3 | 0.807 | PASS |
| **Cover** | | | | | |
| Min cover top | mm | 30 | 22 | 0.733 | PASS |
| Min cover bottom | mm | 30 | 22 | 0.733 | PASS |

## ; TEST 1.3

## RC slab design in accordance with EN1992-1-1:2004 incorporating corrigendum January 2008 and the UK national annex

Tedds calculation version 1.0.18

## Design summary

| Description | Unit | Provided | Required | Utilisation | Result |
|---|---|---|---|---|---|
| **Short span** | | | | | |
| Reinf. at midspan | $mm^2/m$ | 377 | 321 | 0.852 | PASS |
| Bar spacing at midspan | mm | 300 | 231 | 1.301 | FAIL |
| Reinf. at support | $mm^2/m$ | 565 | 444 | 0.785 | PASS |
| Bar spacing at support | mm | 200 | 252 | 0.795 | PASS |
| Shear at cont. supp | kN/m | 56.6 | 43.1 | 0.761 | PASS |
| Shear at discont. supp | kN/m | 50.3 | 38.3 | 0.760 | PASS |
| Deflection ratio | | 35.97 | 24.63 | 1.460 | FAIL |
| **Long span** | | | | | |
| Reinf. at midspan | $mm^2/m$ | 393 | 249 | 0.635 | PASS |
| Bar spacing at midspan | mm | 200 | 299 | 0.668 | PASS |
| Reinf. at support | $mm^2/m$ | 565 | 341 | 0.603 | PASS |
| Bar spacing at support | mm | 200 | 300 | 0.667 | PASS |
| Shear at cont. supp | kN/m | 53.3 | 41.1 | 0.772 | PASS |
| Shear at discont. supp | kN/m | 47.4 | 38.3 | 0.807 | PASS |
| **Cover** | | | | | |
| Min cover top | mm | 30 | 22 | 0.733 | PASS |
| Min cover bottom | mm | 30 | 22 | 0.733 | PASS |

## ; TEST 1.3

## RC slab design in accordance with EN1992-1-1:2004 incorporating corrigendum January 2008 and the UK national annex

Tedds calculation version 1.0.18

## Design summary

| Description | Unit | Provided | Required | Utilisation | Result |
|---|---|---|---|---|---|
| **Short span** | | | | | |
| Reinf. at midspan | $mm^2/m$ | 670 | 282 | 0.421 | PASS |
| Bar spacing at midspan | mm | 300 | 300 | 1.000 | PASS |
| Reinf. at support | $mm^2/m$ | 565 | 381 | 0.674 | PASS |
| Bar spacing at support | mm | 200 | 284 | 0.703 | PASS |
| Shear at cont. supp | kN/m | 63.2 | 45.0 | 0.712 | PASS |
| Shear at discont. supp | kN/m | 56.6 | 39.9 | 0.706 | PASS |
| Deflection ratio | | 30.86 | 31.48 | 0.980 | PASS |
| **Long span** | | | | | |
| Reinf. at midspan | $mm^2/m$ | 393 | 221 | 0.562 | PASS |
| Bar spacing at midspan | mm | 200 | 300 | 0.667 | PASS |

| Description | Unit | Provided | Required | Utilisation | Result |
|---|---|---|---|---|---|
| Reinf. at support | mm$^2$/m | 565 | 290 | 0.512 | PASS |
| Bar spacing at support | mm | 200 | 300 | 0.667 | PASS |
| Shear at cont. supp | kN/m | 60.0 | 42.9 | 0.715 | PASS |
| Shear at discont. supp | kN/m | 52.5 | 39.9 | 0.761 | PASS |
| **Cover** | | | | | |
| Min cover top | mm | 30 | 22 | 0.733 | PASS |
| Min cover bottom | mm | 30 | 26 | 0.867 | PASS |

