Paper:

Cyclic Behavior of Low Ductility Walls Considering Perpendicular Action

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Low ductility wall buildings became part of the Peruvian construction boom in the first decade of the 21st century. Through government promotion under the "Mi Vivienda" ("My house") program, the construction of low rise buildings of 5 stories using walls with wire mesh reinforcement, provided a partially solution of an apartment deficit, at reasonable cost. The heights of buildings started to grow, reaching 12 to 16 stories. In the design of these walls, provisions recommend walls corners confinement, because the action of the walls ensemble provide limited ductility under seismic behavior. A comparison of H-shaped wall with one-plane wall is presented in this paper. Here, an experimental test has been performed by a cyclic loading test considering the action of a constant axial load of 40 kN, where the elastic stiffness of H-shaped wall is higher than that of a one-plane wall. Also resistant of the H-shaped wall increases, but ductility in both walls remains similar.

Keywords: low ductility wall, concrete wall Perpendicular effect

1. Introduction

In 1997 as the initiative of Professor A. Galvez, who propose the idea of replacing the masonry wall bricks with a thin concrete wall, brought the opportunity to the CISMID Structural Lab to start in Peru the study of low ductility walls. The purpose of studying the behavior of these walls using low strength concrete ($f'_c = 100$ kg/cm^2) and the reinforcement of Q62 wire mesh became a benchmark of the study for walls to be used in 4 storey buildings. In that research, walls with very light reinforcement and low compressive stress, are considered as lower stress limit for this kind of walls. However number of stories in buildings grows between 1997-2003 as in **Fig. 1**. Investigations like those performed by UNICON-PRODAC at the PUCP Structural Lab, were used as basic material for discussion among the members of the Peruvian Concrete Standards committee to fill the gap of the design standards. In 2003 the Peruvian Concrete Standards Committee published an addendum that included recommendations for the design of low ductility walls. By that time new research had been performed on walls and full scale tests, like in the study of Eng. Gabriela Medina at CISMID Structural Lab, with the support of UNICON-FORSA-PRODAC. This study produced parameters considered as a high limit of stress for these walls. Since that time low-ductility walls have been widely used in middle and low-rise buildings in Peru. Since in low rise buildings, the behavior of these walls had a predominant shear failure, however during the knowledge gap on the standards, buildings of 12, 14 and 16 stories were build under unknown criteria.

One of the concerns here is to understand when flexural behavior will be predominant and for what number of stories. Also, how is the influence in the stiffness from the perpendicular wall against one-plane wall. In this paper the compares the action of a perpendicular wall with a one-plane wall. Here an experimental test is presented by using cyclic lateral loading considering the action of a constant axial load.

2. Main Differences Between a Low Ductility Wall and a Standard Wall

In **Fig. 2** two of the main differences between a low ductility wall and a standard concrete wall are presented.

The first difference is the thickness of the wall, where a low ductility wall could be 100 mm or even 80 mm versus the 150 mm that is the minimum thickness of the standard concrete wall.

The second difference is reinforcement showing deformed ductile bars at the edges of the walls and electro welded wire mesh on the center of the wall. Also connection between wire mesh through dowels tied from basement or tied from lower story will produce uniformity, against the deformed bars on center of the wall used in the standard concrete wall.

Figure 3 presents the difference in construction where builders offer a production of story and slab per day as an efficiency parameter. However this massive and continu-

Fig. 1. Low ductility wall.

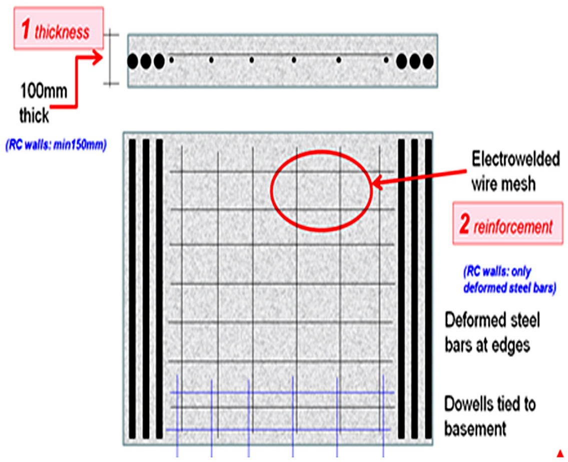

Fig. 2. Low ductility wall reinforcement and configuration.

