PERFORMANCE OF THE REINFORCED CONCRETE BEAM WITH ARCH SHAPED TENSION STEEL BAR

MANGAIBAGAN A/L RAJANDRAN

B.ENG (HONS.) CIVIL ENGINEERING
UNIVERSITI MALAYSIA PAHANG

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MANGAIBAGAN A/L RAJANDRAN

Report submitted in partial fulfilment of the requirements for the award of the degree of
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DEDICATION

Special dedication to:

My beloved father Mr. Rajandran Muniandy
My beloved mother Mrs. Shanthi Ramasamy
My sibling Baagam Piriyal Rajandran
My respected lecturers
My beloved friends
For their unconditional love, inspiration and support to finish this study successfully.

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ABSTRACT

Reinforced concrete beams are designed to resist compressive force and tensile force resulting from various combinations of ultimate loads. In the design of reinforced concrete beam, the effect of flexural tensile stresses needs to be considered as they contribute to flexural failure such as deflection and cracking. A study was conducted in the laboratory to investigate the performance, in term of ultimate load deflection ratio, of simply supported reinforced concrete beam with different arch height and angle of the steel bar in tension zone. Four reinforced concrete beams was casted with same concrete grade of 31.9Mpa and area of steel bar but with different arrangement of longitudinal steel bar in tension zone where one is control sample and the other three are modified sample. Each beam was design in accordance with Eurocode 2 and with dimensions 2000mm x 200mm x 150mm. All specimens underwent laboratory testing with loading as one point load onto the centre of beam with support at each corner of the specimens. The specimens were tested until failure. The result of the test emphasize that the ultimate load and deflection of simply supported reinforced concrete beam is influenced by the arch shaped steel bar with different arch angle and height in tension zone. Moreover, the result implies that all the specimens show only major flexural failure where vertical cracks happen at the middle part of specimens. It can be concluded that among the entire simply supported reinforced concrete beam with different arch angle and height of steel bar in tension zone, Specimen 2 shows the optimal ratio of ultimate load over deflection which is 2.950.

ABSTRAK

Rasuk konkrit, direka untuk menahan daya mampatan dan daya tegangan yang terhasil daripada pelbagai kombinasi beban maksimum. Dalam mereka bentuk rasuk konkrit yang kukuh, kesan tegasan lenturan perlu dipertimbangkan kerana ia menyumbang kepada kegagalan lenturan seperti pesongan dan keretakan. Satu kajian telah dijalankan di makmal untuk mengkaji kekuatan, dari segi nisbah beban tertinggi kepada pesongan , daripada hanya disokong konkrit yang dikukuh dengan ketinggian dan sudut lenturan bar keluli dalam zon ketegangan. Empat rasuk konkrit, telah disiapkan dengan gred konkrit 31.9Mpa dan saiz tetulang sama tetapi dengan susunan yang berbeza dari aspek lengkungn tetulang di zon ketegangan. Satu sampel adalah sampel kawalan dan sampel tiga yang lain diubahsuai. Setiap rasuk konkrit, telah direka bentuk berdasarkan “Eurocode 2” dan dengan dimensi 2000mm x 200mm x 150mm. Semua spesimen diuji dengan menggunakan “Three Point Flexural Test” dan spesimen diuji sehingga patah. Hasil ujian menekankan bahawa beban tertinggi dan pesongan rasuk konkrit dipengaruhi oleh bar keluli berbentuk lengkungan dengan sudut dan ketinggian yang berbeza dalam zon ketegangan. Selain itu, hasil kajian menunjukkan bahawa semua spesimen mengalami kegagalan lenturan utama di mana retak menegak berlaku pada bahagian tengah spesimen. Kesimpulanya, Spesimen 2 menunjukkan nisbah optimum beban tertinggi terhadap pesongan yang 2.950.

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LIST OF SYMBOLS

α_R	Concrete stress block factors
β_R	Concrete stress block factors
γ_4	Numerical factor

LIST OF ABBREVATIONS

b	Width of flange
b_w	Width of beam
d	Depth of beam
EI	Bending stiffness of the arch
f	Arch rise
f_y	Yield stress
h	Height of beam
I	Moment of inertia
L	Span
q_{cr}	Critical load
w_c	Density of normal weight concrete

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Concrete is a non-homogenous solid matrix of materials that is the most widely used man made material on the earth (Lamborg, 2001). In its simplest form, concrete is made up of four basic components which is cement, water, fine aggregate and coarse aggregate , whereas the density of normal weight concrete is approximately 25 kN/m^3 (2500 kg/m^3). A hydration reaction between cement and water creates a hardening paste that binds the aggregates with strength of the resulting concrete found to be predominantly governed by its water-to-cement ratio. Using a small water-to-cement ratio, reinforced concrete with high compressive strength of 100MPa can be produced for commercial use (ACI Committee 363, 2006).

Although concrete can develop high compressive strengths, plain concrete is unsuitable for structural applications due to a low tensile capacity, in the order of 10 per cent of its compressive strength. In order to enhance the tensile capacity of plain concrete, steel reinforcing bars are then introduced to form a composite system, called reinforced concrete, where the tensile forces are resisted by steel and the compressive forces are resisted by concrete. Concrete and steel acting in tandem and it’s becomes an excellent construction material with many advantages over other structural media (ACI Committee 213, 2006).

Since, the reinforced concrete is able to resist compression force and tension force at the same time, therefore reinforced concrete is used to construct various type of structural member such as beam, column, slab, wall, and foundation. Reinforced concrete beam are important element that used as horizontal members transferring the load from the floor slab above them to the vertical members below them.

The most common reinforced concrete beams come in the form of solid rectangular shapes and the beams can be classified as narrow beam or wide beam according to their geometry of cross-section as shown in Figure 1.1. A reinforced concrete beam is classified as narrow beam when its width, b_w to height, h ratio smaller than 2.0 and while classified as wide beam when its width, b_w to height, h ratio equal or larger than 2.0. There are some benefits in using wide reinforced concrete beams within the construction industry. One of the benefit of wide reinforced concrete beam is it can be act transition beam between substructure and super structure which could transfer large amount of load to column. Therefore, the selection of the geometries of beam is constrained by both structural and architectural requirements. (Alluqmani, A.E & Haldane, 2011)

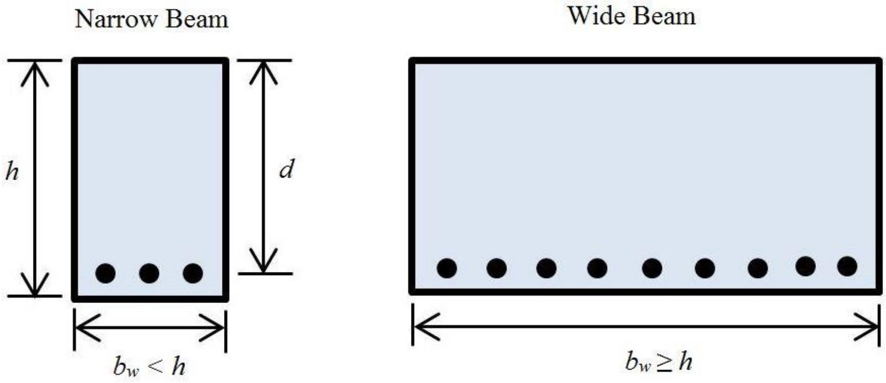


Figure 1.1: Classified of reinforced concrete members according to their geometry.

Source: (Alluqmani, A.E & Haldane, 2011)

The cross-section shape of the reinforced concrete beam, which shows the main tensile reinforcing bar, and shear reinforcement bar can have an effect on the beam design for flexure and shear capacity (Grant, 2003). In rectangular slender beams, either shallow and deep beams, or narrow and wide beams, the shear and ultimate flexure stresses increase when the member width, b_w to effective depth, d ratio increases. In addition any increase in beam width, b_w has the effect of increasing both the flexure and shear strengths of beams (Alluqmani, 2010).

Reinforced concrete beam is a flexural member designed within the ultimate limit state which allowing the beam for a certain local damage to occur, by assuming steel bars carry all the tensile forces. The limit of damages in a cross-sectional design process is governed by the ultimate compressive strain of concrete. This will avoid crushing of reinforced concrete when yielding of reinforcement bars occurs. The occurrence of deflection in reinforced concrete beam is a rather expected phenomenon for fairly high loads. However in cases where no pre-stressing is applied, the deflection is estimated to form even for a small portion of the ultimate load.

Deflection in concrete is accompanied by overall stiffness reduction, cracking, lack of homogeneity of the cross-section, and it is also aesthetically undesired. Furthermore, large deflection will cause cracking and contribute to the permeability of structural member increase, which under severe environmental conditions could enhance corrosion of reinforcement, spalling of the concrete cover and local bond deterioration at the interface between the constitutive materials.

Therefore, in recent years, there have been significant improvements were made in properties of concrete and modification of reinforcement. In comparing both categories of improvements, reinforcement modification dominates in the strengthening process of reinforced concrete beam to minimize the deflection when it reaches the ultimate limit state.

1.2 BACKGROUND OF STUDY

For several decades, the strengthening and rehabilitation of reinforced concrete structures are becoming increasingly important in construction. Especially, the horizontal member, reinforced concrete beam requires a high level of attention where it is undergoes major deflection which leads to cracking when reach its ultimate limit state. This is due to its low flexural capacity which influence by the steel reinforcement in tension zone.

Therefore, this low flexural capacity can be upgraded by the modification of steel reinforcement in tension zone. Instead of the horizontal steel bar in tension zone, an arch shaped tension steel bar can be used to increase the flexural capacity of the reinforced concrete beam because the arch shaped steel bar able to cater bending moment of the beam.

The arch is designed in order to produce a system which transports the applied loads to supports primarily through compression stresses in the arch, eliminating the possibility of tensile stresses occurring within the chosen material. This is achieved, to some degree, through design of the arch shape to match as closely as possible to the line of thrust within the arch (Heyman, 1982). This emphasize that an arch shaped steel bar has high bending restrain capacity compare to horizontal steel bar. Therefore, there is potential that the replaced arch shape steel bar in tension zone instead of conventional horizontal steel bar can improve the flexural capacity of the reinforced concrete beam.

1.3 PROBLEM STATEMENT

In order to increase the ultimate flexural strength of the reinforced concrete beam, or to control deflection and cracking, the tension zone of the beam need to be strengthen. One of the methods which provide the required strength is by replacing the conventional steel bar in the tension zone with an arch shaped tension steel bar.

This study is carry out to identify the most suitable height and angle of the arch shaped steel bar as tension reinforcement in the tension zone in order to increase the flexural and shear capacity of reinforced concrete beam.

1.4 OBJECTIVE

The objectives of this study are as follows;

i. To identify the performance of simply supported reinforced concrete beams with different arch angle and height of steel bar in tension zone.
ii. To determine the optimal ratio of ultimate load over deflection of simply

supported reinforced concrete beam with different arch angle and height of steel bar in tension zone.

iii. To study the crack behaviour of simply supported reinforced concrete beam with different arch angle and height of steel bar in tension zone.

1.5 SIGNIFICANCE OF STUDY

Reinforced concrete beam is a horizontal member in a structure which plays a vital role in construction industry. This horizontal member is used in almost all buildings, bridges, infrastructures, and many more. Therefore, it is important to produce reinforced concrete beam with less defects in order to build a high strength and long last building.

The modification of the reinforced concrete beam with arch shaped steel bar in tension zone may have potential to produce a beam with high flexural strength compare to the conventional reinforced concrete beam. This could potentially reduce the deflection and cracking of the beam compare to the conventional beam when subjected to load. Therefore, buildings with less defects and high strength are achievable through this potential modification of reinforced concrete beam.

Moreover, with the same amount of concrete, concrete grade, tensile strength of steel bar and area of steel bar the modified reinforced concrete beam may has the potential to have higher ultimate load compare to the conventional reinforced concrete beam. Since, a beam with high ultimate load is potentially achievable with the same material consumption as for conventional reinforced concrete beam, the modified reinforced concrete beam can be used in construction to withstand larger load when compare to conventional reinforced concrete beam . This will lead to the reduction in the cost of the construction with high where a high strength reinforced concrete beam can be potentially produced with same cost as for conventional reinforced concrete beam.

1.6 SCOPE OF STUDY

The scopes of the study are as follows;

i. Reinforced rectangular concrete beam with concrete grade 30 and steel bar with tensile strength of 500N/mm^2 was casted for this study.
ii. All beams were designed according to Eurocode 2 as a simply supported beam with a point load of 60kN
iii. The entire beam sample have identical dimensions which is 2000m x 200mm x 150mm and steel bar size 12mm, 10mm and 6mm was used for tension reinforcement, compression reinforcement and shear reinforcement respectively.
iv. The beam was modified by replacing an arch shaped steel bars in tension zone with three different arch height and angle instead of the conventional steel bar in tension zone.
v. Three beams with different arch height and angle of arch shaped steel bar and one beam with conventional steel bar arrangement in tension zone as control sample was used in this study.
vi. The entire beam samples were cured for 28 days and tested by Three Point Flexural Test and parameters such as ultimate load, deflection distance and cracking pattern will be take in account in this study.

1.7 EXPECTED OUTCOME

There are three expected outcomes in this study;

i. The performance of simply supported reinforced concrete with different arch height and angle of the steel bar in tension zone will be identified.
ii. The optimal ratio of ultimate load over deflection of simply supported reinforced concrete beam with different arch angle and height of steel bar in tension zone can be determined.
iii. The crack behaviour of simply supported reinforced concrete with different arch height and angle of the steel bar in tension zone will be studied.

CHAPTER 2

LITERATURE REVIEW

2.1 REINFORCED CONCRETE TECHNOLOGY

In the mid of 1880’s the advantages of using reinforced concrete in building construction was first discovered by a man called Joseph Louis Lambot (Amy Nutt, 2007). The discovery is about a modification in concrete where steel fibres or steel bar is added to concrete which result in a drastic increase in the strength of concrete and making it better for use in variety of applications. In the early years, this modification was used to produce a number of items, such as reinforced beam, reinforced garden tubs, and road guardrails. Most of the construction firm wanted to use the available different types of reinforced concrete product in the market. However, there is no standard method of producing reinforced concrete has yet been developed.

Over time, many different companies involved themselves in creating the perfect types of steel reinforced concrete. Through many trials and errors, the best version of steel reinforced concrete production became widely known and used while the lesser brands and ineffective methods faded away. The high strength of reinforced concrete causes the constructed building with reinforced concrete to have stronger support and last long. Moreover, this situation allowed builders to start constructing high rise building with less limitation on height and weight of the buildings. As the result, one of the construction companies in Europe countries completed over 7,000 buildings using reinforced concrete during its first ten years of its operation.

The first system of reinforced concrete manufacturing was patented in 1878 and done in United States by an American called Thaddeus Hyatt. The Pacific Coast Borax

Company refinery building which located in California was the first building constructed in the United States using the reinforced concrete. The popularity of constructing buildings using reinforced concrete increases rapidly in early 1900’s where a majority of developers in the country were using steel reinforced concrete in the construction of buildings.

Nowadays, most of the building located in industrialized nations used steel reinforced concrete to make the building stronger and better which enable to withstand the ravages of time and the weather.

2.2 REINFORCED CONCRETE

Britannica Concise Encyclopaedia defined reinforced concrete as a concrete in which steel is embedded in such manner that the two materials act together in resisting forces. The reinforcing steel – rods, bars, or meshes – absorbs the tensile, shear and sometimes the compressive stresses in a concrete structure (Britannica Encyclopaedia, 2009).

