Nonlinear analysis of shear panel elements

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ABSTRACT

The shear behavior of reinforced concrete member has been studied for a long while by various researchers, and the shear panel has been regarded as a basic element of reinforced concrete members subjected to in-plane biaxial stresses. Although various experimental studies on shear panel element have been conducted, there are still a lot of uncertainties related to what influencing factors are dominant in the performance mechanism of shear loaded elements. To identify the uncertainties, the diverse analytical method can be utilized, which enables to investigate the impact of specific variables such as the reinforcement ratio, the shear retention factor, and the material model including aggregate interlock, tension stiffening, compressive softening, shear behavior at the crack surface, and the cracking model. In this study, ATENA, which was developed to be suitable for non-linear finite element analysis of reinforced concrete structures, was utilized to analyze the panel specimens collected from literature. ATENA provides a lot of detailed material models for concrete and users can easily manipulate the detailed variables for research purpose. The analysis results showed that the shear cracking model and shear retention factor are important variables among others affecting the shear behavior of the panel element.

1. INTRODUCTION

ATENA (Cervenka et al. 2007) was used in order to analyze the Hsu's (Mansour and Hsu 2005) shear panel element tested in the University of Houston. In this study, the proper modelling method is to be checked considering influencing factors such as

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Table 1 Specimen detail

Specimen	Degree (degree)	f_c (MPa)	ρ_x (%) (yield stress)	ρ_y (%) (yield stress)	Thickness (mm)
CA2	45	45	0.77 (424.1)	0.77 (424.1)	178
CA3	45	44.5	1.70 (425.4)	1.7 (425.4)	178
CA4	45	45	2.7 (453.4)	2.7 (453.4)	203
CE2	0	49	0.54 (424.1)	0.54 (424.1)	178
CE3	0	50	1.2 (425.4)	1.2 (425.4)	178
CE4	0	47	1.9 (453.4)	1.9 (453.4)	203
CB3	45	48	1.7 (425.4)	0.77 (424.1)	178
CB4	45	47	2.7 (453.4)	0.67 (424.1)	203

material model, mesh element size and boundary condition. Table 1 shows the target panel detail. For the first trial, specimens CA2, CA4 and CB4 were analyzed. Among them, the specimen CB4 is asymmetrically reinforced in orthogonal directions and the inclination angle of reinforcement with respect to applied load direction for the three specimens are all 45 degrees. The analysis results are compared to the test result obtained using the PARC_CL 2.0 crack model (Belletti et al. 2017) implemented in ABAQUS (Hibbitt 2011) user subroutine UMAT.for.

This analytical study is going to be extended with fractile based sampling procedure (FBSP) in order to analyze the reliability and subsequently to investigate the influencing factors on shear behavior of the panel element in an effective manner. The FBSP is fundamentally based on Latin Hypercube Sampling (Huntington 1998) and correlation between variables (Cosma 2017). This method would be very useful for time-intensive calculation such as finite element analysis, in which the rational results can be obtained compromising between feasibility and accuracy. The basic concept is shown in Fig. 1 in which the simulations are conducted with several selected variables according to fractile value instead of tens of thousands of input sets for a fully probabilistic approach.

