Analysis Modelling of Seismic Behaviour of Lightweight Concrete Shear Walls

Werasak Raongjant , Meng Jing

Abstract—**A reasonable three dimensional finite element model was developed in this study to predict the seismic behaviours of lightweight reinforced concrete shear walls. Based on the experiments, numerical model of concrete and reinforcements in four specimens were established through optimum modelling strategy, controlling mesh density, defining appropriate material properties and accurately locating the internal reinforcement. The comparisons of calculated results with the experimental results indicate that, this model can capture the non-linear response of lightweight reinforced shear walls under cyclic load conditions well. Using this model, further research works on the shear transport mechanism and function of bidiagonal web reinforcements were processed.**

Index Terms—Shear walls, Reinforced concrete, Lightweight concrete, Finite element analysis, Seismic behaviour

I. INTRODUCTION

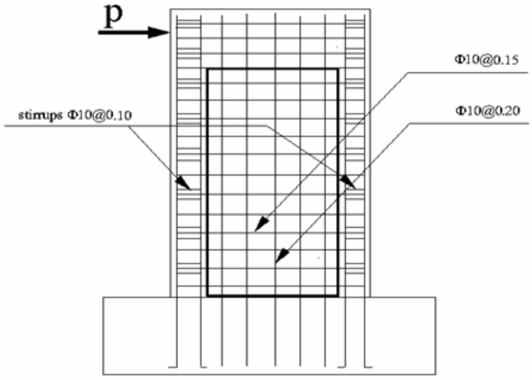
In the last five decades structural lightweight concrete has been used in many civil engineering applications as a very convenient alternative to conventional concrete. The reduced weight may make it preferable for structures in seismic zones because of the reduced dynamic actions. In recent years, many experimental researches have been done on the seismic behavior of lightweight concrete shear walls [1],[2],[3]. However, due to the financial and the time reason, it is not enough that only getting the results from experiments. Finite element method supplied a new way to study shear walls by computer, which can help the researcher to analyze and complete the experimental results and have a better understanding of it.

In recent years, using ANSYS finite element software, many research works have been done successfully to simulate the seismic behavior of reinforced concrete shear walls. This software has plentiful element types and offer some default parameters, which make it easy to develop the model to simulate the cooperation work of concrete and other materials. Monique C. Hite and Harry W. Shenton [4] presented modeling the nonlinear behavior of wood frame shear walls. Johnn P. Judd and Fernando S. Fonseca [5] presented nonlinear analysis of wood diaphragms and shear walls using commercial finite-element software (ANSYS and ABAQUS). N. Mohammad [6] studied afterwards a numerical study on a hybrid shear wall system under cyclic load by ANSYS 5.7. The recent work has been done by Lu Xinzheng and Jiang Jianjing [7], which presented analysis for concrete structure under complex stress condition with element SOLID 65 of ANSYS. These study show that ANSYS can simulate concrete precisely.

In this study, ANSYS 8.0 was used to do the numerical study on the seismic behavior of lightweight reinforced concrete shear walls. The analytically predicted response of the lightweight aggregate concrete shear wall specimens were compared with the experimental results. Also the development of strain and stress in reinforcements and concrete were analyzed based on the finite element analysis results and tested results. Further studies on the shear transfer mechanisms and the function of web diagonal reinforcements of lightweight aggregate concrete shear walls were considered in this paper.

II. TEST PROGRAM

Four lightweight reinforced concrete shear wall specimens were constructed and tested to investigate the influence of diagonal web reinforcement on the hysteretic response of structural lightweight concrete shear walls. All walls had a barbell-shaped cross section with a web thickness of 100 mm and 250x250 mm boundary elements. The overall length of the cross section was 1500 mm. Vertical and diagonal reinforcement was anchored in a 600 mm thick base girder that was bolted to the laboratory floor. A 250 mm wide by 500 mm deep beam was cast on top of the wall panel, and a hydraulic actuator was attached to the specimen at mid depth of the top beam. Lateral loads were applied 2150 mm above the base of the wall.



