3D NONLINEAR FINITE ELEMENT ANALYSIS OF CONCRETE UNDER DOUBLE SHEAR TEST

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1. INTRODUCTION

This paper presents an experimental study on shear strength of different types of concrete, mortar and paste specimens under double shear test. A linear relationship between compressive and shear strength has been found for all materials. 3D nonlinear finite element analysis closely predicted experimental shear strengths. Some aspect of failure mechanism was discussed by investigating deformation, stress and strain distribution of the numerical model.

2. EXPERIMENT

2.1 Detail of Tested Specimens

The experimental work consisted of specimens made by four types of concretes, two types of mortar and cement paste materials. Table 1 shows different types of material together with W/C ratio and quantity of specimens for each series of tests. There are 21 series of tests. Each series has 12 specimens and the total number of specimens is 252. Shear test specimen is a beam of dimensions 10×10×40cm. The selection of mix proportions for paste, mortar and concrete specimens is presented in Table 2.

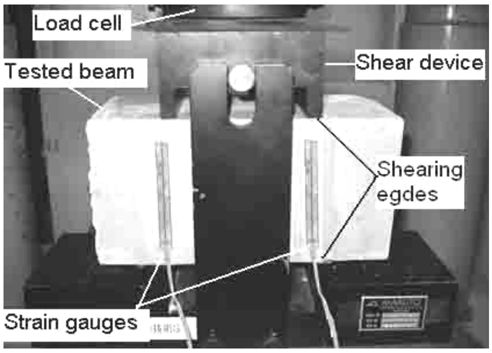


Photo 1 Test arrangement

2.2 Test Arrangements and Procedure

Photo 1 shows loading arrangement of the double-shear test. A specimen block was symmetrically positioned within a shear device. The shear device consists of two parts, a base and a top part. The outer surface of shearing edges of the top part is coincided with the inner surface of shearing edges of the base. The intersection of this surface and the beam is the tested section that is the section used to calculate shear strength. Along two tested sections there were strain gauges glued on the surface of the beam. These gauges were used to monitor and adjust eccentric loading. Monotonic, force-controlled loading was applied with speed of increment of shear stress of 0.1N/mm^2 per second.

2.3 Test results

Fig.1 shows plots of shear strength versus compressive strength for all selected specimens. It can be seen from the distribution of data points that shear strength increases with increment of compressive strength. Linear regression analysis showed that concrete and mortar specimens have nearly identical relationship between shear and compressive strength which can be presented by the solid line, whereas paste specimens show slightly difference as shown by dotted line.

3. FINITE ELEMENT SIMULATION

Table 1 Test specimens

Series name	W/C (%)	Qtt. (unit)	Description
P-1	86	12	Cement paste
P-2	58	12	
P-3	43	12	
NS-1	86	12	Normal aggregate mortar
NS-2	58	12	
NS-3	43	12	
LS-1	86	12	Lightweight aggregate mortar
LS-2	58	12	
LS-3	43	12	
NSNG-1	86	12	Normal weight concrete.
NSNG-2	58	12	
NSNG-3	43	12	
NSLG-1	86	12	LWA concrete of normal fine and LW coarse aggregates
NSLG-2	58	12	
NSLG-3	43	12	
LSNG-1	86	12	LWA concrete of LW fine and normal coarse aggregates
LSNG-2	58	12	
LSNG-3	43	12	
LSLG-1	86	12	LWA concrete of LW fine and coarse aggregates
LSLG-2	58	12	
LSLG-3	43	12	

Table 2 Mix propotion

Series name	W/C (%)	s/a (%)	Weight per unit volume (kg/m^3)							
			W	C	LS	S_N	S_L	G_N	G_L	SP
P-1	86			672	566					1.34
P-2	58	-	578	1003	283	-	-	-	-	5.02
P-3	43			1335	0					10.7
NS-1	86			305	257					0.61
NS-2	58	-	256	456	129	1418	-	-	-	2.28
NS-3	43			606	0					4.85
LS-1	86			305	257					0.61
LS-2	58	-	256	456	129		955	-	-	2.28
LS-3	43			606	0					4.85
NSNG-1	86			192	162					2.67
NSNG-2	58	48	165	287	81	892	-	977	-	3.81
NSNG-3	43			381	0					4.95
NSLG-1	86			192	162					1.14
NSLG-2	58	48	165	287	81	892	-	-	587	2.29
NSLG-3	43			381	0					3.43
LSNG-1	86			192	162					0.76
LSNG-2	58	48	165	287	81	-	652	977	-	1.52
LSNG-3	43			381	0					2.29
LSLG-1	86			192	162					0.76
LSLG-2	58	48	165	287	81	-	652	-	587	1.91
LSLG-3	43			381	0					3.05

Fig.2 shows three-dimensional model of the double shear test. Concrete specimen is modeled using 3D solid 8 nodes isoparametric element having dimension of 5×5×5 mm. Upper part of loading device and supports are modeled using rigid element. Lateral expansion of specimen is allowed by modeling support edges as rollers in horizontal direction or x direction. A modified Ahmad triaxial stress-strain relationship proposed by Naganuma[1] is used as a constitutive model for concrete.The Ottosen[1] four parameters concrete failure criterion is also used in this study.

