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Modelling of the Tension Stiffening using the Fracture Energy Criterion in ABAQUS

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A B S T R A C T

The study attempts to implement the stress-displacement concept for tension stiffening rather than the stress-strain model for the concrete damage plasticity model in order to predict the crack propagation in RC beam and validate the results using the numerical and experimental study carried out by (Sihua, Qie and Wang, 2015). The stress- strain data of the concrete material under compression was based on constitutive model developed by Hognested, Hanson, McHenry (1955). While the tension stiffening was modelled by a fracture energy cracking criterion. The result of the maximum displacement of the present study showed very close similitude with the result from Sihua, Qie and Wang (2015) simulation. This showed that the fracture energy criterion was not dependent on the mesh size.

Keywords: *Fracture Energy Criterion, Concrete Damage Plasticity*

Introduction

Reinforced concrete has been known to exhibit non-linear properties due to non-linear stress-strain relation in multi axial stress, tension softening, pull out of reinforcement and aggregate interlocking. Many researchers have made valuable contributions in understanding the behavior of reinforced concrete and has developed sophisticated methods of analysis (Chandler, Chakrabarti, 2012). The finite element method has been used to provide numerical solution to the behavior of reinforced concrete failure (Shama, Nasrellah, Acid and Abdulraeg, 2021).One of the commercial software used in analyzing the behavior of reinforced concrete with the concrete damage plasticity model is the ABAQUS Software. The concrete damage plasticity model is a continuum. It assumes that the main two failure mechanism are tensile cracking and compressive crushing of the concrete material. In the present work, an attempt has been made to implement the stress-displacement concept in a finite element model and validate the results to the numerical and experimental study carried out by (Sihua, Qie and Wang, 2015).

Sihua, Qie and Wang, (2015), conducted a nonlinear analysis of reinforced concrete beam bending failure experimentation based on ABAQUS. Constitutive model for concrete axial compression and tension was based on the model formula suggested by Hognestad et al (1955).

Literature Review

Tension Stiffening is a phenomenon that occurs in cracked concrete reinforced with bars, where the concrete between cracks still carries a tensile force and contributes to the structural stiffness. This happens because of the bond between the concrete and the reinforcement bars. This phenomenon occurs when the steel-reinforced concrete members are under tension. However, some of the tensile force is transferred to the surrounding concrete through the bond between the reinforcement and concrete. In the ABAQUS Software, tension stiffening can be modelled by means of a post failure stress-strain relation or by means of a material softening or by applying a fracture energy cracking criterion. The fracture energy cracking criterion unlike the material softening is dependent on the energy required to open a unit area of crack.

In ABAQUS, if a concrete is not adequately reinforced, it often introduces mesh sensitivity in the analysis result in the sense that the finite element predictions do not converge to a unique solution as mesh refinement leads to narrower crack bands. Which means that if you have a finer mesh, your result can be different than when you have a coarser mesh due to strain localization.

Fracture Energy Cracking Criterion

According to the model code (1990), the fracture energy of concrete is the energy required to propagate a tensile crack of unit area. In the absence of experimental data, Fracture Energy (G_f) may be estimated from: $G_f = G_{fo}(Fcm/Fcmo)^{0.7}$ (1)

Where $Fcmo = 10mpa$

$G_f = Base\ Value\ of\ Fracture\ energy.\ it\ depends\ on\ the\ value\ of\ d_{max}$

Where d_{max} is the base value of the maximum aggregate size

Table 1: Base Value of Fracture Energy

d_{max}	$G_f(Nmm/mm^2)$
8	0.025
16	0.030
32	0.058

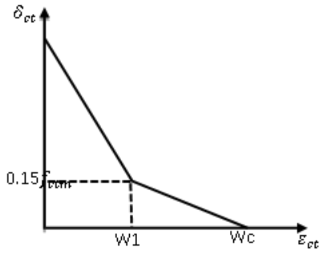

Fig. 1 - stress-crack opening diagram for uniaxial tension

For a cracked section a bilinear stress-crack opening relation given in equation 2 and 3 of the Model Code (1990) may be used to calculate the cracking displacement of the concrete.

