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# **Modelling of High Strength Concrete Reinforced with Helical Reinforcement**

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## **Abstract**

This paper investigates the behaviour of high strength concrete beams reinforced with helical reinforcement in the compression zone. Using helical reinforcement increases the strength and ductility of high strength concrete. The finite element packages ANSYS and Strand7 have been used to model high strength concrete beams with helical pitches of 25, 50, 75, 100 and 150 mm. Three dimensional elements were used to model the concrete and bar elements to model the steel. Special care had to be taken when modelling the helices. The results of finite element analyses were compared with experimental results which showed a good correlation.

**Keywords:** high strength concrete, beams, helical reinforcement, finite elements.

## **1 Introduction**

In this paper finite element modelling (FEM) is used to analyse the behaviour of helically-confined high strength concrete beams. High strength concrete (HSC) has different characteristics than normal strength concrete (NSC). High strength concrete is less ductile than normal strength concrete. However, by using helical reinforcement in HSC; the ductility issue can be improved. Helices confine the concrete and bring it to a three dimensional state of stress due to Poisson's effect.

Several studies found that the helical pitch and diameter significantly influence the ductility and strength of helically confined HSC beam. If the helical pitch equals to the confinement core diameter then the failure becomes brittle. Conversely, the pitch size of helical reinforcement should not be very small so as it can separate the concrete cover from its core. In this paper, the analysis of helical reinforcement in high strength concrete beams with five different pitches 25, 50, 75, 100, and 150 mm, are performed by using finite element software: ANSYS and Strand7.

## 2 High Strength Concrete

### 2.1 Introduction

The use of high strength concrete (HSC) has been more popular in recent years. In the last 20 years, extensive research of high strength concrete has been continually performed to improve the quality of high strength concrete. Several studies found that HSC is more effective than normal strength concrete (NSC) in particular the cost in different types of constructions. Furthermore, high strength concrete increases the durability of a structure. Accordingly, durability factor also influences the project cost. Generally, after several years a concrete structure needs maintenance and repair cost. In fact, it is found that the use of high strength concrete reduces the cost of rehabilitation. In recent years, the use of high strength concrete (HSC) has become common and it has been in fact used in large projects in many countries. Briefly, there are some examples of the use of HSC in several countries, in Japan, Rail Bridge with compressive strength 80 MPa. In Australia, Shell House, Melbourne centre and Central Palace with compressive strength 70 MPa. In US, Two Union Project, Seattle with compressive strength 119 MPa, Two Prudential Plaza, Chicago, and Trump Tower Apartment, New York with compressive strength of 82 MPa. Furthermore, with the continuous advancement in concrete technology, it is now easily possible to produce concretes with compressive strength 100-150 MPa [1].

A main problem of high strength concrete is ductility. According to the dictionary of Civil Engineering, ductility or ductile deformation is the ability to undergo cold plastic deformation without cracking and breaking. An increase in concrete strength increases its brittleness. Yet, very high strength concretes are considerably more brittle. The stress-strain relations for high strength concrete are steeper than normal strength concrete. It seems that ascending branch situates nearly linear for much higher stress. Moreover, the descending branch in the post-ultimate range appears very sharp and it becomes vertical at higher strength concrete. It means that high strength concrete is brittle and explosive when the ultimate load is reached. For high strength concrete, the value of the strain  $\epsilon_0$  at the maximum stress  $f_{cm}$  can be significantly higher than 0.002. Building codes generally apply a maximum compressive strain in high strength concrete designed at 0.003.

Hadi and Schmidt [2] also reported that HSC in a reinforced beam has a low ductility, which consequently creates the brittle failure, even though it enhances the strength of concrete. In fact, ductility is very important to determine whether a large deformation and deflection on a structure can occur under overload conditions or it will otherwise experience catastrophic collapse. Therefore, due to natural behaviour of concrete material, the use and continual improvements of HSC seems to be hampered by a decrease in ductility [3].

## 2.2 Helical Reinforcement in High Strength Concrete

Studies indicate that the ductility and the strength of full potential flexural strength of reinforced high strength concrete can be increased by confining the concrete in the compression zone with helical reinforcement. The findings by Hadi [3] showed that the helical reinforcement in the compression zone of high strength concrete beams can prevent extremely brittle behaviour. When the concrete is subjected to load, it would create an expansion, due to passive confining pressure. Then, the helical reinforcement confines the concrete core and resists its expansion (see Figure 1). As a consequence, it would decrease the tendency for internal cracking and lead to improving its strength and ductility [3].

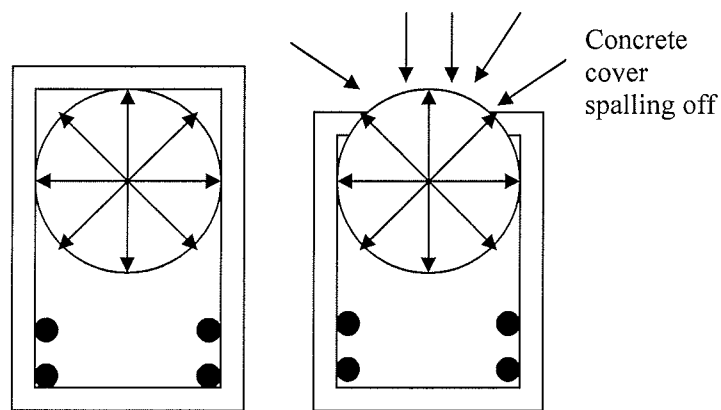


Figure 1 Effect of Helical Reinforcement in HSC Beams before and after the Concrete Spalling off [4]

Elbasha and Hadi [4] reveal that helical pitch and diameter significantly influence the ductility and strength of helically reinforced HSC in reinforced concrete beams. The finding has shown that high strength concrete beam is very brittle in its failure, if the helical pitch equals to the confinement core diameter which is caused by concrete core shed concurrently with its cover. Conversely, the size of pitch of helix should not separate the concrete core and its cover, unless it can physically cause the failure of the cover at the beginning (concrete cover spalling-off).