Plain concrete does not easily withstand the tensile and shear stresses caused by vibration, wind, earthquakes, and other forces and are therefore it is unsuitable for most of the structural applications. Due to the low tensile strength of concrete, the concrete is easily undergoes tensile cracking and failures. In order to solve the low tensile strength problems, reinforced concrete becomes an alternative choice for a higher demand construction industry. The applied moment in reinforced concrete is resisted by compression of the un-cracked portion of the concrete section and by tension in the reinforcing bars (O'Brien, 1995).

Reinforcement in reinforced concrete may be used to resist compressive forces or to improve dynamic properties of reinforced concrete. Steel usually used as reinforcement in the casting of reinforced concrete. It is elastic, yet has considerable reverse strength beyond its elastic limit. Under a specific axial load, its length changes about one-tenth as much as concrete. In compression, steel is 10 times stronger than concrete, an in tension, more than 100 times stronger than concrete. The internal tensile forces are carried by the reinforcements that placed within the concrete members to prevent the cracks and failures. The compressive strength of concrete and tensile strength of steel works together to allow the members sustain these stresses over considerable spans.

2.3 ADVANTAGES AND DISADVANTAGES OF REINFORCED CONCRETE

Reinforced concrete is one of the most famous and effective construction materials which lead to a great revolution in construction industry. Reinforced concrete widely used in constructing building due to its advantages over other construction material.

The major advantage of reinforced concrete is ability to withstand both compressive forces and tensile forces. Generally, concrete tends to be brittle, breaking easily under sudden stress and crumbling under the influence of time and weather. This characteristic of concrete makes it difficult to use in structures intended to hold a large amount of weight or last a long time. Therefore, the introduction of steel into concrete results in the production of composite material which could cater both compressive forces and tensile forces. The ability of reinforced concrete in withstanding both compressive forces and tensile forces causes the reinforced concrete to prevent failure and cracking in concrete as well as cater large amount of load (Nilson, 2003).

Moreover, another advantage of reinforced concrete as a construction material is its resistance to fire over some period of time. In other word, the reinforced concrete does not react chemically or physically when exposed to fire for some period of time. The time of resistance to fire is much higher when compare to other construction material such as steel and timber. This fire resistance ability of reinforced concrete increases the usage of reinforced concrete in construction where it ensures the safety of the user toward fire accidents. Therefore, this advantage of reinforced concrete makes it a better construction material when comparing to other construction material.

Besides that, using reinforced concrete in construction is economical when compared to other materials. In the hands of experienced designers and builders, reinforced concrete offers a wide range of customizable building systems that improve efficiency in both design and cost. The ability of reinforced concrete in withstanding the large load result in the changes of building design which reduce the cost of the building. This advantage of reinforced concrete emphasizes the usage of reinforced concrete in construction industry widely.

Last but not least, the durability of the reinforced concrete relatively long. There are no other building system is more durable than a reinforced concrete system. This unique advantage provides owners and designers with the opportunity to extend the ultimate sustainability of the building by many years.

On the other hand, although reinforced concrete has many advantages, it is also accompanied by some disadvantages. One of the disadvantages is reinforced concrete can corrode easily. The presence of steel in the reinforced concrete as reinforcement is the primary factor which causes corrosion. Basically, steel is a reactive material and its reach with moisture and oxygen to form an electrochemical process which leads to corrosion. Essentially, the iron in the steel is oxidised to produce rust, which occupies approximately six times the volume of the original material. Therefore, when the steel in reinforced concrete happen to expose to moisture and oxygen, the corrosion in steel will take place and this will reduce the strength of reinforced concrete.

The following disadvantage of reinforced concrete is the increase in the probability of cracking in reinforced concrete. This is due to the reinforcement which exists in the reinforced concrete. The probability of the cracking increases in reinforced concrete because of shrinkage and creep in freshly lay concrete and hardened concrete. This disadvantage of concrete reduces the strength and aesthetic value of the reinforced concrete structure.

The above advantages of reinforced concrete are the reason behind the increase in the reinforced concrete building in the world. Although there are many advantages in reinforced concrete, there are some disadvantages of this composite material which need to be improved in order to produce a perfect reinforced concrete.

2.4 REINFORCED CONCRETE BEAM

Reinforced concrete beam is defined as a linear structural member predominantly loaded in flexure which made up of reinforced concrete (Engström, 2011). According to Eurocode 2 the structural member is considered as a beam if the span to depth ratio is greater than 3 and the width is less than 5 times the depth of the member (CEN, 2004).

As a structural member, reinforced concrete beam response to the load in two major way which is flexural and shear. The flexural behaviour of the reinforced concrete beam is due to the moment while shear behaviour is due to shear force that develops in reinforced concrete beam when subjected to load.

2.4.1 Flexural Behaviour of Reinforced Concrete Beam Subjected to Load

The flexural behaviour of reinforced concrete beam subjected to load can be explained with three models as in Eurocode 2 (CEN, 2004). The three models are named state I, state II and state III and can be seen in Figure 2.1.

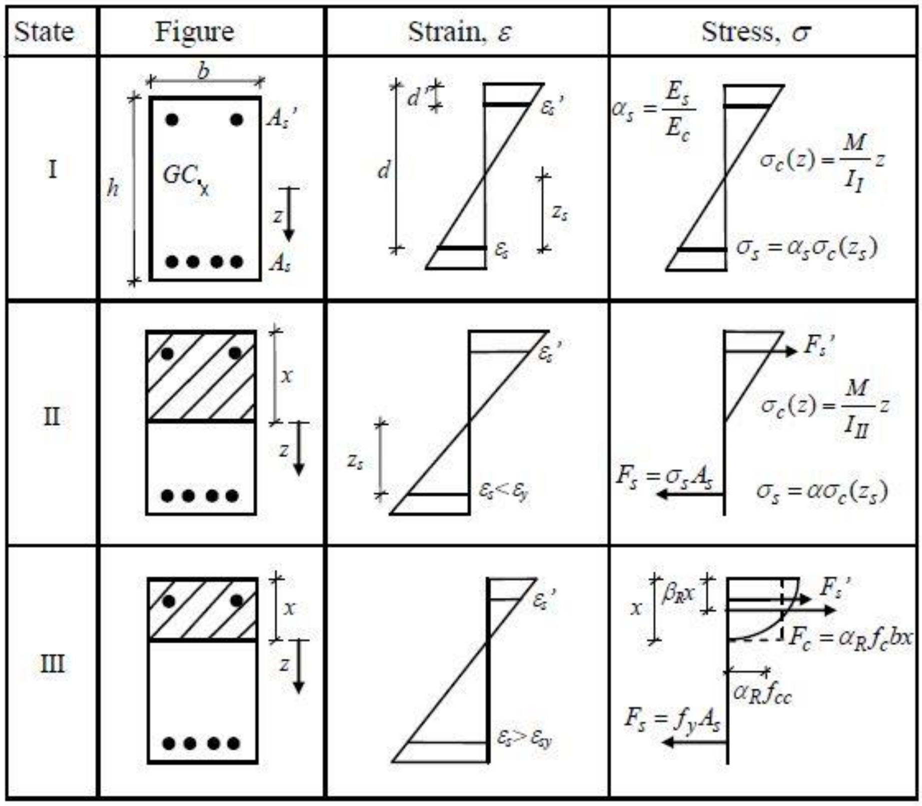


Figure 2.1: The different states of a reinforced concrete section and internal forces.

Source: (CEN, 2004)

A reinforced concrete beam considered to be in State I when the concrete is not cracked and the behaviour is assumed to be linear elastic. It is often reasonable to neglect the influence of reinforcement in this state. Thus, the crack resisting moment of the cross-section can be easily determined with help of the moment of inertia *I*, the location of the neutral axis and concrete tensile strength.

Concrete is weak in tension and will crack early. A State II model is often used when a cracked concrete beam is studied for low loads. This model assumes linear elastic behaviour both for concrete and reinforcement but neglects the influence of cracked zones. It is an adequate assumption for the reinforcing steel and for concrete at stresses below the steel yield stress. The reinforcement can be converted into an equivalent concrete area. Thereafter a moment of inertia for State II can be calculated and consequently the moment capacity.

When the steel begins to yield and the concrete has non-linear compression strength a State III model is used. It takes both concrete cracking and steel reinforcement yielding into account. The moment capacity is determined by using moment equilibrium. The ultimate capacity can be calculated by assuming reinforcement yielding and ultimate compressive strain in concrete in most outer fibre. Concrete stress block factors α_R and β_R are used to approximate the non-linear distribution in the concrete with a stress block with a lever arm to the neutral axis. If the steel in a state III model has not begun to yield, the concrete will suddenly fail in compression. This is brittle failure mode and should be avoided if possible.

When a section in a reinforced concrete beam cracks, it will suddenly lose stiffness and the remaining stiffness will depend on the provided reinforcement. The parts that are un-cracked will be stiffer and moment redistribution will take place as they attract more moment. When the concrete cracks it is often assumed that the cracked part of the section cannot take any stress. However, the un-cracked concrete between flexural cracks will carry some stress with help of the bond between the reinforcement and the concrete. This contribution is large just when the concrete cracks but declines as more sections crack. This is referred to as the tension stiffening effect and can be seen in Figure 2.2. In further investigations, this thesis does not consider tension stiffening.

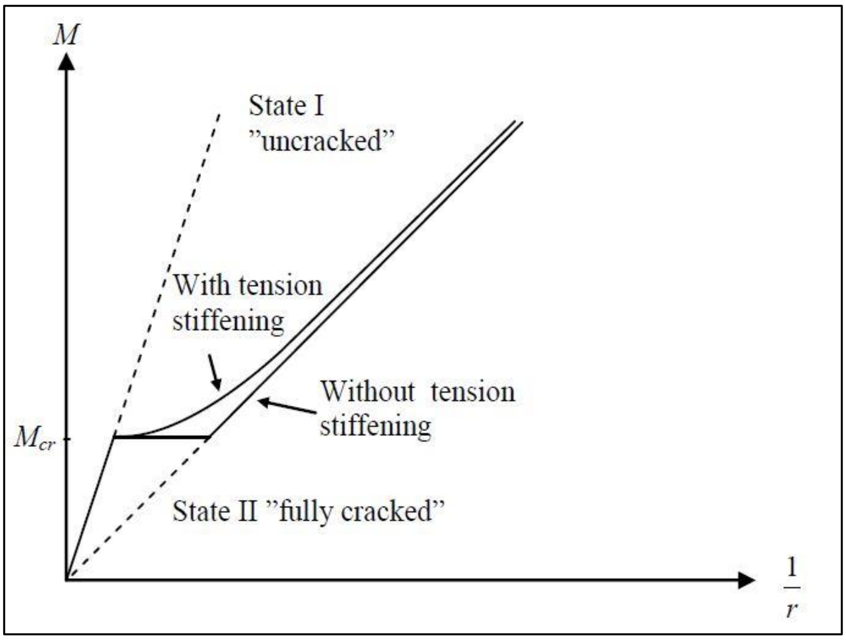


Figure 2.2: Response of a region with regard to 'tension stiffening' in a concrete member subjected to pure bending (Based on linear stress-strain relationship for both concrete and steel).

Source: (CEN, 2004)

After a while cracking will exist all along the length of the concrete beam and the stiffness of each section is merely dependent on the amount of reinforcement. The stiffness distribution in the cracked state may be different from that in the un-cracked state due to uneven reinforcement arrangement within the beam. Loading the beam even further will result in reinforcement yielding. The yielding will start in the highest stressed section and in this section the steel deforms more than in adjacent sections where the steel still have an elastic response. This will create a region with concentrated plastic rotation, a so called plastic hinge.

2.5 FLEXURAL FAILURE IN REINFORCED CONCRETE BEAM

The reinforced concrete beam undergoes failure when it reaches its ultimate limit state. The failure in reinforced concrete beam can be categorise into two, where one is flexural failure and another is shear failure. The flexural failure is occur due to the moment that develop in reinforce concrete beam when subjected to load. The flexural failure takes place when the beam reaches its ultimate flexural capacity. The flexural failure in reinforce concrete beam can be classify into two types which is flexural cracking and flexural deflection.

2.5.1 Flexural Deflection

Flexural deflection of reinforced concrete beam cannot be avoided because it is part of the load carrying mechanism. Excessive deflections of reinforced concrete beams can cause damage to non-structural element such as partitions attached to them. Large deflections may also result in unnecessary ponding of water in exposed areas causing difficulties to the occupants. To avoid these adverse effects, designers need to ensure that the resulting deflections of reinforced concrete beams under service loads are within acceptable limits.

i) Short-term and long-term deflections and allowable deflection limits of reinforced concrete beam

The deflection of a reinforced concrete beam increases with time due to the creep of concrete, in cases where the applied load is sustained for a long period of time. Self-weight and other superimposed dead loads fall in to the category of sustained loadings. To minimise the adverse effects of deflections, it is necessary to limit the short-term deflection as well as the total deflection including the long-term effects of creep. Various building codes have stipulated deflection limits for different types of members, depending on their intended use. Tables 2.1 and 2.2 present these limits prescribed by American Concrete Institute (ACI Committee 318, 1995) and the British Standards Institution (BS 8110: Part 1, 1997) respectively.

Table 2.1: Maximum allowable deflections.

Type of member	Deflection to be considered	Deflection Limit
Flat roofs not supporting or attached to non-structural elements likely to be damaged by large deflections	Immediate deflection due to live load	span/180
Floors not supporting or attached to non-structural elements likely to be damaged by large deflections		span/360
Roof or floor construction supporting or attached to non-structural elements likely to be damaged by large deflections	The part of the total deflection occurring after attachment of non-structural elements (sum of the long term deflection due to all sustained loads and the immediate deflection due to additional love load)	span/480
Roof or floor construction supporting or attached to non-structural elements not likely to be damaged by large deflections		span/240

Source: (ACI Committee 318, 1995)

Table 2.2: Maximum allowable deflections.

Type of member	Deflection to be considered	Deflection limit
All members	The total deflection	span/250
	The deflection which occurs after the addition of finishes and partitions	span/350 or 20mm whichever is less

Source: (BS 8110: Part 1, 1997)

ii) Control of Deflections in Flexural Members

A reinforced concrete beam needs to be design in such a way that the resulting deflection under service load should be less than allowable deflection limit. In order to identify the deflection of a reinforced concrete beam, designers limit the span-to-depth ratio to the values specified in relevant building codes, for a range of members commonly encountered in practice. If the span-to-depth ratio of a particular reinforced concrete member is less than the specified value, the resulting deflection is deemed to be within the allowable limit, and the design is considered satisfactory. Limits on span-to- depth ratios for the control of deflections in reinforced concrete members specified by two different building codes which is ACI 318 (1995) and BS 8110: Part 1 (1997).

The Table 2.3 shows the maximum span-to-depth ratios specified in ACI 318 (1995) for beams and one-way slabs, which are not supporting or attached to partitions or other attachments likely to be damaged by large deflections. Larger values of span-to-depth ratios are permitted only if the calculated deflections are shown to be within allowable limits. Values shown in Table 2.3 are applicable for normal weight concrete with density w_c =2325kg/m^3 and high tensile steel with yield stress f_y = 410MPa. For other values of w_c and f_y, the span-to-depth ratios shown above should be modified using the procedure described in ACI 318 (1995). While the span-to-depth ratios given in Table 2.3 are widely used in practice, a comparison of calculated deflections shown that the values specified for one-way slabs are conservative for span lengths typically found in building structures.

Table 2.3: Maximum span-to-depth ratios.