Fig. 3. Construction process.

ous placement brings failures, however, such cold joints at bases of walls or air bags inside the concrete. It increases the time needed in the construction process due to actions for repair these deficiencies. After a series of bad experiences, some builders propose the use of fluid concrete with fibers in order to reduce the total time needed for construction.

From 1998 to 2003, non regulation was applied in the design and construction of low-ductility walls due to they were not qualify as shear walls. The application was sup-

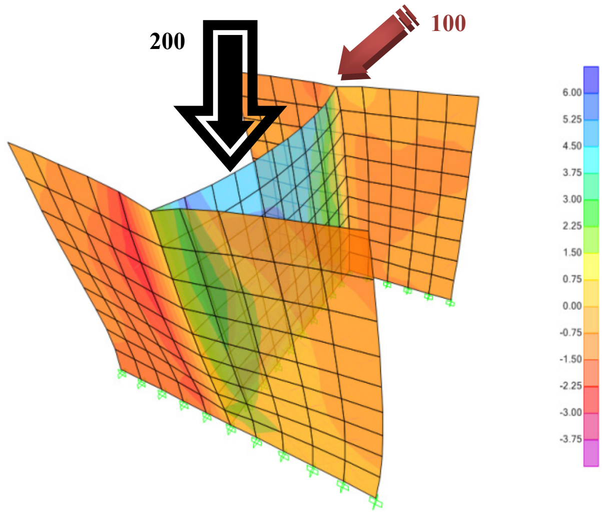

Fig. 4. Load condition for H wall and deformation under shear stress component.

posed to be to 5 story buildings, but many construction companies started immediately building structures of 12, 14 and 16 stories, without confinement columns.

On 2003 the NTE-060 Peruvian Concrete Standard include recommendations for design and construction of low-ductility walls. Stiffness contribution of the perpendicular wall is need in order to find how contribute on the inelastic behavior under lateral load with and without perpendicular wall.

3. Theoretical Influence of the Perpendicular Wall Effect

For a theoretical investigation of the influence of the perpendicular wall versus the in-plane wall, we consider an H-shaped wall of 2500 mm in length, and 2600 mm in height and 100 mm in thickness. In speaking of an H-shaped wall as a steel shape, the in-plane wall is a web, and the perpendicular walls are flanges of the wall. The flange length is therefore 2500 mm, with the same height and thickness as the web.

Theoretically speaking, walls under perpendicular action and combined load demand show primary axial deformation, due to the axial forces, assigned as dead load and live load in the building design process. Therefore these axial forces produced a pattern of axial stresses. Seismic action then appears, lateral deformation changes the configuration of axial stress and shear stress produces concentration and also the dissipation of stress on the wall flange.

As an example, the load configuration and the deformation of the H wall under a lateral load with a constant axial load is presented in **Fig. 4**, for simulation developed with SAP2000. Here, 200 kN axial load is applied, producing a confinement axial stress of 8 kg/cm^2. This axial stress is reduced by the application of the lateral load to a level of 7.2 kg/cm^2 on the web, and increase on the

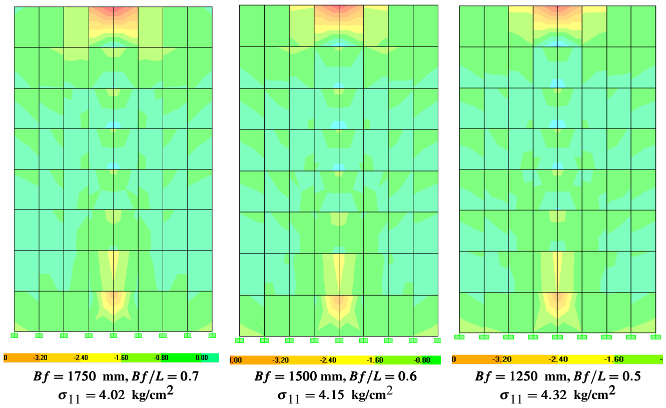

Fig. 5. Horizontal stress on perpendicular wall for different flange length – web length ratio.

