MODELLING OF STRUCTURAL FAILURES IN RC BEAM ELEMENTS USING ANSYS

M. Rokilan,
Department of Civil Engineering, University of Moratuwa.
(email: rokilan90@gmail.com)
K. Baskaran,
Department of Civil Engineering, University of Moratuwa.
(email: baskaran@uom.lk)

Abstract: Simulation of failures using laboratory experiments will be expensive and time consuming. To overcome these problems making use of finite element methods and advantages of computational software are key considerations. However, proper simulation of structural behaviour is a key factor in the use of FEM analysis. Worldwide a lot of research studies have given attention in this context but in Sri Lanka, concern on this point is considerably less. This paper contains: identification of type of elements like solid-65 and link-8, material models, boundary conditions and other relevant modelling parameters suitable to model structural failures in RC structural elements using ANSYS. Further it seeks to identify the suitability of discrete modelling of reinforcement model. The initial crack formation, failure load and load-displacement curve of beams from laboratory experiments are compared with the nonlinear finite element models using ANSYS to ensure accuracy of model parameters. The accuracy of model is further checked with mesh density and analysis type by conducting different model analysis by changing the parameters and the observations are reported. This paper concludes simulation of flexural failure can be done using ANSYS by small displacement static analysis (equilibrium equations are constructed based on initial position) or large displacement static analysis (equilibrium equations are constructed based on deflected position). However simulation of shear failure is a difficult task since ANSYS has limitations in modelling shear failure using large displacement analysis or small displacement analysis. Further difficulty to converge a solution can be reduced by large displacement static analysis.

Keywords: Reinforced concrete beam, finite element analysis, ANSYS, structural failures

1. Introduction

Researchers have to think about economical form of elements to overcome resource scarcity in the world. In this context, proper simulation of behaviour of structural element, plays a vital role. Experimental models will be expensive and time consuming. Therefore researchers have to considertheoretical models. However representation of analytical model is difficult because of nonlinear behaviour of concrete, composite materials and complexway of interaction between reinforcement and concrete. Numerical modelling of reinforced concrete element is made easier by advancement of computer technology and finite element theories. Proper simulation of element behaviour is an important factor in numerical modelling, while using different type of computational packages like ANSYS, LS DYNA, ABAQUS, MSC.NASTRAN and STRAND 7.

2. Objective

The objective of this study is identifying suitable element types, material models, failure criteria, boundary conditions and relevant modelling parameters for concrete and reinforcement to represent the behaviour in numerical model using ANSYS. The accuracy of these parameters were ensured by comparing mid span deflection, stresses in reinforcement and concrete and failure pattern of both laboratory experimental model beam and ANSYS numerical model beam. Further consideration was given on mesh density, analysis type and tolerance values. Besides anattempt was made to identify the relationship between shear failure and factors affecting the shear failure.

3. Methodology

1. Literature review was conducted to identify the past attempts by others on this study area about available element types, material models and failure criteria.
2. Experimental results of RC elements were collected from experiments conducted in University of Moratuwa.
3. The Numerical model of reinforced concrete beam was created and analyzed using ANSYS software package.
4. The factors affecting shear failure in reinforced concrete beam were identified and an attempt was made to find the relationship between the factors and failure pattern using ANSYS numerical model.
5. Results were compared and conclusions were made.

4. Experimental study

The experiment conducted at University of Moratuwa for academic purposes in year 2013 was used to validate the numerical model parameters.

4.1 Detail of test specimens

In this experiment, four beamswith shear links and four beams without shear links were cast. In these beams pairs of beams with and without shear links were selected for thecalibration of finite element model. The loads were applied using Amsler testing machine on beams after fourteen days of hardening with proper curing. Load deformation response, initial crack load and failure pattern were recorded during the load application process. Further, cube strength test, E-value test and splitting tensile strength test were conducted on concrete samples to collect required strength and stiffness properties of concrete. The reinforcement cover was obtained using cover meter.

Beams with shear links (BS) and beams without shear links (B) were cast with beam section of 125mm x 200mm, effective span of 1800 mm and beam length of 2000 mm.Two 10mm mild steel bars were used for top reinforcement and two 12mm tor steel bars were used for bottom reinforcement. In case of beam with shear links 26 numbers of 6mm mild steel bars were used at 75mm centre to centre distance, but in beam without shear link 3 number of shear links were used at mid point and endpoints for easy fabrication.

4.2 Test setup and loading arrangement

The testing arrangement is shown in Figure 1. The applied load and corresponding mid span deflection were recorded manually from Amsler testing machine and dial gauge fixed at mid span of beam.

