Finite Element Analysis within Reinforced Concrete Structures

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# *Abstract*

Reinforced concrete is a common material used in the construction industry. It is used to add more strength to the structure for high durability. Several studies that have been undertaken regarding reinforced concrete indicate that it is an important component of materials, and its application determines the stiffness, strength, and durability of a structure. The type of models of reinforced concrete depends on the type of structure being constructed by construction engineers. Reinforced concrete structures are usually designed to ensure that certain criteria of safety and serviceability are achieved. To make sure that the serviceability requirement is met, it is important to predict the cracking and deflections of the reinforced concrete structures which are under service loads. The main objective of the design is to provide room for the creation of economical and safe structures. Advanced analytical tools used for testing and checking the safety of concretes can be a crucial aid for the assessment of the safety of any proposed design. This study, therefore, establishes the components of reinforced concretes and its importance to the structure of buildings. The study, therefore, analyzes the finite element, which exists within reinforced concrete structures, to provide an understanding of how strength and stiffness of the structures can be achieved. However, the use of beams and slabs is an important factor for the stability of a structure. Therefore, the study analyzes the structure of beams and slabs, especially materials which are used for the construction of slabs and beams.

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## *Section One: Material Modeling*

## *General Information*

For decades, reinforced concrete (RC) has been widely used in several types of engineering structures. Reinforced concrete is regarded as the most important building material used in the construction industry because of its strength, durability, stiffness and the economical nature of the materials (Kwak & Filippou, 2014). Concrete must meet a certain condition for it to be used as a structural material by construction engineers and other builders. According to Kwak and Filippou (2014), reinforced concrete must be strong and safe because it must provide strength and be able to stand any kind of collapse which may occur as a result of overload. Therefore, there must be a sufficient margin of safety in any structure, and this can only be provided by strong and durable concrete. The durability of the concrete is an essential factor for any construction or structural engineer. It can be achieved through a proper curing process and the use of the right materials for the production. Therefore, modelling materials determine the strength, stiffness and workability of reinforced concrete. The production of concrete should be done based on the standard established for the demanded quality to be achieved. As pointed out by Kwak and Filippo (2014), the materials must be utilized efficiently because the difference that exists between steel and concrete is comparatively large.

The main objective of the design is to provide room for the creation of economical and safe structures. The advanced analytical tools, which are used for testing and checking the safety of concretes, provide the best mechanism to test the safety of structures constructed using reinforced concrete (Babu, Benipal, & Singh, 2005, p. 25). This is because several complex modern structures that have been established worldwide are of high loads and some are used for the production of high content materials, and therefore, during the process of production, a lot of cracks form and deflation takes place. However, some of the complex modern structures are a nuclear power plant, offshore platforms for oil and gas exploration, bridges and underground tunnels. These structures are subjected to a high and very complex load which can easily cause a split in the walls of the structure. Without the use of strong and stiff concretes to build such structures, the structures would not stand the load and therefore, would split easily. The important factor in construction of any structure is the materials used, one of which is concrete.

The structures which are constructed using reinforced concrete are designed to make sure they meet the criteria of safety of a building. In order to make sure that the serviceability requirement is met, it is important to predict the cracking and deflections of the reinforced concrete structures which are under service loads. Welch, Fletcher, Carvel, and Torero (2007, p.12) pointed out that the best way to evaluate the margin of safety of RC structures is by assessing some of the failures which may occur. This can be done through conducting accurate estimation of the load and prediction of load-deformation behaviour. It can be achieved through the use of elastic and elastic. This ensures that the strength required is achieved, which is essential for the construction of the structure.

## *Concretes*

Concrete’s durability, stiffness, versatility, and sustainability have made it one of the world’s widely used construction materials. According to Halahla (2018),) tons of concrete are produced yearly per person worldwide. It is estimated that about 1.7 tons per person are produced in the United States alone. In Australia, concretes are widely used in the construction industry, and according to Farooq & Ahmad (2015), about 1.2 tons of concretes are produced and used for construction across the country. The concept of concrete is referred to as the mixture of aggregates, which are usually sand and either gravel or crushed stones. Water and cement are other supplementary materials that are used for the production of cement. For the last years, different types of concretes have been established using technologies. The types of concrete produced are based on the materials used for the production of the concrete. As stated by Tantawi(2015, p. 23), polystyrene concretes or lightweight concretes are widely produced and used by the industrial sector. Lightweight concrete is durable, has high strength, stiffness and environmentally friendly compared to other concretes. For these reasons, it is widely preferred by structural and construction engineers. However, the production of any type of concrete relies on the benefits it provides to the construction industry. This has made experts prefer high durable, stiff, strong and economy concretes for the constructions of various modern structures.



***Diagram 1: Concretes of mixture; made using various materials such as sand, cement, and aggregates (Farooq & Ahmad, 2015, p. 25)***

As shown in diagram 1 above, concrete is produced using composites such as sand, water, cement, and other aggregates. The materials used for the production of concretes determine the strength and durability of the concretes. A study conducted by Cotsovos, Pavlovic, & Kotsovos (2008), concluded that the use of polystyrene and other recycled materials are some of the technological methods used to derive the best, environmentally friendly, durable and strong concretes. The above image in diagram 1 is an example of concretes produced using locally collected aggregates, cement, and sand is much different from other concretes produced using polystyrene. From this perspective, it is evident that concrete is a versatile material that can be mixed to meet different special needs of the industry in the form of shape, and the size needed for specific structures. Compared with the image in diagram 2 below, there is a clear difference between the two concretes. The concretes produced using polystyrene which is synthetic and recycled materials, and mostly locally assembled materials, are quite different in terms of texture, strength and durability. It is evident that the materials used for the production of concrete determine the type of concrete produced. The expanded lightweight concrete is different since it is produced using recycled materials. It is, therefore, evident that concretes are produced using a variety of materials and the strength, durability, and workability of the concrete depends on the materials used for the production.