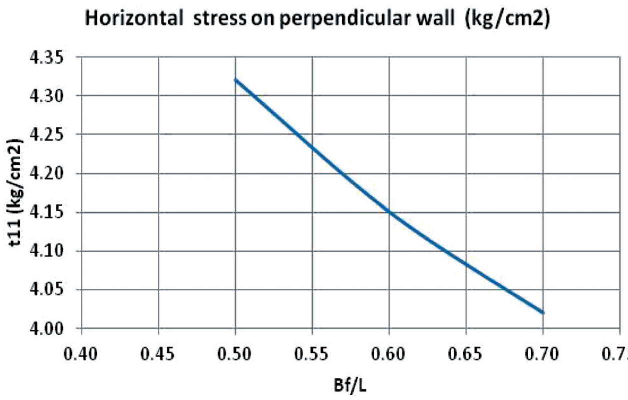

Fig. 6. Horizontal stress variation for Bf/L ratio.

toe to 18 kg/cm^2 near the intersection of web and flange. Also horizontal stress on the flange wall shows the average value of a level of 4.0 kg/cm^2. Consider the variation in the geometrical parameter flange length, and produce the variation in the flange length and web length ratio for the component of the horizontal stress. Results of the investigation are presented in **Figs. 5** and **6**.

If is repeated the example to investigate the change of stress in the axial component in the H wall, considering that this kind of stress will have an initial level of axial stress of 18 kg/cm^2, producing the stress change function with the Bf/L ratio is presented on **Fig. 7**. **Fig. 8** presents the stress distribution for each case. If we consider the division in elements and the amount of the elements on the flange wall, we can find that stresses have a similar level of axial stress for $bf/4$. It means as long is the flange less increment on the axial stress is reached.

Let's consider the variation in the shear stress under constant axial and shear force. **Fig. 9** presents the patterns of the shear stress for different values of Bf/L. We must take into account that 6.85 kg/cm^2 is the starting point, since the value will decrease as the Bf/L ratio decrease as is presented at **Fig. 10a**.

Also the ratio between Bf/L and shear stress for the flange wall is presented in **Fig. 10b**, where the level of shear stress on the flange wall is almost the same as the

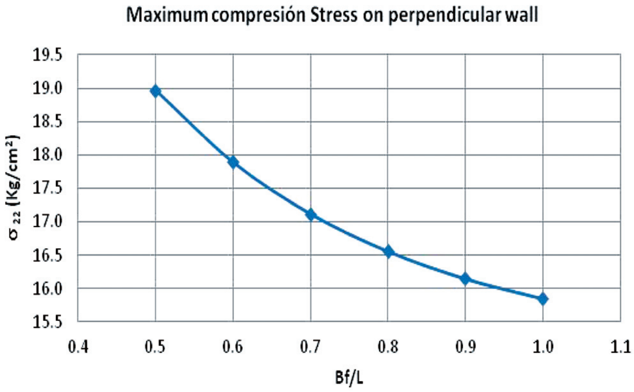

Fig. 7. Maximum axial stress variation for Bf/L ratio.

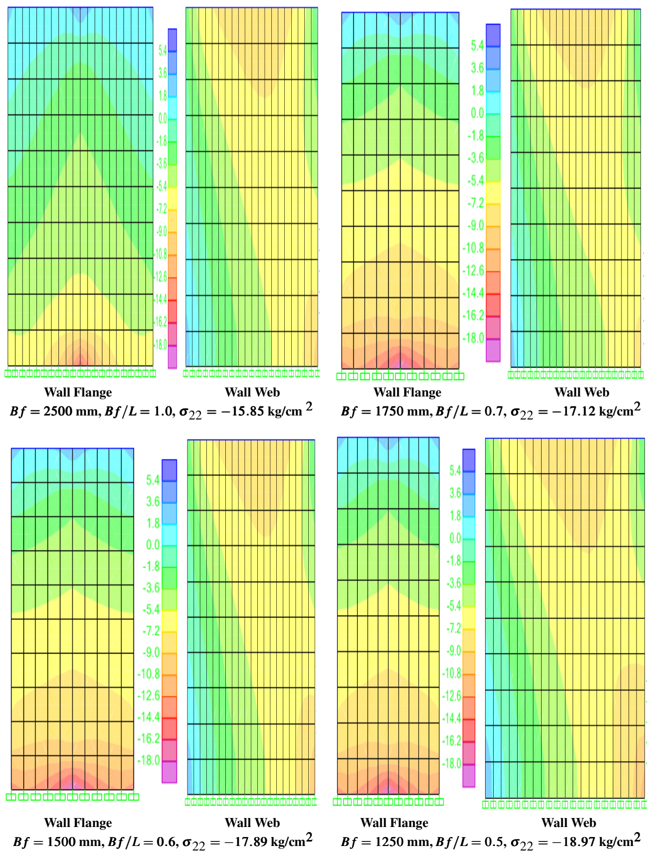

Fig. 8. Axial stress on perpendicular wall for different flange length - web length ratio.