$\delta_{ct} = f_{ctm}\left(1 - \frac{0.85w}{w1}\right)$ For $0.15f_{ctm} \leq \delta_{ct} \leq f_{ctm}$ (2)

$\delta_{ct} = \frac{0.15f_{ctm}}{wc-w1}(wc - w)$ For $0 \leq \delta_{ct} < 0.15f_{ctm}$ (3)

Where w1= $\frac{2G_f}{f_{ctm}} - 0.15wc$ (4)

wc = $\alpha_f \frac{G_f}{f_{ctm}}$ (5)

Where, w is the concrete crack displacement

w1 = crack opening for $\delta_{ck} = 0.15f_{ctm}$

wc = crack opening for $\delta_{ck} = 0$

$f_{ctm} = Tensile\ Strength$

$\alpha_f\ depends\ on\ the\ maximum\ aggrgate\ size\ d_{max}$

Table 2: Maximum aggregate size d_{max}

d_{max}	**8**	**16**	**32**
α_f	8	7	5

Research Methodology

The model of the concrete geometry used in this study was presented by Sihua et al(2015) which is a reinforced concrete beam with span of 1500mm, section height of 180mm, breadth of 100mm and cover of beam 20mm as shown in figure 2. The concrete part of the geometry and the reinforcement part were done separately as 3D deformable solid elements and merged together in an assembly module with the use of parallel face constrain (to align the reinforcement on the same direction with the concrete beam) and translating instance (to place the reinforcements on the corresponding location).

For the study, a three dimensional brick element with 8 nodes was used. In order to produce result in bending that are comparable to quadratic element but at a significant lower computational cost, Hexahedra incompatible mode with linear geometric order was adopted.

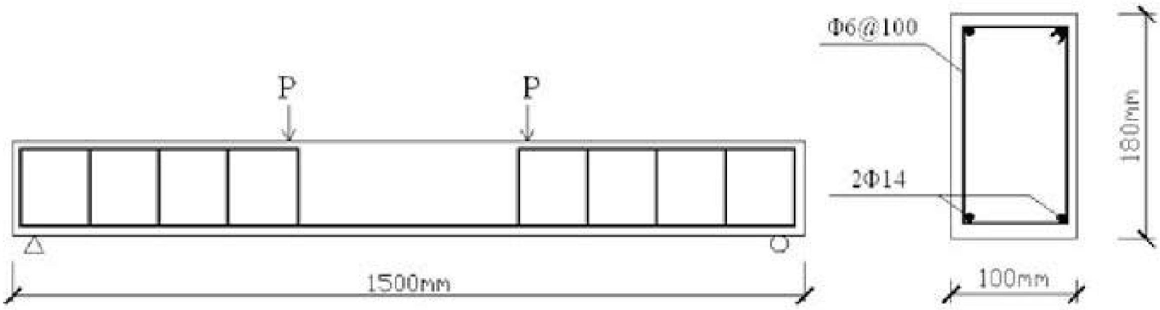

Fig. 2 - Reinforced Concrete Beam

For the study, the stress- strain data of the concrete material under compression was based on constitutive model developed by Hog nested et al (1955)

$\frac{fc}{f'c} = \frac{2\varepsilon c}{\varepsilon' c}(1 - \frac{\varepsilon c}{2\varepsilon' c})$ (6) for $0 < \varepsilon_c < \varepsilon' c$

$\frac{fc}{f'c} = 1 - 0.15(\frac{\varepsilon c}{\varepsilon u} - \frac{\varepsilon' c}{2\varepsilon' c})$ (7) for $0 < \varepsilon_c < \varepsilon u$

Table 3: Compressive inelastic stress-strain data

YIELD STRESS	INELASTIC STRAIN
12.5	0
14	8.73514E-05
16	0.000214
18	0.0003557
20	0.000519574
22	0.000721181
24	0.001014003
26	0.001414
27	0.001814
26	0.002214
25	0.002614
24	0.003014
23	0.003414

Where $f_c = 25Mpa, \varepsilon' c = 0.002, \varepsilon u = 0.0038$.

The stress-cracking displacement data of the concrete material under tension was used to model the tension stiffening in the concrete using equation 3.