***Diagram 2: expanded lightweight concrete properties***

### *Behaviour of concrete*

Concrete has brittle post behaviour. According to Tejchman & Bobiński(2014), the majority of the concretes depend on the materials used for the production of concretes. An experiment conducted on the behaviourof concretes indicates that concretes are generally abrasive, stiff and hard. However, the stiffness or strength of the concrete is based on the components used in the production. There is lightweight concrete, which is produced using polystyrene and traditional concrete. In general, concretes behave differently when exposed to different levels of temperature. The behaviour of concretes, when placed on high temperature, is easily comprehended by discovering the effect of temperature on the properties of concrete. It is pointed out that fire has an effect on the density of the structure of the concrete in a small percentage(Das, Painkra, & Babu, 2016, p. 21). But it does not have an effect on the thermal conductivity of concrete. Therefore, it means that the behaviour when concrete is exposed to temperature is unique. The exposure of concrete to high temperature increases heat by almost 20% which is relative to the room temperature (Farzampour, 2019). However, temperature that is higher than 500-degree Celsius can reduce the strength of the concrete. A study conducted by Farzampour (2019, p. 32) established that a higher temperature caused the split of the concrete and therefore, it made the concrete weaker. Concrete does not undergo the melting stage when exposed to high temperatures. The high temperature only brings change to the material composition and properties of the concretes. But when exposed to an environment of hydrocarbon fire or thermic lance, the concrete, therefore, would melt. The behaviour of concrete’s internal structure, strength, and reinforcementwhen placed on fire is unique. Therefore, the evidence indicates that high temperature reduces the strength and durability of the concrete (Mirmiran & Shahawy, 1999, p. 12).

Several studies have been conducted recently on the potential of inclusion of different types of fiber into the production of concrete so that the effect of spalling can be mitigated. Other studies have been conducted using polypropylene fibres into the mix of concrete. The main idea is that when concrete is exposed to high heat, the polypropylene fibres would certainlymelt, to make a pathway within the material for low energy of water vapour and other gaseous products. This will definitely reduce the build-up pressure. It is, therefore, evident that the production of concrete is achieved by using several materials and the strength and durability of the concrete obtained depends on several factors which include environment and temperature. The concrete in cold temperature behaviour much different compared to when it exposed to high temperatures.



***Diagram 3: Concrete exposed to cold weather and cold weather curing (Akinwumi & Gbadamosi, 2014 )***

The durability of concrete depends on several factors which include the environment of exposure during the production stage. A study by Hamelin, Berthet, & Ferrier (2005), investigated the durability of the concrete against the free-thaw cycles and it was discovered that concrete has the ability to stand against weathering action. In order to improve the durability of the concrete, it is recommended to increase the ratio of the mixture of cement and water.

* 1. ***Concrete Models***

There are various types of concrete models used in the building and construction industry. The concrete behaviour such as linear elastic, empirical model, nonlinear elastic and plasticity are some of the models which exist in the concrete. The linear elastic model is regarded as the simplest constitutive model available in literature. In linear elastic models, concrete is viewed and treated as linear elastic until it obtains the ultimate strength and consequently, it does not succeed in a brittle manner. For concretes which are under tension because the failure strength is very small, the linear elastic models become sufficient and accurate, making the prediction of the behaviour of concrete easy. This removes any kind of failure which may exist in the concrete. It is established that linear elastic is a stress-strain in relation and therefore, it utilizes the index notation (Babu, Benipal, & Singh, 2005). However, for concrete which is under tension because the failure strength is very small, the linear elastic model is very precise and sufficient and therefore, it is able to predict the behaviour of the concrete until it fails. The linear elastic strain connection is used in the index notation which can be written (Higgins, Forth, Neville, & Jones, 2016).

However, it is established that the weight of the concrete with polystyrene is lighter because it is mostly produced using light waste materials. In the study, it is pointed out that concrete with polystyrene has a stress-strain relationship and elastic modules under uniaxial loading(Akinwumi & Gbadamosi, 2014 ). It means that concrete with polystyrene provides high strength and durable. These are some of the factors which have enabled concrete polystyrene to have an advanced performance compared to traditional concretes. The traditional concrete is heavy and this makes it a less preferred material when compared to concrete with polystyrene (Coderre, Barbuda, Rosca and Serbanoiu (2018, p. 12).

Lee, Kang, Yu-Jin, and Hong (2018, p.23) have pointed out that polystyrene can be used as a normal concrete to replace the structure shield. It can also be used as a heat or energy absorber. The ability to absorb heat is due to its homogenized microstructure. The polystyrene concrete has the ability to prevent any damage by ballistic loading. The use of cement as one of the mixtures gives concrete with polystyrene a strong surface and durability required for the concrete to last. Therefore, most builders would prefer using concrete with polystyrene if the mixture’s ratio is matching and meeting the standard. Lee, Kang, Yu-Jin, and Hong (2018, p.235) in their study to investigate the preferred polystyrene concrete and the proportional mixture, concluded that components of concrete determine the quality of the concrete.

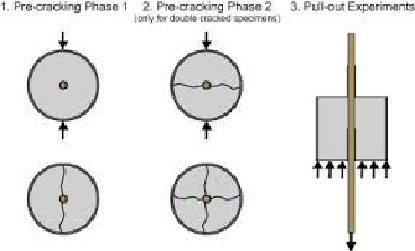
## *The behaviour of cracked concrete*

### *Description of a crack*

Crack is regarded as a sharp divide on the surface of a material. Concrete crack is regarded asa broken line which is marked by harshness or failure of concrete. As stated by Wu, Chen, & Gu ( 2015), a crack in concrete occurs when concrete is exposed to a high temperature which makes it generate tension and causes the crack. A crack in a structure can occur due to various reasons such as chemical reaction from the construction materials, settling of buildings, environmental stresses such as the movement of a train and the earthquake. Studies of different cracks by Song, Wu, Chen, & Gu ( 2015) concluded that that cracks can either be longitudunal or latitudinal depending on the load placed on the concrete. The crack mostly starts from the ends causing crack across the longitude. It is also stated that the crack normally occurs along the orientation rib of the concrete. An experimental study conducted by Zhang, Qiang, Zhang, & Ding (2015) concluded that the crack of concrete occurs due to high density or tension resulting from a lot of load. It is, therefore, evident that the more load is added to the concrete ,the higher the chances of experiencing a lot of cracks. However, most cracks occur within the first 10 days from the time concrete is exposed to high load, after that the concrete does not experience any cracks as a result of more loads.