## 2.3 Experimental Studies of High Strength Concrete (HSC)

Several studies and experiments testing of several models of helical confinement in reinforced high strength concrete beams are presented to investigate the properties of helical reinforcement in increasing the ductility and strength of concrete. These studies aim at studying the behaviour of helical confinement in reinforced HSC beams.

A number of studies have been conducted to investigate the effect of helices on the behaviour of reinforced concrete beams, for example [3-6]. All these studies have proven that the use of helices in the compression zone of beams increase their strength and ductility.

### **3 Finite Elements in Modelling Reinforced Concrete**

Barbosa and Riberio [7] used finite element program, ANSYS 5.3 to investigate the brittle behaviour of reinforced concrete model which was subjected to a uniformly distributed loading. The dimensions of the reinforced concrete beam were 4000 mm in length and cross section of 200 mm in width and 300 mm in depth. The compressive concrete strength of concrete was 30 MPa which can be categorised as normal concrete strength (with modulus of elasticity of 25,000 MPa). The beam was reinforced with 1142 mm<sup>2</sup> (with yield strength of 500 MPa). Furthermore, they studied two different beam models, the first model was the element concrete model with discrete reinforcement (with adopting truss bars) in which it connects to the solid element nodes. The second model was element concrete model without discrete reinforcement but it contains a smeared reinforcement. Based on four material models, Barbosa and Riberio [7] analysed four mesh models for each reinforced concrete beam. In this study, the finite element model (FEM) was used to perform nonlinear analysis. Furthermore, based on comparison between the two different reinforcement models of smeared and discrete, it was concluded that both models have a similar behaviour in finite element modelling. Furthermore, Barbosa and Riberio [7] also state that nonlinear stress-strain relationship for concrete mainly play a significant role to obtain a good result and predict the behaviour of failure of concrete.

Kachlakev et al. [8] used ANSYS to study concrete beam members with externally bonded Carbon Fibre Reinforced Polymer (CFRP) fabric. The geometry of the full-size beams was 305 mm x 6096 mm x 768.4 mm. The symmetry of the beams allowed one quarter of the beam to be modelled. In order to provide the perfect bond, the two materials share the same nodes. Thus, the truss element (reinforcing bars) was connected between the nodes of each adjacent concrete solid element. Furthermore, at planes of symmetry, the displacement in the direction perpendicular to the plane was set to zero. A single line support was utilised to allow rotation at the supports. Loads were placed at the third point along the full beam on the top of the steel plates. The mesh was refined immediately beneath the load. The nonlinear Newton-Raphson method was used to analyse the equilibrium path during the load-deformation response. Kachlakev et al. [8] found that convergence of solutions for the model was difficult to achieve, due to the nonlinear behaviour of reinforced concrete material. At certain stages in the analysis, load step sizes were varied from large (at points of linearity in the response) to small (when instances of cracking and steel yielding occurred). Kachlakev et al. [8] conclude that the results of finite element appears (particularly load-deflection results) to equal the experimental results from full-scale beam test.

Fanning [9] modelled the beam that has a length of 3000 mm, height of 240 mm, and width of 155 mm. The beam contains three reinforcing bars (diameter of 12 mm) in tension area and two reinforcing bars (diameter of 12 mm) in compression area. The shear reinforcement has a diameter of 6 mm (250 MPa). The assumption was made by considering there is full displacement compatibility between the reinforcement and the concrete and that no bond slippage occurs. Fanning [8] reported that the finite element predicted flexural cracks that occurred at perpendicular planes of the model and propagated uniformly through the depth of the beam before becoming less uniform as the comparison was approached. However, the smeared crack model was not able to withstand the discrete nature of the flexural cracks. In addition, due to increasing plastic strains developed in the tension reinforcement, the mode of failure based on numerical method is similar to the flexural mode based on experiment. In this study, a smeared crack model was used to allow for concrete cracking with using discrete model for modelling the reinforcement.

The use of FEM in reinforced concrete has become more popular in recent years. Nowadays, it is a common belief that along with progress of research in FEM, to construct the high complexity model is more possible. Modelling of concrete with using smeared and discrete approach has significantly contributed to the progress in reinforced concrete modelling. In discrete model, cracks are assumed to occur along the inter-element boundaries. But, in smeared model it is assumed that the fracture is distributed over a band. It is fact that the smeared approach is commonly used to model reinforced concrete in FEM. Each model has advantages and disadvantages that depend on its structure model. The smeared model is adequate to plate or shell structure, but for non-uniform spacing reinforcement and differential cross-section area of bars, the discrete and the embedded methods are more appropriate. Commonly, a finite element method in reinforced concrete has two main goals: the load-deflection relations and cracking analysis.