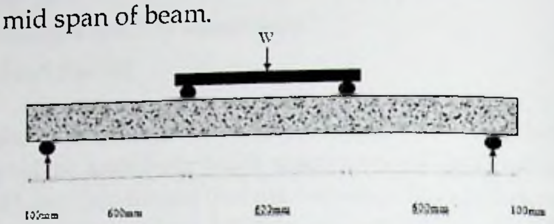

Figure 1:Geometry and loading arrangement of tested beam

4.3 Experimental results

The loads Deformation curve of four beams are given in Figure 2 andthe test results used for model the numerical model is shown in Table 1. Further failure behaviour is illustrated in Table 2.

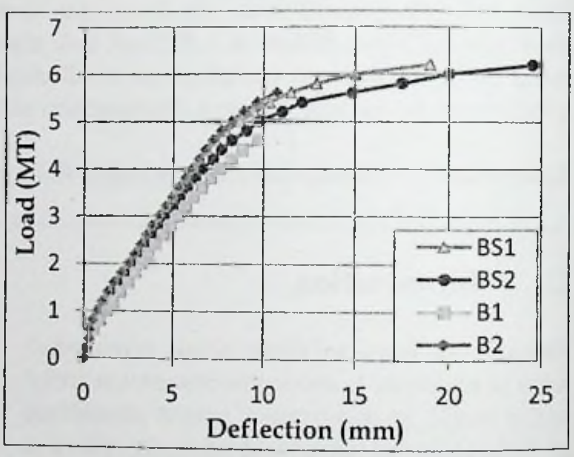

Figure 2:Load deflection curve

Table 1: Test results used for model the numerical model

Parameters	Value
Concrete compressive strength	40 N/mm^2
Concrete tensile strength	2.5 N/mm^2
Tor steel strength	460 N/mm^2
Mild steel strength	250 N/mm^2
Bottom R/f cover	25 mm

Table 2: Initial crack load, failure load, mid span deflection at failure

Beam number	Initial crack load (N)	Failure load (N)	Mid span deflection (mm)
BS1	-	60822	19
B1	10791	45126	9.75
BS2	13734	60822	24.5
B2	11772	54936	10.75

Vertical cracks in constant moment region and inclined cracks in constant shear region were observed in both types of beams. In case of beam without shear links the inclined crack movedtowards loading point and sudden failure was gained in constant shear region but in case of beam with shear links failure was observed within constant moment region by crushing of concrete in compression region. These are shown Figure 3 and Figure 4.

Figure 3: Failure of beam with shear links

Figure 4: Failure of beam without shear links

5. Element type and material model

Three types of elements were used for modelling purposes. The concrete was modelled using Solid-65 elements which specially recommended by ANSYS to model concrete with or without r/f. The r/f was modelled as discrete element using Link-8 element which does not haverotational degree of freedom. The Solid-45 element was used to model the steel plate. The steel plates were modelled at supports and loading points to avoid force concentration effect.

The nonlinear material behaviour of concrete was modelled using Desayi and Krishnan (1964) model. Further linear elastic isotropic property of concrete also assigned,with elastic modulus as 27100 N/mm^{2}and Poisson's ratio (v) as 0.2 (Bangash 1989). The concrete material model is shown in Figure 5.

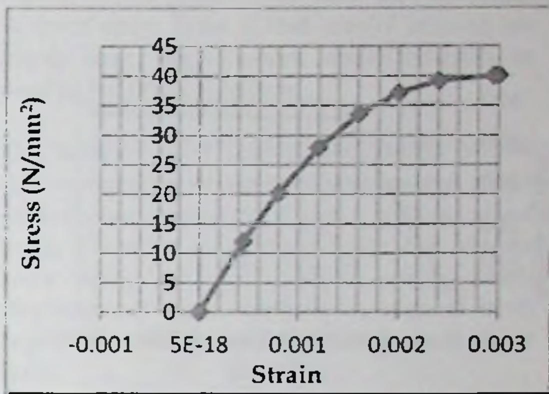

Figure 5: Stress strain relationship of concrete

Willam and Warnke failure criterion was used to simulate the concrete failure. The behaviour of concrete after formation of crack is represented through shear transfer coefficient. This coefficient falls between one and zero. Value 1 mean rough crack (no loss of shear transfer) and value zero mean smooth crack (complete loss of shear transfer). This plays an important role in convergence of solutions. While open shear transfer coefficient moves towards zero and closed shear transfer coefficient moves towards 1 convergence difficulty was observed. Uniaxial crushing stress was kept as -1 to turn off crushing capability of concrete. Otherwise it will make crushing of concrete at loading point. Even though crushing capability was removed, the failure is caused by secondary tensile strain which is induced by Poisson's effect (Mindess and Young 1981; Shah, et al. 1995). Uniaxial tensile cracking stress was assigned from splitting tensile test. A parametric study was conducted and it was found that ANSYS always take default value of 0.6 for tension stiffening after crack formation (Vasudevan. G and Kothandaraman.S - 2011).