(a) Specimen LW-1

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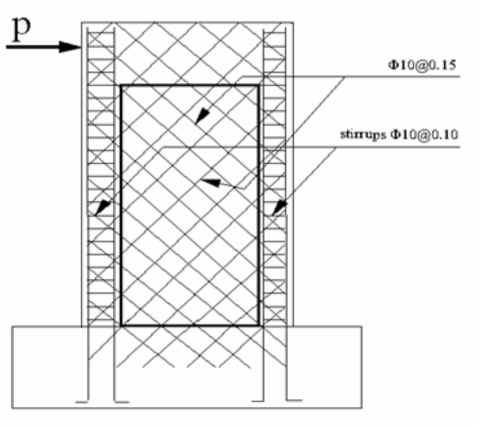
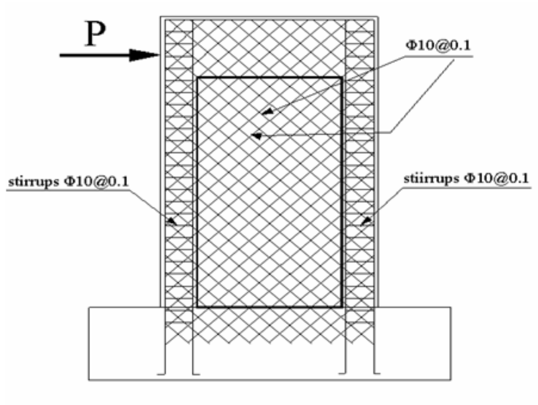
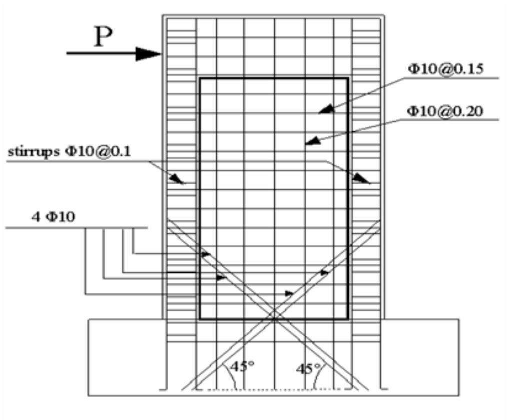


(b) Specimen LW-2



(c) Specimen LW-3



(d) Specimen LW-4

Fig.1 Web reinforcement in four test specimens

Longitudinal and transverse reinforcement in the boundary elements and the top beams were the same in all four specimens. A single layer of web reinforcement was used in all walls. The primary experimental parameters were the amount and orientation of the web reinforcements. Only the web reinforcements of four specimens are shown in Fig.1.

III. FINITE ELEMENT ANALYSIS BY ANSYS

A. *Geometrical modelling*

Concrete

An eight-node solid element, SOLID 65, was used in this analysis to model the concrete. The two input strength parameters, ultimate uniaxial tensile and compressive strength, were needed to define a failure surface for the concrete. The poisson's ratio for the concrete was assumed to be 0.2. The shear transfer coefficient of open crack $\beta_t = 0.5$ and the shear transfer coefficient of closed crack $\beta_c = 0.8$. For the compressive uniaxial stress-strain relationship of concrete, the multilinear isotropic hardening model (Concrete + Miso) was used.

Numerical expression (1) was used to construct the uniaxial compressive stress-strain curve for lightweight concrete in this study (in Fig.2).

$$f_c = (2\beta - 3)\left\{\frac{\varepsilon_c}{\varepsilon_o}\right\}^4 + (4 - 3\beta)\left\{\frac{\varepsilon_c}{\varepsilon_o}\right\}^3 + \beta\left\{\frac{\varepsilon_c}{\varepsilon_o}\right\} \qquad (1)$$

In which f_c is the concrete stress, ε_c is the concrete strain and $\beta = E_{itm}\dfrac{\varepsilon_o}{f'_c}$.

In the case of lightweight concrete, the equation to calculate elastic modulus, E_{itm} , proposed by Wang et al [8] was (2).

$$E_{itm} = 2.1684 f_c'^{0.535} \qquad (2)$$

The concrete strain at peak stress, ε_0, in the case of lightweight aggregate concrete, was calculated by (3) proposed by Almusallam and Alsayed [9]..

$$\varepsilon_o = \left(65.57 f_c'^{0.44} - 6.748\right) \times 10^{-5} \qquad (3)$$

in which f_c' is the concrete compressive strength. Once the value of f'_c is known, ε_o and E_{itm} can easily be determined.