## **4 Finite Element Analysis of Helically Confined HSC Beams**

### **4.1 Properties of Helically-confined HSC beams**

In this paper, the properties of helically confined HSC beam used are from a previous experiment performed by Elbasha and Hadi [4]. The experiment aimed to investigate the behaviour of different pitch size of helical reinforcement in high strength concrete beams and to determine the effect of helical pitch on their strength and ductility. Tables 1 and 2 show the properties of five helically-confined HSC beams that were modelled.

Beam No	Concrete Strength (MPa)	Concrete Cover (mm)	Stirrup Bars (mm)	Spacing (mm)	Tensile Steel
1	105	20	10	80	4N32
2					
3					
4					
5					

Table 1 Properties of Concrete and Reinforcing Bars in HSC Beams [4]

Beam No	Dimensions (mm)	Helical Reinforcement					
		Steel Bar Size	Steel Diameter (mm)	Tensile Strength MPa	Helix Dia. (mm)	Pitch (mm)	Type Helical Steel
1	4000X300X200	N12	12	500	150	25	Single
2						50	
3						75	
4						100	
5						150	

Table 2 Properties of Helical Reinforcement in HSC Beams

The beams were tested under a four-point loading regime. The structural behaviour under load was measured by using electrical resistance strain gauges that were glued throughout the beams at the bottom, top, and sides of the helical reinforcement. The mid-span deflection was measured throughout the loading by using linear variable differential transformers (LVDTs). Figure 2 shows the geometry and the properties of the helically confined HSC beams.

The finite element software used in this current study was ANSYS Release 10 and Strand7. The goal of this study is to compare the finite element results and the experimental results previous work performed by Elbasha and Hadi [4].

In this study, it is realised that the main problem was to connect the nodes of helical reinforcement and concrete elements. The concrete elements which were fastened by helical reinforcement were modelled using Solidwork 2000 software which was then converted to IGES file and imported to ANSYS (see Figure 3).

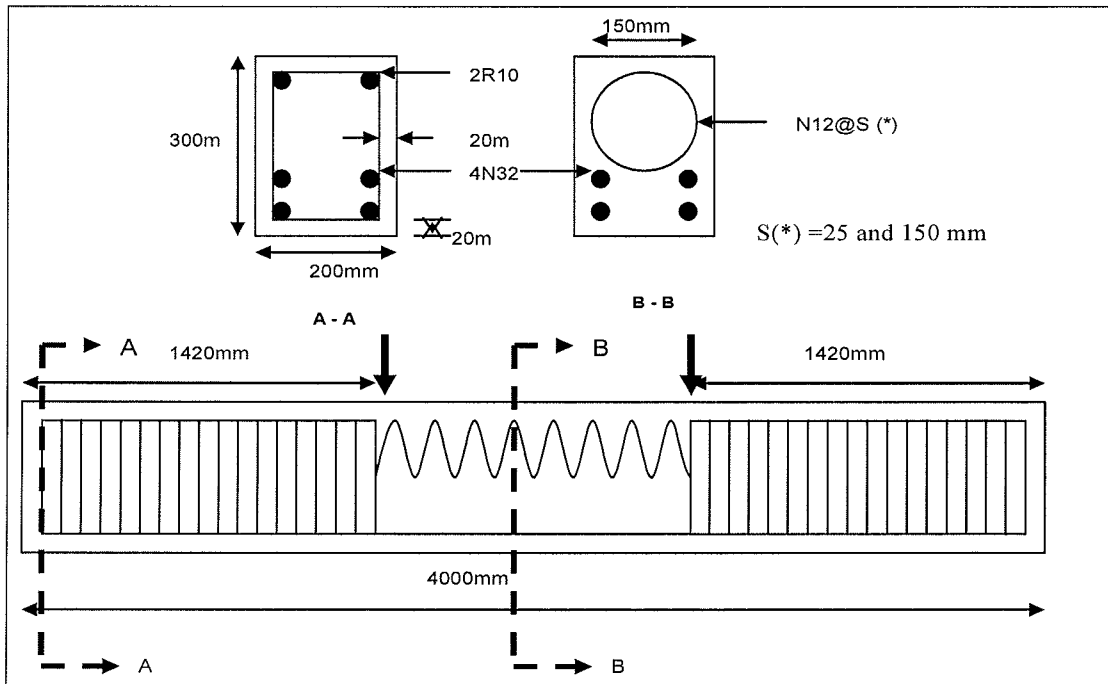


Figure 2 The Geometry and Properties of Helically Confined HSC Beams

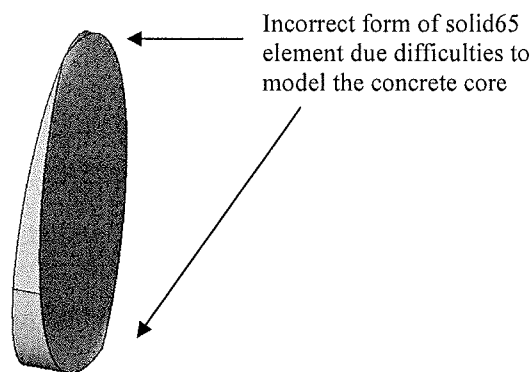


Figure 3 Concrete Core Element

The model was simplified by using circle reinforcement instead of helix. The circle reinforcement was used by assuming that circle reinforcement could work as good as helical reinforcement to brace the concrete core in compression area, which prevents failure caused by horizontal forces as a result of compression forces in the concrete beams.