Member	**Support conditions**			
	Simply-supported	One end continuous	Both ends continuous	Cantilever
Solid one-way slabs	20	24	28	10
Beams or ribbed one-way slabs	16	18.5	21	8

Source: (ACI Committee 318, 1995)

The Table 2.4 shows the maximum span-to-effective depth ratios recommended in BS 8110: Part 1 (1997) for beams and one-way slabs with span lengths less than 10 metres. For flanged beams with b_w/b greater than 0.3, linear interpolation between the values given for rectangular and flanged beams is permitted. For spans exceeding 10 metres, the design should be justified by calculation, in cases where the increase in deflection after the construction of partitions and attachments needs to be limited. The span-to-effective depth ratios given in Table 2.4 are called the basic values. To determine the span-to-effective depth ratio applicable for a particular member, the basic value needs to be multiplied by modification factors, depending on the calculated tensile steel stress, amount of compression reinforcement (if any) and, creep and shrinkage coefficients. The procedure for calculating these modification factors are described in BS8110: Part 1 (1997).

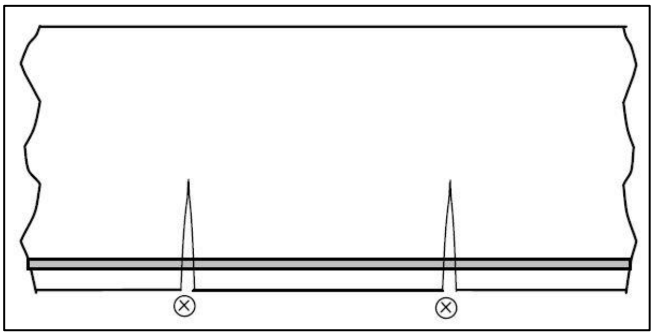
Table 2.4: Maximum span-to-effective depth ratios.

Support conditions	**Cross sectional shape**	
	Rectangular	Flanged $bw/b \leq 0.3$
Cantilever	7	5.6
Simply supported	20	16.0
Continuous	26	5.6

Source: (BS 8110: Part 1, 1997)

2.5.2 Flexural Cracking

Cracks formed in reinforced concrete members can be classified into two main categories, namely cracks caused by externally applied loads, and those which occur independently of the loads (Leonhardt, 1977). Flexural cracks are the cracks which caused by externally applied load. Flexural cracks are formed in the tensile zone of the member and have a wedge shape, with the maximum crack width at the tension face and zero width near the neutral axis (Warner, 1998). The typical view of the flexural cracks is shown in Figure 2.3.



Note: ⊗ indicates the location of crack initiation

Figure 2.3: Typical view of flexural cracks.

Source: (Warner, 1998)

i) Spacing and width of flexural cracks

Flexural cracks begin to occur when concrete stress in the tension face of a member reaches the flexural strength of reinforced concrete. After formation of a crack some elastic recovery takes place in concrete on the member surface, contributing to the crack width. However, some stress and strain is maintained in concrete surrounding the reinforcement due to the action of bond. This contributes to a reduction in the crack width near the bar compared to that at the tension face (Goto , 1971).

Flexural cracks in a varying moment region of a beam develop at a regular interval; however, in a constant moment region, these cracks develop at discrete intervals. Their locations depend partly on the occurrence and distribution of zones of local weakness in concrete, and therefore cracking is somewhat a random process (Fantilli, 1998). As a result, the exact locations of cracks in a constant moment region may not be predicted accurately. However, maximum and minimum spacing of adjacent cracks and the resulting maximum crack width may be predicted with sufficient accuracy by investigating concrete stresses developed in the tensile zone of a member.

2.6 BACKGROUND OF ARCH

Arches were first used on a wide range of structures by the Ancient Romans. Stone was used as building material which has a low tensile strength. Since arches works mainly in compression it was a suitable geometry for span structures in stone. Due to simple scaffolding the arch often used was semi-circular, see Figure 2.4 (Crocetti, 2013).

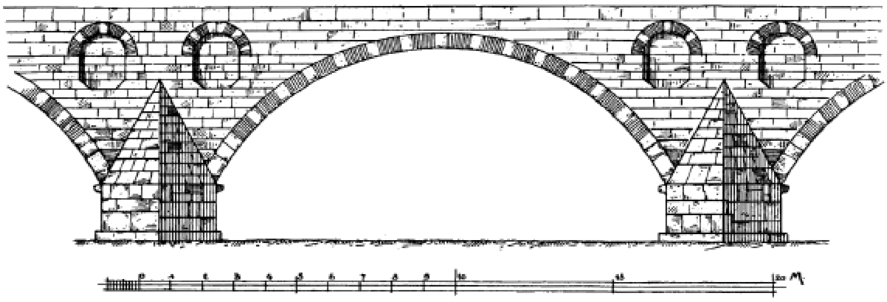


Figure 2.4: Macestus Bridge built by the Romans in the north-western part of modern-day Turkey.

Source: (Crocetti, 2013)

The arch is a form where the forces from dead load are transferred as compression, and tensile forces are eliminated as shown Figure 2.5. Depending on the shape of the arch this is more or less true – the “perfect” arch will only carry compression, but there is only one perfect arch for any given set of loads so heavy moving loads can often put parts of an arch into tension. Because the arch relies on compression to carry load it is well suited to both masonry and concrete, materials that are strong in compression but weak in tension (Boyd, 1978).

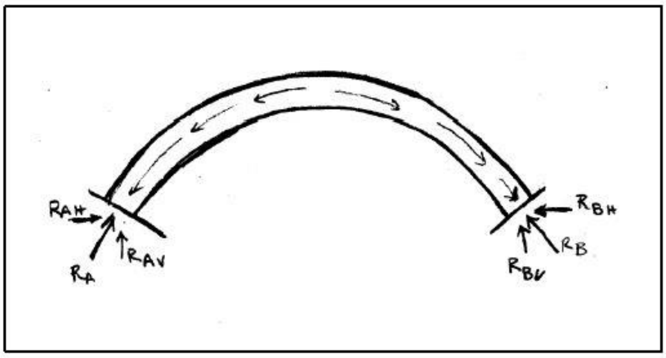


Figure 2.5: Forces in an arch.

Source: (Boyd, 1978)

2.6.1 Theory of Arches

When a cable is subjected to a load, it deforms following the funicular shape. The shape of the cable when it is submitted only to its self-weight is called catenary which illustrated in Figure 2.6. It is often approximated by an ellipse or an arc of circle.

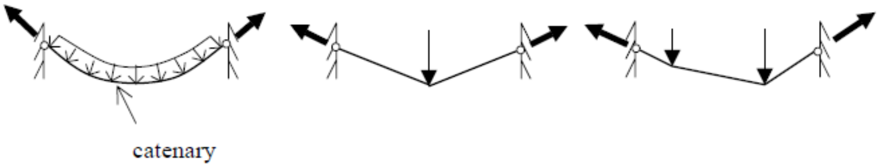


Figure 2.6: The shape of a rope under different loads.

Source: (Borg & Gennaro, 1959)

The changing of the shape is depends on the length of the cable. All the possible shapes under a load case are a family of funicular shapes as shown in Figure 2.7.

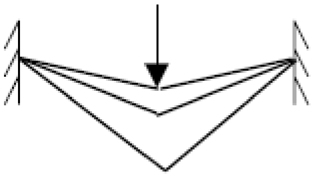


Figure 2.7: A family of funicular shape.

Source: (Borg & Gennaro, 1959)

The forces in the cable are only tensile forces. Let’s now imagine that the cable is upside down. If the same load is applied, the cable will sustain the same force magnitude but in compression. In this case, it will be called an arch and will be also a funicular of this load case as shown in Figure 2.8.

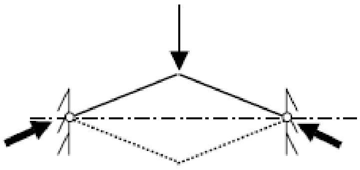


Figure 2.8: Funicular arches under a concentrated load.

Source: (Borg & Gennaro, 1959)

The great property of an arch is to be able to transfer the load to the support only with compressive forces. This characteristic has made the success of the arches in construction because it allowed the use of stones, which basically cannot carry tension.

A bending moment appears in the arch when the load is not the same than the one defined by the funicular shape but this moment does not necessarily imply tensile stresses if the section is high enough.

2.6.2 Buckling of Arches

Since a parabola is the funicular shape of a uniform load no bending of the arch will occur while subjected to such load. By gradually increasing the load on the parabolic arch a condition at which the equilibrium becomes unstable can be reached. The shapes of buckling modes are dependent of boundary conditions, and for a three hinged parabolic arch the first in plane buckling mode is illustrated in Figure 2.9.

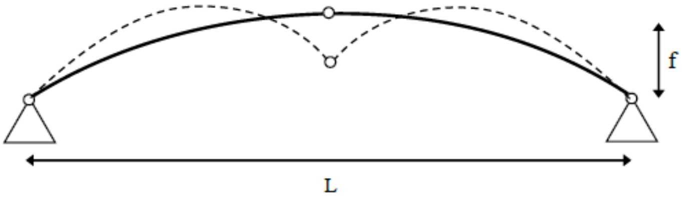


Figure 2.9: First in-plane buckling mode for a parabolic arch.

Source: (Timishenko & Gere, 1961)

For a parabolic arch with constant cross-section and uniform load the critical load can be expressed by the following formula (Timishenko & Gere, 1961):

$$q_{\mathrm{cr}} = \gamma_4 \frac{EI}{L^3}$$

Where,

EI is bending stiffness of the arch (Nm^2)
L is span (m)
γ_4 is numerical factor depending on the ratio *f/L* and the number of hinges in the arch.

The dashed line in Figure 2.10 corresponds to symmetrical forms of buckling. In these cases asymmetrical buckling will still occur and to obtain values of γ_4 curves for arches without central hinge must be used (Timishenko & Gere, 1961).

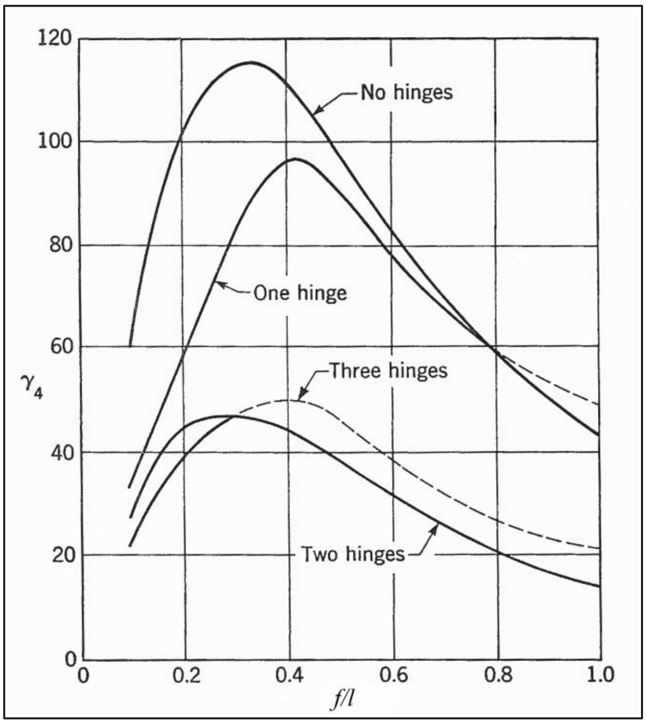


Figure 2.10: Numerical factor 4 expressed graphically as a function of *f/L*.

Source: (Timishenko & Gere, 1961)

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter will discuss briefly about the methodology that has been used in this study. The methodology includes processes which are design process, casting process, curing process and testing process. All these process was done with appropriate procedure and standards. The methodology of this study has been summarized in the flow chart shown in Figure 3.1.

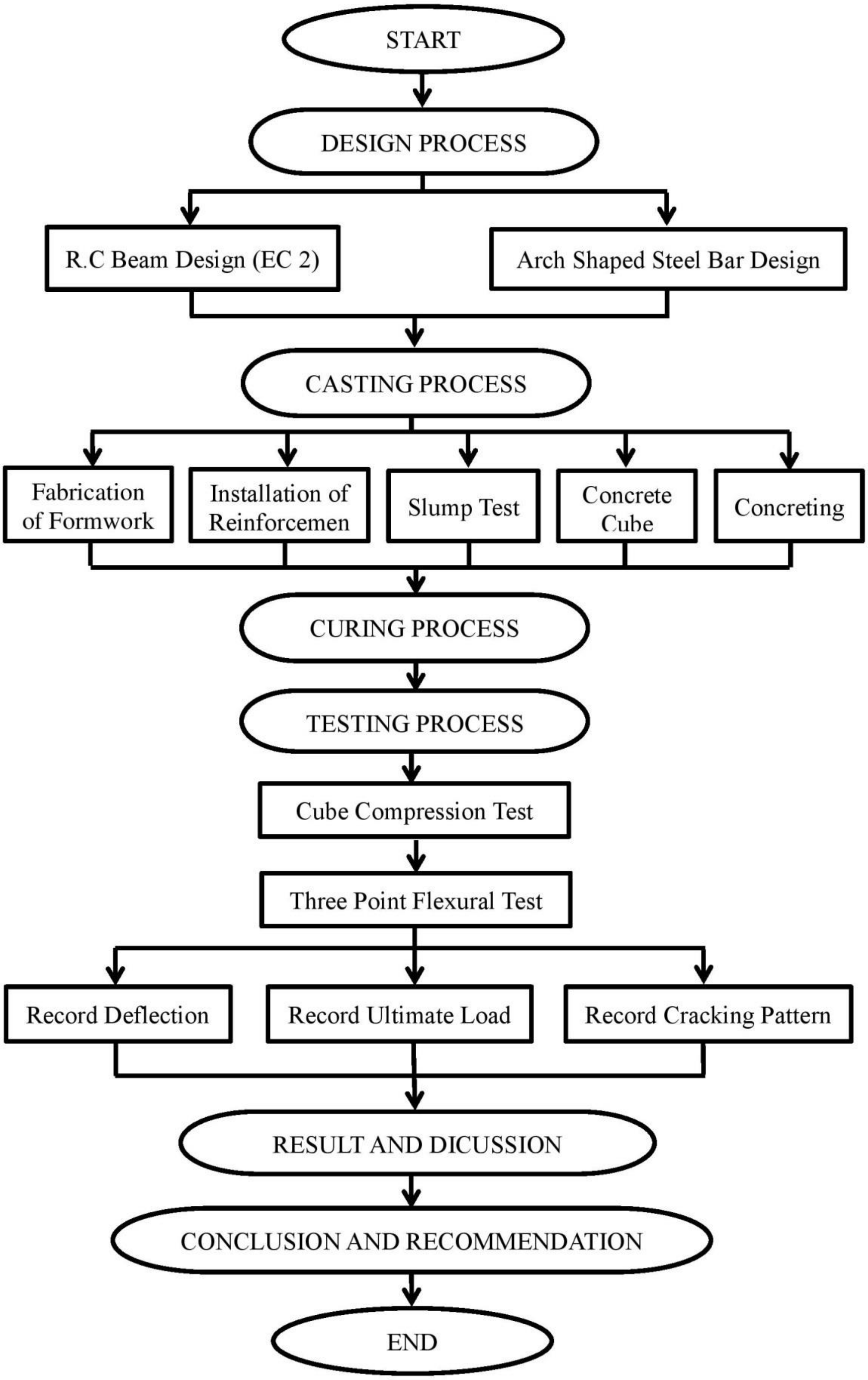


Figure 3.1: Flow chart of methodology.

3.2 DESIGN PROCESS

The first process is design process which includes reinforced concrete beam deigns and arch shaped tension steel bar design. All of the above design was done according of the respective design procedure and criteria.

