3D NONLINEAR ANALYSIS OF SHEAR FAILURE OF LIGHTWEIGHT CONCRETE BEAMS

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1. Introduction

This paper presents experiment results and 3D nonlinear finite element analysis (FEA) of artificial lightweight aggregate RC beams under shear loading. The results showed that nominal shear strength of sand lightweight (density of 2150 kg/m^3) and coarse aggregate lightweight (density of 2000 kg/m^3) concrete beams, reduced by 10% and 30% respectively compared to that of normal weight concrete beams. Using the same set of material models in FEA, it was possible to capture the brittle failure behavior and predict ultimate shear capacity of beams with reasonable accuracy.

2. Test programs

A total of 9 shear-critical reinforced concrete beams without web reinforcement were tested. **Table 1** shows details of tested beams. All beams are slender beams having a/d ratio of three. For each type of concrete there are three beams with target concrete strengths 25N/mm^2, 40 N/mm^2 and 55 N/mm^2. **Figure 1** shows details reinforcement and loading configuration of a tested beam. The beam has 200×200mm cross section and 1600mm total length. Except the case of beam CLW40-3P, all other beams are longitudinally reinforced with 16 SD345-D10 bars around the perimeter of cross section. Loading was force-control monotonic.

3. Test results and discussion

Niwa's equation[1)] was used in this study to calculate diagonal crack load of tested specimens. Summary of this calculation as well as related experimental results are given in **Table 3**. The ratio of experimental crack load to calculated one using Niwa's formula ($V_{c\text{-}exp}/V_{c\text{-}cal}$) is lower for lighter weight concrete. This indicates dependence of shear capacity to unit weight of concrete as reported elsewhere. **Figure 2** shows these normalized shear strengths versus unit weight of tested beams. From this figure it has been found that shear strength of sand lightweight (SLW) concrete is less than that of normal concrete by 10%, whereas reduction of shear strength of coarse lightweight (CLW) concrete is approximately 30%. In addition, nominal shear strength of the CLW40-3 was about 20% larger than that of the CLW40-3P. It is almost certain that the effect of side reinforcement is that shear strength of beam increased.

Table 1 Details of tested beams

No.	Beams Name	Concrete target strength (N/mm^2)	Size (cm)	a/d	Steel Ratio (%)
1	N25-3	25.0	20x20x160	3	1.5
2	N40-3	40.0	20x20x160	3	1.5
3	N55-3	55.0	20x20x160	3	1.5
4	SLW25-3	25.0	20x20x160	3	1.5
5	SLW40-3	40.0	20x20x160	3	1.5
6	SLW55-3	55.0	20x20x160	3	1.5
7	CLW40-3	40.0	20x20x160	3	1.5
8	CLW40-3P	40.0	20x20x160	3	1.0
9	CLW55-3	55.0	20x20x160	3	1.5

Table 2 Concrete mixture proportion

Beams Name	W/C (%)	s/a (%)	Weight per unit volume (kg/m^3)								
			W	C	LS	S_N	S_L	G_N	G_L	SP C	AF
N25-3	83	48	165	199	190	879	-	960	-	2.189	0.398
N40-3	60			247	126					3.705	0.494
N55-3	47			349	62					6.282	0.698
SLW25-3	72	48	165	228	165	-	653	960	-	2.508	0.456
SLW40-3	51			324	83					4.860	0.648
SLW55-3	39			420	0					7.560	0.840
CLW40-3	56	48	165	293	109	879	-	-	584	3.223	0.586
CLW40-3P	56			293	109					3.223	0.586
CLW55-3	39			421	0					5.473	0.842

4. Finite element analysis

In this study, concrete behavior and cracks development are described using rotating crack model. Modified Ahmad stress-strain relationship was used in this study for concrete constitutive model in compression. The model was originally proposed by Ahmad[2)] but later modified by Naganuma[3)] to improve descending branch of stress-strain curve. Tension stiffening effectiveness is characterized by slop of the descending branch of tensile stress-strain curve. A model proposed by Izumo et.al.[4)] was used for concrete stress-strain relationship in

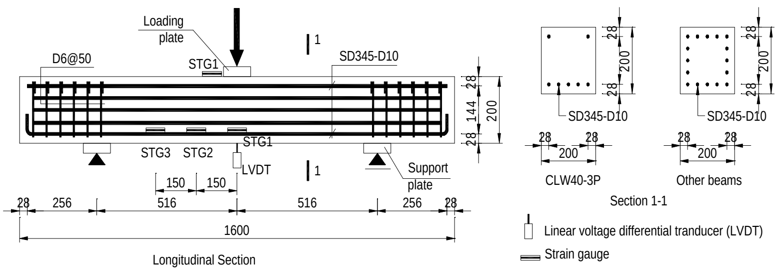

Figure 1 Test beam and loading configuration

Keywords: : shear strength, smeared crack model, nonlinear finite element analysis
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Table 3 Test results