## 4.2 Modelling using ANSYS

In ANSYS, the element that is generally used for 3-D modelling of concrete solid is Solid65 element. As concrete is a nonlinear material, this element enables it to undergo cracking in tension and crushing in compression. Solid65 element can be used with or without reinforcement. If smeared approach is adopted, the rebar material should not be equal to zero. Otherwise, it removes the reinforcement capability of SOLID65 element. It is noted that the rebar material in this element does not have capability in resisting shear strength, but it has capabilities to carry tensile and compressive strength, plastic deformation and creep.

In this study, discrete approach was used to model the reinforcement. Therefore, truss elements were used to model reinforcement. This element is called Link Spar 8 element which has a plastic behaviour. Similar to a real reinforcing bar, this element has a cross sectional area, an initial strain, and material properties.

An eight-node solid element, Solid45, was used for the steel plates for load application and supports in the beam. This steel plate element was used as a connector between the applied loads and the concrete surface. Support was also used to hold the structure.

The dimensions of the full-size beams were 4000 mm x 300 mm x 200 mm. The span between two supports was about 3600 mm. Figure 4 illustrates typical dimensions for the concrete beam. The beams were modelled by taking advantage of the symmetry of the beams; a quarter of the full beam was used for modelling. This approach was aimed to reduce computational time and the need of harddisk memory.

The concrete model was firstly constructed by plane element in the Y-Z direction. It was very important to determine the meshing shapes before the structure was modelled, especially area of concrete elements that were fastened by circle reinforcement. Indeed, the meshing shape considered the connection between nodes of circle reinforcement and concrete core elements. In this study, meshing was performed manually together with modelling step. Figure 5 shows the 2D elements in the Y-Z coordinates.

Furthermore, all the 2D plane elements were extruded along the x-direction until a half of full length beam size was reached (up to 2000 mm in the x-direction). The mesh of concrete elements was created simultaneously, while the 2D plane elements were extruded. The size of the concrete elements depends on the positions of reinforcement which occupy the same nodes. After the beam structure was modelled, the concrete elements were meshed.

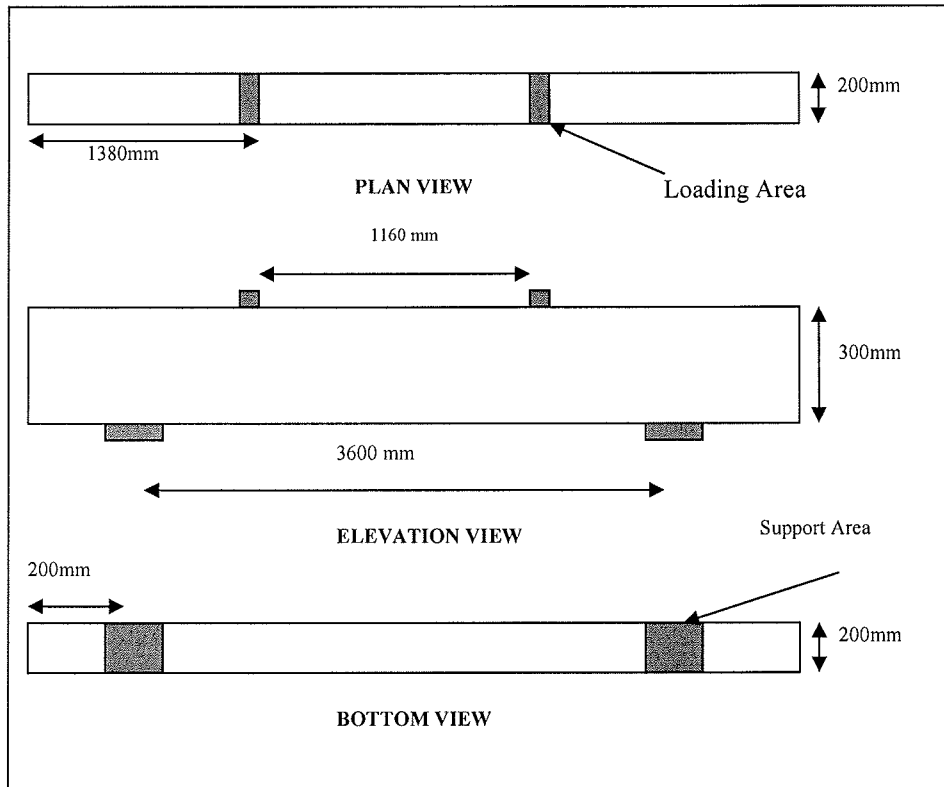


Figure 4 Geometry of the Beam

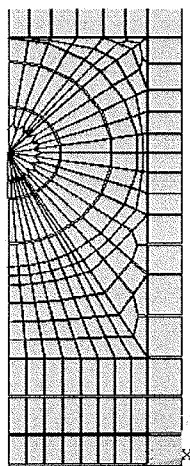


Figure 5 The 2D Plane for Modelling 3D Concrete Beam in ANSYS

The discrete approach was used for modelling reinforcement. The reinforcing bars were created by considering the nodes at each intersection between shear reinforcement, tensile reinforcement and reinforcement in the compression area. Then, they were meshed without dividing the lines into several pieces, because each reinforcing bar was already created to be fit with the size of concrete elements. Subsequently, after the model has already been meshed, the merge command in ANSYS was used to merge nodes and key points that situate on the same location. Hence, the elements of reinforcement and concrete were assumed to be connected perfectly (perfect bond). Figure 6 shows concrete elements and truss elements (reinforcement).