The elastic behaviour of reinforcement was represented by linear elastic isotropic parameters and plastic behaviour of reinforcement after yielding of reinforcement, represented by inelastic, rate independent, isotropic hardening, Vonmisses bilinear model. The failure surface for reinforcement was defined using Vonmisses yield criterion since other available yield criterion which is Hill's yield criterion is mostly used for anisotropic materials. Steel plate is modelled with Elastic modulus EX as 2×10^5 N/mm² and Poisson's ratio (v) as 0.3. The bilinear behaviour of tor and mild steel are illustrated in Figure 6 and Figure 7.

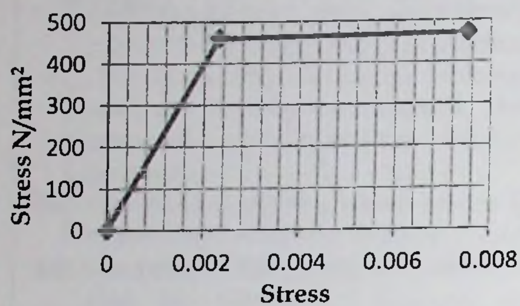

Figure 6: Bilinear stress strain curve for tor steel

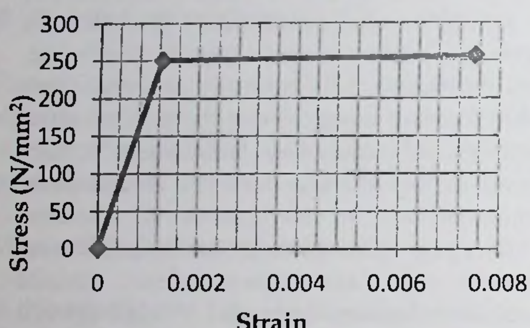

Figure 7: Bilinear stress strain curve for mild steel

The two types of beams were modelled with proper mesh arrangement (connection of elements were ensured at nodes) and real constants (Geometry arrangement). Merging option was used after meshing of each element to make two nodes as one node. Proper boundary conditions were assigned with one support as pinned and other support as roller. Load on beam was applied as line of point load on nodes. Increment of load was set up by ANSYS through load steps. The number of sub step was used to eliminate convergence problems under each load increment. Higher number of sub step makes lesser convergence problem. The analysis is based on Newton-Raphson method of iteration. Further Line search option was activated to reduce the problem in converging solution but by activating this option analysis time increases. Value of 0.05 for displacement and 0.005 for force were used as tolerance values at lower load level and for higher load level force tolerance was changed to 0.03 to reduce problem in converging solution and displacement tolerance was kept as it is. The typical mesh arrangement is shown in Figure 8.

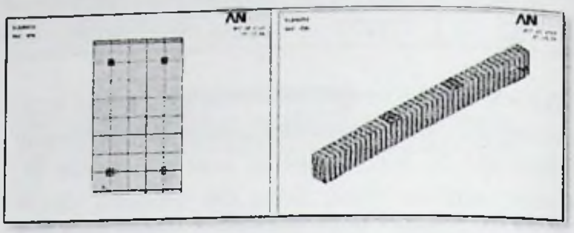

Figure 8: Typical mesh arrangement of beam

5. Results and Discussion

Beam with shear links and beam without shear links were modelled using different mesh sizes and they were analyzed using large displacement static and small displacement static analyzing methods. The selected mesh sizes were 25mm, 50mm, 75mm, 100mm along longitudinal axis and cross section of each beam was kept as 25mm X 25mm mesh. Even though the convergence test results for different mesh sizes look similar the selected mesh size was 50mm mesh since other models show difficulties in converging solution.

5.1 Comparisons for beam without stirrups

The load deflection curves for beams without shear link are shown in Figure 9 and Figure 10. The termination of load deflection curves are not failure points other than 50 mm mesh's curve in smaller deflection case. Beside, termination of 75mm mesh's load deflection curve under large displacement static is also not a failure point. The termination occurred due to diverging solutions.