shear stress of the web stress. The tendency of the stress is almost the same, stress decrease as Bf/L ratio decrease. It means less flange less stress.

4. Experimental Test Considering Perpendicular Wall Effect

In order to investigate in experimentally the influence of the perpendicular wall on and H-shaped configuration versus one-plane wall, two experiments were performed:

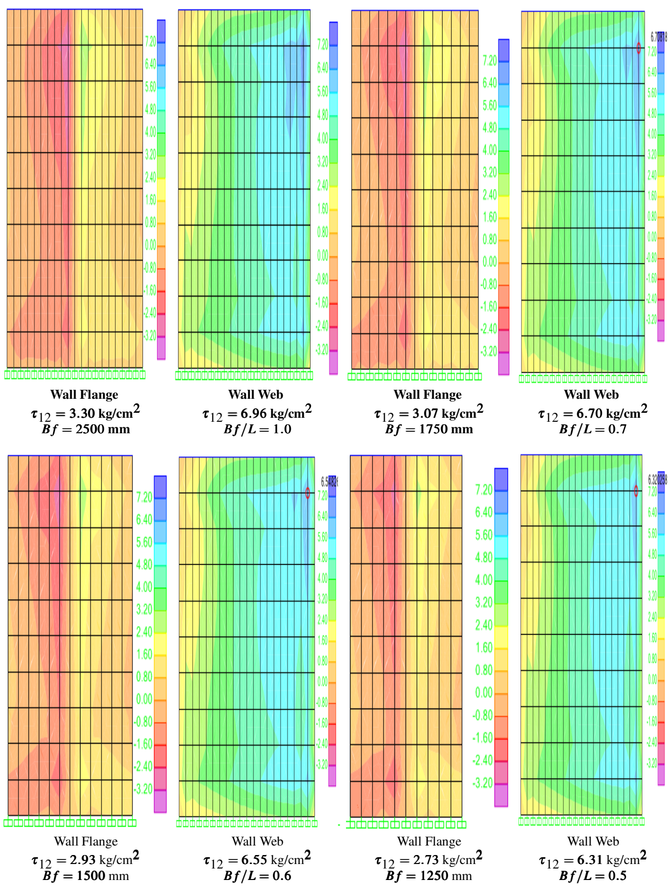

Fig. 9. Shear stress on wall and web walls.

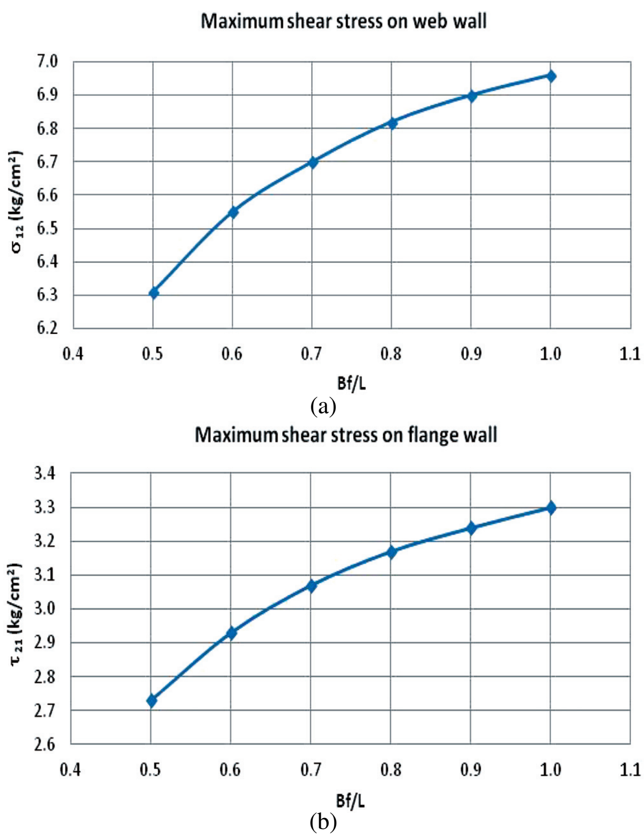

Fig. 10. Shear stress variation for Bf/L ratio.