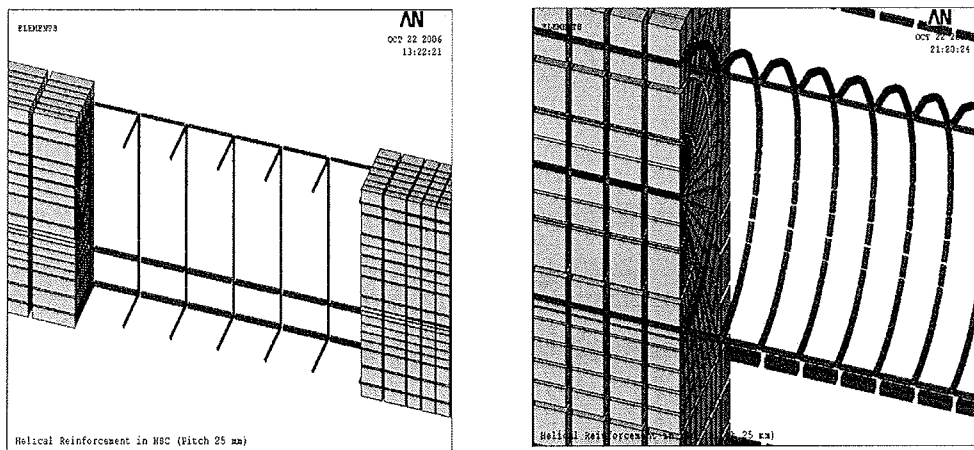


Figure 6 (a) Concrete Elements and Stirrups; (b) Concrete Elements and Circle Reinforcement

The steel plate was also modelled to connect between the applied load and beam. As shown on the Figure 7, the load was applied across the centreline of the steel plate. The steel plate dimensions were 100 mm x 80 mm x 10 mm. Indeed, the loads were applied at the same locations as the real beam structure. The support was also modelled as steel material. The support was assumed to be 100 mm x 80 mm x 30 mm.

As quarter of the beam was modelled, the planes of symmetry were constrained in the perpendicular direction. Figure 8 shows the perpendicular plane was constrained in the x -direction and the z-direction.

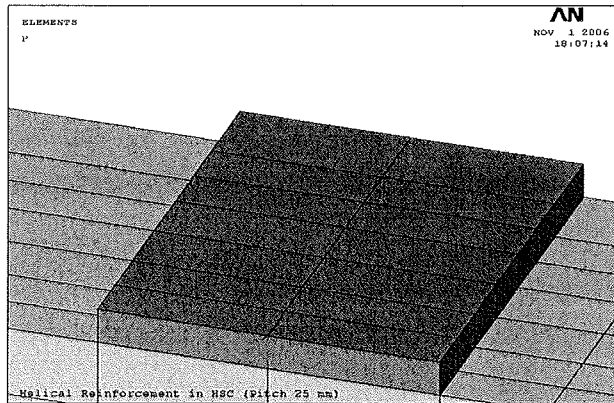


Figure 7 Applied Load on Steel Plate

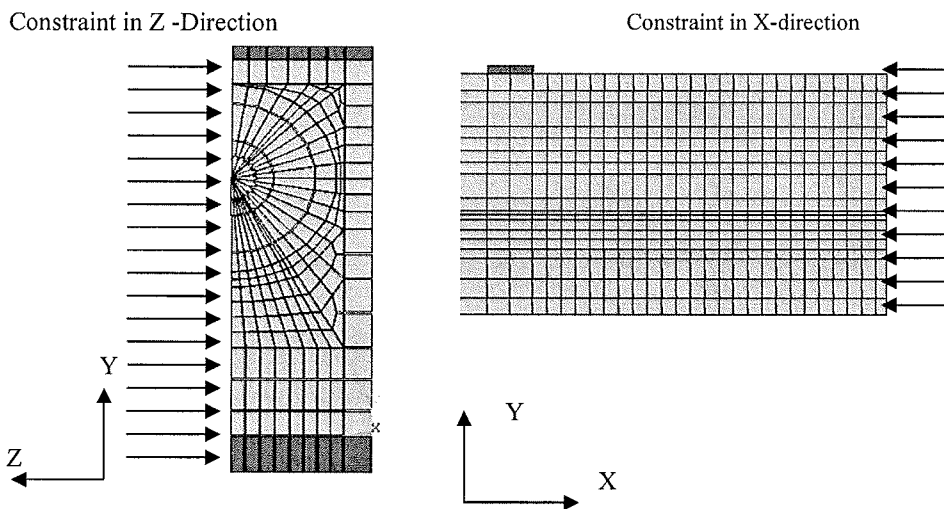


Figure 8 Constraints for Plane in x and z-direction

ANSYS uses Newton-Rahpson method to perform nonlinear analysis. In nonlinear analysis, the total applied load is divided into several load steps. In other words, nonlinearity consists of a series of simpler pieces of linear steps. The load was applied in small increments and iterations were used to obtain the equilibrium of forces during analysis. After the result of displacement was obtained, they were added to obtain the total deflection of concrete beam structure.

### 4.3 Modelling Using Strand7

Strand7 has also been used to model high strength concrete beams. Similar way to ANSYS, the elements used for modelling were truss elements for reinforcement, brick elements for concrete and steel plate. Initially, the model was begun by modelling plane 2D with constraint strain triangle elements (TRI3 elements) and linear quadrilateral elements (QUAD4 elements) in coordinate X (0,0,0). Subsequently, it was extruded to derive the volume of concrete (see Figure 9).