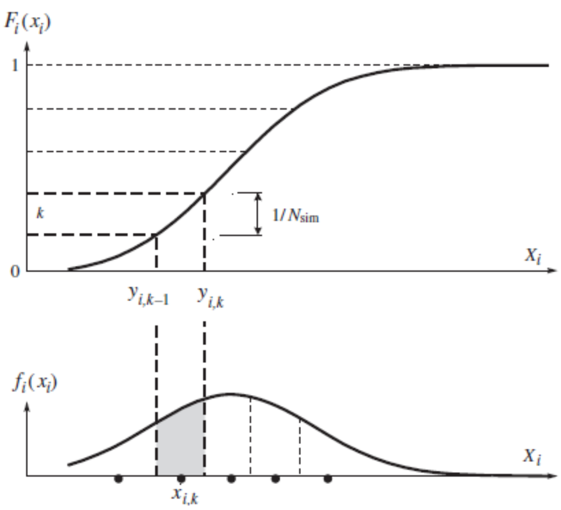
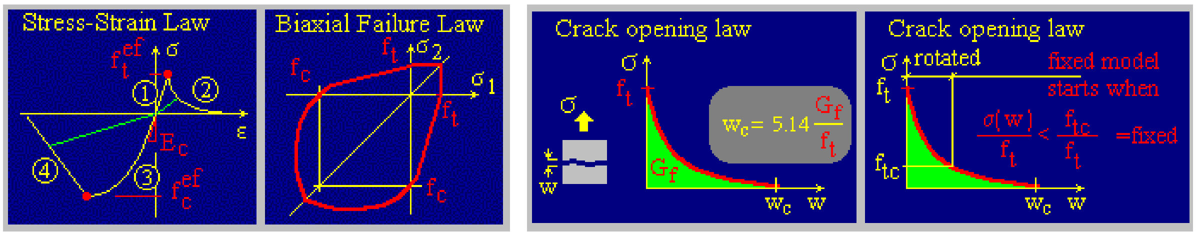


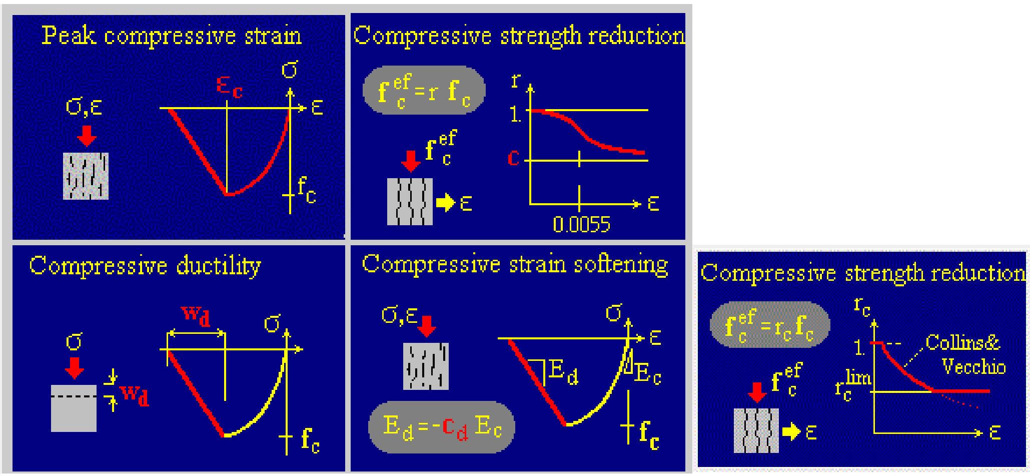
Fig. 1 Samples as the probabilistic means of the intervals

2. MODELLING IN ATENA

The panel was modelled with 4 nodes, 4 lines and 1 surface element in 2-Dimension, in which the plane stress state was assigned. The reinforced concrete material model was chosen to regard concrete and reinforcement as smeared materials. For the concrete material, the biaxial stress model called CCSBETA presented in Fig. 2. The concrete properties a user can modify in tension and compression are shown in Fig. 2(b) and Fig. 2(c), respectively. The reinforcement was assigned as reinforcing ratio and elasto-perfect plastic bilinear curve. The considering parameters that might affect the analysis result are boundary condition, number of mesh elements and crack model.