To investigate the failure process NSNG-3 is selected as a representative case. This is a normal concrete series of specimens with the following properties obtained from experiment:

Compressive strength: 65.35 N/mm^2

Splitting tensile strength: 4.06 N/mm^2

Young's modulus : 30.91 kN/mm^2

Poisson ratio: 0.18

Cracks occurred along the sheared section in the side surface faces (Y=0.0mm and 100mm)of specimen.These were initiated by the tensile stress which is concentrated along the sheared section and grew from the bottom to the top of the specimen. The crack developed under combined stresses or so called mixed mode of failure. Fig.3b shows principal strain distribution at the peak load. Those elements with large horizontal strain (tensile) are places where crack occurred due to mostly tensile stress.However close to shearing edges is the regions where cracks had occurred under shear stress. Fig.3a shows distribution of shear stresses in the same plane of outer face of specimen. Actual damaged of tested beam is shown in Photo 2.

Analytical average shear strengths are plotted together with linear regression line of experiment data in Fig.4. From the figure it is clear that distribution of shear strengths obtained from FE analysis distributed quite closely to experimental line. And analytical results showed lower strengths compared to experiment one.

4. CONCLUSIONS

(1) Concrete and mortar has the same linear relationship between shear and compressive strengths which is slightly different from that of paste material.

(2) FE simulation showed that material in double shear test failed due to tensile and shear stresses or mix-mode failure.

(3) Shear strengths obtained from analysis are closely approximate actual experimental strengths. Analytical strengths are slightly lower than that of experiment giving conservative evaluation of shear strength.

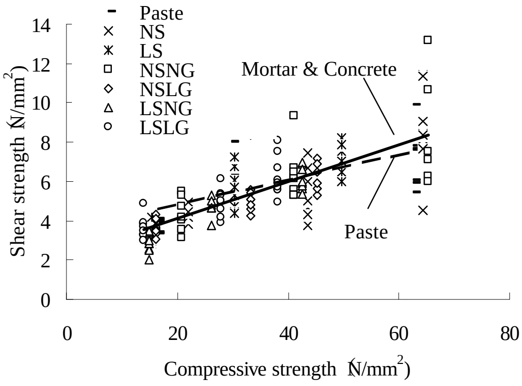


Fig.1 Compressive-Shear strength relationship

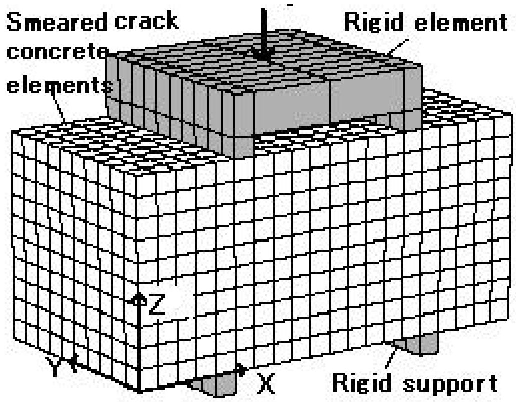
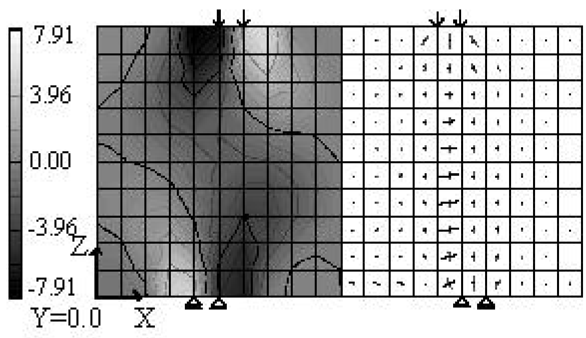


Fig.2 Analytical model



a) ZX-Shear stress b) Principal strain

Fig.3 Mixed mode failure at peak load

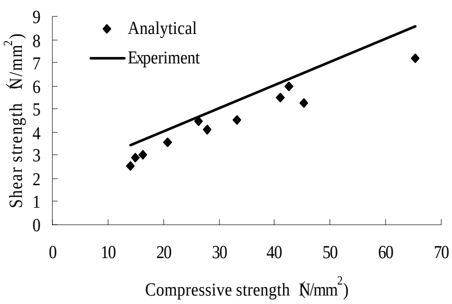


Fig.4 Comparison between analytical and experimental shear strengths

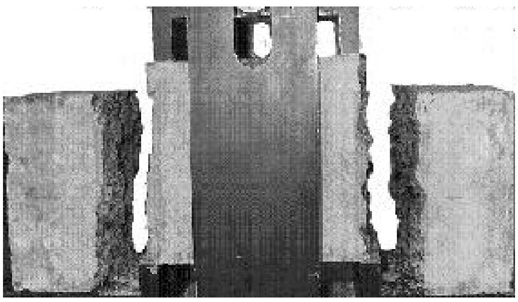


Photo 2. Damaged specimen

REFERENCES

1) K. Naganuma: Stress-Strain Relationship for Concrete under Triaxial Compression, Journal of Construction Engineering, AIJ, No.474, pp.163-170, August 1995.