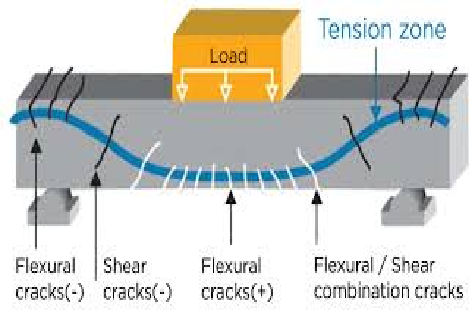
 Researchers have established that there is a significant loss of bond strength when concrete cracks (Grefenstette & Sadrzadeh, 2015). A study conducted by Grefenstette and Sadrzadeh (2015) concluded that cracked concrete caused a lot of bond loss of about 65% for any double cracked specimen. This means that a cracked concrete is weaker and should not be used for the purpose of construction of any structure. Concrete is produced using certain components such as water, cement, aggregate and sand. Each of these component’shave certain strength which reduces when a cracked is initiated on the concrete. According to (Pieter, Lees, & Morley, 2015, p. 21), the loss of bond of the strength of the concrete depends on the type of crack that occurred on the concrete. The study established that a crack that occurred along the orientation of the ribs pattern does not have much effect on the concrete compared to concrete cover(Lee, Kang, Yu-Jin, & Hong, 2018). Therefore, thebehaviours of concrete when crack occurs, are some of the crucial characteristics of concrete.

However, using the experimental result conducted by (Higgins l. , Forth, Neville, Jones, & Hodgson, 2013, p. 21), regarding the strength of reinforced concrete when submitted to load, indicates that reinforced concrete stiffness is maintained within the first 10 days. However, as the beam is subjected to more loads, the behaviour changes and the beam is likely to experience crack on the edges. The additional loads cause damage to the zone of the beams. This means that when concrete is subjected to too much load, crack is likely to be developed which can result in damage of concrete. The measure ofsurface stain of both the tension and the compression zone of the beam is considerably higher when a beam is subjected to a lot of loads. Higgins L., Forth, Neville, & Jones (2016) pointed out that this is because of the effect of the cyclic creep from the compression zone and a huge cracking that occurs within the tension. This means that the crack on the concrete affects the stability of any structure despite the cause of the crack. For the beam, the more the load is subjected to the beam, the high force, or tension is injected and the beam continues to get weaker. Therefore, the durability of the structure constructed using concrete depends on the load subjected to the structure and the materials used for the construction beside the concrete. It was pointed out that long term progressive increase of deflection results in strain development in the compression zone. The strain increases at the point of tensile reinforcement level approximately after 10 days, regardless of the type of load applied to the structure.It is therefore evident that the cracking of the concrete structure can only occur within the first 10 days. The addition of more loads after 10 days does not have any effect on the concrete. It is pointed out that the tensile would remain the same. It is high unlikely for any crack to occur on reinforced concrete(Herki, Khatib, & Negim, 2013). As illustrated in the image in diagram 4 below, the crack behaviour occurs in phases. The first phase is pre-cracking, where the force is injected into the concrete and the crack emerges due to tension. The more load is added to the structure, a crack is generated further as indicated in the phase of the image below and it finally cracks along the longitude of the concrete, making concrete less stiff.



***Diagram 4: Cracking behaviour of concrete (Higgins L., Forth, Neville, & Jones, 2016, p. 21)***

A study conducted indicates that the crack behaviour of concrete depends on the load and period in which the concrete is subjected to high load. An experiment conducted by Pieter, Lees, & Morley (2015), established that crack begins at the edge of the concrete and extends to the middle and the lower part of the concrete as illustrated on the image in diagram 5 below. The image indicates that the tension increases and then reduces and, therefore, when the tension zone is high, the crack occurs. It also shows that tension is high only where the load force is injected and after a while, tension reduces with the crack rate reduction. This could mean that a structure constructed using concrete can be subjected to unique crack depending on the load placed on the structure.



***Diagram 5: tension behaviour when concrete is subjected to load***

It is, therefore, evident that the crack behaviour of concrete is different and the type of crack depends on the load, which generates the tension causing a crack on the long the longitude of the concrete. The behaviour of concrete, when exposed to high temperature and load, is different though the end results if cracking. It is important to point out that it is significant to ensure that the concrete is used appropriately and the correct load is used on the structure based on theconstruction model. A 56 stayed building and 3 stayed building are constructed using different quality of materials to give concrete support to contain high load without experiencing any crack (R.B.Jensen, 2009). Without providing appropriate quality structural materials, concrete cannot contain the load and therefore, the strength of any structure does not depend only on the concrete but the general materials used for the construction of a structure.

### *Cracked model*

In the algebraic simulation of the structure of reinforced concrete, their various tendencies have been derived to represent the reinforced concrete crack. The model of the crack is smeared, discrete and incorporated. These three crack models are driven by different ideas and theories. The application of the ideas of crack models is always limited to the study of the problems, which involves the progression of cracks (Higgins L., Forth, Neville, & Jones, 2016). The discrete crack models are based on the idea that working with the portion of the solid will always remain continuous and without any damages. The design is applied to allow the formation and incorporation of the outline of solid during the progression of the existing crack. According to Trautwein, Menin, & Bittencourt (2018), the discrete crack is hindered in the way it is used and mostly, by the way, reinforced concrete is structured. Since it is started to be used in the reinforced concrete structure, the finite method has indicated more advantages by representing cracks through the establishment of changes of the constitutive equations.