3.2.1 Reinforced concrete beam design

Four reinforced rectangular concrete beam were tested in this study which includes one controlled reinforced concrete beam and three modified reinforced concrete beam. All the specimens were designed according to Eurocode 2. In the design of reinforced concrete beam, several criteria were taken into consideration, including the specimen dimensions, strength of concrete, equipment availability, and the reinforcement provided in the design.

For Specimen1, which is a controlled sample, the design was done according to Eurocode 2 and all reinforcement was arranged according to the conventional method. This controlled beam was designed and tested in order to compare the ultimate flexural strength and deflection of the modified reinforced concrete beam.

For Specimen 2, Specimen 3, and Specimen 4, the entire beams were design according to the Eurocode 2 and modification of the steel reinforcement bar in tension zone was done in order to increase the flexural capacity of the beam and reduce the deflection of the beam. The conventional steel reinforcement bar in tension was replaced with an arched shaped tension steel bar in order to increase the flexural capacity of the reinforced concrete beam. This is possible where an arch have a capacity to transport the applied load through compression stress, eliminating the possibility of tensile stresses occurring within the structure.

The reinforcement used in the specimens were of the same material whereby high yield steel (T) strength 500N/mm^2 was used as flexural reinforcement while mild steel (R) strength 250N/mm^2 was used as shear reinforcement. The dimensions of the specimens were 2000mm x 200mm x 150mm. Each specimen was constructed with identical amount of reinforcement. Four bars were used in each specimen. The dimensions and detailing of the specimens is as shown in Figure 3.2 and Figure 3.3.

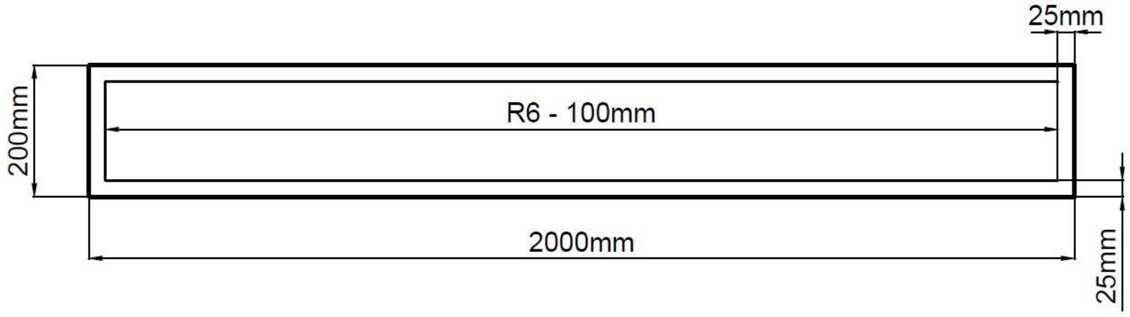


Figure 3.2: Dimension and detailing of the beam (front view).

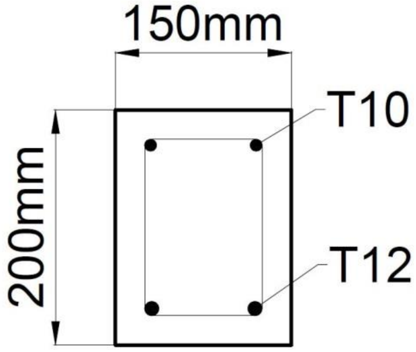
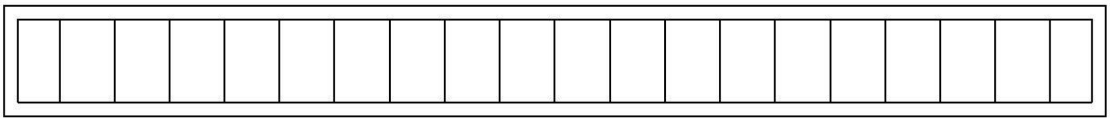


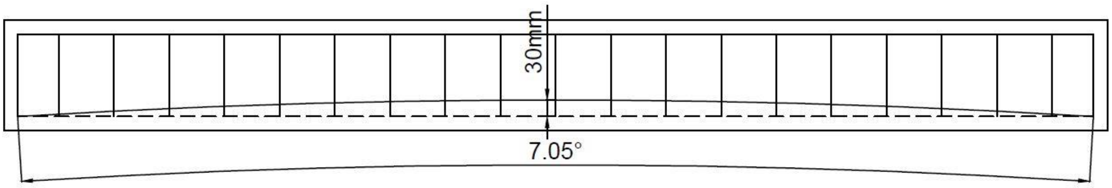
Figure 3.3: Dimension and detailing of the beam (cross-sectional view).

3.2.2 Arch Shaped Tension Steel Bar Design

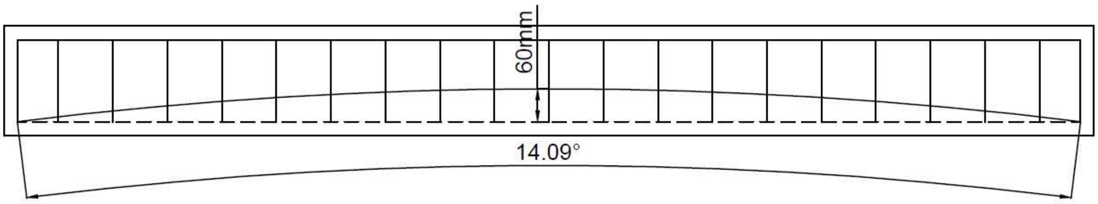
Four types of specimens were designed in this project and they were named as Specimen 1 (control), Specimen 2, Specimen 3 and Specimen 4. Each specimen has different arrangement of steel reinforcement bar in tension zone. For Specimen 1 (control) the steel reinforcement bar was placed horizontally. For Specimen 2, an arched shaped steel reinforcement bar with an angle of 7.05˚ and height of 30mm. For Specimen 3, the angle and height of arch shaped steel reinforcement bar was increased to 14.09˚ and 60mm respectively. For Specimen 4, an arch shaped steel reinforcement bar which have an angle of 21.10˚ and height of 90mm was used. The arrangement and specification of the reinforcement bar is shown in Figure 3.4.



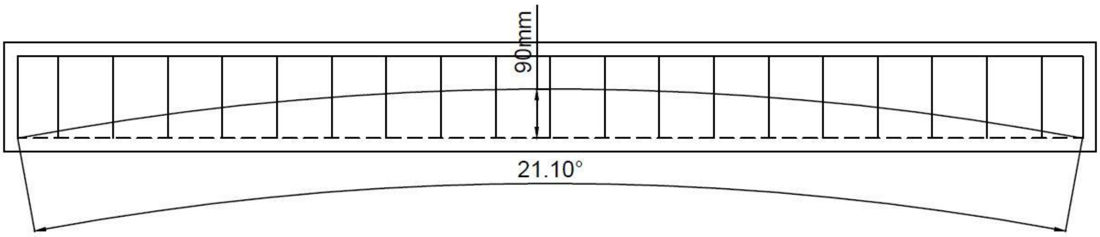
(a) Cross section of Specimen 1 (control).



(b) Cross section of Specimen 2.



(c) Cross section of Specimen 3



(d) Cross section of Specimen 4.

Figure 3.4: Arrangement of longitudinal reinforcement bar with different shape, arch height, and arch angle.

3.3 CASTING PROCESS

The casting process was done carefully and in a proper way because it could affects the strength of the specimen. Casting process includes five stages which was fabrication of formwork, installation of reinforcement bar, slump test, concrete cube and concreting.

The total number of beam that was casted for this study was 8 beam samples. The beam specimen name, description of the beam specimen and number of beam samples are summarized in the Table 3.1 below.

Table 3.1: The description summary of the casted beam.

Specimen Name	Description of Specimen	No of Samples
Specimen 1 (control)	Horizontal tension steel bar.	2
Specimen 2	Arched shaped tension steel bar with an angle of 7.05˚ and height of 30mm.	2
Specimen 3	Arched shaped tension steel bar with angle 14.09˚ and height of 60mm.	2
Specimen 4	Arched shaped tension steel bar with angle 21.10˚ and height of 90mm.	2

3.3.1 Fabrication of Formwork

The main material used for formwork in this project was 18mm plywood. It was cut into components at accurate sizes using a cutting machine. All of the components were combined together using nails.

After the formwork was ready, the inner surface of formworks was applied with a thin layer of oil to prevent the concrete from adhering on the plywood. The gabs between the connections of formwork were filled with silicon in order to prevent the concrete leaking during casting. The reinforcement cages were then put into the formwork. Spacers were used to provide the required space for the 25mm cover. The typical formworks for all the specimens are shown in Figure 3.5.

Figure 3.5: Isometric view of typical formwork for all specimens.

3.3.2 Installation of Reinforcement Bar

High yield steel, T12 was used as main reinforcement while high yield steel, T10 was used as secondary reinforcement in the specimen. This is so that the shear link can be tied to the main reinforcement in proper position.

The main reinforcements and shear links were cut into required length by using cutting machine. Shear links were prepared by bending them into required shape with correct dimensions. Steel wire and pliers were used to tighten the shear link to the bars. The distance between shear links was maintained at a distance of 100mm. The completed reinforcement for Specimen 1, Specimen 2, Specimen 3, and Specimen 4 are shown in Figures 3.6, Figure 3.7, Figure 3.8, and Figure 3.9 respectively.

Corroded bar was knocked on the floor to remove the residue on the bar surface. It was assumed that the strength of the bars would not be affected by the corrosion on the surface. All the bars underwent tensile test to determine the maximum tensile strength of the bars.

Figure 3.6: Front view of reinforcement cage for Specimen 1 (control).

Figure 3.7: Front view reinforcement cage for Specimen 2.

Figure 3.8: Front view reinforcement cage for Specimen 3.

Figure 3.9: Front view reinforcement cage for Specimen 4.

3.3.3 Slump Test

The workability of a concrete mix I defined as the case with which it can be mixed, transported, placed, and compacted in position. Slump test is carried out to measures the consistency of plastic concrete. It is suitable for detecting changes in workability. This test is being used extensively on site. There are four types of slump true slump, zero slump, collapsed slump, and shear slump which are shown in Figure 3.10.

In this study, slump test was also conducted for ready mix concrete once it's arrived on site in order to measure the workability of the concrete mix. The concrete mix was compacted in four layers in the slump cone. Each layer was compacted for 25 times by using compactor rod. After the first layer was compacted, second layer of concrete was put inside the cone and compacted. The same step was repeated for third and fourth concrete layer inside the cone.

After the compaction process has been done, the cone was lifted up carefully and slowly in order to determine type of slump occurred. The height of the slump was measured before and after the cone was lifted up. The difference of height between the cone and concrete height obtained after the cone was lifted up is the slump height. The allowed slump height was between 30mm to 60mm in order to obtain high concrete workability without affecting the required concrete strength. The workability of the concrete increase as the slump obtained from slump test was big and vice versa.

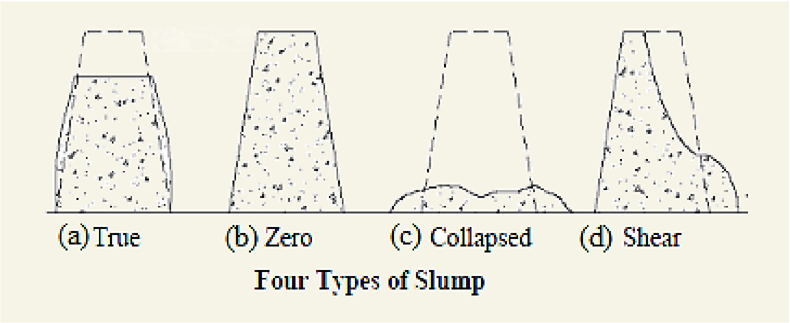


Figure 3.10: Four types of slump: (a) True Slump; (b) Zero Slump; (c) Collapsed Slump; (d) Shear Slump.

3.3.4 Concrete Cube

In this study, ready mix concrete was used to cast all the specimens. The ready mix concrete with Grade 30 was ordered form nearby ready mix concrete batching plant. Ordinary Portland Cement, 20mm coarse aggregate, fine aggregate and water was used in the ready mix concrete. The amount of ready mix ordered was 1.00mm^3. During the casting of specimen, few concrete cubes were cast using the ready mix concrete to identify the compressive strength of the concrete after 28 days.

About 9 concrete cubes were casted using ready mix concrete as shown in Figure 3.11. At first, 9 Compressive Moulds of dimension 100mm x 100mm x 100mm for concrete cube was prepared. A layer of grease was applied in the inner surface of the mould. The ready mix concrete mix was poured and compacted into three layers in mould. Each layer was compacted for 35 times by using a rectangular compactor rod. The well compacted concrete mix was able to produce high strength with the concrete strength equally distributed. Good technical skills in concrete compaction were achieved during the process of trial mix. After the casting was done, the cubes were unmoulded after 24 hours and then the cubes were placed in curing tank.

Figure 3.11: Concrete cubes.

3.3.5 Concreting

The ready mix concrete that arrived on site was verified with the delivery order in order to ensure that the delivered ready mix concrete was in accordance with requested specifications. The item that was checked is concrete grade, type of cement used, size on aggregates and batching time. After the verification was done, slump test was carried out to measure workability and consistency of ready mix concrete. The range of the slump that was maintained is around 30mm to 60 mm.

After that, the concrete was poured into the specimens mould in 2 layers. During the pouring process, it is important to ensure that the concrete was completely compacted. While pouring the concrete into the formwork, compaction work was carried out by using the poker vibrator to ensure that the concrete was well compacted in order to prevent the existence of honeycomb. The concrete was vibrated at the correct frequency as it will not only fluidize the mix, but also coat the aggregate with cement paste and release trapped air. The mix cannot be exposed to air too long to prevent segregation.

After the compaction work was done, the screeding work was carried out on the surface of the concrete in order to level and smooth the surface of the concrete as shown in the Figure 3.12. To prevent the concrete moisture to evaporate from the concrete surface, wet gunnies were laid on top of the concrete surface.

Figure 3.12: Screeding of specimens.

3.4 CURING PROCESS

Curing process is one of the most important processes which enhance the strength of the concrete. This is important to retain the moisture inside the concrete for hydration process.

After the reinforced concrete beam was unmoulded, wet gunnies were placed on top of the beam surface to prevent moisture from evaporating from the concrete surface as well as to prevent shrinkage from occurring. The curing process was carried out for 28 days. The specimen was able to achieve the required concrete strength in the proper curing process.

3.5 TESTING PROCESS

The testing process in this study comprise of two test which is cube compression test and three point flexural test. These two tests were carried out according to the respective procedures and standards. The both test was conducted after the curing process in accordance with the standards.

3.5.1 Cube Compression Test

Compression test of moist-cured specimens is conducted immediately after the removal of specimens from moist storage or curing tank, with three hardened concrete specimens shall be used in the measurement of concrete strength at the designed age. To avoid excessive result inaccuracy, test specimens shall be made, cured, and stored in accordance to the standard and compression testing shall not be performed on the improperly assembled specimens. The standards that were used for this test are BS 1881: Part116:1983 and ASTM C 39 – 03.

In this study, compression test was carried out to measure concrete strength of the concrete cube. The concrete cube was tested in the compression test machine as shown in Figure 3.13. Every 3 concrete cubes were tested on the 7th, 14th and 28th days of curing respectively to identify the compressive strength of the concrete cubes. Compression cube test was done right after the cubes were taken from the curing tank. Three cubes were used in this test and the average taken as the compressive strength of the concrete. The concrete cube with correct concrete mix design was able to achieve two thirds of designed concrete strength on the 7th day of curing process. The average compressive strength of the concrete cubes that was achieved after curing process for 7 days, 14 days and 28 days are 21.4MPa, 26.7MPa and 31.9MPa respectively.