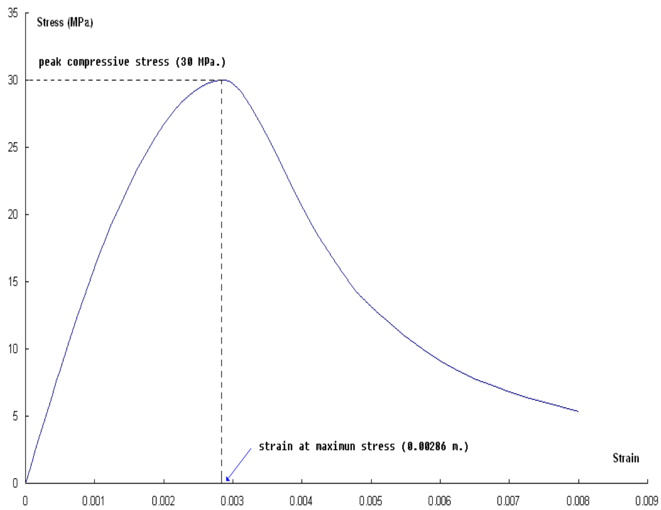


Fig.2 Compressive stress-strain curve for lightweight concrete used in ANSYS model.

Reinforcement

In this study, the smeared model, in which the steel is assumed to be distributed over the concrete element with a particular orientation angle, was used to simulate reinforcement in specimen LW-2 and LW-3 for its convenience reason, since only reinforcement ratio and steel properties of each direction need to be introduced. For specimen LW-1 and LW-4, reinforcements were modeled by using separate element called LINK 8, a 3-D spar element. The bond between concrete and reinforcement was assumed to be perfect and modelling of bond itself was not undertaken in this study.

The bilinear kinematic hardening model (BKIN) was used. Constitutive law for steels is that

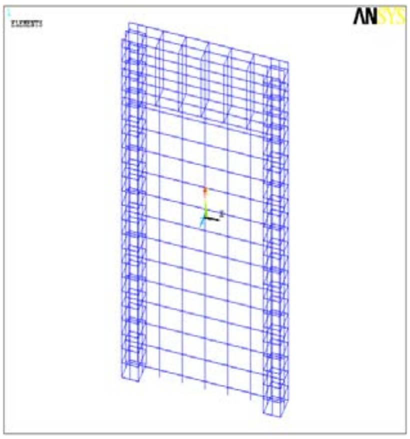
$$\begin{cases} \sigma_s = E_s \varepsilon_s & , \quad \varepsilon_s \le \varepsilon_y \\ \sigma_s = f_y + E_s^{'} \varepsilon_s & , \quad \varepsilon_s > \varepsilon_y \end{cases} \quad (4)$$

in which σ_s is the steel stress; ε_s is the steel strain; E_s is the elastic modulus of steel; $E_s^{'}$ is the tangent modulus of steel after yielding, $E_s^{'} = 0.01E_s$; f_y and ε_y is the yielding stress and strain of steel respectively.

Finite mesh

In this study, four different three dimensional finite element models were generated to analytically predict the response of them under the cyclic load condition (shown in Fig.3, Fig.4 and Fig.5). Concrete of the shear wall specimen was meshed with cubes element of dimension 25 mm or 50 mm and all the reinforcement were meshed with 50 mm or 100mm long link element.

