Seismic Behavior of Thin Shear Wall under the Exerted Loads

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Abstract—While the shear walls are not economical in buildings, thin shear walls are widely used in the buildings. In the present study, the ratio of different loads to their plasticity and seismic behavior of the wall under different loads have been investigated. Modeling and analysis are carried out by the finite element analysis software ABAQUS. The results show that any increase in the exerted loads will have adverse effects on the seismic behavior of the thin shear walls and causes the wall to collapse by small displacements.

Keywords—Thin shear wall, nonlinear dynamic analysis, reinforced concrete, plasticity.

I. INTRODUCTION

SHEAR wall has been used in reinforced concrete structures to provide resistance against lateral forces such as wind and earthquake. In general, shear walls can be implemented in combination with and without columns. In addition, the thin shear walls with high load-bearing capacity can also be used as lateral bracing systems. According to the ACI code, ratio of the height to the length of the walls ranges from 0.5 to 2.5 [1], [2]. Most of the walls are thick regards to the length. In high-rise buildings, columns and thick shear walls cause many architectural problems. Moreover, the high cost of heavy reinforced concrete shear wall lead the engineers to other structural systems. Thin shear wall as a lateral load resistance system, which has a high axial load capacity, causes to eliminate most of the columns in the building and makes it more suitable as a lateral load resistance system when compared with other systems. According to the previous experimental results [8], it is demonstrated that the ratio of the axial load can have a significant influence on the nonlinear response of reinforced concrete structural elements. Unfortunately, no sufficient attention is paid to this factor in most studies. In fact, the accurate estimation of the axial load ratio needs understanding the behavior of the reinforced concrete elements under the exerted seismic forces. In this study, the seismic behavior of the thin shear wall is studied under different loads and the results are shown in figures.

II. REVIEW OF THE PREVIOUS EXPERIMENTS

Many studies have been conducted on shear walls. Lefas et al. studied shear walls with low shear span ratio and with and without low axial load ratio. For this reason, a smaller percentage of cross and longitudinal bar has been used. In this case, all samples have been broken because of ductility [2].

Gupta and Rangan have also studied shear walls with low shear span ratio, and also with low axial load ratio or without any axial load [3]. However, due to the large size of the longitudinal and cross bars, the walls have been failed. Salonikios also investigated shear walls with low shear span ratio, and with negligible or without axial load ratio [4]. Comparison of the samples in the experimental study shows that axial load which causes shear failure to be occurred changed to be ductility failure. Therefore, minimum axial load ratio is not an issue, but it is important because it can modify the displacement and behavior of the walls. The research of Tasnimi is one of the few studies in which the shear span ratio is highly used [5]. However, no axial load is applied in this study. It can be seen that all samples have failed under shear load. With regards to the previous experiments, in the presence of low axial load ratio, the samples might have failed in ductility. Experimental study on shear wall by Zhang and Wang indicate that the ratio of shear span to the percentage of cross steel is constant and a valid comparison is done between 0.24 and 0.35 axial loads [6]. It is observed that increasing this ratio within a certain range can be favorable, but if the increasing the ratio exceeds ranges, it causes ductility failure into brittle failure. In [7], the experimental model shown in Fig. 1 was modeled as a wall in some real residential buildings which reinforcement composition is similar to the reinforcement composition of local buildings in Hong Kong. By the results, it can be concluded that the load ratios of building with shear wall and central core is 0.3, but while it was used as load factor it changes to 0.2. In an experimental analysis, the dimension of the wall is taken as 400 x 80 x 1640 mm and its shear span ratio is about 4. In this study, the longitudinal reinforcement ratio and the cross reinforcement ratio were equal to 4% and 0.5%, respectively. For reinforcement distribution, further information is provided in Figs. 2 and 3. Wong et al. [8] studied the behavior of the concrete wall under high axial load for different earthquake zone.

III. NUMERICAL MODELING

Designing, modeling and analysis were carried out by the ABAQUS finite element software. The wall elements were of deformable type and the beam and flange elements were of rigid type due to their high stiffness compared to the wall. The materials used in ABAQUS include steel and concrete. The elastic properties of armatures used in the experiment are defined according to Table I, while their plastic properties are