## ; TEST 1.3

### RC slab design in accordance with EN1992-1-1:2004 incorporating corrigendum January 2008 and the UK national annex

Tedds calculation version 1.0.18

## Design summary

| Description | Unit | Provided | Required | Utilisation | Result |
|---|---|---|---|---|---|
| **Short span** | | | | | |
| Reinf. at midspan | mm$^2$/m | 804 | 282 | 0.351 | PASS |
| Bar spacing at midspan | mm | 250 | 300 | 0.833 | PASS |
| Reinf. at support | mm$^2$/m | 565 | 381 | 0.674 | PASS |
| Bar spacing at support | mm | 200 | 284 | 0.703 | PASS |
| Shear at cont. supp | kN/m | 63.2 | 45.0 | 0.712 | PASS |
| Shear at discont. supp | kN/m | 56.6 | 39.9 | 0.706 | PASS |
| Deflection ratio | | 30.86 | 31.48 | 0.980 | PASS |
| **Long span** | | | | | |
| Reinf. at midspan | mm$^2$/m | 393 | 221 | 0.562 | PASS |
| Bar spacing at midspan | mm | 200 | 300 | 0.667 | PASS |
| Reinf. at support | mm$^2$/m | 565 | 290 | 0.512 | PASS |
| Bar spacing at support | mm | 200 | 300 | 0.667 | PASS |
| Shear at cont. supp | kN/m | 60.0 | 42.9 | 0.715 | PASS |
| Shear at discont. supp | kN/m | 52.5 | 39.9 | 0.761 | PASS |
| **Cover** | | | | | |
| Min cover top | mm | 30 | 22 | 0.733 | PASS |
| Min cover bottom | mm | 30 | 26 | 0.867 | PASS |

## ; TEST 1.3

### RC slab design in accordance with EN1992-1-1:2004 incorporating corrigendum January 2008 and the UK national annex

Tedds calculation version 1.0.18

## Design summary

| Description | Unit | Provided | Required | Utilisation | Result |
|---|---|---|---|---|---|
| **Short span** | | | | | |
| Reinf. at midspan | mm$^2$/m | 1005 | 282 | 0.281 | PASS |
| Bar spacing at midspan | mm | 200 | 300 | 0.667 | PASS |
| Reinf. at support | mm$^2$/m | 565 | 381 | 0.674 | PASS |
| Bar spacing at support | mm | 200 | 284 | 0.703 | PASS |
| Shear at cont. supp | kN/m | 63.2 | 45.0 | 0.712 | PASS |
| Shear at discont. supp | kN/m | 56.6 | 39.9 | 0.706 | PASS |
| Deflection ratio | | 30.86 | 31.48 | 0.980 | PASS |
| **Long span** | | | | | |
| Reinf. at midspan | mm$^2$/m | 393 | 221 | 0.562 | PASS |
| Bar spacing at midspan | mm | 200 | 300 | 0.667 | PASS |
| Reinf. at support | mm$^2$/m | 565 | 290 | 0.512 | PASS |
| Bar spacing at support | mm | 200 | 300 | 0.667 | PASS |
| Shear at cont. supp | kN/m | 60.0 | 42.9 | 0.715 | PASS |
| Shear at discont. supp | kN/m | 52.5 | 39.9 | 0.761 | PASS |
| **Cover** | | | | | |
| Min cover top | mm | 30 | 22 | 0.733 | PASS |

| Description | Unit | Provided | Required | Utilisation | Result |
|---|---|---|---|---|---|
| Min cover bottom | mm | 30 | 26 | 0.867 | PASS |