(a) Concrete model



(b) Reinforcement model

Fig.3 Finite element model for specimen LW-1

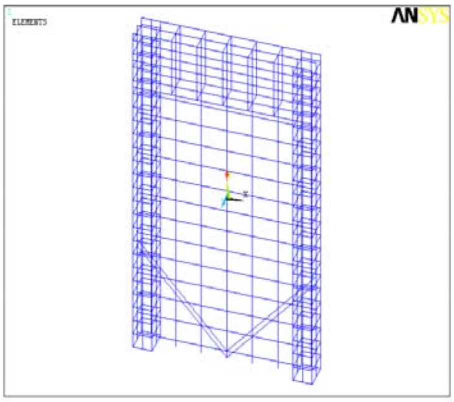
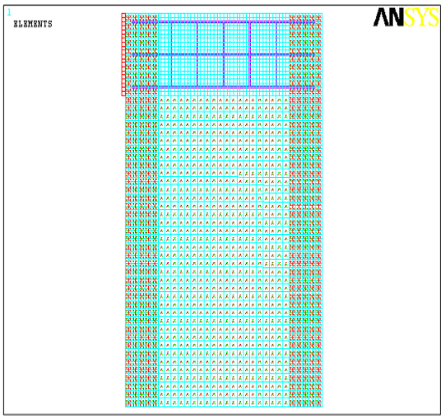
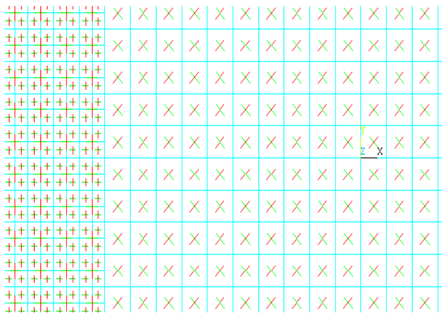


Fig.4 Finite element model of reinforcement for specimen LW-4.



(a) Concrete element with smeared rebar



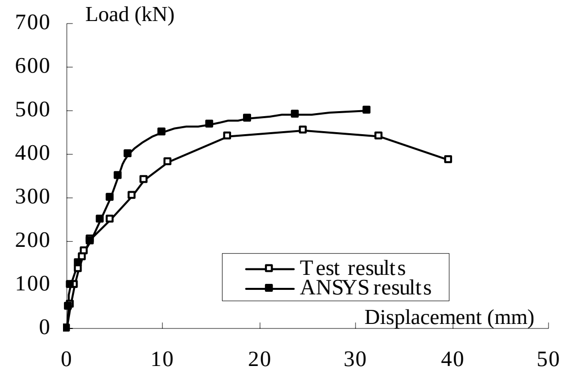
(b) Details of smeared rebar

Fig.5 Finite element model for LW-2 and LW-3.

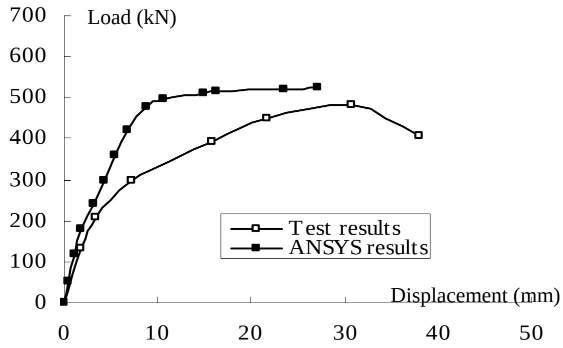
V. Comparison of Analytical and Experimental Results

A. Force - displacement behaviours of four specimens

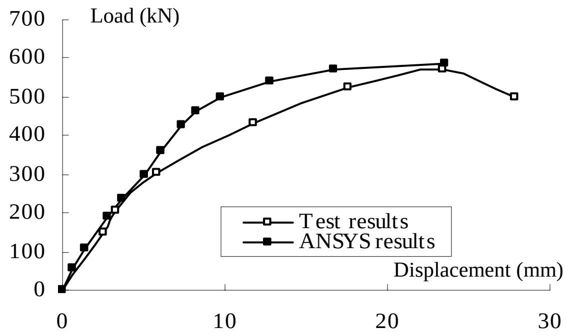
The tested and ANSYS results of top horizontal force versus top horizontal displacement curves of four specimens are shown in Fig.6. Finite element analysis results show similar trends to the tested results and capture well the non-linear load-displacement response of the specimens up to peak load.



