

Damage Modelling of Reinforced Concrete Beam

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Abstract: *Damage mechanics deals with the study of material damage based on the introduction of damage variables and their evolution under the applied loading conditions. Damage mechanics is one of the most important and interesting branches of solid mechanics although it is still developing, it has already been applied to many engineering problems. Analysis of reinforced concrete beam was done with material model available in ANSYS library. When the results are compared with the experiment conducted result is not satisfactory. Hence it is found that some parameters are necessary to make the results comparable. For that damage modelling of reinforcement steel was done using GursonTvergaardNeedleman(GTN) model by finding GTN parameters. Damage modelling of concrete was done using DruckerPrager model by finding cohesion, friction angle and dilation angle of concrete. Analysis was done by considering damage models of steel and concrete and found that the result obtained was same as that of experimental result. Hence it was concluded that without conducting experiment, the ultimate load can be predicted if the material damage is correctly modelled.*

Keywords: Damage Modelling, DruckerPrager(DP), GursonTvergaard Needleman(GTN)

1. Introduction

The pioneer of the damage parameter proposal was Murzewski, who put forward a probabilistic interpretation of the decohesion parameter. Following in his footsteps, Continuum Damage Mechanics was initiated by Kachanov to model creep damage in metals. The theory considered the description of state variables in the framework of thermodynamics of irreversible process. Number of models are now available for various types of materials including metals, laminated fibre reinforced composites, concrete, rocks, etc. At the micro scale level, damage is governed by only one general mechanism of debonding. The types of damage includes: brittle damage, ductile damage, creep damage and fatigue damage. The methods of measurement of damage may be broadly classified into two categories, viz. direct measurements and indirect measurements.

The process of damage mechanics is to translate the underlying microscopic failure phenomena to a macroscopic description in a phenomenological model. In all cases, the models are considering one or more parameters and when these parameters reach a critical value failure is expected. The damage parameter explains how much of the material is damaged. A number of failure criteria have been proposed to characterize the fracture of a body, e.g.: by Coulomb, Rankine, Tresca, and Von Mises. These simple failure models only consider stress or strain. In recent years models concerning different type of damages have been studied, e.g. by Gurson, John-Cook and Wilkins, which all are trying to describe the new formation, growth and coalescence of micro voids in terms of mechanical properties for tensile materials and DruckerPrager for compressive materials. The ductile failure of metallic materials most often occurs by nucleation, growth and coalescence of micro voids.

Flexure test of reinforced concrete beam was conducted to obtain Load Deflection graph. Finite element analysis of reinforced concrete beam using Solid65 and Link180 was done using ANSYS. Since experimental and numerical results were not of comparable values, damage modelling of reinforcement steel (Fe500) was done and found GTN

parameters. Also damage modeling of concrete cylinder (M20) was done using DruckerPrager criteria. Finite element modeling of reinforced concrete using GTN for steel and DP for concrete and found results seems to be similar with that of experiment conducted.

2. Experimental and Numerical Analysis of RCC Beam

Experimental and Numerical analysis of reinforced concrete beam was conducted.

2.1 Experimental Analysis

Reinforced concrete beam was casted with size 900mmX100mmX80mm. M20 grade concrete and Fe500 steel with 8mm diameter of 2 numbers was used.

It was tested in Universal Testing Machine with point load. The support condition was one end hinged and other end roller. Deflectometer was connected and deflections were noted. The load deflection graph was then plotted using loads and respective deflections.



Figure1: Testing of beam

2.2 Numerical Analysis

Reinforcement concrete beam was modeled by incorporating true stress and true strain. After meshing, loading and boundary conditions were applied and was analysed.

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Modeling was done in ANSYS15.0. Support condition provided was one end hinged and other end roller. Loads were applied. The deflection for each load was found respectively. The load deflection diagram for the beam modeled was plotted.