(a) General concrete (b) In tension



(b) In compression

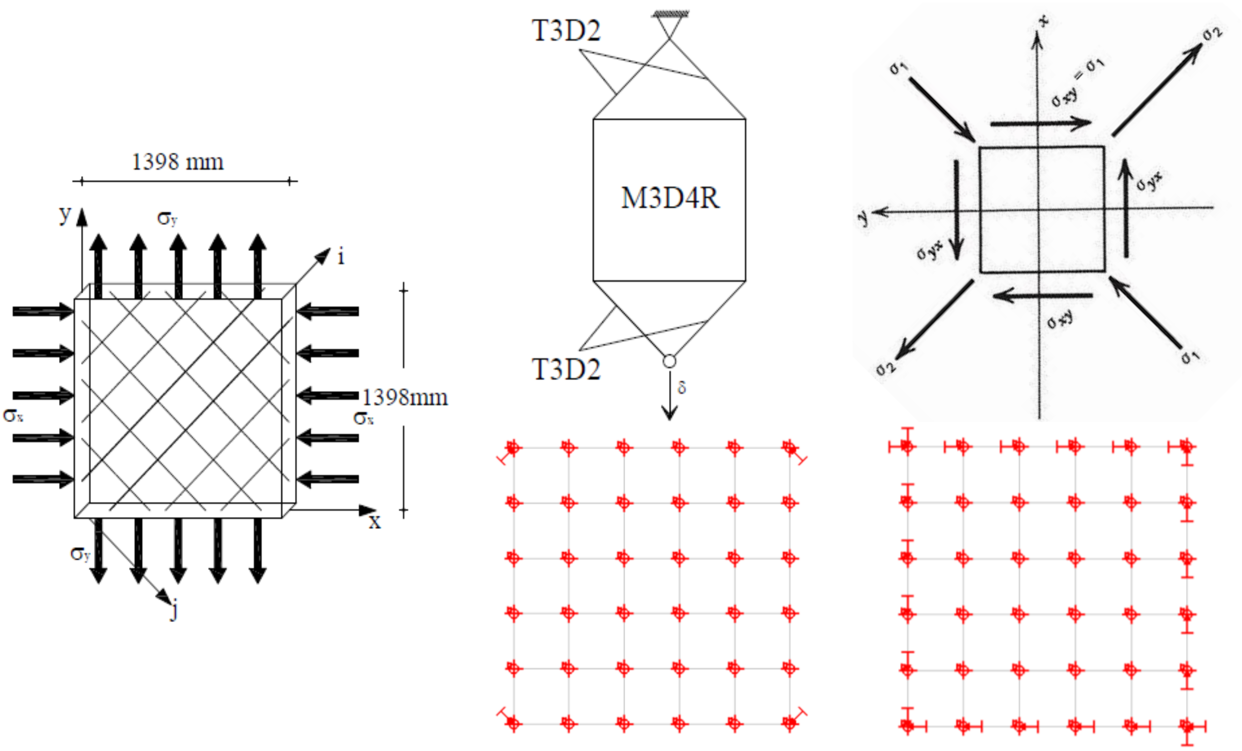
Fig. 2 CCSBETA for concrete material

2.1 Loading and boundary condition

The test specimens were loaded while keeping the pure stress state, for which the principal stresses in longitudinal and transverse directions were kept as the same values. To simulate this, two boundary conditions were considered as shown in Fig. 3. The first method is to duplicate the boundary condition adopted for NLFEA carried out using PARC_CL 2.0 CRACK model (Belletti et al. 2017). In the second scheme, the panel is loaded with displacement controlled method according to the configuration in Fig. 3(c) to apply pure shear stress state.

2.2 Number of mesh elements

The mesh element size can affect the overall shear behavior of the panel element, and then this is considered with the number of mesh elements. The considering numbers were 4, 25, 100, 225, 400, and 625. Only one finite element with one integration point has been used for NLFE analyses carried out using PARC_CL 2.0 crack model.