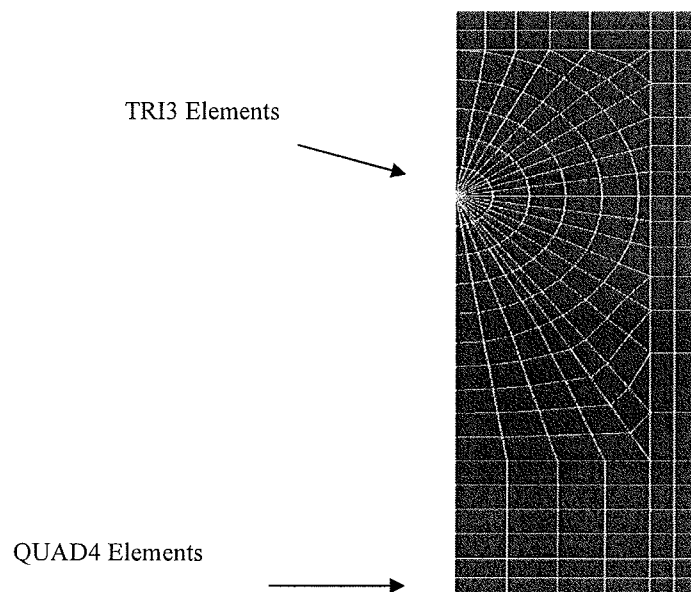


Figure 9 The 2D Plane for Modelling 3D Concrete Beam in Strand7

After the concrete volume was modelled; the reinforcement was created by connecting each node inside the solid. As discrete approach was adopted, the nodes of all reinforcement shared with the solid elements. The meshing of the concrete elements was done in such a way that nodes will coincide when steel (helix, stirrups and main reinforcement) elements were meshed (see Figure 10).

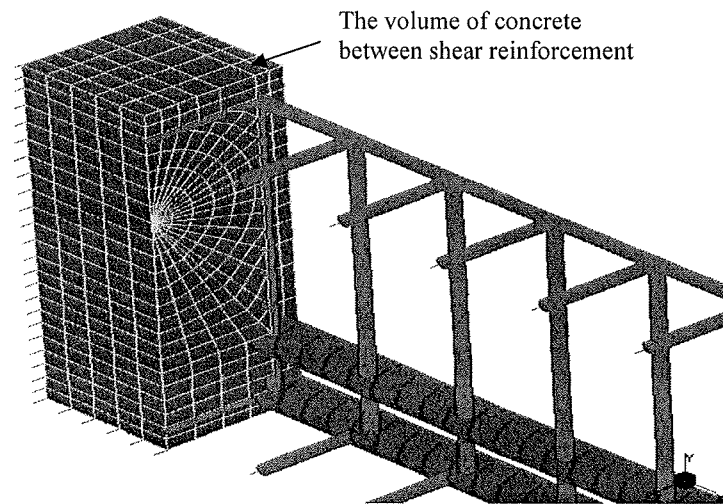


Figure 10 The Volume of Concrete between Stirrups

Furthermore, steel plate and support were also modelled in the same way as using ANSYS. The elements used for steel plate was the eight-node brick elements. The loading was applied on steel plate by using point's node and rollers were used to allow rotation on the support. Moreover, as a quarter of the beam was modelled, the perpendicular plane was constrained in the z and x-directions.

The properties of concrete, reinforcing bars, and steel plate (i.e. stress-strain, modulus of elasticity and Poisson's ratio) were similar to the data that were used in ANSYS.

## 5 Results

Figure 11 shows the load-deflection curve for Beam 1 with helical pitch of 25 mm. Based on experimental result, the cover shed at load of 372,000 N and deflected at 40 mm. Afterwards, the load suddenly dropped; however, the helical reinforcement kept resisting and increase the load to failure load of 411,000 N and ultimate deflection was 240 mm.

Furthermore, according to finite element results, ANSYS indicates the failure load at 405,000 N and the beam deflected at 118 mm. Strand7 surprisingly shows the ultimate load of 407,000 N at deflection of 153 mm. During analysis, ANSYS and Strand7 indicated when the cover began spalling-off, the displacement and force did not converge, and the analysis was terminated.

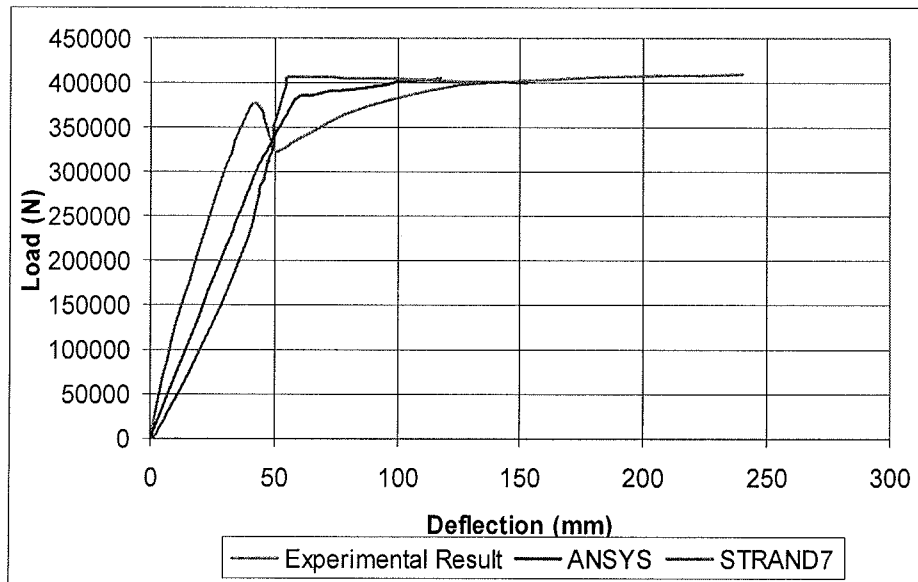


Figure 11 Load-Deflection Curves for Beam 1 (25 mm Pitch)