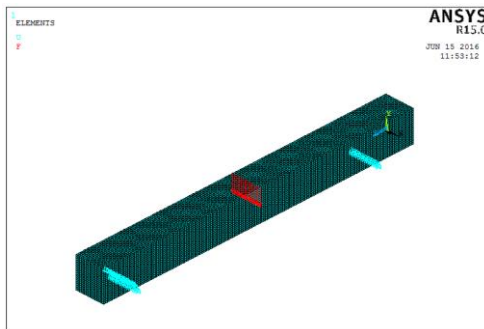


Figure 2: Finite element model of Beam

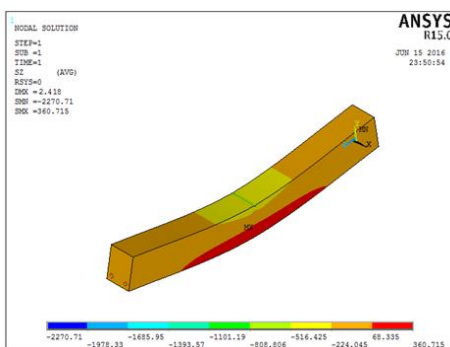


Figure 3: Deflection diagram for maximum load

2.3 Comparison of Experimental and Numerical Results

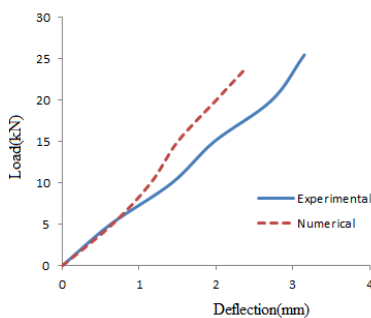


Figure 4: Comparison of Load Deflection graph

The load deflection graph was plotted and compared with an experimental result conducted in SSET Laboratory. Since the results shows a variation of 23.24%, few parameters will have to be considered for steel and concrete and analysed. As a result, GTN model was selected for reinforcement steel. For that GTN parameters should be calibrated and analysis to be done. For concrete, DruckerPrager model was selected. The parametric values should be found and analysis to be done using the same.

3. Damage Modelling of Reinforcement Steel

3.1 Experimental Analysis

For obtaining stress strain graph for reinforcement steel, tension test was conducted in UTM for 8mm Fe500 steel.



Figure 5: Stress strain graph for Reinforcement

3.2 Numerical Analysis

The Multilinear Isotropic hardening option was selected for the present analysis as it best suits for ductile and brittle character. The element chosen for reinforcement was LINK180.

Gauge length = 42.5mm

Gauge diameter = 8mm

Steps in true stress strain modeling

- True stress and true strain from engineering stress and strain are calculated:
 Engineering Stress, $s = \text{load}/\text{original area}$
 Engineering Strain, $e = \text{change in length}/\text{original length}$
 True stress, $\sigma = \text{load}/\text{actual area}$
 True strain, $\epsilon = \text{change in length} / \text{instantaneous length}$
 $\sigma = \log_e(1+e)$
 $\epsilon = s(1+e)$
- Find out \log_{10} true stress and \log_{10} true strain from the above
- Plot the above graph. This will consist of an initial curved zone corresponding to the elastic region and a subsequent straight line corresponding to the strain hardening region.
- Ignore the initial curved portion
- Fit a straight line to the latter portion in the form, $y=mx+c$ using MS excel. Get the equation of this line.
- Convert back the log- log graph to arithmetic form.
 For e.g.: $\log \sigma = m \log \epsilon + c$ to arithmetic form i.e., $\sigma = \epsilon^m \times 10^c$
- Extrapolate the strain hardening portion of the graph till fracture strain, ϵ_f which is calculated as below:
 $\epsilon_f = \ln(1/1-R_A)$
 $R_A = \text{Reduction in area (expressed as fraction)} = 46.1\%$
- This is the true stress strain graph till fracture of the specimen. Choose a few representative points on the graph for inputting into ANSYS code.

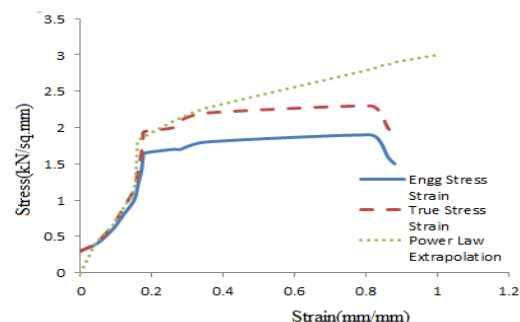


Figure 6: Extrapolated true stress strain graph for steel

Reinforcement steel was modeled by incorporating true stress and true strain. Axisymmetric finite element modeling

of reinforcement steel was done in ANSYS. The material selected was PLANE182.

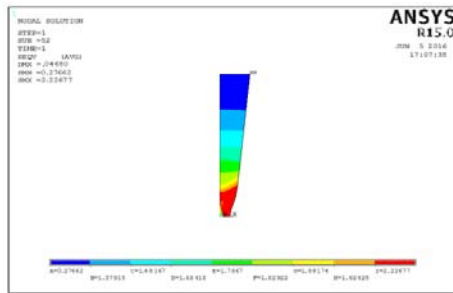


Figure 7: Stress diagram for reinforcement steel

3.3 Comparison of Numerical and Experimental results

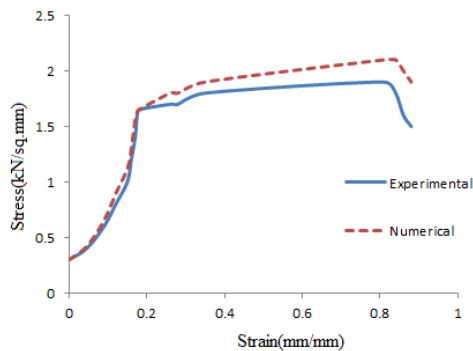


Figure 8: Comparison of stress strain graph for steel

Table 1: Comparison of Results for Steel

Method	Experiment	using ANSYS15.0 (Elasto Plastic)	% variation
Stress(kN/sq.mm)	1.5	1.9	21.05%

Observations:

- The variation was not able to correctly plot.
- This is because of the weakening effects of voids are not considered in conventional model.
- Hence GTN model is used to simulate the above weakening effect.