## 1.6. *Reinforcing Steel*

### *1.6.1.The behaviour of Reinforcing Steel*

The composite action which occurs between reinforced steel and concrete cannot take place without the existence of the bond. Therefore, the bond performance of the rebars normally plays a crucial role in the behaviour of reinforced structure when exposed to dynamic or static load mostly for crack width control (Song, Wu, Chen, & Gu, 2015). The behaviour of reinforced steel is based on strain rates. According to Song, Wu, Chen, and Gu (2015), the high strain rate on the concrete can easily cause a blast. This is because of the high tension injected on the concrete when the strain is high. Therefore, the behaviour of the reinforced steel can be described using the strain curve and stress which occurs on the concrete. The diagrams on the concrete usually illustrate the enhanced dynamic strength at all the values of the strain until the failure point occurs. The RC frame structure can be different when the unique steel model is used to represent the cyclic behaviour of the reinforcing steel bars in reinforced concrete. The behaviour of reinforced steel depends on the structural component and model used to construct a building. The change of the model automatically changed the reinforced steel used in the construction. As stated byCadere, Barbuta, Rosca, & Serbanoiu, 2018), the reinforced steel is used with the concretes to provide high strength and stiffness, which can contain any kind of load. However, the structure of the reinforced concrete can be affected by seismic structure responses such as non-stationary characteristics of earthquakes, concrete confinement, and beam-column joint properties. It is only the reinforcement steel which is needed to be integratedinto a robust constitutive model of the reinforcement model. Moreover, the test conducted to test the Steel Behaviour from Cyclic Tests indicates a different result. Reinforced steel experiences crack when exposed to high temperatures. This is different from concrete which bends upwards and cracks.

## *Bonding Between Reinforcing Steel and Concrete*

### *Bonding Behaviour*

Concrete and steel show different bond behaviour when subjected to a different condition. A study conducted by Micheal (2015) on the behaviour of reinforced beams with non-bonded flexural reinforcement, established that bonding anywhere within the shear is inevitable and it normally leads to cracking, which is regarded as the usual cause of Shear failure. Based on the study conducted by Grefenstette & Sadrzadeh(2015) it is clear that bonding between concrete and steel occurs but it results in cracking of the concrete or bending of the steel.

***Bond Stiffness Matrix***

According to Vishakh and Vasudev (2018, p. 32), the lightweight concrete does not provide a guarantee of the strength required for any load-bearing structure element in order for it to be used for the separation of the walls. The study concluded that lightweight concrete is the best concrete because of the workability and durability it offers. However, in terms of strength, the ratio and curing process of the lightweight concrete must be observed to obtain the strength needed by the constructors. Without observing the curing process, the strength of the lightweight might be compromised and the strength would fade off. A study conducted by Shyan (2009, p. 23) concluded that lightweight performance depends on the mixture ratio and the materials used to produce it. Therefore, lightweight offers high durability and strength because of the content of the materials used for production. Bekhet, Barton, & Craggs (1993, p. 45) pointed out that the high strength of the lightweight aggregate is one of the advantages of using the lightweight. The lightweight concretes which are produced using expanded clay aggregate on the mechanical and physical properties of concrete. These properties are achieved as a result of the proper curing process. The curing process and the materials used for the process, is key to strength and durability. The study established that the usage of lightweight concrete could be the best strategy to reduce the cost of construction and increase the durability of buildings. However, it is also pointed out that it helps in saving cement content and therefore, the cost reduction could be achieved easily.

Gussev, Howard, Terrani, & Field (2017, p. 231) stated that the influence of using a lot of pozzolanic materials and the capillary water absorption, and found out that the strength of the lightweight concrete increases with the sorptivity. Aerated concrete and light weight aggregate concrete can be used as energy absorbent. It is, therefore, evident that the use of polystyrene concrete provides several advantages to the construction industry compared to alternative concretes. As noted by Gussev, Howard, Terrani, & Field (2017, p. 224) builders focus on the strength and durability of a building. Therefore, most engineers or constructors would be interested in materials that can provide a quality result. Other scholars have successfully proved that lightweight concentrate can be modelled with palm oil using palm oil clinker obtained from a by-product of palm oil milling as aggregate. The lightweight concrete can also be made by pumice. In conclusion, the effect of cracking and resistance of lightweight aggregates to freezing and thawing is highly great which makes it strong and durable. However, lightweight concretes are used for the construction of heavy structures. As illustrated in diagram 2 below, the bridge is constructed using lightweight concretes because of the durability and strength of the lightweight. It can stand heavy loads and last longer and therefore, it is preferred by my structural engineers and other builders.

# *Section 2: Finite Element Modeling for Reinforced Beams and Slabs*

A study conducted by several structural and building engineers concluded that external bonded FRP laminates and fabrics can be utilized to improve the strength of sheer reinforced concrete columns and beans (Ibrahim & Mahmood, 2009, p. 21). As indicated in the figure (6) below, which is an example of an FRP shear strengthening configuration. It is evident that strengthening of beams and slabs can be easily achieved by wrapping with a continuous sheet of FRP, to create a ring around the beams. The same method is applied in the slab to improve the strength of the slab of any structure. The FRP is used to improve the strength of the reinforced beams and slabs and therefore, it is important to use appropriate materials for beams and slab to gain the required strength. The slab is an important member of the structure of any building, the strength of the slab determines the entire strength of the structure and therefore, reinforced concrete is an important material, which is used to ensure that the strength of the slab is obtained.

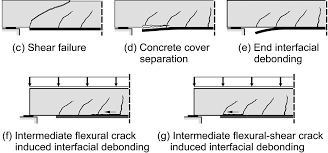


Figure 6: shear crack

As illustrated in figure 6 above, the crack happens because of the failure of the shear. The intermediate flexural crack and concrete cover are importance stages, which are involved in the protection of crack.