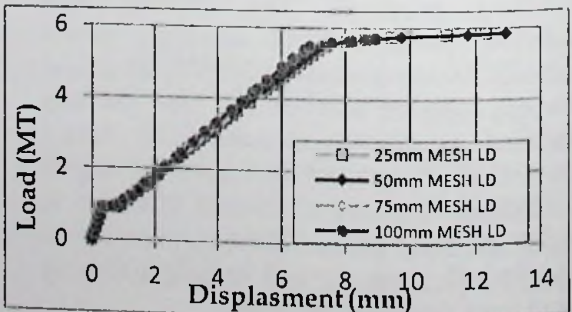

Figure 9: Load – Displacement curve for largedisplacement static analysis

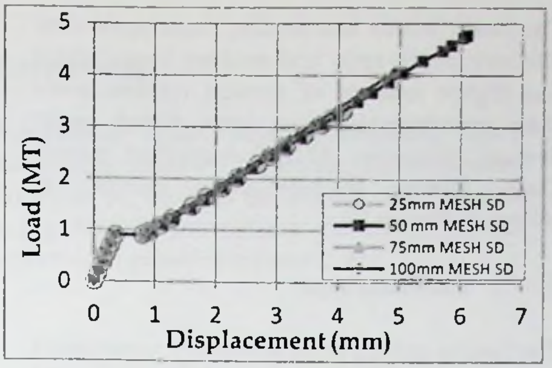

Figure 10: Load - Displacement curve for smalldisplacement static analysis

The load displacement curve for large displacement static analysis, clearly illustrates that the beams without shear links under large displacement static analysis behave like a beam with shear links. These beams have to fail by diagonal tension failure according to the reinforcement amount and span over effective depth ratio is 3.42 (Kani, G N J, 1966). Further, beam at the laboratory experiment also failed by diagonal tensile failure. Beside tensile stress in bottom reinforcement in ANSYS model passed yield stress at failure load in case of large displacement static analysis.

5.2 Comparisons for beam with stirrups

The load deflection curve of 50mm mesh beam with shear links under both small (SD) and large (LD) displacement static analysis and beam without shear links under large displacement (LD) analysis are shown in Figure 11.

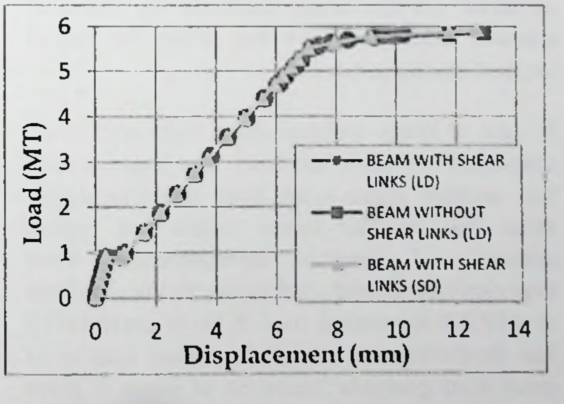

Figure 11: Load deflection curve for 50mm mesh beam with and without shear links

Figure 11 clearly illustrates beam with shear link can be analyzed using large displacement static analysis or small displacement static analysis to predict the behaviour of beam. In analysis small displacement static analysisshowed divergence of solution more than large displacement static analysis so numerical problem in analysis can be reduced using large displacement analysis. Further beams with shear link can be modelled without shear links if that model is analyzes using large displacement static analysis to predict the flexural failure.

The results under convergence study shows non suitability of large displacement static analysis for simulation of beam without shear links. Therefore laboratory beam test results were compared with 50mm mesh small displacement static analysis in case of both beam with shear links and beam without shear links.

5.3 Comparisons between numerical and experimental results

The crack initiation load and failure load of experimental and numerical model beams are shown in Table 3. Further comparisons of load deflection curves are shown in Figure 12 and Figure 13.

Table 3: Comparison of experiment and numerical model beams

Beam	Crack initiation load (MT)	Failure load (MT)
Beam without shear links		
B1	1.1	4.6
B2	1.2	5.6
ANSYS beam	0.9	4.77
Beam with shear links		
BS1	Not recorded	6.2
BS2	1.4	6.2
ANSYS beam	0.9	5.91