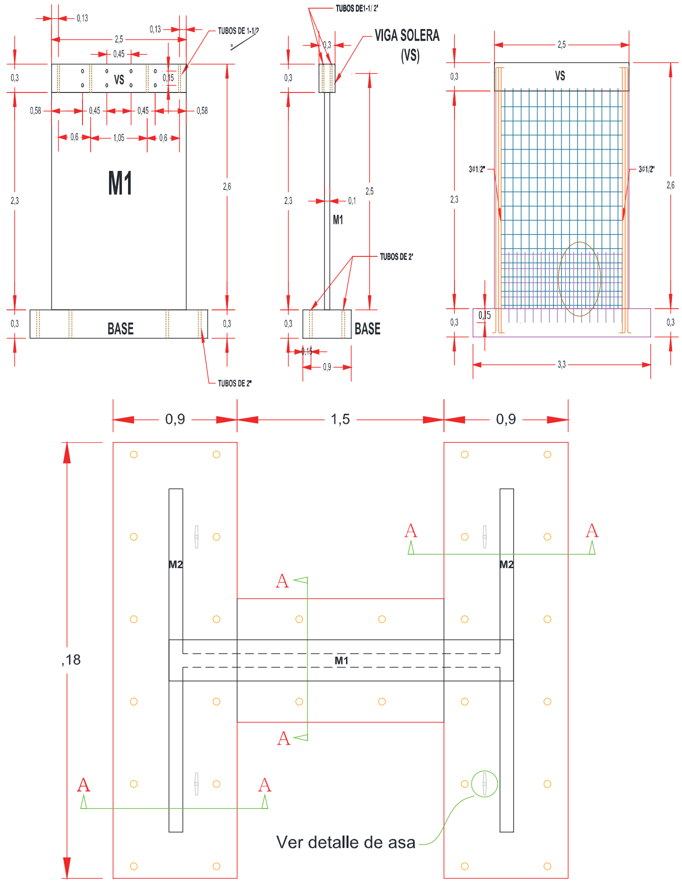

Fig. 11. Test specimen configuration for H-shaped wall.

an experiment on a one-plane wall, and an experiment with a perpendicular wall that produces an H-shaped wall.

4.1. About the Specimens

Both walls, one-plane and H-shaped wall have the same dimensions: 2500 mm in length with 2600 mm in height and 100 mm in thickness. In the case of the H-shaped wall, a flange with a total dimension (Bf) of 2500 mm is incorporated into the one plane wall, in order for investigated the influence by the measured stresses.

The walls have confined reinforce on the corners of 3 bars #4. Wire mesh appears as reinforcement of the web and flange with electro welded mesh Q-158 (5.5 mm diameter 0.15 m $As = 1.58$ cm^2/m). Is common the use of 600 mm dowels between stories on buildings, but in the case of the specimens dowels has same growing from the footing base. **Fig. 11** presents the configuration of both specimens, one-plane and H-shaped wall. Noted that there is a horizontal border beam of 300 mm by 300 mm section on the top of each beam. Also foundation of 900 mm by 300 mm is on the bottom part of the specimen.

The construction process tried to replicate as near the real environment on the site area. So wire mesh from the footing was fixed with the wire mesh of the wall and three ductile bars #4 were placed on the corners of the specimens. Wood forms were used to encase the reinforcement

Fig. 12. Four stages in the construction of the specimens.

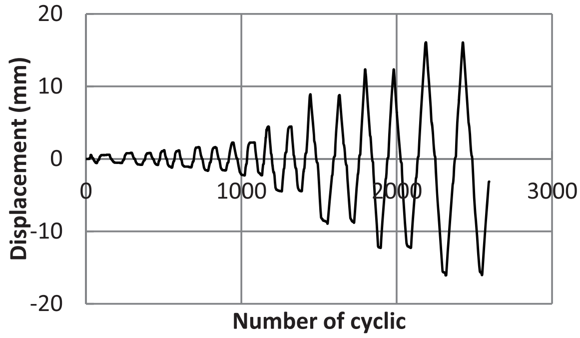

Fig. 13. History of cyclic displacement in test.