## ; TEST 1.3

**RC slab design in accordance with EN1992-1-1:2004 incorporating corrigendum January 2008 and the UK national annex**

Tedds calculation version 1.0.18

## Design summary

| Description | Unit | Provided | Required | Utilisation | Result |
|---|---|---|---|---|---|
| **Short span** | | | | | |
| Reinf. at midspan | $mm^2/m$ | 1340 | 282 | 0.211 | PASS |
| Bar spacing at midspan | mm | 150 | 300 | 0.500 | PASS |
| Reinf. at support | $mm^2/m$ | 565 | 381 | 0.674 | PASS |
| Bar spacing at support | mm | 200 | 284 | 0.703 | PASS |
| Shear at cont. supp | kN/m | 63.2 | 45.0 | 0.712 | PASS |
| Shear at discont. supp | kN/m | 56.6 | 39.9 | 0.706 | PASS |
| Deflection ratio | | 30.86 | 31.48 | 0.980 | PASS |
| **Long span** | | | | | |
| Reinf. at midspan | $mm^2/m$ | 393 | 221 | 0.562 | PASS |
| Bar spacing at midspan | mm | 200 | 300 | 0.667 | PASS |
| Reinf. at support | $mm^2/m$ | 565 | 290 | 0.512 | PASS |
| Bar spacing at support | mm | 200 | 300 | 0.667 | PASS |
| Shear at cont. supp | kN/m | 60.0 | 42.9 | 0.715 | PASS |
| Shear at discont. supp | kN/m | 52.5 | 39.9 | 0.761 | PASS |
| **Cover** | | | | | |
| Min cover top | mm | 30 | 22 | 0.733 | PASS |
| Min cover bottom | mm | 30 | 26 | 0.867 | PASS |

## ; CRACK WIDTH CALCULATION TO BS8110:PART 2:1985

TEDDS calculation version 1.0.02

### Beam details

Section width; b = **1000** mm; Section depth; h = **150** mm

Applied servicability moment; $M_s$ = **11.9** kNm

### Material details

Characteristic strength of concrete;$f_{cu}$ = **20** N/mm$^2$; Characteristic strength of steel; $f_y$ = **500** N/mm$^2$

Modulus of elasticity of concrete;$E_c$ = **12.0** kN/mm$^2$; Modulus of elasticity of steel; $E_s$ = 200 kN/mm$^2$

### Reinforcement details

Area of reinforcement; $A_s$ = **524** mm$^2$; Diameter of reinforcement; $\phi$ = **10** mm

Reinforcement spacing; S = **150.0** mm; Cover to reinforcement; $c_{min}$ = **30** mm

Average strain at beam soffit; $\varepsilon_m$ = **0.001081**

### Design surface crack width

Design surface crack width; w = **0.137** mm

## ; CRACK WIDTH CALCULATION TO BS8110:PART 2:1985

TEDDS calculation version 1.0.02

**Beam details**

Section width; b = **1000** mm; Section depth; h = **150** mm

Applied servicability moment; $M_s$ = **11.9** kNm

**Material details**

Characteristic strength of concrete; $f_{cu}$ = **20** N/mm$^2$; Characteristic strength of steel; $f_y$ = **500** N/mm$^2$

Modulus of elasticity of concrete; $E_c$ = **12.0** kN/mm$^2$; Modulus of elasticity of steel; $E_s$ = 200 kN/mm$^2$

**Reinforcement details**

Area of reinforcement; $A_s$ = **393** mm$^2$; Diameter of reinforcement; $\phi$ = **10** mm

Reinforcement spacing; S = **200.0** mm; Cover to reinforcement; $c_{min}$ = **30** mm

Average strain at beam soffit; $\varepsilon_m$ = **0.001366**

**Design surface crack width**

Design surface crack width; w = **0.187** mm

## ; CRACK WIDTH CALCULATION TO BS8110:PART 2:1985

TEDDS calculation version 1.0.02

**Beam details**

Section width; b = **1000** mm; Section depth; h = **150** mm

Applied servicability moment; $M_s$ = **11.9** kNm

**Material details**

Characteristic strength of concrete; $f_{cu}$ = **20** N/mm$^2$; Characteristic strength of steel; $f_y$ = **500** N/mm$^2$