Figure 3.13: Compressive test machine.

3.5.2 Three Point Flexural Test

Three Point Flexural test was conducted to identify the ultimate load and deflection of the specimens. The tests on the specimens were carried out after the curing process for 28 days.

Magnesframe machine was used to conduct the test. The load was applied on the width of the beam structure. Before the testing was carry out, all the specimens was painted with white paint and grid line with dimension of 50mm×50mm was drawn on the front part of the beam. This white paint on the front part of the beam will ensure the visibility of the crack line and its pattern. Moreover, the gridline was drawn to measure the length of the crack line. The setting up of the specimen for testing is as shown in Figure 3.14 and Figure 3.15. A hydraulic jack was used to apply the load on the specimen. A deflection transducer was fixed at the bottom of the beam which parallel to point load to identify the deflection of beam as shown in Figure 3.15. The readings of the loading were taken in every interval of 1 second. The load was applied on the specimens until it fail.

Photo of the specimens were taken during the testing process in order to obtain the development of deflection and cracking of the specimen. When a specimen fails, a photo was taken to study the deflection and cracking behaviour of the specimen. The ultimate load, deflection and cracking pattern were recorded and marked respectively. Testing area was cleaned after the experiment

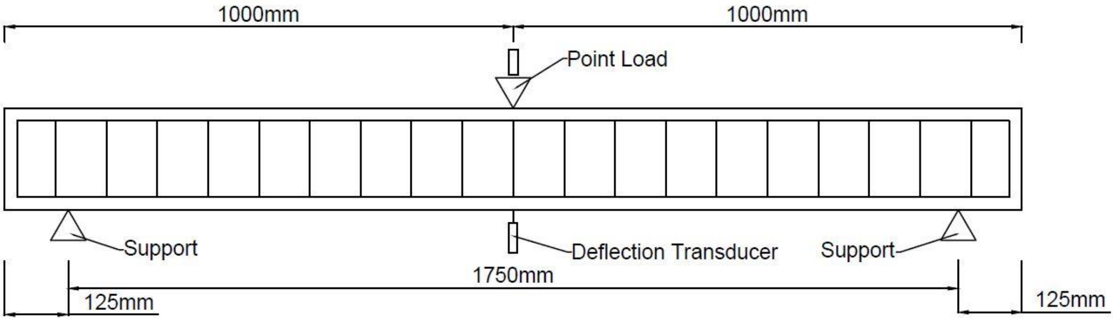


Figure 3.14: Typical set up of the beam for the Three Point Flexural Test.

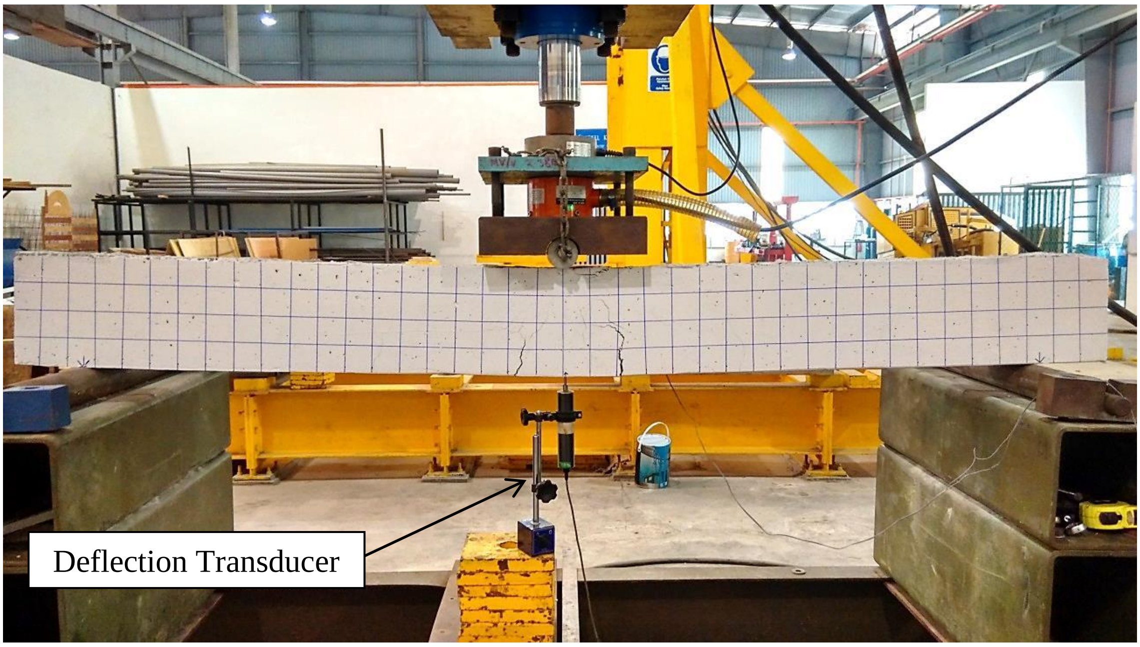


Figure 3.15: The actual set up of the specimen for testing.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter will discuss briefly about the result that has been obtain from the test. All the specimens were tested using three point flexural tests to obtain important parameters such as ultimate load, deflection, and strain of the specimens. The behaviour of the specimens was discussed by referring to the parameters such as ultimate load and deflection, ultimate load deflection ratio as well as cracking pattern.

4.2 FLEXURAL TEST RESULTS

Three point flexural tests were conducted for all four beams and the result of the test was recorded. The parameters which were obtained in the test are ultimate load, deflection, and strain of the specimens. The test result of three point flexural test is tabulated in the Table 4.1 and Table 4.2.

The above stated parameters was obtain during the test was recorded in the time interval of 30seconds. The parameters were recorded from 0 second to 420seconds for all specimens except for Specimen 4. Those parameters were only recorded from 0 second to 150seconds for Specimen 4.

Table 4.1: Three point flexural test result for Specimen 1 (control) and Specimen 2.

Time (sec)	Specimen 1 (control)			Specimen 2		
	Load (kN)	Deflection (mm)	Strain	Load (kN)	Deflection (mm)	Strain
0	0	0	0	0	0	0
30	0.84	0.128	30	0.38	0.01	9
60	7.44	1.011	60	4.74	0.615	106
90	14.31	2.608	90	10.25	1.965	241
120	20.67	4.389	120	15.05	3.53	225
150	28.33	6.223	150	19.83	5.27	241
180	35.91	8.081	180	24.62	7.104	274
210	42.19	10.087	210	29	9.044	278
240	42.55	12.378	240	33.1	11.22	316
270	43.02	14.726	270	33.02	13.609	391
300	42.92	17.134	300	33.01	16.005	388
330	42.87	19.602	330	32.89	18.435	389
360	42.87	22.029	360	32.76	20.852	372
390	42.93	24.424	390	32.58	23.303	424
420	42.94	26.864	420	32.49	25.847	389

Table 4.2: Three point flexural test result for Specimen 3 and Specimen 4.

Times (sec)	Specimen 3			Specimen 4		
	Load (kN)	Deflection (mm)	Strain	Load (kN)	Deflection (mm)	Strain
0	0	0	0	0	0	0
30	3.06	0.234	39	9.29	12.044	1561
60	6.07	1.333	241	9.31	24.568	273
90	8.9	2.615	254	8.16	36.844	213
120	11.32	3.932	239	7.76	46.491	176
150	14.11	5.319	200	7.79	46.494	175
180	16.32	6.699	163	-	-	-
210	19.03	8.177	129	-	-	-
240	20.81	9.7	110	-	-	-
270	22.29	11.337	72	-	--	-
300	22.71	12.994	15	-	-	-
330	22.52	14.77	0	-	-	-
360	22.45	16.46	-13	-	-	-
390	22.35	18.297	0	-	-	-
420	22.37	20.032	18	-	-	-

4.3 ULTIMATE LOAD

The ultimate load is the amount of load applied to a component beyond which the component will fail. In other words, ultimate load indicates the maximum strength of the component. The ultimate load of a reinforced concrete beam is the amount of load that the particular beam can withstand before it fails. Ultimate load can be determined by carry out flexural test. Once the beam reached its ultimate mode, it will begin to crack and further loading will cause failure.

The loading acting on the four types of specimens during test is tabulated in Table 4.3 below. The loading on the beams was recorded respective to the time of the testing.

Table 4.3: Load applied on the specimens respective to the time.

Time (sec)	Load (kN)			
	Specimen 1 (control)	**Specimen 2**	**Specimen 3**	**Specimen 4**
0	0	0	0	0
30	0.84	0.38	3.06	9.29
60	7.44	4.74	6.07	9.31
90	14.31	10.25	8.9	8.16
120	20.67	15.05	11.32	7.76
150	28.33	19.83	14.11	7.79
180	35.91	24.62	16.32	-
210	42.19	29	19.03	-
240	42.55	33.1	20.81	-
270	43.02	33.02	22.29	-
300	42.92	33.01	22.71	-
330	42.87	32.89	22.52	-
360	42.87	32.76	22.45	-
390	42.93	32.58	22.35	-
420	42.94	32.49	22.37	-

The Figure 4.1 shows the loading acting on the Specimen 1 (control) during testing respective to the time of loading. The ultimate load of this specimen which was gained during the test is 43.02kN. This ultimate load was gained at the time of 270 seconds after the test begin. At the time of 30 seconds the loading was 0.84kN and a drastic increase in loading take place until the time of 270 seconds where the Specimen 1 (control) reaches its ultimate load. During this time interval the relationship between loading and time is almost linear. After the time of 270 seconds the loading does not change much and the loading is almost constant over time.

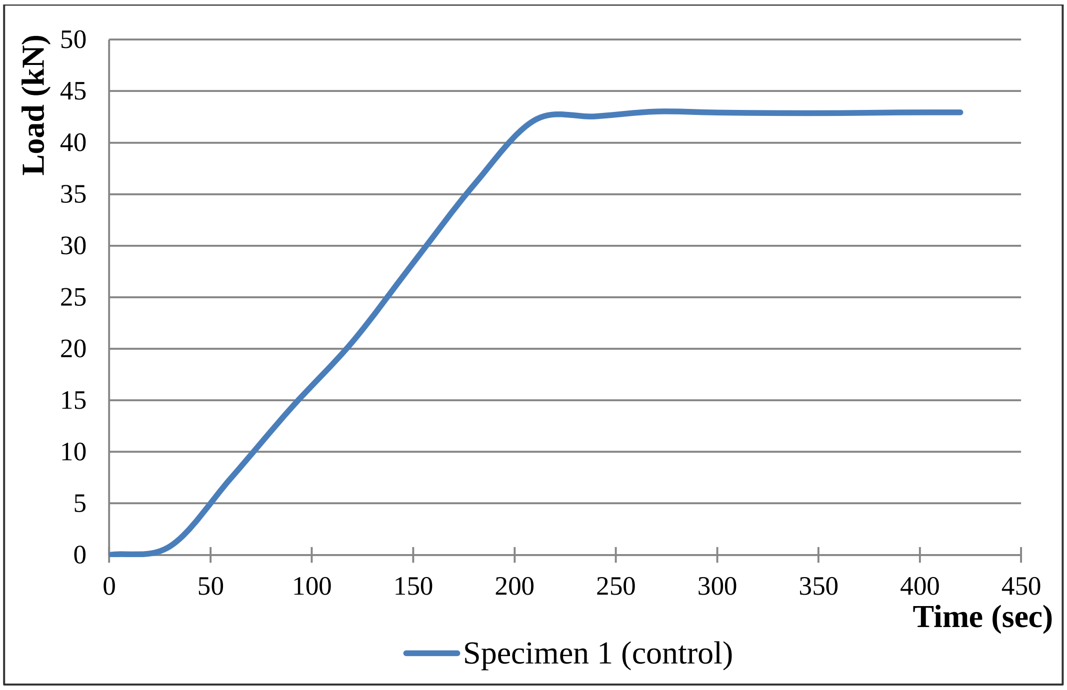


Figure 4.1: Graph load versus time of Specimen 1 (control).

The Figure 4.2 shows the loading acting on the Specimen 1 (control) and Specimen 2 over time of the testing. The Specimen 2 reached its ultimate load of 33.10kN at time of 240 seconds after the test begins. The ultimate load of Specimen 2 is lower than Specimen 1 by 9.92kN. At the time of 30 seconds the loading was 0.38kN for Specimen 2 and a rapid increase in loading take place until the time of 240 seconds where it's reached its ultimate load. During this time interval the relationship between loading and time is linear. After 240 seconds the loading is almost unchanged and the loading is nearly constant over time.

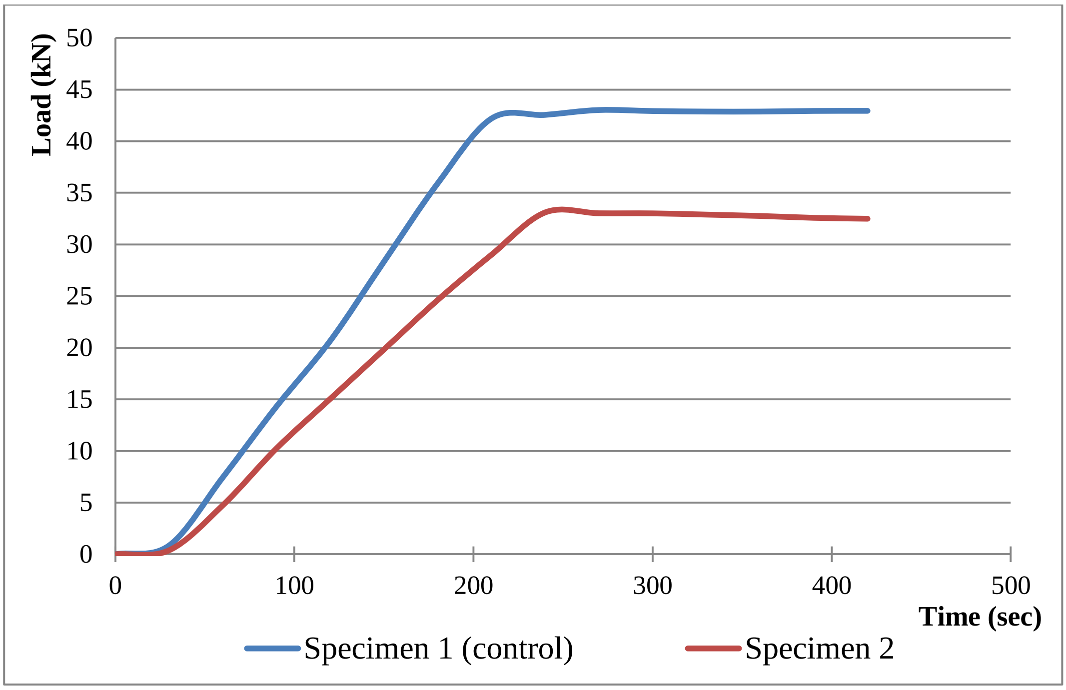


Figure 4.2: Graph load versus time for Specimen 1 (control) and Specimen 2.

The Figure 4.3 shows the loading acting on Specimen 1 and Specimen 3 respect to the time of testing. The ultimate load of Specimen 3 which was recorded in the test was 22.71kN at the time of 300 seconds. Specimen 3 shows a lower ultimate load compare to Specimen 1 by 20.31kN. At the time of 0 second the loading was 0kn for Specimen 3 and a gradual increase in loading take place until the time of 300 seconds where it's reached the ultimate load. The time interval during this period shows a linear relationship between the loading and time. After 300 seconds the loading remained steady and it is almost constant over time.