3.4. Calibration of GursonTvergaard Needleman constants

In order to evaluate the GursonTvergaard Needleman parameters of the reinforcement steel, a parametric finite element analysis of the specimen is done using ANSYS_APDL (Version 15.0) finite element analysis code implemented in a PC. As the first step for this analysis, it is required to find out the true stress strain properties of this material beyond necking.

Table 2: GTN Model Parameters

Sl. No.	Parameter	Calibrated value	Reference value
1	q_1	1.5	1.5
2	q_2	1	1
3	q_3	2.25	2.25
4	f_0	0.007	0-0.01
5	f_N	0.05	0-0.1
6	f_C	0.10	0.15
7	f_F	0.2	0.25
8	ϵ_N	0.3	0.3
9	s_N	0.1	0.1

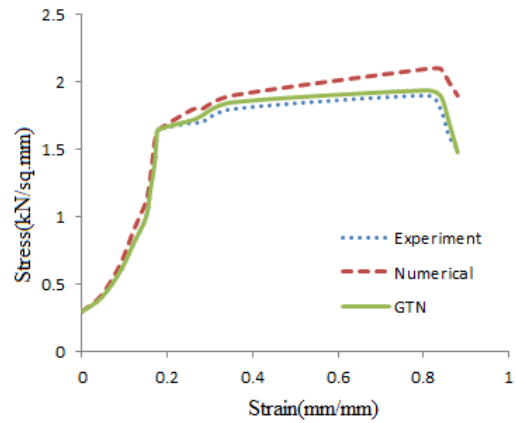


Figure 9: Comparison of results for steel (GTN)

Table 3: Comparison of Results of Steel (GTN)

Method	Experiment	using ANSYS15.0 with GTN	% variation
Stress(kN/sq.mm)	1.5	1.48	1.33%

With the application of GTN model, the percentage variation on stress reduced to 1.33% from 21.05%.

4. Damage Modelling of Concrete

4.1 Experimental Analysis

Concrete cylinder of 150mm diameter and 300mm height was casted and tested in the UTM.



Figure10: Stress Strain graph for concrete cylinder

4.2 Numerical Analysis

Solid65 material was selected since it gives best resemblance to concrete property. Figure 11 shows the cylinder of 150mm diameter and 300mm height modeled in ANSYS 15.0. Load was given as pressure at one end. At the other end, support condition was given.

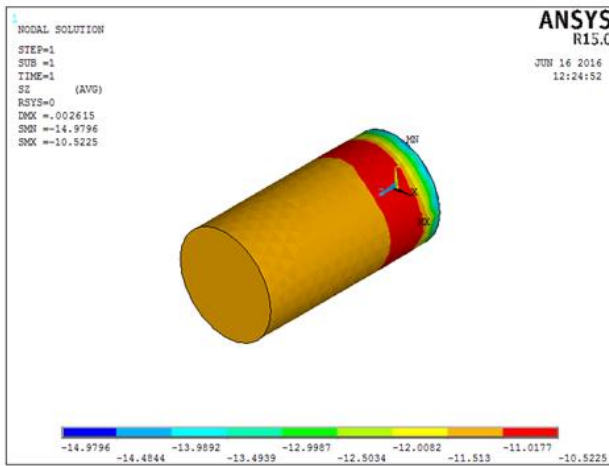


Figure 11: Deflection diagram for cylinder

4.3 Comparison of results for concrete

From experimental and numerical analysis, the results were compared.

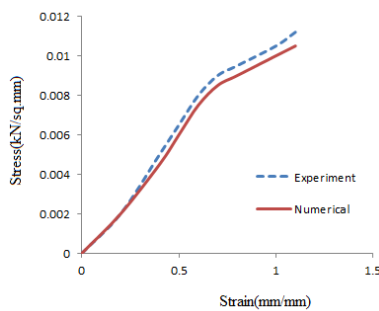


Figure 12: Comparison of results for concrete

Table 4: Comparison of Results of Concrete

Method	Experiment	using ANSYS15.0 (SOLID65)	% variation
Stress(kN/sq.mm)	0.011	0.010	10%

4.4 Damage model for Concrete

DruckerPrager is the damage model which can be applied for compressive materials like soil, rock, concrete etc. Three parameters required for DP modeling are cohesion, internal friction (angle) and dialation angle.