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defined according to Tables II and III. The concrete properties are shown in Table IV. To show the non-elastic response of structures under earthquake loads, nonlinear dynamic analysis has been used.
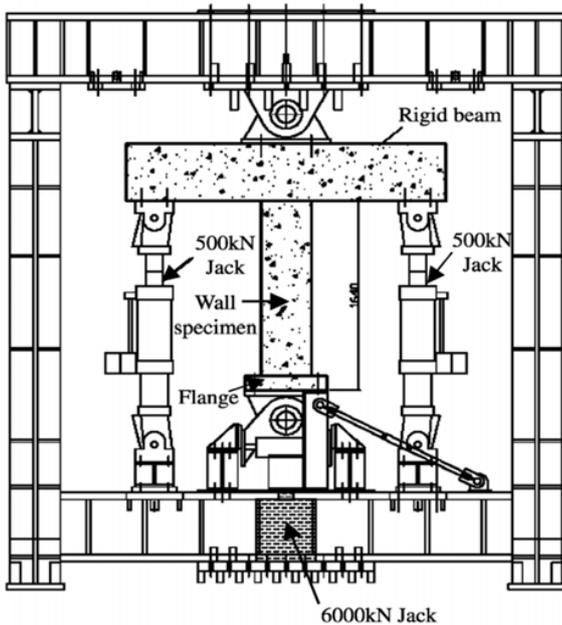
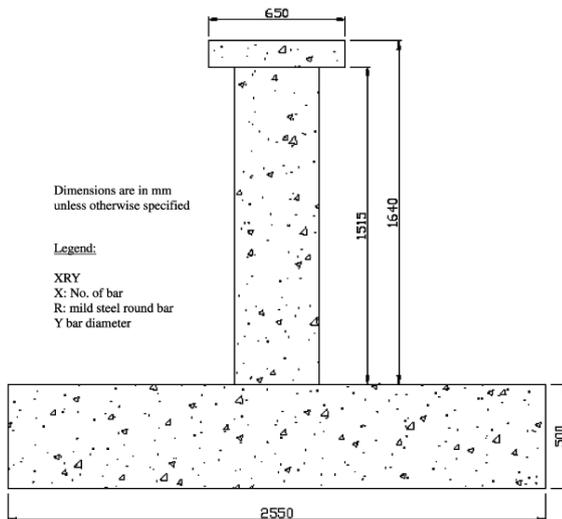

Fig. 1 The Experiment Format [7]

Fig. 2 Reinforced Concrete Details in the Test Samples [7]

TABLE I
THE ELASTIC PROPERTIES OF ARMATURES USED IN THE TEST

Steel properties	Longitudinal rebars	Transverse rebars
Module of elasticity	210 GPa	205 GPa
Yield strength	410 GPa	262 GPa
Ultimate strength	540 GPa	336 GPa
Poisson's ratio	0.3	0.3
The shear elasticity ratio	80.8 GPa	78.8 GPa
Mass density	7800 kg per cubic meter	

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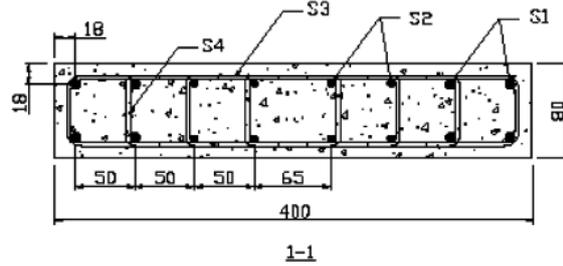
No.	Description
S1	8R8
S2	8R6
S3*	25R3.3 - 60c/c
S4*	150R3.3 - 60c/c

Cover = 10mm
*This configuration applies to Units W1 & W2. For Unit W3, S3 & S4 become 50R3.3 – 60c/c and 300R3.3 – 60c/c respectively.

Fig. 3 Reinforced Concrete Details [7]

TABLE II
PLASTIC STRESS- STRAIN OF LONGITUDINAL STEEL

Flow stress (MPa)	Plastic strain
412	0
422	0.02
540	0.3

TABLE III
PLASTIC STRESS-STRAIN OF TRANSVERSE STEEL

Flow stress (MPa)	Plastic strain
262	0
270	0.02
363	0.3

TABLE IV
THE PROPERTIES OF CONCRETE USED IN THE EXPERIMENT

Module of elasticity	32.7 GPa
Poisson's ratio	0.17
Cubic sample strength	50.2 MPa
Cylindrical samples strength	58.8 MPa
Mass density	2400 kg per cubic meter

Stepwise increase in the analysis time is automatically carried out by the software to provide sufficient accuracy in calculations. The boundary conditions are then defined for the abutment samples in the experiment. Degree of freedom of the beam at the top has been considered to be constrained.

The flanges and beam elements are provided in form of quaternary numeral system and attempts are made to improve the type and number of elements. The elements are defined in linear based on three-dimensional stress. The form of the samples kinematic track is presented based on the average strain and the hourglass effect is controlled based on rigidity control. The scale factor is equal to one. As beam and flanges are rigid, their elements are defined linear, three-dimensional and rigid format.

IV. RESULTS

The numerical and experimental results are shown in Table V. According to the results, only 0.45% time difference can be seen in the 25% axial load ratio while 2.3% time difference is seen in the 50 % axial load ratio. This comparison clearly shows that the analysis is carried out properly.