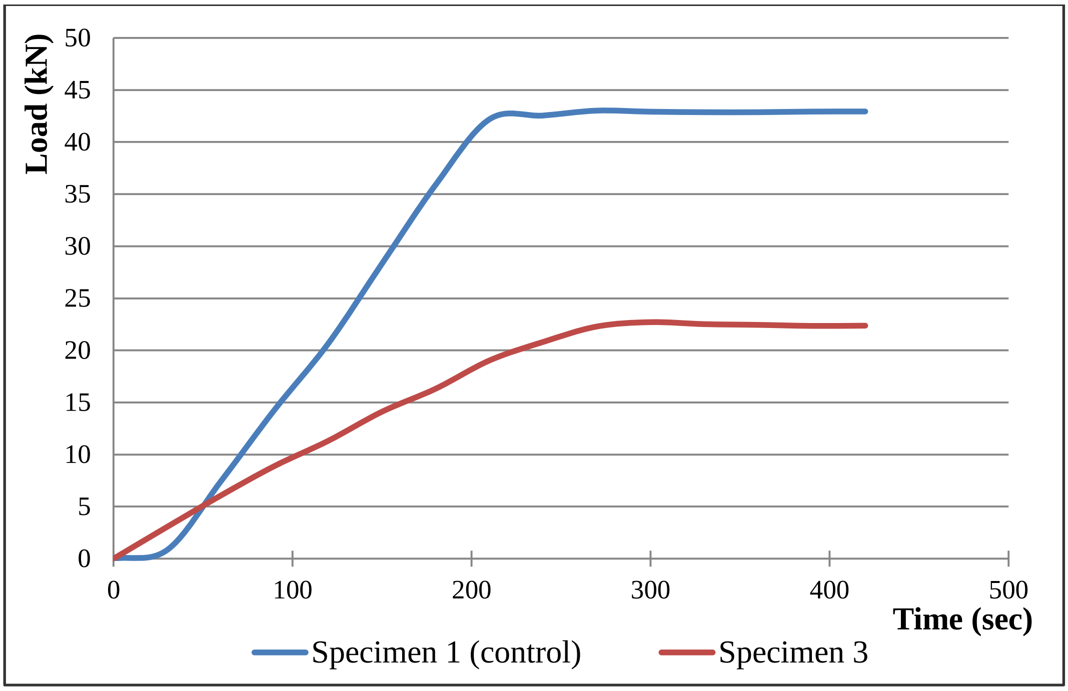


Figure 4.3: Graph of load against time of Specimen 1(control) and Specimen 3.

The Figure 4.4 shows the loading acting on the Specimen 1 and Specimen 4 over time of the testing. The Specimen 4 reached its ultimate load of 9.31kN at time of 60 seconds after the test begins. The ultimate load of Specimen 4 is lower than Specimen 1 by 33.71kN. At the time of 0 second the loading was 0kN for Specimen 4 and a sharp increase in loading take place until the time of 60 seconds where it's reached the ultimate load. During this time interval the relationship between loading and time is linear. After 60 seconds the loading decrease gradually until the time of 90 seconds and for further the loading become almost constant over time.

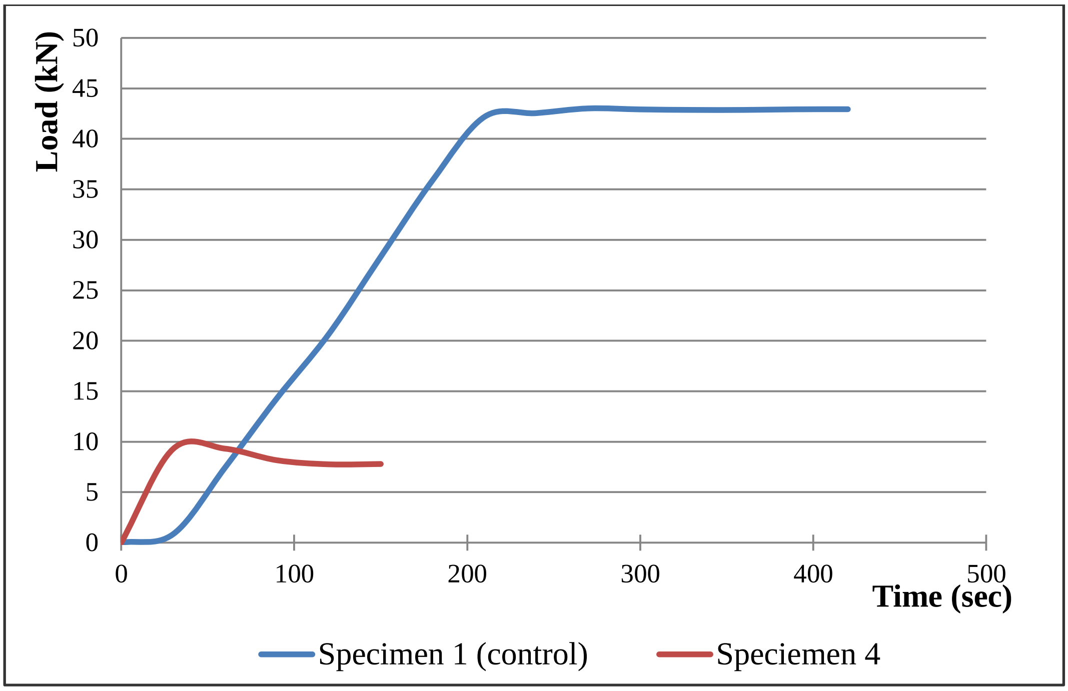


Figure 4.4: Graph load versus time of Specimen 1(control) and Specimen 4.

The Figure 4.5 shows the ultimate load of all four specimens which is Specimen 1 (control), Specimen 2, Specimen 3 and Specimen4. Among all the specimens, Specimen 1 has the highest ultimate load with 43.02kN followed by Specimen 2 with ultimate load of 33.10kN. The ultimate load of Specimen 3 is in third highest place with ultimate load of 22.71kN. Specimen 4 has the least ultimate load compare to three other specimens with ultimate load of 9.31kN.

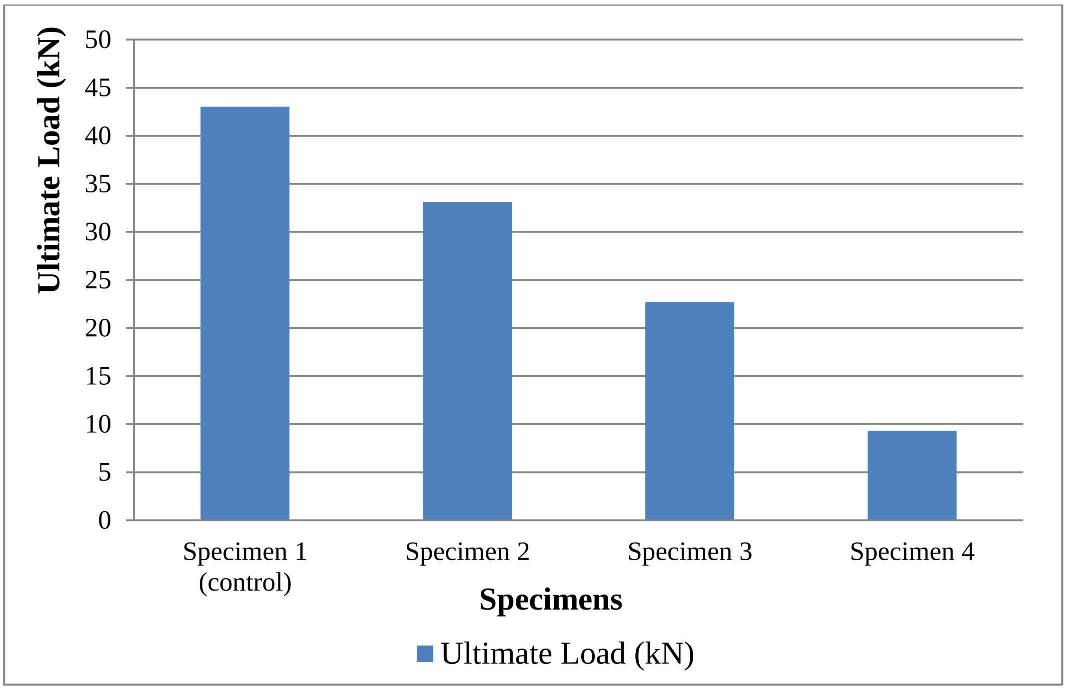


Figure 4.5: Graph ultimate load versus specimens.

The ultimate load of the specimens respective to time shows the increasing of arch angle and height of the longitudinal tension bar causes the ultimate load of the specimens decrease. This variation of ultimate load emphasize that the angle and height of arch shaped tension steel bar influences the ultimate load of reinforced concrete beam.

Table 4.4: The ultimate load percentage differences between specimens.

Specimens	Ultimate Load (kN)	Percentage Difference (%)
Specimen 1 (control)	43.02	-23.06
Specimen 2	33.10	
Specimen 1 (control)	43.02	-47.21
Specimen 3	22.71	
Specimen 1 (control)	43.02	-79.36
Specimen 4	9.31	

The Table 4.4 shows the percentage difference of ultimate load between Specimen 1 (control) and Specimen 2, Specimen 3 and Specimen 4. The ultimate load of Specimen 2 decreases by 23.06% when compared to the ultimate load of Specimen 1 (control). The percentage difference of ultimate load of Specimen 1 (control) and Specimen 2 is -47.21%, which show a decrease in the ultimate load. The Specimen 4 shows the highest percentage difference of ultimate load when compared to Specimen 1 (control) which is -79. 36%. Among all the specimen comparison, Specimen 1 (control) and Specimen 4 shows large percentage differences while Specimen 1 (control) and Specimen 2 shows the least percentage differences.

4.4 DEFLECTION

Deflection is one of the major failure mode that faced by reinforced concrete beam. The deflection that undergo by reinforced concrete beam is can be defined as vertical displacement of the beam when it bend downwards. The load applied on the beam is the reason for this phenomenon. Generally the relationship between the load applied and deflection is linear until certain limits.

The deflection recorded by all the specimens during test is tabulated in Table 4.5. The deflection of the specimens was recorded respective to the time of the testing.

Table 4.5: Deflection of the specimens respective to the time.

Time (sec)	Deflection (mm)			
	Specimen 1 (control)	**Specimen 2**	**Specimen 3**	**Specimen 4**
0	0	0	0	0
30	0.128	0.01	0.234	12.044
60	1.011	0.615	1.333	24.568
90	2.608	1.965	2.615	36.844
120	4.389	3.53	3.932	46.491
150	6.223	5.27	5.319	46.494
180	8.081	7.104	6.699	-
210	10.087	9.044	8.177	-
240	12.378	11.22	9.7	-
270	14.726	13.609	11.337	--
300	17.134	16.005	12.994	-
330	19.602	18.435	14.77	-
360	22.029	20.852	16.46	-
390	24.424	23.303	18.297	-
420	26.864	25.847	20.032	-

The Figure 4.6 shows the deflection of the Specimen 1 respective to the loading on the beam. At the ultimate load of 43.02kN the Specimen 1 gives deflection of 14.726mm. The relationship between the loading and deflection of Specimen 1 is linear until it reaches the ultimate load. After the ultimate load is reached, the deflection is still increase with almost constant loading.

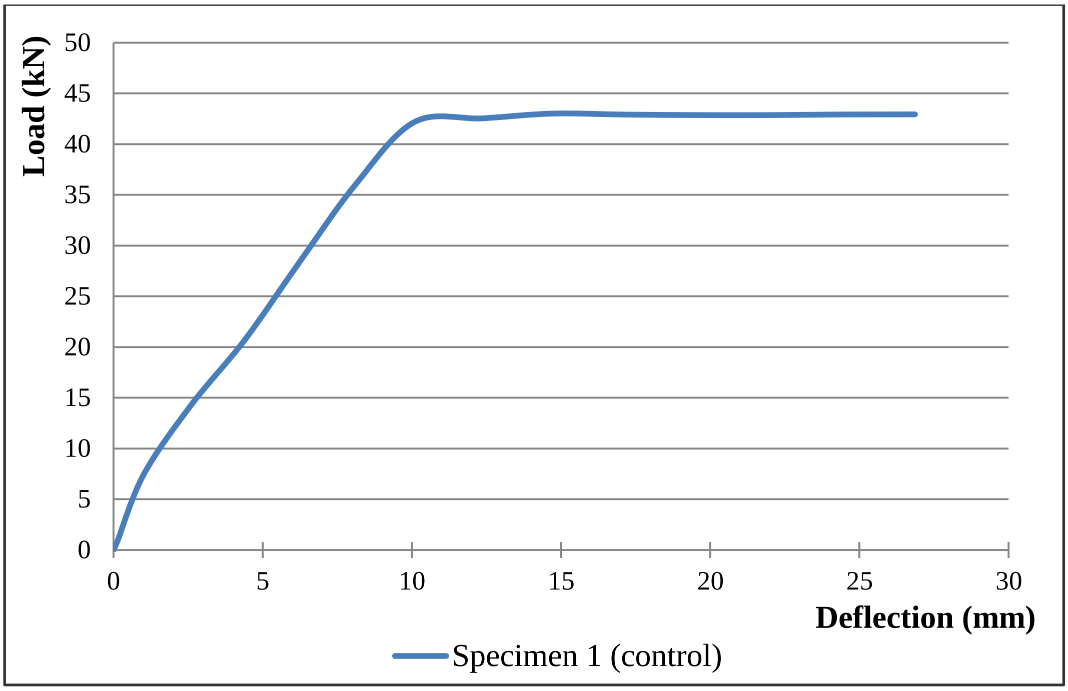


Figure 4.6: Graph load versus deflection of Specimen 1 (control).

The Figure 4.7 shows the deflection of the Specimen 2 over the loading on the beam. The Specimen 2 reaches a deflection of 11.22mm at its ultimate load of 33.1kN. The loading and deflection of this specimen shows a linear relationship until it reaches the ultimate load. The deflection still increased after the ultimate load with nearly constant loading.

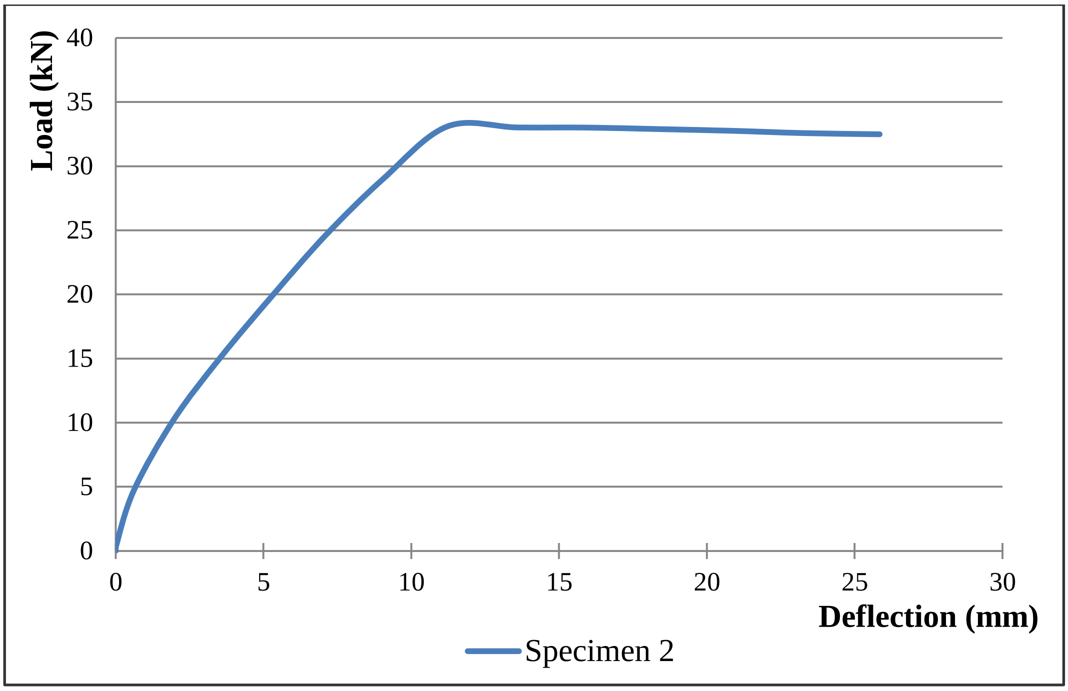


Figure 4.7: Graph load versus deflection of Specimen 2.