## *2.1. Theoretical Consideration*

The traditional assessment of services of life steel-reinforced concrete structure has been about the prediction of the time, which is required to obtain a transition from passive to active corrosion instead to estimate the subsequent corrosion rates. It is stated that the propagation time frame is the time at which the reinforcing steel is dynamically corroding and therefore, it may add a lot too significantly to service life. Consequently, an attempt to ignore the propagation period has proved to be a conservative approach. On the other hand, proper prediction of the level of corrosion rate can result in very complex tasks in view. For the effective account for various influences an essential empirical model an electrolytic resistivity of the concrete should be introduced so that it serves as the major parameter. Studies show that the critical strength mechanism of the shear and flexure is determined by the nature of the formation of the crack not eh reinforced steal. The reinforced steel formed the component for reinforced concrete which is used to add strength and therefore, reinforced steel is an important component of the concrete. The strength of the beam and slabs used in several structures is determined by the reinforced steel used to reinforce the strength and slab of the structure (Gallagher, 2015). The crack angle is regarded as a very important effect of post cracking stiffness and the ultimate strength of the model member. Recent research indicates that the proposed analysis and design model are used for the seismic shear strength of reinforced concrete column members. The stiffness and hardness of the reinforced concrete can result to crack of the beams and slab. It means the strength and durability of the beam and slab of any structure. The modelling for reinforced concrete used in beams and slab defined the layout, strength, and durability of the beams and slab (Kim & Mander, 2017).

## *2.2. Constant Angle Truss*

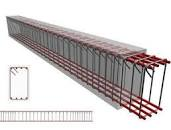
The mechanism of shear transfer used for undisputed regions diagonally cracked long the beam-column as indicated in figure 7 indicated below. The transverse steel is uniformly distributed across the length of the member. It is pointed out that when different forces or loads are applied to the structure of a beam or slab, a crack can be generated, which is regarded as the angle truss. The truss formed is based on the force and therefore, the angle truss would be formed as a result of disrupted force applied to the slab or beam (Ibrahim A., 2014). The deflection of the slab is critical to the strength of the building. In order to increase the strength and the durability of a building, and therefore, the constant angle truss could be avoided through efficient use of reinforced concrete, to make sure that the slabs attain the necessary firmness or stiffness for the slab to last longer.

## *2.3. Finite Element Representation*

The finite element representation indicates the techniques or methods of the formula used in reinforced concrete. The three methods can be applied to identify the finite element representation used in the structural management of buildings. The finite element is developed through the procedure which includes the geometric formation of element and approximation of displacement, constitutive expressions, and even computational algorithms. However, the recent discovery has indicated the tight features of the latter have been poorly understood and it has shown several promising avenues, which can be utilized to address the issues related to strength and stiffness of reinforced concrete especially on the beams and slab structure. The three main distinct approaches to finite element representation can be identified as a mean of three

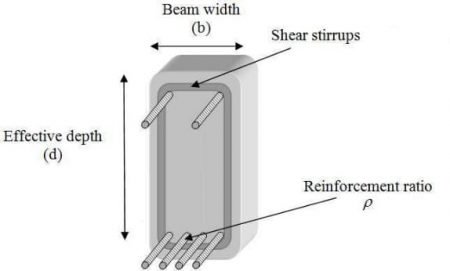
## *2.4. Reinforced Concrete beams*

Reinforced concrete beams are beams with a specific amount of reinforcing materials such as steel. Beams are reinforced to improve the strength and durability of the beam. The beam is designed to carry extra load and therefore, the materials used are of high quality. As shown in figure 8 below, the beam is reinforced using steel of various sizes to get the strength needed for a specific structure. According to Elzaroug(2018, p. 21)), the size of the beam and the materials used depend on the purpose of the structure being constructed. High density or load structures such as bridges, railing, and tall buildings require a strong beam and therefore, strong and large size steels are used for reinforcement. Though the reinforced concrete makes a significant contribution to the strength and durability of the beam, the width and the length of the beam determine the strength established by the reinforced concrete. As indicated in the figure (9) below, the width of the beam is significant to the ability of the beam to stand heavy load, or weight for a longer duration. It is, therefore, recommended that the reinforced concrete should have done with a minimum required length and width, which can provide better stability to the beam and to the entire structure.

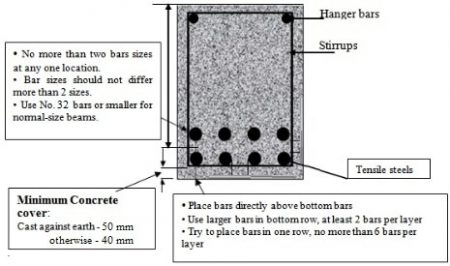


***Figure 8: Reinforced concrete beams***

The width and length of the beam is an important component, which determines the stability of a structure. The strength and reinforced dimension determine the strength of the beam and therefore, creating a beam, which will carry a specific load or the combination of loads a good width and length, is needed and must meet specific measurements.



***Figure 9: reinforced concrete beam with a wider width***

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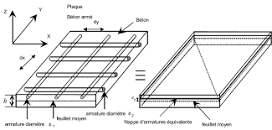
**Figure 10: structural reinforcement for**

## *2.5. Reinforced Concrete slab*

Reinforced slabs are used for the construction of floors, walls, roofs and even decks of bridges. A study conducted by Mosley, Bungey, & Hulse (2017) pointed out that the floor of s structure can be in several forms such as ribbed slab, solid and precast unit. The slab can be constructed of different shapes and facing different directions. The slab should be constructed to meet certain conditions so that it can have the strength required for any structure. The slab needs reinforcement using steel to build a strong and durable structure. Design analysis conducted on slab used for the construction of diver away and pathway established that reinforced steel is not needed and several pathways are constructed without reinforced steel. The reinforced steel, as indicated on the image of figure 10 below, is required to improve the strength and prevent the slab from experiencing crack when exposed to a lot of loads. The reinforcement on the slab is used to add strength to the slab and act as a crack controller, which includes a well-known restraint of shrinkage. Therefore, the use of steel for reinforcement is added additional strength and therefore, makes the slab more durable.