Modulus of elasticity of concrete; $E_c$ = **12.0** kN/mm$^2$; Modulus of elasticity of steel; $E_s$ = 200 kN/mm$^2$

**Reinforcement details**

Area of reinforcement; $A_s$ = **314** mm$^2$; Diameter of reinforcement; $\phi$ = **10** mm

Reinforcement spacing; S = **250.0** mm; Cover to reinforcement; $c_{min}$ = **30** mm

Average strain at beam soffit; $\varepsilon_m$ = **0.001645**

**Design surface crack width**

Design surface crack width; w = **0.239** mm

## ; CRACK WIDTH CALCULATION TO BS8110:PART 2:1985

TEDDS calculation version 1.0.02

**Beam details**

Section width; b = **1000** mm; Section depth; h = **175** mm

Applied servicability moment; $M_s$ = **11.8** kNm

**Material details**

Characteristic strength of concrete; $f_{cu}$ = **20** N/mm$^2$; Characteristic strength of steel; $f_y$ = **500** N/mm$^2$

Modulus of elasticity of concrete; $E_c$ = **12.0** kN/mm$^2$; Modulus of elasticity of steel; $E_s$ = 200 kN/mm$^2$

**Reinforcement details**

Area of reinforcement; $A_s$ = **754** mm$^2$; Diameter of reinforcement; $\phi$ = **12** mm

Reinforcement spacing; S = **150.0** mm; Cover to reinforcement; $c_{min}$ = **30** mm

Average strain at beam soffit; $\varepsilon_m$ = **0.000495**

**Design surface crack width**

Design surface crack width; w = **0.066** mm

**<u>; CRACK WIDTH CALCULATION TO BS8110:PART 2:1985</u>**

TEDDS calculation version 1.0.02

**Beam details**

Section width; b = **1000** mm; Section depth; h = **175** mm

Applied servicability moment; $M_s$ = **11.8** kNm

**Material details**

Characteristic strength of concrete; $f_{cu}$ = **20** N/mm$^2$; Characteristic strength of steel; $f_y$ = **500** N/mm$^2$

Modulus of elasticity of concrete; $E_c$ = **12.0** kN/mm$^2$; Modulus of elasticity of steel; $E_s$ = 200 kN/mm$^2$

**Reinforcement details**

Area of reinforcement; $A_s$ = **565** mm$^2$; Diameter of reinforcement; $\phi$ = **12** mm

Reinforcement spacing; S = **200.0** mm; Cover to reinforcement; $c_{min}$ = **30** mm

Average strain at beam soffit; $\varepsilon_m$ = **0.000613**

**Design surface crack width**

Design surface crack width; w = **0.089** mm

**<u>; CRACK WIDTH CALCULATION TO BS8110:PART 2:1985</u>**

TEDDS calculation version 1.0.02

**Beam details**

Section width; b = **1000** mm; Section depth; h = **175** mm

Applied servicability moment; $M_s$ = **11.8** kNm

**Material details**

Characteristic strength of concrete; $f_{cu}$ = **20** N/mm$^2$; Characteristic strength of steel; $f_y$ = **500** N/mm$^2$

Modulus of elasticity of concrete; $E_c$ = **12.0** kN/mm$^2$; Modulus of elasticity of steel; $E_s$ = 200 kN/mm$^2$

**Reinforcement details**

Area of reinforcement; $A_s$ = **452** mm$^2$; Diameter of reinforcement; $\phi$ = **12** mm

Reinforcement spacing; S = **250.0** mm; Cover to reinforcement; $c_{min}$ = **30** mm

Average strain at beam soffit; $\varepsilon_m$ = **0.000725**

**Design surface crack width**

Design surface crack width; w = **0.113** mm

**; CRACK WIDTH CALCULATION TO BS8110:PART 2:1985**

TEDDS calculation version 1.0.02

**Beam details**

Section width; b = **1000** mm; Section depth; h = **175** mm

Applied servicability moment; $M_s$ = **11.8** kNm

**Material details**

Characteristic strength of concrete; $f_{cu}$ = **20** N/mm$^2$; Characteristic strength of steel; $f_y$ = **500** N/mm$^2$