(a) Test Specimen (b) In PARC (c) Pure shear stress state

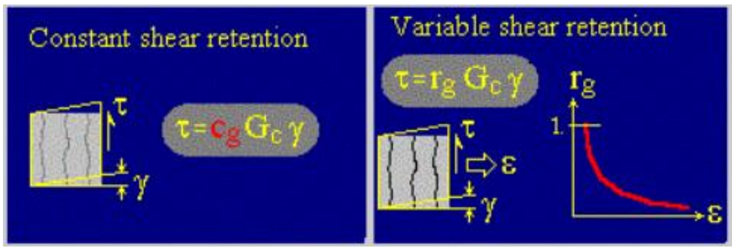
Fig. 3 Boundary conditions

2.3 Cracking model

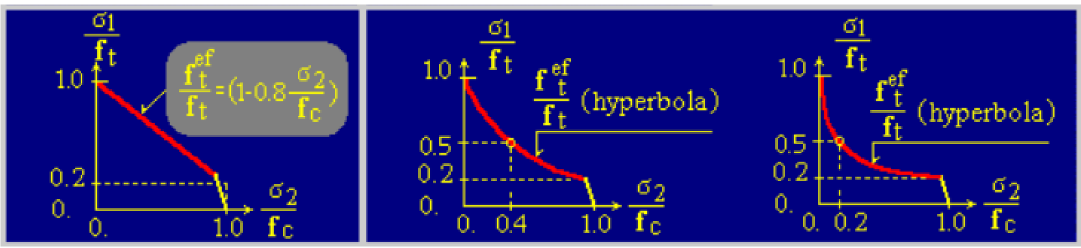
The smeared truss model can be distinguished into fixed and rotating crack models, which affect the overall shear behaviour of a reinforced concrete member. Additionally, the shear model at the crack surface is as important as the cracking model. As shown in Fig. 4, the shear model can be considered in the ATENA by adjusting the shear retention factor and tension-compression failure function for concrete. The former is related to shear modulus and affects the shear stiffness in a relatively early stage of the behaviour, while the latter influences the inelastic behaviour up to the ultimate stage.

3. SHEAR STRESS-STRAIN

The analysis details are described in Table 2 and the analytical shear stress-strain curves for specimen CB4 is shown in Fig. 5. Regarding the crack model, the rotating crack model relatively well estimated the test result, while the analysis results with the fixed crack model were highly affected by shear retention factor and tension-compression failure function presented in Fig. 4. The best fit with the fixed crack model was obtained when the variable shear retention factor and the linear failure function were used. Moreover, Fig. 5(b) shows the effect of the number of mesh elements, in which the behaviour is quite stiff in early displacement and significantly low in the ultimate state. It seems that the mesh elements should be at least over than 100 to obtain reasonable analysis result.