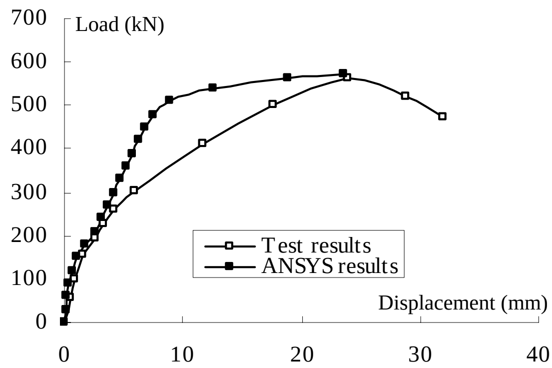
(a) LW-1



(b) LW-2



(c) LW-3



(d) LW-4

Fig.6 Force-displacement comparison for four specimens

Table 1 shows the comparison between the ANSYS calculated results and the tested results of four specimens LW-1, LW-2, LW-3 and LW-4. The analytical peak load values for the four specimens are within 10% bigger than their peak tested load values.

Table 1 Comparison of shear resistance for four specimens

	LW-1	LW-2	LW-3	LW-4
Test results V^{exp} (kN)	460	475	572	562
ANSYS results V^{ansys} (kN)	500	510	585	570
V^{ansys} / V^{exp}	1.087	1.074	1.023	1.014
Average value	1.0495			

B. Development of the strains in steel bars

The load–strain responses in web diagonal steel for four specimens from the test program are plotted with the finite element results in Fig.7, Fig.8, Fig.9 and Fig.10.

The load–strain responses for four walls are captured well by the numerical simulation. The difference between the experiment and FE results is mainly because that, the position of strain gauge in the test is not absolutely consistent with the calculated point in finite element model. The difference of smear crack and cracks in actual shear walls, the measure error of the strain gauge may also results in the differences.