No.	Beams Name	Unit weight (kg/m^3)	f_c' (N/mm^2)	f_t (N/mm^2)	E_c (N/mm^2)	$V_{c\text{-}exp}$ (kN)	$t_{c\text{-}exp}$ (N/mm^2)	$V_{c\text{-}cal}$ (kN)	$V_{c\text{-}exp}/V_{c\text{-}cal}$	$V_{u\text{-}exp}$ (kN)	$V_{u\text{-}FEA}$ (kN)	$V_{u\text{-}exp}/V_{c\text{-}exp}$	$V_{u\text{-}exp}/V_{u\text{-}FEA}$	Failure mode
1	N25-3	2330	24.4	2.2	25.0	57.0	1.66	42.7	1.34	57.7	57.4	1.01	1.00	Diagonal tension
2	N40-3	2367	41.7	3.2	30.9	75.5	2.19	51.0	1.48	77.8	78.9	1.03	0.99	Diagonal tension
3	N55-3	2373	52.8	3.6	30.6	77.8	2.26	55.2	1.41	77.8	88.5	1.00	0.88	Diagonal tension
4	SLW25-3	2137	25.6	2.2	21.9	55.6	1.62	43.4	1.28	59.7	56.5	1.07	1.06	Diagonal tension
5	SLW40-3	2157	46.4	3.2	24.8	67.9	1.97	52.9	1.28	72.5	77.4	1.07	0.94	Diagonal tension
6	SLW55-3	2157	51.0	3.4	24.9	71.2	2.07	54.6	1.30	94.6	81.0	1.33	1.17	Diagonal tension
7	CLW40-3	1960	37.8	2.6	19.1	48.8	1.42	49.4	0.99	66.2	65.9	1.36	1.01	Diagonal tension
8	CLW40-3P	2007	43.0	2.4	18.8	43.0	1.25	45.5	0.94	57.5	58.0	1.34	0.99	Diagonal tension
9	CLW55-3	2020	53.8	3.2	22.1	54.7	1.59	55.5	0.98	80.6	80.0	1.47	1.01	Diagonal tension

tension. Ottosen four-parameter model was selected for concrete failure criteria. According to Naganuma[3] the model performed quite well for concrete under low confinement, which is the case of beam without web reinforcement.

Figure 2 shows a three dimensional finite element model for analysis of beam under one point loading. Some of main features of the model are as follow: a) Solid elements are used to model concrete, loading and supports plates as well as steel bars. Steel bars were modeled using solid element to closely describe the effect of dowel action; b) Concrete elements have common nodes with steel bars and plates.

5. Load-mid span deflection

Figure 3 shows experimental and computed load-mid span deflection of low, medium and high strength concrete beams respectively. Except SLW concrete beam SLW55-3, all other beams load-deflection behavior were very closely predicted. Computed load-deflection curves show nearly the same stiffness with experimental curves up to maximum loads, and then a sharp decrease of computed load was obtained. This is success simulation the shear failure in all beams under consideration.**Figure 3e**confirmed effect of the side reinforcement. CLW40-3P, the beam with no side reinforcement shows lower ascending stiffness and decrease of maximum load compared to beam CLW40-3.

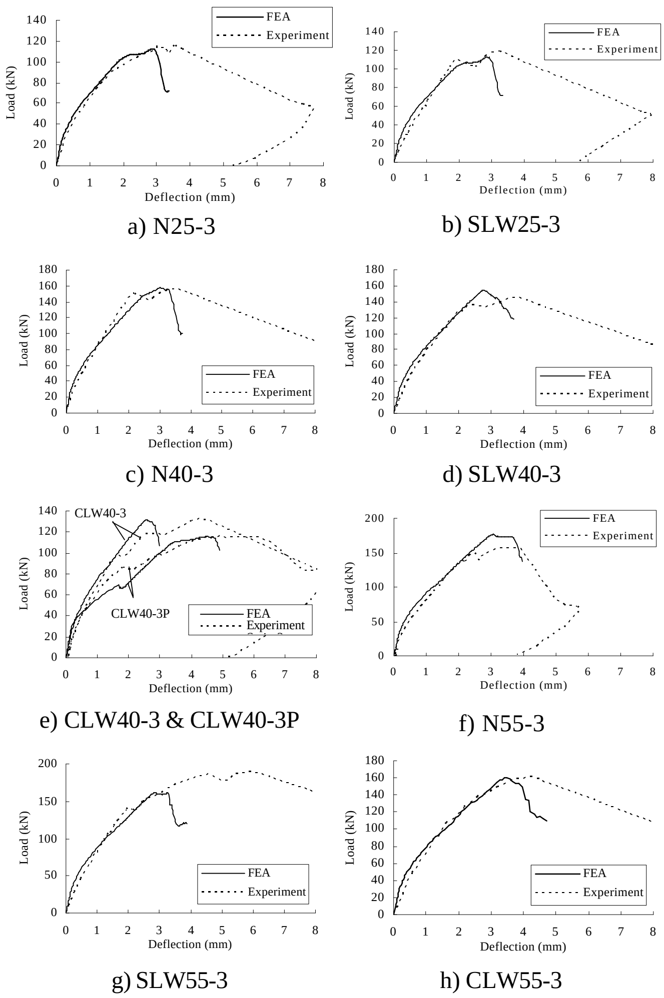

Figure 3. Load-mid span deflection

4. Conclusion

Nominal shear strength of ALWA concrete beams depends on the unit weight of concretes. The sand lightweight concrete (density 2150kg/m^3) and coarse aggregate concrete (density 2000kg/m^3) beams have their shear strength reduced by 10% and 30% compared to that of normal weight concrete. Using 3D nonlinear finite element analysis with the same set of material models, it is possible to capture load-deflection behaviors up to the maximum load, brittle failure characteristic and very closely predict ultimate load of all beam.

5. References

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