TABLE V
COMPARISON OF EXPERIMENTAL AND SOFTWARE RESULTS

The axial load ratio	25%	50%
The max displacement results in the laboratory conditions	30.55	18.87
The max displacement results in the software	29.11	20.2
The difference ratio	4.7%	7%

Comparison of numerical results with experimental results obtained from [7] shows that there is a negligible difference ratio between the results. The difference ratio obtained for, 25% and 50% load ratios was 4.7% and 7% respectively. According to the results, it can be concluded that numerical analysis is properly implemented. The wall is also placed under the axial tensile load ratio of about 10% and axial compressive load ratio of 35%. The required axial force is obtained according to (2) and the results are shown in Table VI.

$$P = ALR \times f_C \times a \times b \qquad (2)$$

where, P is the amount of axial load, ALR is the axial load ratio, f_c is the compressive strength of concrete cube, a is the cross-sectional length of the concrete wall and b is the cross-sectional width of the concrete wall.

TABLE VI
THE EXERTED AXIAL FORCES FOR DIFFERENT AXIAL LOAD RATIOS

ALR	-10 %	0 %	25 %	35 %	50 %
P(MPa)	-158	0	411	545	809

According to Table VII and Fig. 4, it can be seen that the maximum lateral displacement of the wall occurs in the tensile axial load ratio of 10%. As for compressive loads, it can be seen that the lateral displacement and axial load ratio act in opposite directions. The low axial compressive load ratio 15% shows that although the lateral displacement is slightly reduced, this reduction is not significant and is very similar to the displacement obtained under no axial load. Therefore, it can be clarified that the low axial compressive load ratios do not cause any significant difference in the structures behavior. In the case of axial compressive load ratios of 25% and 35%, the reduction in the degree of displacement is more significant and the results show that the pressure of axial load has deprived the structures' free behavior. Although the ductility of the wall changed according to the level of displacement, it can be concluded that it is still behaves properly and the walls' failure is because of the ductility of the wall. With the axial compressive load ratio of 50%, which is counted as a large axial load ratio, it is observed that according to Fig. 4, the curve slope sudden decreases and change significantly and displacement is sharply reduced. The low level of maximum lateral displacement

cannot be attributed to the greater resistance of the wall; rather, it indicates lower ductility of the wall and its early brittle fracturing. However, considering the specific behavior of concrete, as well as cracking and rapid loss of strength under the tensile force of (10%) as shown in Fig. 4, the gradient of lateral displacement changes in samples is very subtle and insignificant. Also, this cannot be attributed to lack of axial tensile load effect on the wall behavior, but can rather be attributed to the fact that the displacement mainly occurs in the vertical direction. Responses have been illustrated both in figures and tables for comparison. In addition, the force-displacement behavior of shear walls under axial tensile load ratio of 10% is shown in Fig. 5.
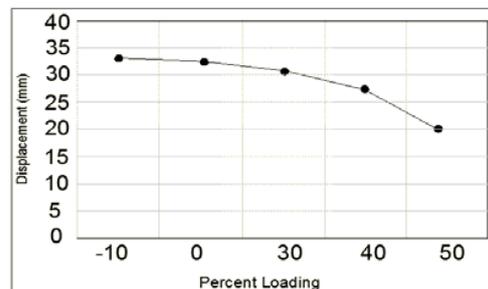

Fig. 4 Linear Diagram of Displacement under Different Axial Load Ratios

TABLE VII
DISPLACEMENTS OBTAINED UNDER DIFFERENT AXIAL LOAD RATIOS

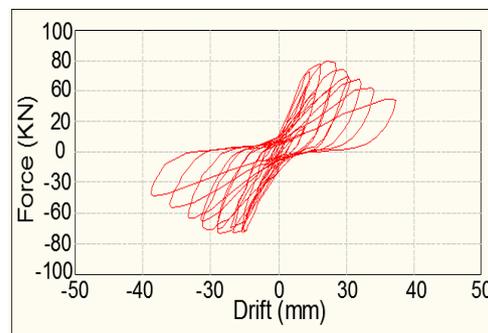| ALR	-% 10	% 0	% 25	%35	% 50
Drifts (mm)	34/54	33/12	30/41	26/35	19/32

Fig. 5 Load-Drift Responses

V. CONCLUSION

The present study provides the following results:

Thin shear walls can be used in places where it is impossible to use the conventional shear wall due to architectural, economic or structural issues.

In the wall sample under-rotation, any increase in the axial compressive load leads to reduction in the lateral displacement of the wall, such that the maximum lateral displacement occurs in the absence of axial load.

As for the reasons for reduction in lateral displacement of wall with increase in the axial compressive loads, it can be said

that under low axial loads, this reduction takes place very slowly due to the good tolerance and ductility of the wall, however, with increase of axial loads to the levels higher than 35%, the lateral displacement of the wall declines significantly and the wall will not tolerate further displacement.

In the under-rotation sample wall, the axial load ratios higher than 35%, are not recommended due to the rapid deterioration and crisp breaking in low displacements

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