The Figure 4.8 shows the deflection of the Specimen 3 respective to the loading on the beam. At the ultimate load of 22.71kN the Specimen 2 gives deflection of 12.994mm. The relationship between the loading and deflection of Specimen 3 is linear until it reaches the ultimate load. After the ultimate load is reached, the deflection is still increase with almost constant loading.

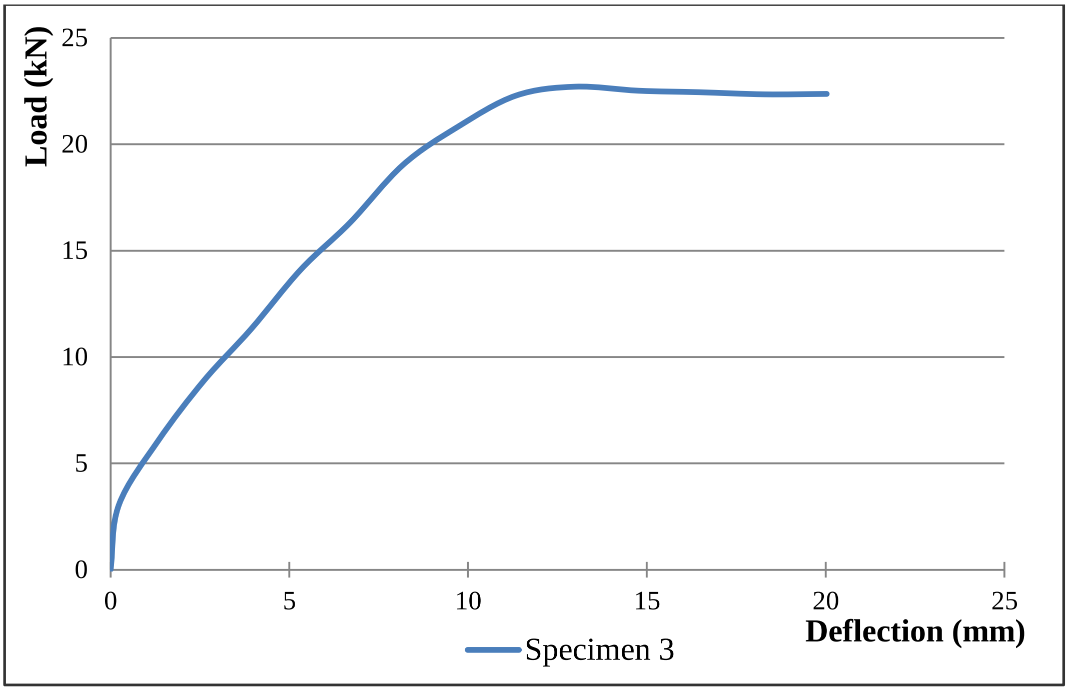


Figure 4.8: Graph load versus deflection of Specimen 3.

The Figure 4.9 shows the deflection of the Specimen 4 over the loading of beam. The Specimen 4 reaches a deflection of 24.568mm at its ultimate load of 9.31kN. The loading and deflection of this specimen shows a linear relationship until it reaches the ultimate load. The deflection still increase after the ultimate load with a gradual decreasing loading.

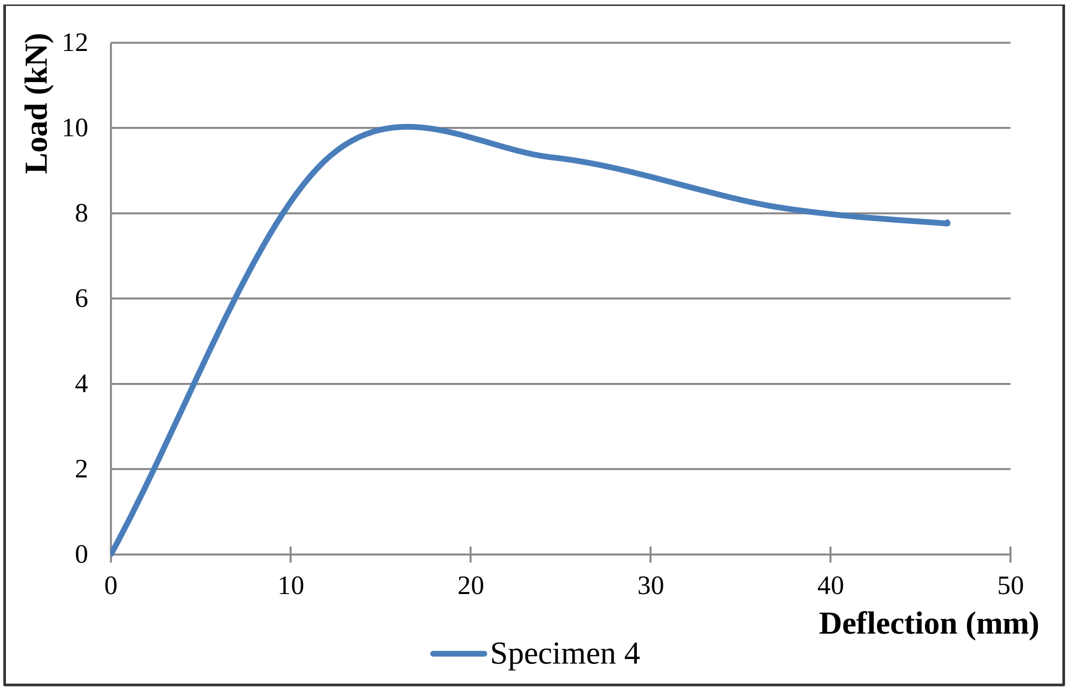


Figure 4.9: Graph load versus deflection of Specimen 4.

The Figure 4.10 shows the deflection of the specimens respective to its ultimate load. Among all the specimens, Specimens 4 shows highest deflection 24.568mm when it reaches the ultimate load of 9.31 kN. The second highest deflection of 14.726mm was recorded by Specimen 1 (control) at the ultimate load of 43.02kN followed by Specimen 3 with deflection on 12.994mm with an ultimate load of 22.71kN. The lowest deflection was achieved by the Specimen 2, which is 11.220mm, with an ultimate load of 33.1kN.

This shows that the Specimen 2 is stronger when compared to Specimen1 (control), Specimen 2, and Specimen3 in term of deflection when the specimen reaches its ultimate load. The arch shaped tension steel bar with an angle of 7.05° and height of 30mm able to decrease the deflection by 3.506mm when compare to the conventional design of horizontal tension steel bar. The deflection was successfully reduced by 23.81% with the new modification of tension steel bar. As conclusion that the angle and height of arch shaped tension steel bar influences the deflection of reinforced concrete beam.

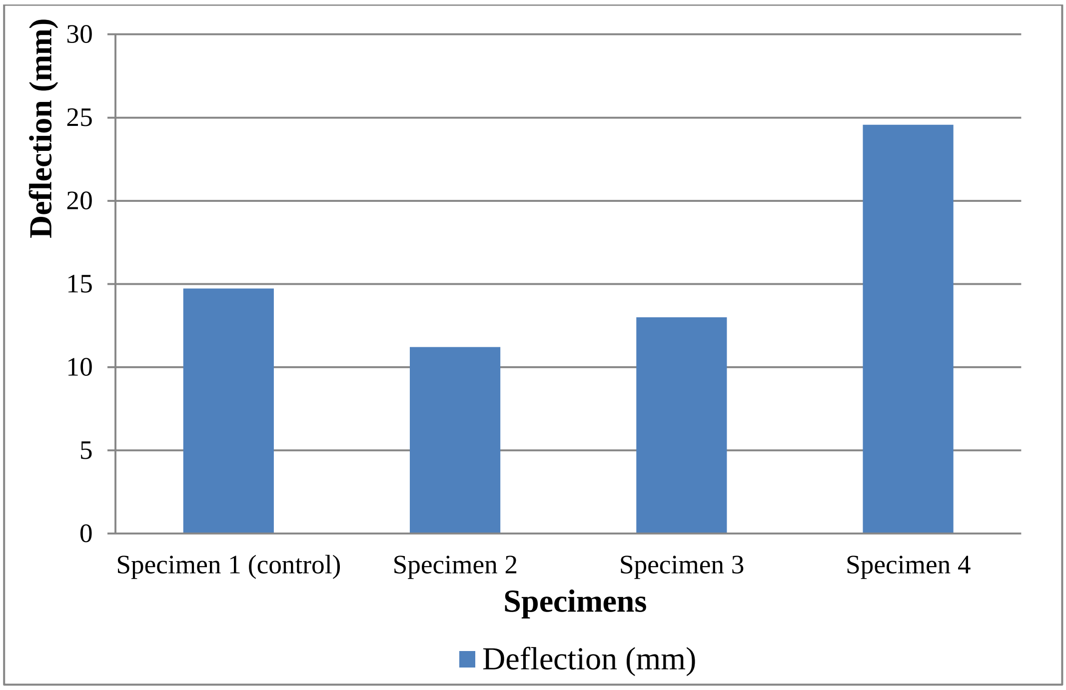


Figure 4.10: The deflection of the specimens respective to its ultimate load.

4.5 ULTIMATE LOAD DEFLECTION RATIO

Ultimate load deflection ratio defined as the amount of ultimate load required for the reinforced concrete beam to reaches a deflection of 1mm. This ratio will be used to identify the effectiveness of reinforced concrete beam in term of both ultimate load and deflection.

The Figure 4.11 shows the ultimate load deflection ratio of all the specimens. Among all the specimens Specimen 2 shows the highest ultimate load deflection ratio of 2.950 while Specimen 4 shows the lowest ultimate load deflection ratio of 0.379. Specimen 1 (control) records the second highest ultimate load deflection ratio of 2.921 and Specimen 3 record the third highest ultimate load deflection ratio of 1.748. As conclusion, Specimen 2 shows the highest ultimate load deflection ratio of 2.950 where it records ultimate load of 2.950kN for the deflection of 1mm.

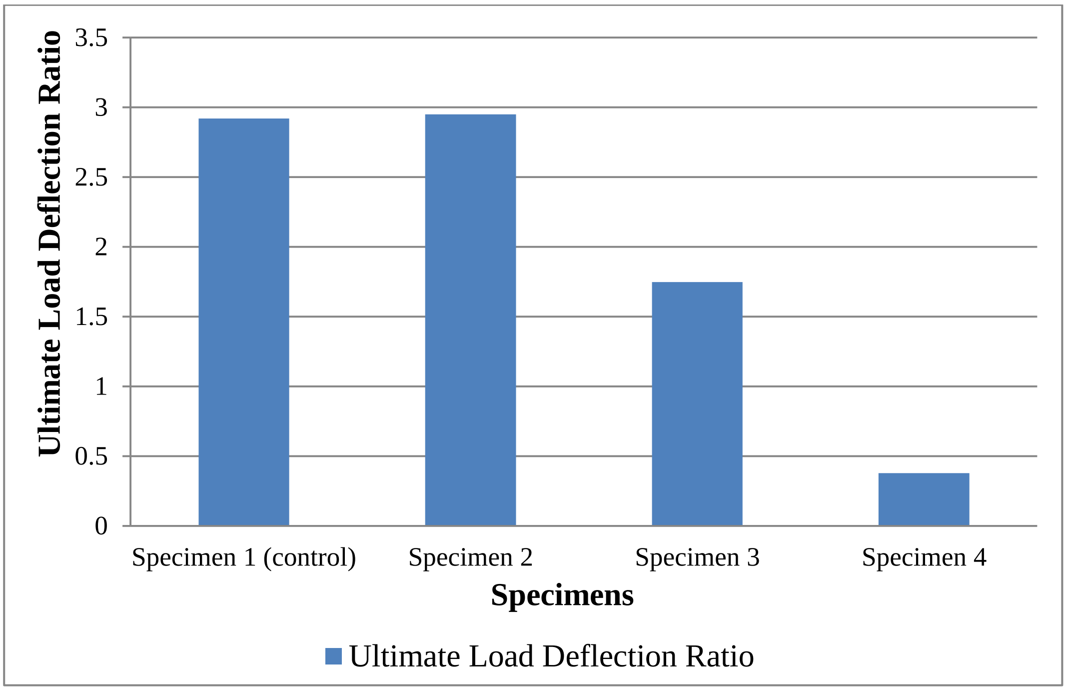


Figure 4.11: The ultimate load deflection ratio of the specimens.

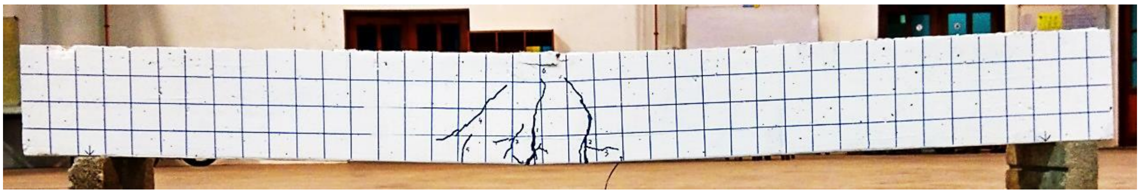
4.6 CRACKING

Cracking is the most visible failure mode that takes place in a reinforced concrete beam. A reinforced concrete beam begins to crack when tensile capacity of the concrete is reached. The further loading of beam will lead to the increase in the width of the crack produced.

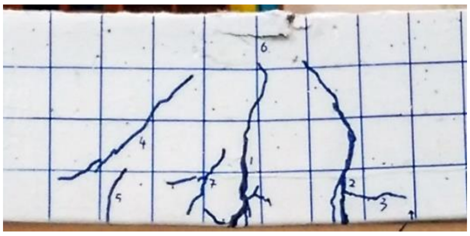
All the specimens show only major flexural failure where vertical cracks happen at the middle part of specimens. The major flexural cracks for Specimen 1 are crack number 1, 2 and 4. Meanwhile, for Specimen 2 the major flexural crack numbered as 1, 2 and 3. On the other hand, Specimen 3 has major flexural cracks with number of 1, 2, 3, 4, 5, 6, and 10. Lastly, the major flexural cracks for Specimen 4 are crack number 1, 2, 3, and 4. The Table 4.6 shows the maximum length of the crack of specimens with its number. Among all the specimens, Specimen 2 has the highest maximum crack length of 20mm and Specimen 4 has the lowest maximum crack length of 17mm.

Table 4.6: The maximum crack length of the specimens.