***Figure 10: reinforced concrete with steel.***

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***Figure 11: reinforced Slab structure***

The concrete slab behaviour primarily flexural members and they are designed like beams. The structure and materials used for the construction of the slab are similar to the materials that are used for the construction of beams. As indicated in figure 11 above, which is the structure of the slab before add concretes and other materials to add the strength. The layout and the design of the slab are similar to the beams, and therefore, the slab plays an important role in reinforcing the strength of a structure.

# *3.0. Section 3: Effects of Creep and Shrinkage on Finite element analysis results*

## *3.1. General Background*

Time-dependent deformations one of the effects of creep and shrinkage in structures constructed using complex concrete. Such deformations lead to bending and shearing of some floors, which is a risky occurrence. The changes are attributed to the differential shortening of both the column and the available structural walls. Shrinkage also leads to training of the floors of large structures which yield strong tension on selected areas of the floor. The resulting tension results in increased bending of the supporting columns and walls. In cases where time-effects are not rectified, extensive cracking occurs on the structure leading to the development of both esthetic and durability issues. It is important to carry out finite element analysis as an excellent way to detect the presence of cracks within structures and taking actions meant to prevent shrinkage and creeping.

The finite element method is a common technique used to make predictions of time-dependent deformations occurring on concrete structures. The method is used alongside integration that is carried out using a step by step process to help identify creep strains as they occur over a duration of time. Computer storage is used to store the stress history for complex structures where computation tends to increase as more steps are involved in order to improve the overall accuracy. In cases where the shrinkage is minor, methods such as AAEM are used where it is assumed that the shrinkage strain is similar to the creep. Such a method is not effective in cases where the shrinkage strains fail to have a linear variation with the identified creep coefficient (Unger, 2016). Creep and shrinkage are common causes of deformations in complex concrete structures. Analysis of the effects of the time-dependent deformation is thus an important component of civil engineering to help prevent collapsing of buildings.

# *3.2. Effects of Creep and Shrinkage on Finite element analysis in longer-term deflection of Reinforced concrete structures*

Upon every desire to design structures that satisfy both strength and serviceability requirements, there still exists limitations triggered by creep and shrinkage. This is arguably the most significant stimulant to the knowledge behind the ultimate load behaviour of reinforced concrete flexural members. Besides, the notion, as mentioned earlier, has triggered the inception of final state theories as well as higher strength building components resulting in a much longer life span within structures. There are various paths subjected to designing and creating reinforced concrete structures. It is in this context that finite elements approach to reinforced concrete structures was incepted as one of these paths to assessing the effects of creep and shrinkage. The Finite element approach is a perfect paradigm targeting unavoidable solutions to long term deflections of reinforced concrete elements.

The elastic deformations are bound to occur the concrete immediately is loaded; hence, the finite element analysis should be given priority when developing both the columns and structural walls. The deformations are in line with the Hooke's Law such that they continue to increase as the load is increased. For the inelastic deformations, they show a decreasing rate at the loading period. A significant creep is known to take place during the first month after loading. The creeping process continues such that the ultimate creep is achieved by the end of the first year.

    Creep and shrinkage have been previously proven to affect longer-term deflections on reinforced concretes. No matter the effect or the intensity of its technicality, they are still triggered by the strain brought on by the intuitions mentioned above. Besides, time-dependent fractures on a concrete structure are not only limited to the viscoelastic behaviour of tension in the context of creep but also include phenomena like the effects of inertia weight propagation and the rate of dependence on the breakage of linear bonds. Thought most effects are regarded in the context of slow swift dynamic features, creep and shrinkage are the concept's only relevant to slow static fractures.

The effects of creep and shrinkage are, in most cases calculated by time integration. The technical perspective of the concept, as mentioned above, includes a series of mathematical calculations. The total strain on reinforced concrete is calculated by integrating time, modulus of elasticity as parameters. This formula stands as the most basic finite element formulation and is easily extended to include creep and shrinkage. A more technical view of finite implementation as per creep and shrinkage is expressed in terms of linear stress-strain. On the contrary, stresses in structures which are, in most cases, represented as <50% of the concrete strengths might be regarded inaccurate due to micro cracking when the pore humidity changes.

    A long term study of the responses perceived on reinforced concrete shells as per the finite elements is asserted by the consideration of structures working under the action loads of constant service strains. Creep and shrinkage also contribute to the plasticity in concrete that further affects the linear strength of the structures. Creep structure effects are always time-dependent and are limited to the structural behaviour under applied service load. The notion mentioned above is preferably one of the most critical conditions that prompt for the effect of creep, even in variable environments. Creep is ideally expressed as a compliant function that further integrates shrinkage. As the complement variable within the creep parameters increases, the creep value diminishes. This phenomenon results in the aging process of concrete. On the same line of view, any increment in the corresponding value of the creep's parameters produces a similar strain history. The relation can further be generalized to suit any material and even assume the anisotropic element. The new relationship now yields volumetric stress-strain relations. A later effect of such strains on longer deflections encompasses both bulk and shear compliance functions.

    Mathematically, the displacement-based finite element implementation involves discretizing a structure and dividing it into many sole elements. As creep is closely related to shrinkage and both concepts result in generalized nodal displacements of concrete structures, a relational formula can be formulated to can affirm the effect of generalized displacements triggered by the effect of generalized nodal displacements as:

q = N ex, y, z) Q.

An allowance made in AS3600 (Australian concrete code) to factor creep and shrinkage in deflection results.

    With the increasing deflections in concrete structures, the need for a unified system of laws regulating construction intensified. It is in this context that the AS 3600 was created to provide construction managers and other involved personnel with nationally acceptable rules for the design and reinforcement of concrete structures. The standards are regularly updated to include the most modern allowances regarding the safety and serviceability of structures. Besides, the general performance and strength of concrete structures are affected by several factors. These conditions can, on the other hand, be generalized as per the quality of construction materials used and the construction process implemented. It is equally important to consider any negative deflection that would be caused by wrong construction policies. AS3600 works together with AS 5100 to provide a factor of consideration applied to calculated deflections. The element above works to account for the additional deflection effects of creep and shrinkage on concrete structures. Generally, standards included in the AS3600 for design reinforcements should be taken as prescribed properties or as the base to tests on the strength of concrete structures.