• Cohesion

The contribution of cohesion to the concrete can be calculated as $0.085\sqrt{f_{cd}}$.

Where,

f_{cd} = design compressive strength of concrete

Therefore, cohesion = 380.132 kN/m^2

• Internal friction

Considering Wedge theory and split tensile test, internal friction,

$$\phi = \tan^{-1}(\pi/2) = 57.5^\circ$$

• Dialation angle

$$\text{Dialation angle, } \beta = \frac{3}{2} \frac{\text{plastic volumetric strain}}{\text{plastic shear strain}}$$

$$\text{Plastic volumetric strain} = \frac{(\sigma_x + \sigma_y + \sigma_z)}{E} \left(1 - \frac{2}{m}\right)$$

From the analysis result,

$$\sigma_x = 0.162 \text{ N/mm}^2$$

$$\sigma_y = 0.144 \text{ N/mm}^2$$

$$\sigma_z = -10.51 \text{ N/mm}^2$$

$$\text{Plastic shear strain} = 0.375 \text{ e-}03$$

$$\text{Therefore, } \beta = 57.238.$$

The analysis was again performed by considering these three parameters and the comparison of results were plotted.

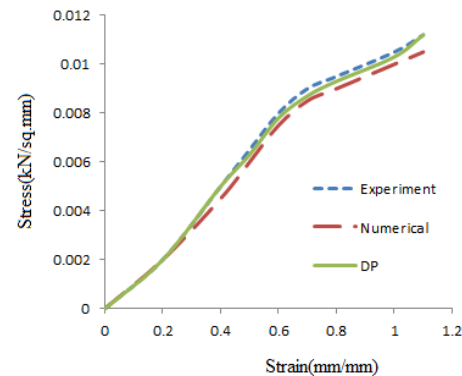


Figure 13: Comparison of results of concrete (DP)

Table 5: Comparison of Results (DP)

Method	Experiment	using ANSYS15.0 with DP	% variation
Stress(kN/sq.mm)	0.011	0.01081	1.8%

With the application of DP model, the percentage variation on stress reduced to 1.8% from 10%.

5. Prediction of Collapse Load of RCC Beam Using GTN and DP

For an FEA analysis, it's the stress strain curve that makes the analysis perfect. So if correct variation of the stress strain was able to plot, better results will be obtained. And so, the variation obtained for numerical and experimental analysis can be minimized and without doing an experiment we can predict the ultimate load. Considering the stress strain graph of GTN and stress strain graph of DP, FEA analysis was again done to the beam modeled.

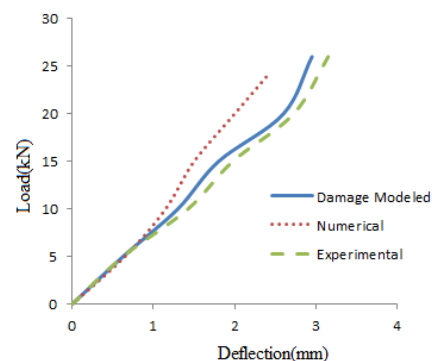


Figure 14: Load Deflection graph for damage modeled beam

Table 7: Comparison of Results for Damage Modelled Beam

Method	Collapse Load (kN)	Deflection (mm)	% variation of Load	% variation of Deflection
Experiment	25.5	3.15	-	-
ANSYS	24	2.418	6.25	23.24
GTN & DP	26	2.979	1.923	5.4

After modifying the stress strain graph of steel with GTN and concrete with DP, the result of load deflection graph seems to be similar to experiment conducted.

Brittle Materials." *J. Eng. Mech.*, 10.1061/(ASCE)0733-9399(2002)128:8(889), 889-897.

6. Conclusion

- Flexure test of reinforced concrete beam was conducted to obtain Load Deflection graph. The same beam was modeled in ANSYS15.0 using materials SOLID65 for concrete and LINK180 for steel. The percentage variation obtained was 23.24%.
- The damage of reinforcement steel (Fe500) was obtained after finding GTN parameters. It is then compared with the experimental result of tensile test. The percentage variation reduced to 1.33% from 21.05% after modeling using GTN.
- Modeling of concrete cylinder (M20) was done and damage was modeled using DruckerPrager criteria. The percentage variation reduced to 1.8% from 10% after modeling using DP.
- Finite element modeling of reinforced concrete beam using GTN for steel and DP for concrete was done the percentage variation between the same and experimental result, reduction for deflection was 5.4% and load was 1.923%.

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