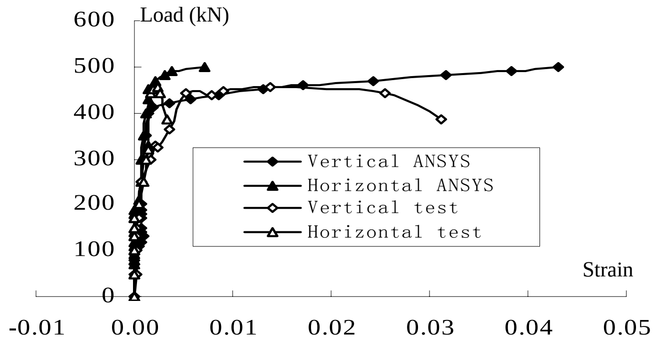


Fig.7 Strain in steel of LW-1

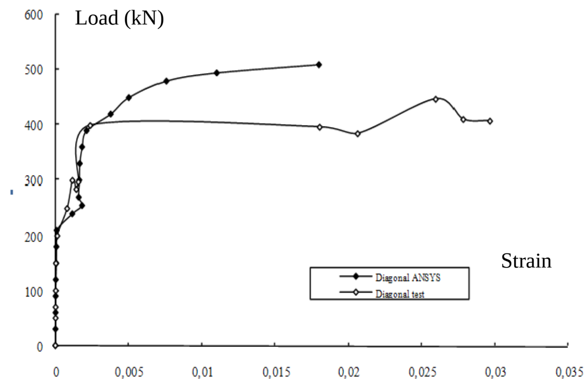


Fig.8 Strain in steel of LW-2

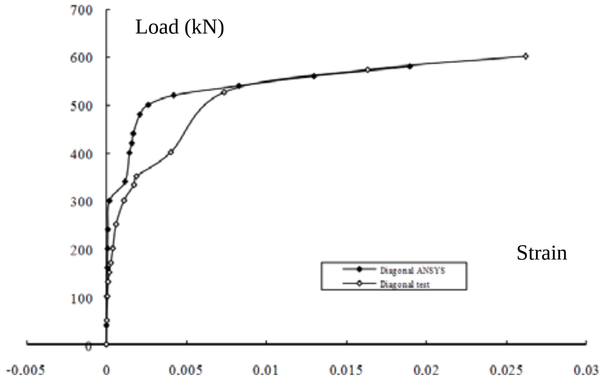


Fig.9 Strain in steel of LW-3

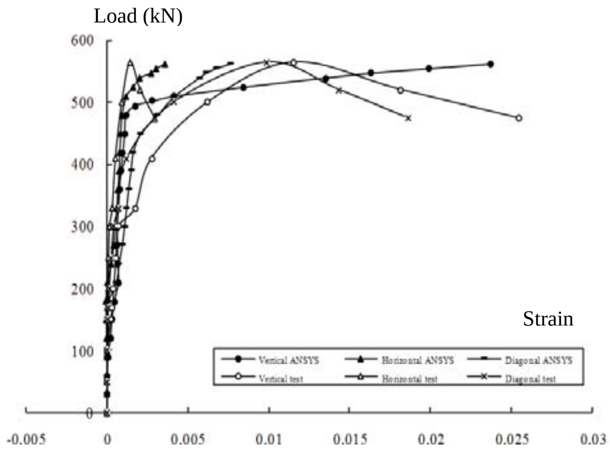


Fig.10 Strain in steel of LW-4

V. Discussion on the numerical results

The comparison indicates that the finite element model used in this study is capable of predicting the experimental behaviour of the specimens when these are subjected to a monotonic horizontal load. Therefore, the seismic behaviour of lightweight concrete shear walls are discussed in detail based on the numerical results.

A. Shear transfer mechanisms for walls with conventional and diagonal web reinforcements

The load–stress development curves for concrete element of specimen LW-1, LW-2 and LW-3 based on the finite element model results are compared in Fig.11. It can be seen that, increase speeds of concrete stress for wall LW-2 and LW-3 are distinctly slower than that for wall LW-1. The more web diagonal reinforcements it has, the more obvious this phenomenon is. All lateral force in walls with conventional web reinforcement must be transferred through concrete by compressive struts and aggregate interlock and by dowel action in the reinforcement at the base of the walls. Web crushing failures occur when the compressive stress exceeds the average compressive strength of the concrete in the strut. The diagonal web reinforcement helps transfer part of shear force directly to the foundation by tension in the web reinforcement. As a result, the shear force carried by the compressive struts is reduced.

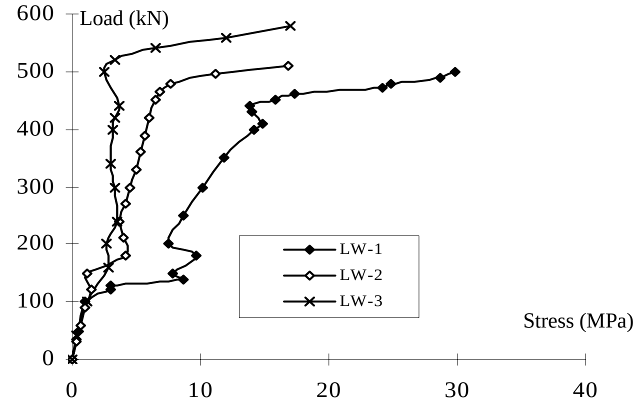


Fig.11 Comparison of concrete stress development in LW-1, LW-2 and LW-3

The load–stress development curves for reinforcement element of specimen LW-1, LW-2 and LW-3 based on the finite element model results are compared in Fig.12. It can be seen that, stresses in steel rebar were small when walls began to suffer top horizontal load. At that moment there was no diagonal crack in web concrete and most of the loads were supported by concrete. At the load level of about 200 kN, diagonal cracks appeared in the web concrete and stress redistribution took place between the concrete and reinforcements, which was represented as the abrupt increase of stress in steel. This has been observed in experiment also.

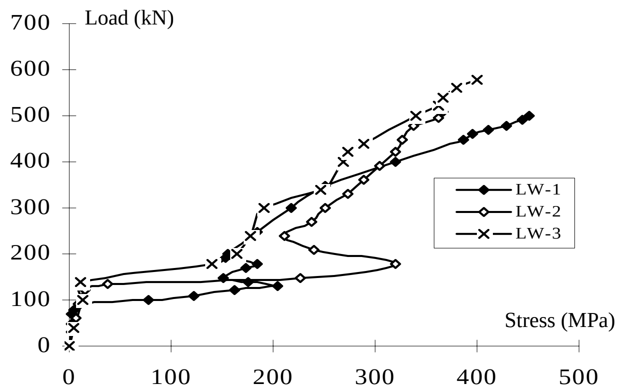


Fig.12 Comparison of steel stress development in LW-1, LW-2 and LW-3

From Fig.12 it can be also seen that, increase speeds of steel stress in specimen LW-2 and LW-3 are evidently slower than that of specimen LW-1. The more diagonal reinforcement the wall has, the more evident this rule is. It proves that, diagonal web reinforcement has better mechanisms for transferring shear force so that stress can develop more evenly in the web steel bars. As a result more web reinforcements reached to or exceed its yielding strength.