As shown on the Figure 12, experimental results of Beam 2 show that the load at cover spalling-off was 386,000 N and failure load was 340,000 N at ultimate deflection of 193 mm. Based on ANSYS results, the ultimate load was 364,500 N at which the beam structure deflected at 116 mm. Furthermore, as can be seen in Figure 12, the maximum deflection of Strand7 was 115 mm, when the beam failed at 354,621 N.

According to experimental result and finite element results, the differences of load at concrete cover spalling off are 5.898% for ANSYS and 8.848% for Strand7. Additionally, the difference of ultimate deflection between ANSYS and Strand7 was less than 1%.

Figure 13 shows the load-deflection curve for Beam 3 with pitch of 75 mm. It can be seen that the load at concrete cover spalling off was 388,000 N and ultimate load was 310,000 N. The concrete cover shed at yield deflection of 32 mm and it failed at deflection of 65 mm.

Figure 14 shows the load versus deflection curves of Beam 4. Based on experimental result, the yield load was at 398,000 N and remains stable until the yield deflection of 33 mm changed to 35 mm. At the end, the beam failed at the load of 260,000 N and it finally deflected up to 52 mm.

Figure 15 shows the load versus deflection curves for Beam 5 with helical pitch of 150 mm. This beam has very small amount of ductility compared with other beams. The maximum load was recorded at 413,000 N and dropped suddenly down to 150,000 N at ultimate deflection of 38 mm. This beam was very brittle.

Based on ANSYS results, the yield load was quite large 414,750 N and yield deflection was 40 mm. This result shows a decrease in ultimate load of 0.42% to 413,000 N based on experimental result. The difference of yield deflection was 5.263% from total deflection of experimental result.

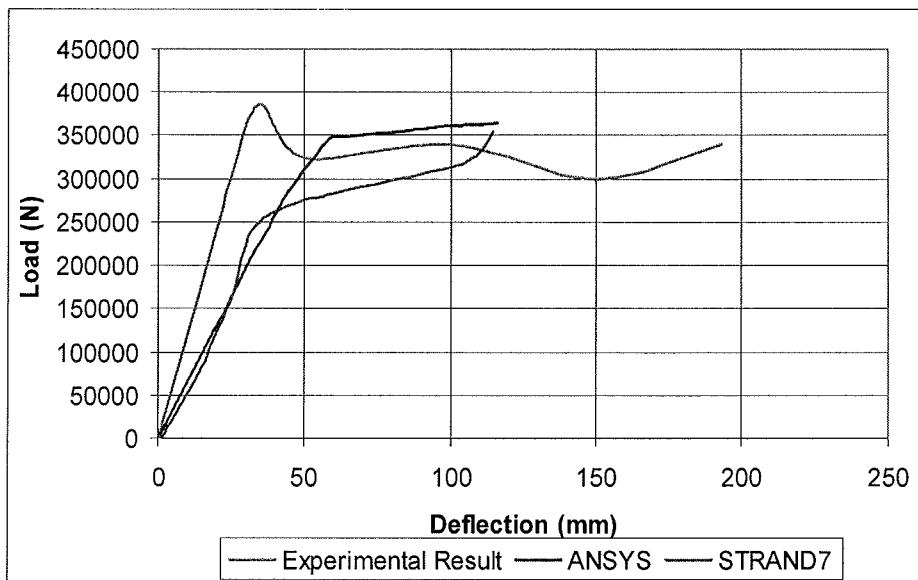


Figure 12 Load-Deflection Curves for Beam 2 (50 mm Pitch)

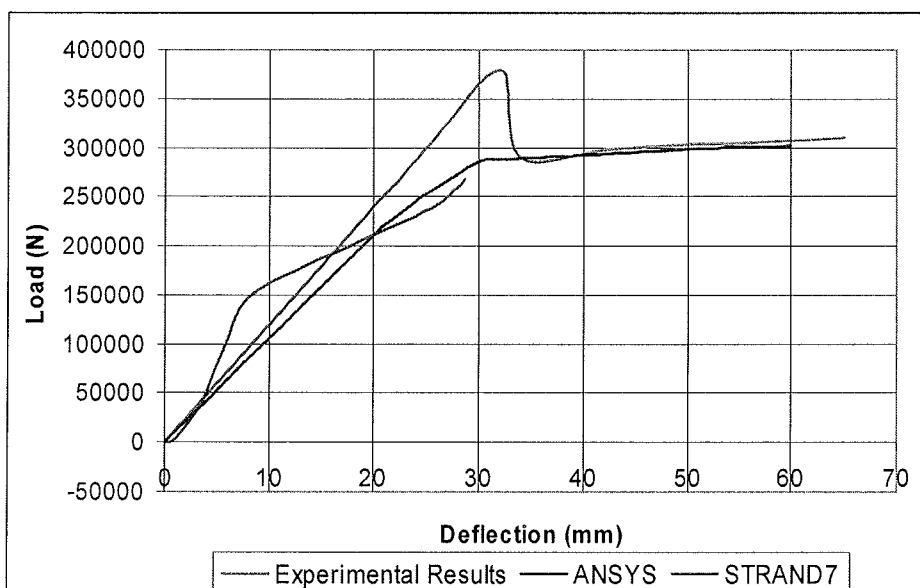


Figure 13- Load-Deflection Curves for Beam 3 (75 mm Pitch)