Modulus of elasticity of concrete; $E_c$ = **12.0** kN/mm$^2$; Modulus of elasticity of steel; $E_s$ = 200 kN/mm$^2$

**Reinforcement details**

Area of reinforcement; $A_s$ = **452** mm$^2$; Diameter of reinforcement; $\phi$ = **12** mm

Reinforcement spacing; S = **250.0** mm; Cover to reinforcement; $c_{min}$ = **30** mm

Average strain at beam soffit; $\varepsilon_m$ = **0.000725**

**Design surface crack width**

Design surface crack width; w = **0.113** mm

**; CRACK WIDTH CALCULATION TO BS8110:PART 2:1985**

TEDDS calculation version 1.0.02

**Beam details**

Section width; b = **1000** mm; Section depth; h = **200** mm

Applied servicability moment; $M_s$ = **11.6** kNm

**Material details**

Characteristic strength of concrete;$f_{cu}$ = **20** N/mm$^2$; Characteristic strength of steel; $f_y$ = **500** N/mm$^2$

Modulus of elasticity of concrete;$E_c$ = **12.0** kN/mm$^2$; Modulus of elasticity of steel; $E_s$ = 200 kN/mm$^2$

**Reinforcement details**

Area of reinforcement; $A_s$ = **1340** mm$^2$; Diameter of reinforcement; $\phi$ = **16** mm

Reinforcement spacing; S = **150.0** mm; Cover to reinforcement; $c_{min}$ = **30** mm

Average strain at beam soffit; $\varepsilon_m$ = **0.000198**

**Design surface crack width**

Design surface crack width; w = **0.027** mm

__; CRACK WIDTH CALCULATION TO BS8110:PART 2:1985__

TEDDS calculation version 1.0.02

**Beam details**

Section width; b = **1000** mm; Section depth; h = **200** mm

Applied servicability moment; $M_s$ = **11.6** kNm

**Material details**

Characteristic strength of concrete;$f_{cu}$ = **20** N/mm$^2$; Characteristic strength of steel; $f_y$ = **500** N/mm$^2$

Modulus of elasticity of concrete;$E_c$ = **12.0** kN/mm$^2$; Modulus of elasticity of steel; $E_s$ = 200 kN/mm$^2$

**Reinforcement details**

Area of reinforcement; $A_s$ = **1005** mm$^2$; Diameter of reinforcement; $\phi$ = **16** mm

Reinforcement spacing; S = **200.0** mm; Cover to reinforcement; $c_{min}$ = **30** mm

Average strain at beam soffit; $\varepsilon_m$ = **0.000234**

**Design surface crack width**

Design surface crack width; w = **0.035** mm

__; CRACK WIDTH CALCULATION TO BS8110:PART 2:1985__

TEDDS calculation version 1.0.02

**Beam details**

Section width; b = **1000** mm; Section depth; h = **200** mm

Applied servicability moment; $M_s$ = **11.6** kNm

**Material details**

Characteristic strength of concrete;$f_{cu}$ = **20** N/mm$^2$; Characteristic strength of steel; $f_y$ = **500** N/mm$^2$

Modulus of elasticity of concrete;$E_c$ = **12.0** kN/mm$^2$; Modulus of elasticity of steel; $E_s$ = 200 kN/mm$^2$

**Reinforcement details**

Area of reinforcement; $A_s$ = **840** mm$^2$; Diameter of reinforcement; $\phi$ = **16** mm

Reinforcement spacing; S = **250.0** mm; Cover to reinforcement; $c_{min}$ = **30** mm

Average strain at beam soffit; $\varepsilon_m$ = **0.000260**

**Design surface crack width**

Design surface crack width; w = **0.042** mm

;