B. Function of web bidiagonal steel bars in LW-4

The load–stress development curves for concrete element of specimen LW-1 and LW-4 based on the finite element model results are compared in Fig.13. The increase speeds of concrete stress with increase of load for wall LW-4 is distinctly slower than that for wall LW-1. It indicates that web diagonal steels can transfer shear force directly to the wall foundation so that the compressive stress in diagonal concrete strut was reduced.

The load–stress development curves for vertical and horizontal web reinforcement of specimen LW-1 and LW-4 based on the finite element model results are compared in Fig.14.

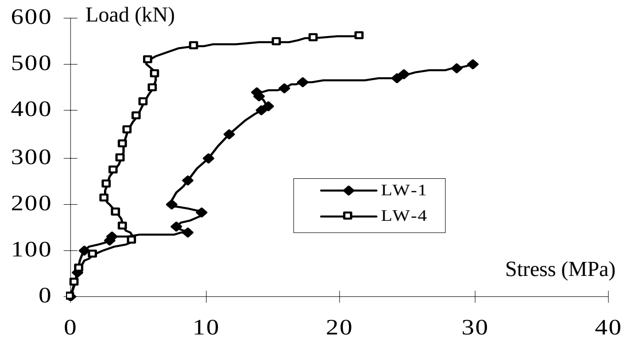


Fig.13 Comparison of concrete stress development in LW-1 and LW-4

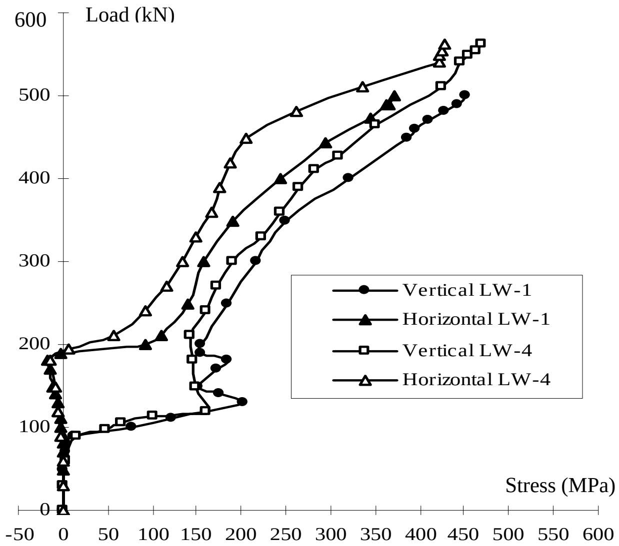


Fig.14 Comparison of steel stress development in LW-1 and LW-4

After diagonal cracks appeared in web concrete, stress redistribution between concrete and reinforcements took place, which is behaved as sudden increase of steel stress in Fig.14 at about horizontal load level of 150 kN. Stress in horizontal and vertical reinforcements of wall LW-4 increase slower with the increase of load than those of wall LW-1. It indicates that, due to existence of additional web diagonal rebar, conventional steel bars sustain less stresses.

VI. CONCLUSION

1) The calculated and tested results of horizontal load versus top displacement curves of four specimens showed a good agreement. Moreover, the load–strain responses in steel for four walls were captured well by the numerical simulation.
2) The finite element models of four lightweight aggregate concrete shear walls in this study could provide a wide-range of information that were useful for the study of the behaviour of lightweight reinforced concrete shear walls. Finite element model in this paper supplied a new way to study lightweight reinforced concrete shear walls by computer, which can help the researcher to have a better understanding of it.
3) The numerical results in this study indicates that, diagonal web reinforcement was effective in transferring shear force to the foundation and the shear forces carried by the compressive struts were evidently reduced due to the existing of diagonal web reinforcement.

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