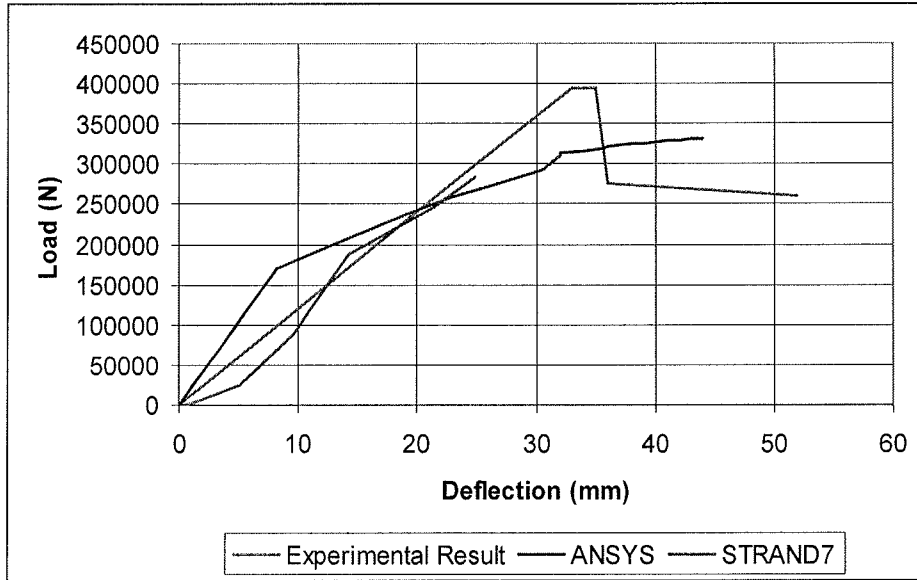


Figure 14 Load-Deflection Curves for Beam 4 (100 mm Pitch)

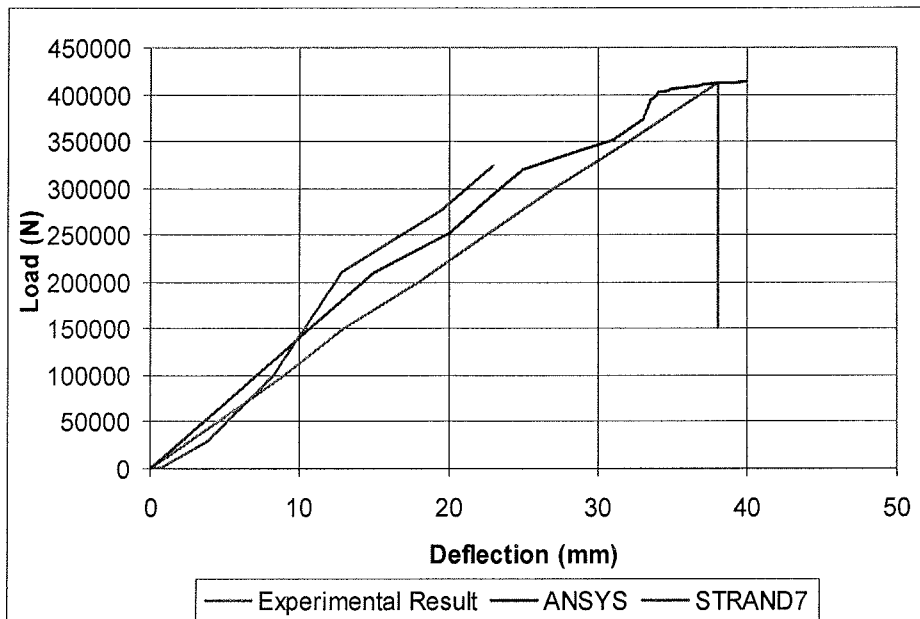


Figure 15 Load-Deflection Curve for Beam 5 (150 mm Pitch)

## 6 Conclusions

Finite element method has been used to model the helically-confined high strength concrete beams. In this paper the model of reinforced concrete beams was constructed by using finite element software: ANSYS and Strand7. Smear approach was used to model the concrete elements and reinforcement modelling used discrete model. The meshing shape used was mapped mesh, except to meshing shape on the area of circle reinforcement to enable the connection of nodes of reinforcement and concrete elements.

The total deflection of the beam structure was calculated as the sum of the deformations of each increment. According to finite element results, the general behaviour of finite elements models represented by the load-deflection plots for five beams with different pitches 25, 50, 75, 100 and 150 mm indicate good agreement compared to the experimental results obtained by Elbasha and Hadi [4]. There are many factors that may influence the result; one of significant factor is the complexity of mesh, which needs more accurate analysis than simple meshing shape (rectangular elements).

Finally, results of the finite element analyses resulted in load-mid span deflections that are comparable with the experimental results.

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