(a) Shear retention factor



(b) Tension-compression failure function for concrete

Fig. 4 Shear model at crack surface

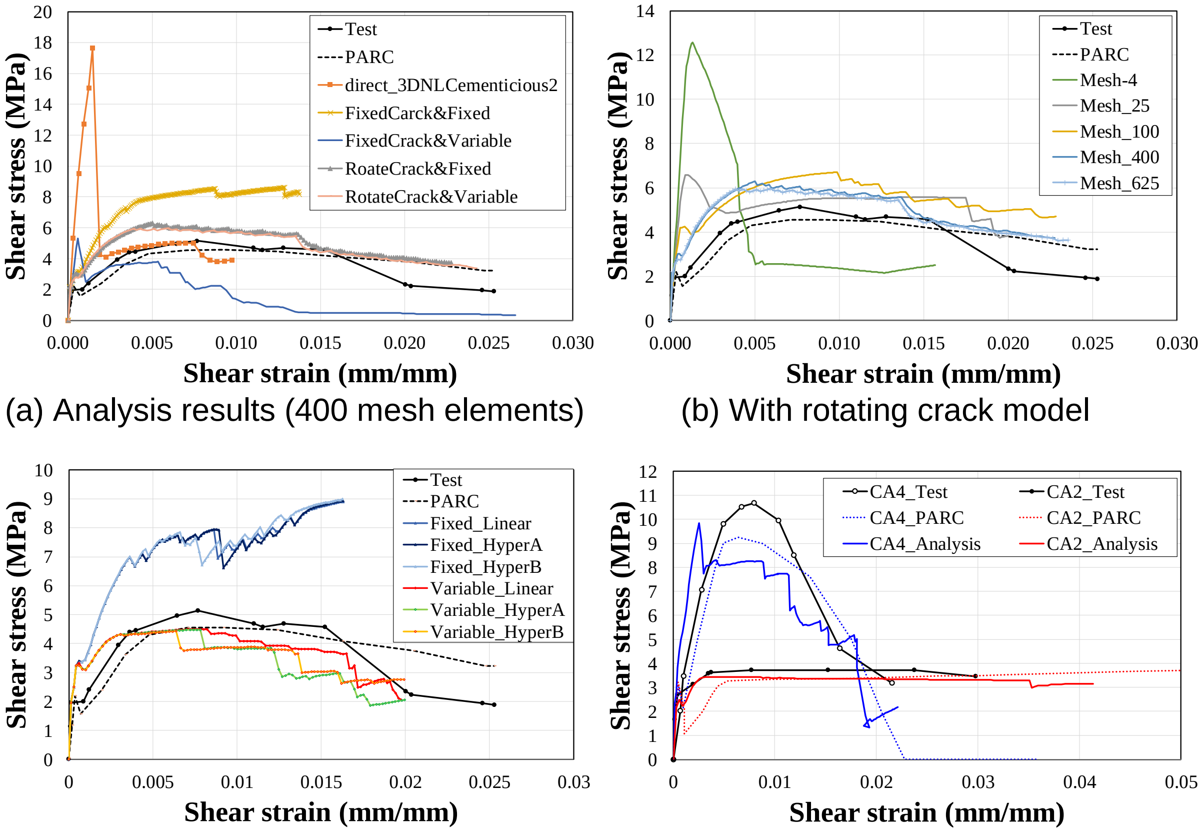
Table 2 Detail feature of analysis

Item	Description	
Test	Test result reported in Hsu's paper	
PARC	PARC model with tested material properties	
Direct_3DNL	ATENA with boundary condition Fig. 3(b)	
FixedCrack & Fixed	Fixed crack model with fixed shear retention factor	ATENA with boundary condition Fig. 3(c)
FixedCrack & Variable	Fixed crack model with variable shear retention factor	
RotateCrack & Fixed	Rotating crack model with fixed shear retention factor	
RotateCrack & Variable	Rotating crack model with variable shear retention factor	

4. CONCLUSION

- The analysis with the rotating crack model showed the good accuracy regardless of how the shear retention factor is applied, in which the analysis result can be even closer to test result with a much finer mesh, but the results don't show large differences if the number of mesh is larger than 100.

- The analysis with the fixed crack model should be conducted with appropriate shear retention factor and tension-compression failure function, and the variable shear retention factor with linear failure function presented the best fit with the test result.



(a) Analysis results (400 mesh elements) (b) With rotating crack model

(c) With fixed crack model (d) Panels CA2 and CA4

Fig. 5 Validation of the proposed model

REFERENCES

Belletti, B., Scolari, M., and Vecchi, F. (2017), "PARC_CL 2.0 crack model for NLFEA of reinforced concrete structures under cyclic loadings", Computers and Structures, **191**(1), 165-179.

Cervenka, V., Jendele, L., Cervenka, J. (2007), ATENA program documentation – Part 1: Theory, Cervenka consulting. Prague, Czech.

Cosma, M.P. (2017), Fractiles Based Sampling Procedure: a new probabilistic approach to evaluate the design resistance of a structural element. University of Parma, Parma, Italy.

Hibbitt, H.; Karlsson, B., Sorensen, P. (2011), ABAQUS Analysis User's Manual. Version 6.10; Dassault Systems Simulia, RI, USA.

Huntington, D.E., and Lyrintzis, C.S. (1998), "Improvements to and limitations of Latin Hypercube Sampling", Probabilistic Engineering Mechanics, **13**(4), 245-253.

Mansour, M., and Hsu, T.T.C. (2006), "Behavior of Reinforced Concrete Elements under Cyclic Shear. I: Experiments", *Journal of Structural Engineering*, **131**(1), 44-53.