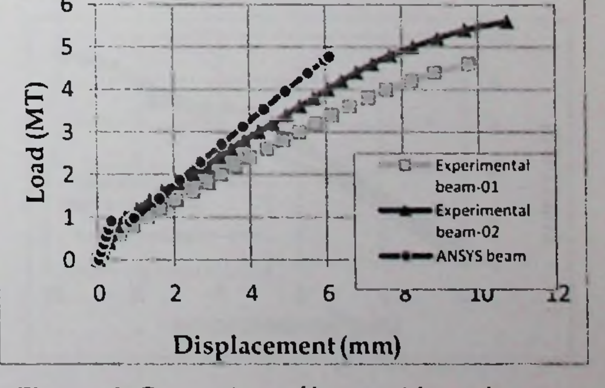

Figure 12: Comparison of beam without shear links

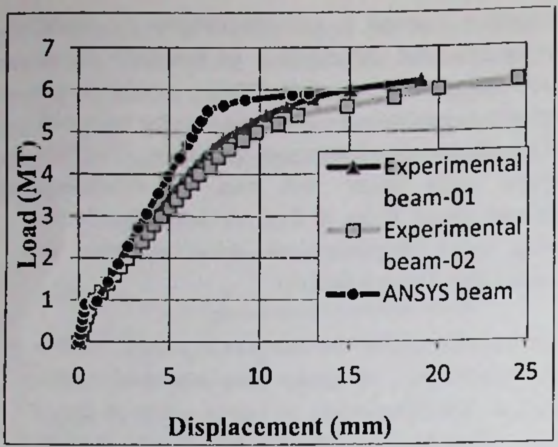

Figure 13: Comparison of beam with shear links

Figure 12 and Figure 13 clearly illustrate that the ANSYS numerical model shows a satisfactory level of prediction of behaviour in case of both beams with and without shear links. However as mentioned earlier ANSYS take default value of 0.6 for tension stiffening after crack formation. Therefore the deflection of ANSYS numerical beam shows a lesser value than experimental beam.

5.3 Limitation in ANSYS to model the shear failure of beam

Even though beam without shear links shows similar behaviour in case of small displacement static analysis ANSYS has limitation in predict the shear failure of beam since it include only shear transfer coefficient to include the behaviour of beam under shear forces. This was observed while try to find the relationship between shear failure and factors effecting shear failure. In this study different shear span over effective depth ratio and different amount of tension reinforcement were considered.

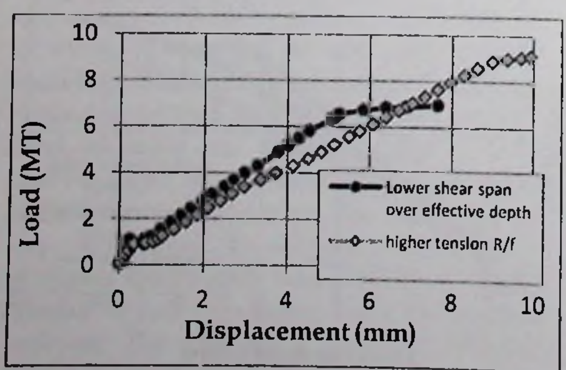

Figure 14: Load displacement curve to illustrate non suitability of shear failure simulation

The beam which has smaller shear span over effective depth ratio and another beam which has higher amount of tension reinforcement than experimental beam were failed under flexural failure in ANSYS numerical model. Those beams' load-deflection curves are shown in Figure 14.

5. Conclusions

The results gained from laboratory experiment beam and ANSYS numerical beam model conclude following.

The load deflection curves of experimental and numerical beams show similarity. Therefore the flexural failure of beams can be simulated to a satisfactory level using solid-65 and link-8 elements, Desayi and Krishnan concrete material model and Willam and Warnke failure criterion. Further both large and small displacement static analysis can be used for beam with shear links and small displacement can be used for beam without shear links.

The beam without shear links under large displacement static analysis shows similar behaviour as beam with shear links. So the behaviour of flexural failure for beam with shear link can be simulated by modelling the beam without shear links, using large displacement static analysis. So flexural behaviour of beam with shear links can be model using smeared reinforcement which is facilitated by Solid-65 element in ANSYS software package if the model is analysed using large displacement static analysis.As smeared reinforcement facilitate by Solid-65 element does not have the ability to model vertical reinforcements.

In case of beam without shear links and small displacement static analysis, the beam which has smaller shear span over effective depth ratio and another beam which has higher amount of tension reinforcement than experimental beamfailed under flexural failure in ANSYS numerical model. So it saysANSYS has limitation to model the shear failure of reinforced concrete beam. So at times it gives flexural failure of beam instead of shear failure. Further this report concludes numerical problem in converging the solution make difficulties in simulation of beam behaviour. This phenomenon increase the time required to analyze the model.

References

Vasudevan. G,& Kothandaraman.S. 2011. Parametric study on Nonlinear Finite Element Analysis on flexural behaviour of RC beams using ANSYS. *International journal of civil and structural engineering volume 2, no 1.*