Specimens		**Crack Number**	**Maximum Length of Crack (mm)**
Specimen 1 (control)	**(Side)**	2	18
	(Bottom)	1	19
Specimen 2	**(Side)**	1	20
	(Bottom)	1	18
Specimen 3	**(Side)**	2	19
	(Bottom)	2	18
Specimen 4	**(Side)**	3	17
	(Bottom)	3	17



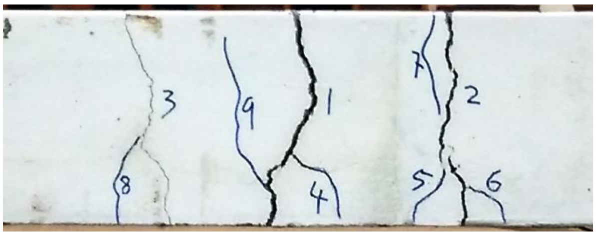
(a) Full side view



(b) Zoomed side view

Figure 4.12: Failure and crack pattern in Specimen 1 (control): **(a)** Full side view, **(b)** Zoomed side view.

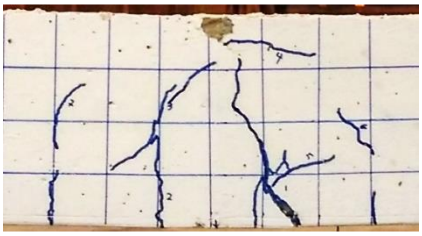
(a) Full bottom view



(b) Zoomed bottom view

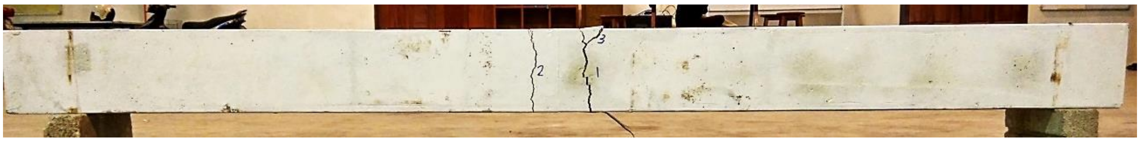
Figure 4.13: Failure and crack pattern in Specimen 1 (control): **(a)** Full bottom view, **(b)** Zoomed bottom view.

(a) Full side view

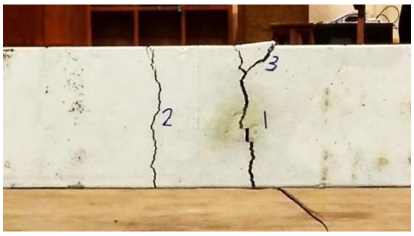


(b) Zoomed side view

Figure 4.14: Failure and crack pattern in Specimen 2: **(a)** Full side view, **(b)** Zoomed side view.

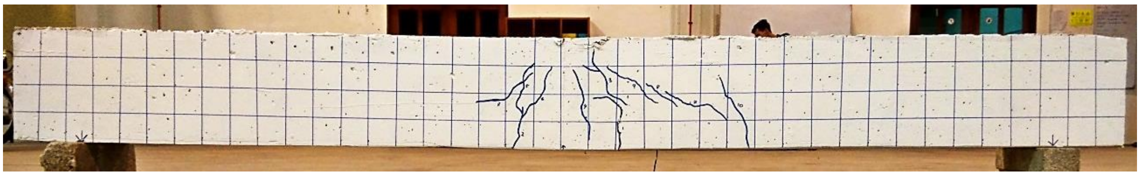


(a) Full bottom view

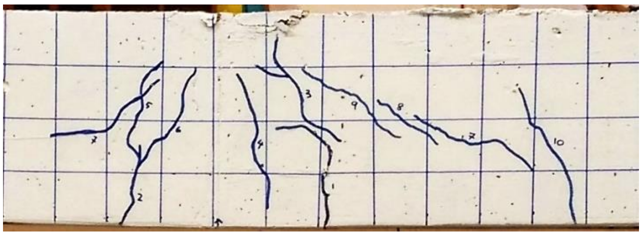


(b) Zoomed bottom view

Figure 4.15: Failure and crack pattern in Specimen 2: **(a)** Full bottom view, **(b)** Zoomed bottom view.



(a) Full side view



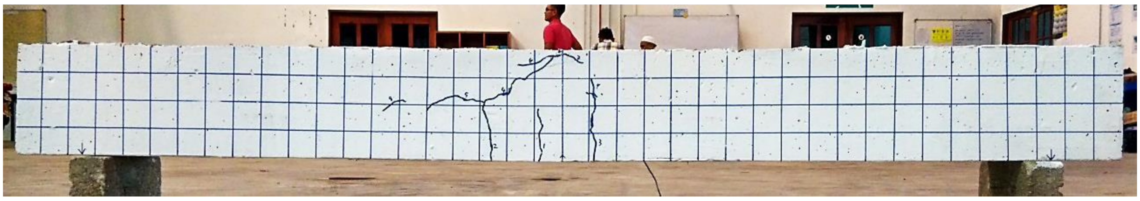
(b) Zoomed side view

Figure 4.16: Failure and crack pattern in Specimen 3: **(a)** Full side view, **(b)** Zoomed side view.

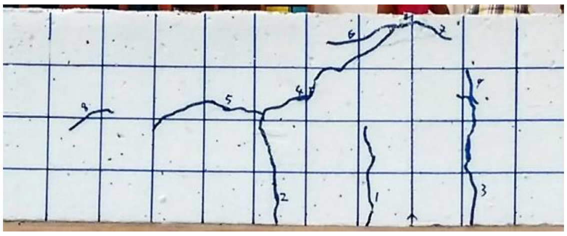
(a) Full bottom view

(b) Zoomed bottom view

Figure 4.17: Failure and crack pattern in Specimen 3: **(a)** Full bottom view, **(b)** Zoomed bottom view.

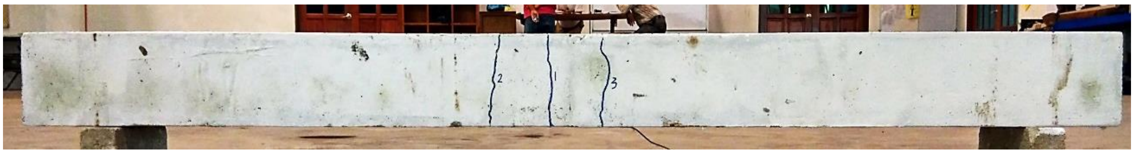


(a) Full side view

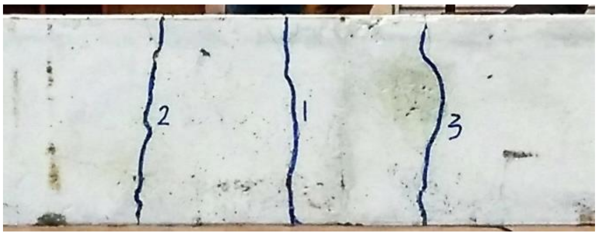


(b) Zoomed side view

Figure 4.18: Failure and crack pattern in Specimen 4: **(a)** Full side view, **(b)** Zoomed side view.



(a) Full bottom view.



(b) Zoomed bottom view.

Figure 4.19: Failure and crack pattern in Specimen 4: **(a)** Full bottom view, **(b)** Zoomed bottom view.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Reinforced concrete beam is an important structural element which play vital role in construction industry. The existing conventional reinforcement design of the reinforced concrete beam has been taken into some modification in order to produce beam with high strength and low defects. This study was carried out to identify the performance of the reinforced concrete beam which was modified with arch shaped tension steel bar. From this study, three main conclusions can be drawn:

i. The ultimate load of Specimen 1 (control), Specimen 2, Specimen 3, and Specimen 4 is 43.02kN, 33.10kN, 22.71kN, and 9.31kN respectively. In addition, the deflection in accordance with the ultimate load of the Specimen 1 (control), Specimen 2, Specimen 3, and Specimen 4 is 14.726mm, 11.220mm, 12.994mm, and 24.568mm respectively. This shows that the performance, in term of ultimate load and deflection, of the simply supported reinforced concrete beam influenced by the arch shaped steel bar with different arch angle and height in tension zone.

ii. Among the entire simply supported reinforced concrete beam with different arch angle and height of steel bar in tension zone, Specimen 2 shows the optimal ratio of ultimate load over deflection which is 2.950. This emphasize that Specimen 2 records an ultimate load of 2.950kN for the deflection of 1mm.

iii. From the study, the crack patterns showed by all beams are the crack pattern of flexural failure at the middle part of the specimens. Moreover, among all the specimens, Specimen 2 has the highest maximum crack length of 20mm and

Specimen 4 has the lowest maximum crack length of 17mm. As conclusion, all the specimens show only major flexural failure where vertical cracks happen at the middle part of specimens.

5.2 RECOMMENDATIONS

Following are some recommendation for further study in order to improve the accuracy of the study.

i. During the three point flexural test, the amount of the load exerted on the beam should be increased in constant rate to provide a constant failure pattern.
ii. Further studies on implementing the modification of tension steel bar in rein forced concrete beam in the lightweight structures.

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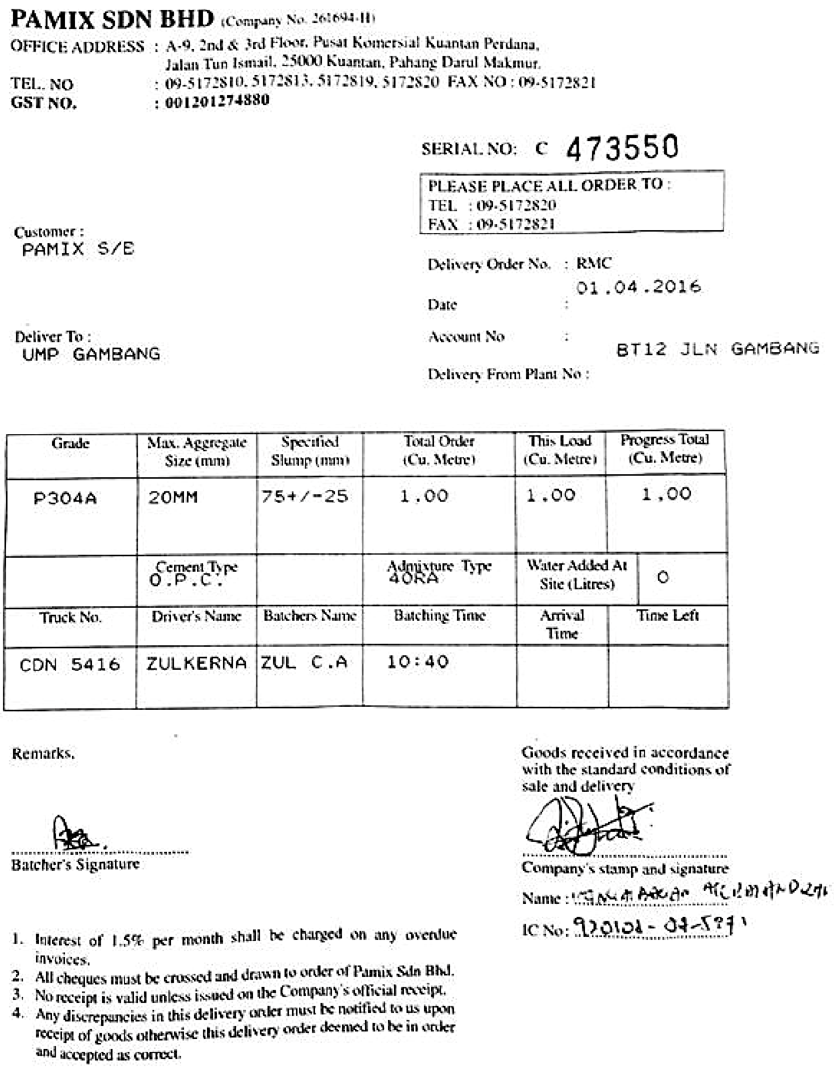
APPENDIX A

DELIVER ORDER OF READY MIX CONCRETE



PAMIX SDN BHD (Company No. 261694-H)
OFFICE ADDRESS : A-9, 2nd & 3rd Floor, Pusat Komersial Kuantan Perdana,
Jalan Tun Ismail, 25000 Kuantan, Pahang Darul Makmur.
TEL. NO : 09-5172810, 5172813, 5172819, 5172820 FAX NO : 09-5172821
GST NO. : **001201274880**

SERIAL NO: C 473550

PLEASE PLACE ALL ORDER TO :
TEL : 09-5172820
FAX : 09-5172821

Customer :
PAMIX S/E

Delivery Order No. : RMC
Date : 01.04.2016
Account No :
Delivery From Plant No : BT12 JLN GAMBANG

Deliver To :
UMP GAMBANG

Grade	Max. Aggregate Size (mm)	Specified Slump (mm)	Total Order (Cu. Metre)	This Load (Cu. Metre)	Progress Total (Cu. Metre)
P304A	20MM	75+/-25	1.00	1.00	1.00
	Cement Type O.P.C.		Admixture Type 40RA	Water Added At Site (Litres)	0
Truck No.	Driver's Name	Batchers Name	Batching Time	Arrival Time	Time Left
CDN 5416	ZULKERNA	ZUL C.A	10:40		

Remarks.

Batcher's Signature

Goods received in accordance with the standard conditions of sale and delivery

Company's stamp and signature
Name : [illegible]
IC No: 920101 - 04-[illegible]

1. Interest of 1.5% per month shall be charged on any overdue invoices.
2. All cheques must be crossed and drawn to order of Pamix Sdn Bhd.
3. No receipt is valid unless issued on the Company's official receipt.
4. Any discrepancies in this delivery order must be notified to us upon receipt of goods otherwise this delivery order deemed to be in order and accepted as correct.

Figure 1: The delivery order of ready mix concrete.

APPENDIX B

REINFORCED CONCRETE BEAM

Figure 2: Casting of reinforced concrete beam.

Figure 3: Reinforced concrete beam after curing process.

APPENDIX C

THREE POINT FLEXURAL TEST

Figure 4: Three Point Flexural Test Machine “Magnesframe”.

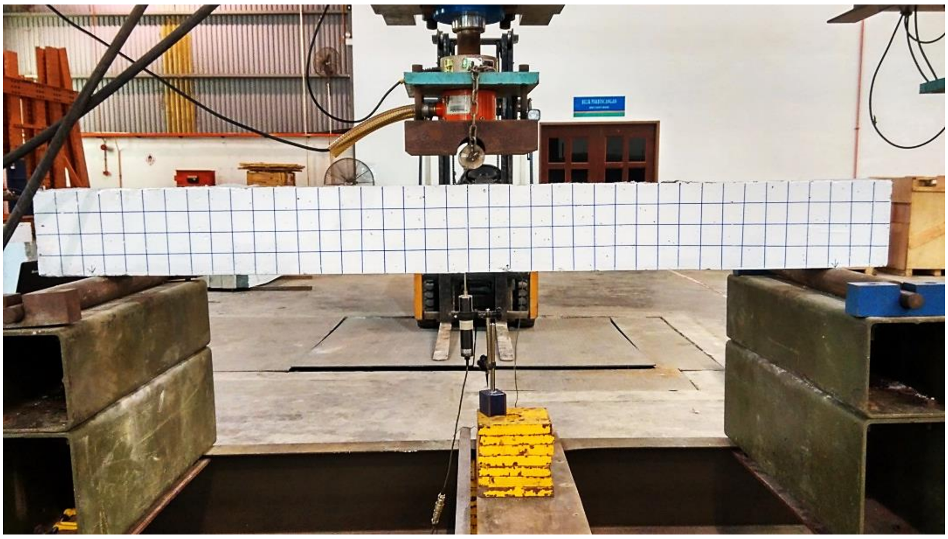


Figure 5: Placing of specimen in the testing machine according to specifications.

APPENDIX C (CONTINUED)

Figure 6: Data Processor.

Figure 7: Testing machine operating panel.