Pursuant to the AS3600 standards policy, shrinkage is a critical part of the construction process. Unraveling as the decrease in volume of already hardened concrete, shrinkage is a significant stimulant to deflections of reinforced concrete structures. The notion above is independent of the load above and the construction process implemented during design, creation or reinforcement. Also, shrinkage chiefly depends on the relative humidity and temperature of the adjacent environment to the subject structure. The standards also speculate the necessary steps for measuring shrinkage strain. The basic measurements are done on test specimens wet-cured for seven days. The samples are then stored at 230C at a relatively maintained humidity of 50%. The standards give examples of nationally acceptable values in terms, all within the range of 800 to 1000 (\* 106). This range reflects the best estimate and the most recommendable values for design and reinforcement of the whole range of normal-class concretes available in Australia. The suggested accuracy for the calculation of an acceptable value in the shrinkage is calculated using nominated figures deviating both positively and negatively by a range of 30. The standards, however, guides on the need of assessing the need and essence of including more strict procedures before embarking on expensive methods both financially and in the context of time. The structural engineers are expected to consider the standards formulated to prevent shrinkage and to creep and should make the details available to personnel used on the ground. Such considerations are important because they avoid cases where structures are not approved after completion due to either shrinkage or creeping.

    The shrinkage gauge for most concrete structures must be calculated as per the standards clause 3.1.7.2 which demands the inclusion of the sum of comical shrinkage strain and the drying shrinkage strain. In most scenarios, the chemical shrinkage strain is a constant value for a specific chemical. The drying basic shrinkage strain, on the other hand, depends on the quality of the local aggregates. Each aggregate holds its unique value as the basic shrinkage strain. While including the factor of shrinkage, the standards also consider concrete that undergoes early shrinkage due to capillary action.

    Where shrinkage is relevant, creep also stands to hold similar characteristics that ultimate for factor to include its effect in concrete strength analysis. As per the standards, the basic creep coefficient of concrete is an aftermath value of the final creep strain against the elastic strain for a specimen within a defined set of conditions. The sample of consideration must be loaded 28 days under the constant stress of 0.4*f’c.*Concretes from different geographical region varies as per the minerals and aggregates included. The standard as such only asserts the basic creep coefficient following a similar local concrete. The national standards also include creep of concrete as a significant contributor to the time-dependent losses of pre-stress. In such scenarios, shrinkage is given much higher privilege prompting the consideration of its effect on the stress of tendons. The stress-strain calculated also takes in space for the modification of the impact of reinforcements on concrete structures. The loss of pre-stress due to creep, on the other hand, is assessed from an analysis of the creep strains implemented in the concrete.

## *3.3. Creep and Shrinkage effects on modelling accuracy for finite element analysis long-term/serviceability checks*.

    As described earlier, the finite element method is perhaps the most relevant and successful methods of analyzing the strength of a concrete building. The method also includes cracking queuing algorithms to include any discrete crack analysis demands. As in the context of this research, the only relevant stimulants affecting the accuracy of finite element analysis are creep and shrinkage. The concrete is simulated by two-dimensional, steel bars, and four-dimensional quadrilateral. Through finite element analysis asserts the latter effect of current structural conditions, shrinkage is perceived as an initial strain to finite element analysis. A technical perspective of the same notion relates to a mathematical formula that takes care of both the current and initial strains as earlier perceived.

Finite element analysis always considers the whole project as divided elements. The creep and shrinkage aspect of deflection, especially in a long-term context, is not only affected by time but by also other factors. The two intuitions, as mentioned above, set the hypothesis for the conclusion of creep and shrinkage affecting the accuracy of finite element analysis. An earlier perception revealed various aspects concerning the strength of concrete structures as having high-speed dynamic fracture properties. Creep and shrinkage held an opposing trait by having a slow static fractured nature. Finite element analysis does not take into consideration long time-varying effects. This, as such, might not encompass all the required elements from creep and shrinkage.

    Shrinkage is, in most cases affected by the pores statute and humidity content in the environment. The relation base of these components can be expressed as a nonlinear diffusion equation where:

h = V • [D (h) He]

The equation cited above is only relatable in cases of nonlinear and infinite increments. On the other hand, in cases where the time increment is considered on a finite range, the shrinkage pore pressure is related concerning the context of each aggregate and its complementary time interval. Wittmann and Bezant had earlier concluded on the shrinkage scale influence by different environmental scales to fit the expected shrinkage strain. A suitable analysis of concrete structures much includes internal forces redistribution that requires three-dimensional static schemes. Besides, though finite element analysis can counter complex structures, many buildings are constructed using coupled shear walls or shear wall-frames systems that integrate matrix condensation techniques. Fictitious beams are further implemented in these techniques. A finite element implementation technique further requires creep and shrinkage concepts to cover such elements, as mentioned above.

An important application of finite element analysis is in assessing cracks and rate-dependent crack growth. Rate dependent crack growth can only be valid if all the viable conditions that prompt its occurrence and affect its pace are considered. Sluys, in 1992, asserted the notion that the time-dependence of fracture is not only affected by the creep in the bulk of material but also the rate and pressure inflicted on the concrete by shrinkage properties. A similar case study regarding the same subject of concern links the rate of cracking in the Netherlands to shrinkage properties related to concrete structures. Structures in the Netherlands as such cannot be considered valid for creation, design or even reinforcement if their restrained shrinkage rate and pressure values are initially asserted. Some may perceive creep and shrinkage as an independent variable in the effect of a structure's strength. This is perhaps a pervasive thought owing to the various concepts linking shrinkage to other strength influencing components. Tensile strength, as an essential factor in determining the durability and serviceability, is still affected by shrinkage, which, on the other hand, is an aftermath of creep.