Table 4: Inelastic Stress-Displacement data

YIELD STRESS	DISPLACEMENT
3.5	0

2.47861697680314	0.00875268571428571
1.78793013121816	0.0175053714285714
1.33611980614308	0.0262580571428571
1.04514442931252	0.0350107428571429
0.856103012636879	0.0437634285714286
0.72801834690164	0.0525161142857143
0.634279679760854	0.0612688
0.558763789390735	0.0700214857142857
0.492474231400926	0.0787741714285714
0.430945853039335	0.0875268571428571
0.372389604675687	0.0962795428571429
0.316448636684655	0.105032228571429
0.263415189931161	0.113784914285714
0.213772573630455	0.1225376
0.167953662714668	0.131290285714286
0.126235382343	0.140042971428571
0.0887128084826973	0.148795657142857
0.0553154284979548	0.157548342857143
0.025841985167911	0.166301028571429

Table 5: Damage Plasticity Parameter

PLASTICITY	**VALUE**
Dilation angle	30
Eccentricity	0.1
Fbo/fco	1.16
K	0
Viscosity parameter	0
Density of concrete	0.0000024
Density of steel	0.0000765
Poisson’s ratio of concrete	14.2GPa
Poisson’s ratio of Steel	0.3
Concrete Strength	C25

Result/Finding

We applied a uniform force of 16N on the simply supported reinforced concrete beam. According to the simulation carried out by Sihua et al (2015) in figure 3, the displacement of nodes in the middle of the beam was 2.210mm while for the present study, the displacement of nodes in the middle of the beam is 2.296mm.

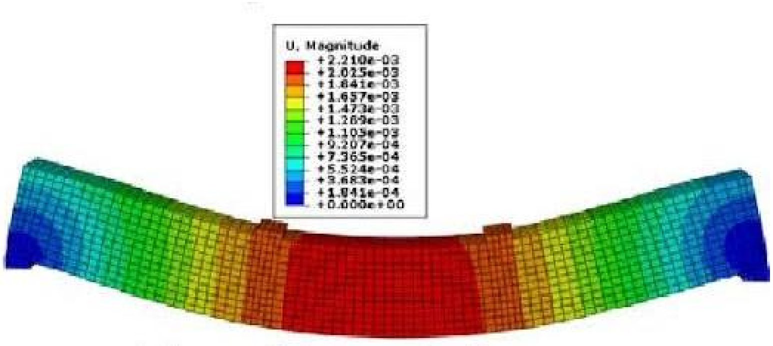

Fig. 3 - Displacement mode at the middle of the beam by Sihua et al (2015)

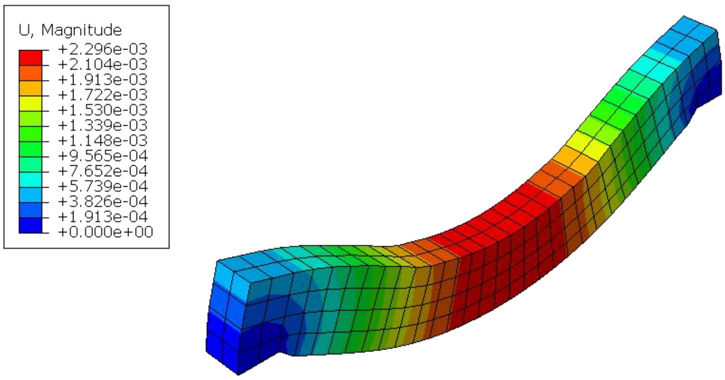

Fig. 4 - Displacement at middle of the beam for the present study

Conclusion/Summary

The study compared the result of the numerical analysis conducted by Sihua, Qie and Wang (2015) to the present study. In the present study an attempt has been made to predict the crack propagation in RC beam by FRACTURE ENERGY CRACKING CRITERION instead of the MATERIAL SOFTENING MODEL adopted by Sihua, Qie and Wang (2015) in order to simulate the nonlinear behavior of the reinforced concrete beam. Sihua,Qie and Wang(2015) simulation, used a finite element model with fine mesh and smaller load increment whereas, the present study used a coarser mesh in order to check if the result of the study will be affected by mesh sensitivity.

From the result of the simulation carried out by Sihua, Qie and Wang (2015), it was shown in figure 3 that the displacement of nodes in the middle of the beam was 2.210mm whereas for the present study, the displacement of nodes in the middle of the beam is 2.296mm (Figure 4). The result of the maximum displacement of the present study showed very close similitude with the result from Sihua, Qie and Wang (2015) simulation. This showed that the fracture energy criterion was not dependent on the mesh size.

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