## *3.4. Methods to improve the accuracy of finite element analysis results in long term deflection.*

The accuracy of finite element analysis is determined by the finite element size adopted. According to the finite element analysis, small mesh densities which imply small element sizes, yield highly accurate results. These sizes, however, have a limitation in that they take longer computing time. Large element sizes may lead to less actual results from finite element analysis but do save time consumption concerning computational processes. The above –acclaimed notion is preferably the most critical concept that has triggered the need for choosing appropriate element sizes in the bid of increasing accuracy and efficiency.

Mesh Convergence as perhaps one of the most underrated and overlooked concepts in computational mechanics, proves to be one of the best mechanisms that help maintain consistent yet accurate results from finite element analysis. This technique ensures results are not affected by the changing size of the mesh density. The mesh convergence method is, however, not as secure as perceived. The initial processes demand one first to identify the quantity of interest. These points which should at least be three, should be outside the scope of the actual value. As the mesh density increases, the chosen points of interest should, in the same manner, converge to a particular value. If two subsequent values do not change their positive as per the convergence expected, then the result is considered as already converged.

The other important factor to consider is if the elements are static or dynamic. From previous explanations and experiments regarding the same context, errors of bending were assessed from these values. These assertions helped maintain a more accurate result as one source of error; bending was determined and removed. The fact mentioned above grants anchorage from the notion that stresses and strains are never accurately estimated as-is with displacements since their intensity is determined by the initially established movements. Impact analyses are also quite crucial to the process of determining a valid finite element analysis result. The above-mentioned condition relies on the dependency aspect of concrete strength on creep and shrinkage. Impact analyses will give a better picture of the actual effect of creep and shrinkage on a longer-term deflection of concrete structures.

The linearity of the element used can also affect the efficiency and accuracy of results from the finite element analysis. It is in this same context that there exist mechanisms to counter and bring a better progression from the non-linearity of elements. Contact, the material used and other relevant construction processes are also assessed to affirm the accurate results from the finite element analysis.

## *3.5. Summary*

Finite element analysis has been a significant contributor to the analysis methods in assessing the stability and serviceability of concrete structures. There still exist limitations in the method's efficiency. Creep and shrinking as one the concepts contributing to the deflection of structures are one the most significant stimulants affecting the efficiently of finite element analyses. Finite element implementation techniques can accomplish each sophisticated analysis program proven not possible with conventional analysis methods.

Owing to the stress-strain distribution between concrete and other environmental components, the shrinkage, and creep of reinforced concrete is different from that of plain concrete. Each calculation about reinforced concrete can also be asserted as valid if calculated concerning the creep effect evident in such environments. Failure to this or ignorance would lead to significant errors; if the creep effect is ignored. Reinforcement ratios, affect creep and shrinkage in general, which in turn have an impact on the more considerable deflections. The concept mentioned above has also created the gauge of finite element analysis by the mesh size density. These facts have further integrated the need for modification of the current construction, design and reinforcement methods to counter any effects encompassed within the finite element analysis results as well as previous failures from trusted practices. Some states and countries have also adopted nationally acceptable standards of constructions to uphold the best interest, safety, stability and serviceability in concrete structures.

# *4.0. Conclusion*

The objective of the study is to create computationally and reliable, efficient finite element models for the investigation of reinforced concrete slab beams and beam-column joint at the edges and the end and different loading conditions and environment. It was conducted to investigate the behaviour of reinforced concrete when exposed to different temperatures as well. Since this is an important part of the study, it was conducted by using different loads under different environments to record how reinforced concrete (RC) behaves. In order to ensure that the reinforced concrete was analyzed on bonding and high-temperature conditions and the result obtained is registered for further studies. It is pointed that concrete and reinforced steel are of the separate model and brought together so that the behaviour of reinforced concrete can be properly described. However, the behaviour of reinforced concrete can be described by the result obtained from the crack concrete when more loads are added. It is established that the crack and bend of the reinforced steel and concrete is the best composite behaviour which can fit reinforced concrete.

The finding of the studies presented here shows that reinforced concrete shows different properties when exposed to a different environment. The analysis indicates that the reinforced concrete system shows that non-standard solution techniques are needed to solve the system which represents materials softening. The result of more complex reinforced concrete system and comparison of computed and observed result shows that some modification of the parameter model is needed to represent the general reinforced concrete systems. The most important of the inclusion of reinforced steel for the construction of the structure is meant to give improved strength to the structure. The result indicates that the behaviour of reinforced concrete, when exposed to high temperature and moisture, is different. The finding indicates that reinforced concrete crack when placed on high temperature. According to the experiments analyzed from various kinds of literature, the high temperature reduces the strength and durability of reinforced concrete. In one of the experiments as indicated in the above image in diagram 5, the crack of reinforced concrete depends on the level of heat or moisture and therefore, it is recommended to ensure that reinforced concrete maintains its room temperature and pressure.

The finding also indicates that the behaviour of reinforced concrete also changes based on the load and the environment as well. In an experiment analyzed, it is established that a lot of loads increased tension to the concrete and therefore, result from cracking. The analysis of the crack shows that crack occurs along the longitude line. From the edge, the crack increases depending on the weight of the load. The more load is added to the concrete the tension increase and the crack expand for the first 10 minutes. However, analysis of the experiments states that the crack and strength of the concrete depends on the model. The most significant of these include using a one-dimensional bond element, the introduction of relatively high initial shear strength for cracked concrete surfaces and moderate residual concrete shear and tensile strengths. It is established that the comparison of computed and observed feedback shows that the model proposed represents a well-localized response occurrence such as the orientation of concrete cracking within flexural and anchorage bond zones. The model represents well the behaviour of relatively systems such as plain concrete beams, bond zone models and sheer panels. In addition, the model predicts with acceptable accuracy the strength of more ductility systems such as reinforced concrete flexural elements.

However, the correlation study between the experiment, analytical result and the parameter studies of the reinforced concrete indicate that the effect of stiffness of tension is more important for the analysis of the RC beam and the RC slab.It is also important for the independence of the analytical result obtained from the experiment and the other sources.

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