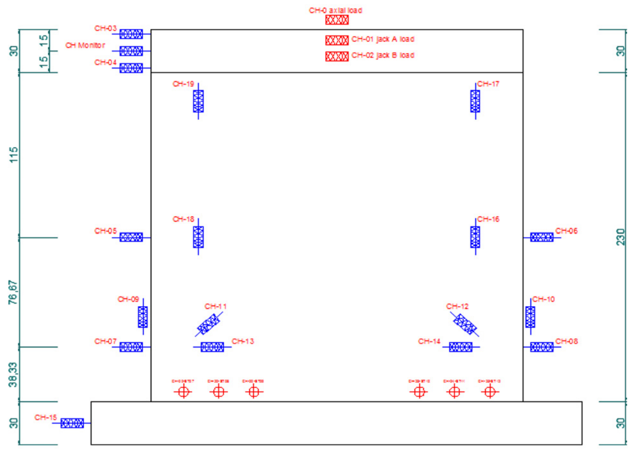

Fig. 14. Displacement transducer setting.

and set the fluid mix of concrete inside to produce the concrete wall.

On the top of each wall a loading beam is set to be use for as loading steel frame. **Fig. 12** presents four stage of the constructions of the specimens.

5. About the Test Execution

For the execution of the test 2 jacks and one actuator were used for the application of the loads. Axial load equivalent to 200 kN that approximate represents the load of four stories over the wall.

During the execution of the test, this load will be applied at the beginning of the load process, and after reaching 200 kN, the load will remain constant during the whole test. To simulate lateral action such as earthquake movement, an increasingly cyclic displacement is applied to the specimen in order to start the movement of the wall and to measure the load in each step. **Fig. 13** presents the history of the cyclic displacement applied to the wall. The displacement was applied using the new jack system provided by JICA under the SATREPS project. This jacks (Rikken System) had a capacity of 500 kN and 400 mm stroke.

To measure displacement, transducers were placed to measure displacement at different locations on the walls. On the one plane wall and web wall (on H-shaped specimen), displacements transducers were set at the locations presented on **Fig. 14**.

Fig. 15. Test set up for one plane wall and H-shaped wall.

Here sensors on the wall were set on the diagonal, vertical and horizontal directions in order to reproduce the displacement in all directions. To measure stress at points, strain gauges were glued to the surface of the concrete and to the reinforce bars. All the sensors and gauges, were connected to an scanning box and Tokyo Sokki TDS 530 data logger.

The test setup of both specimens is presented in **Fig. 15**. Note here the difference in setup due to the need for the

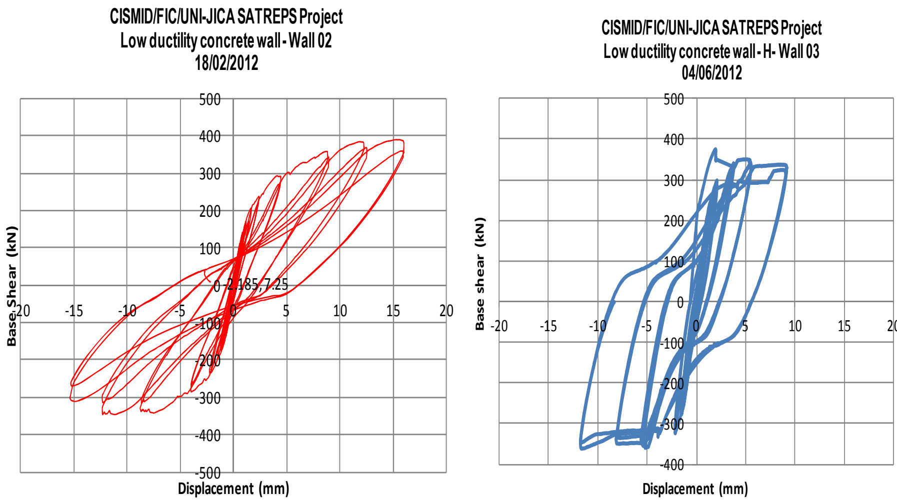

Fig. 16. Hysteresis curves of one plane wall and H-shaped wall.

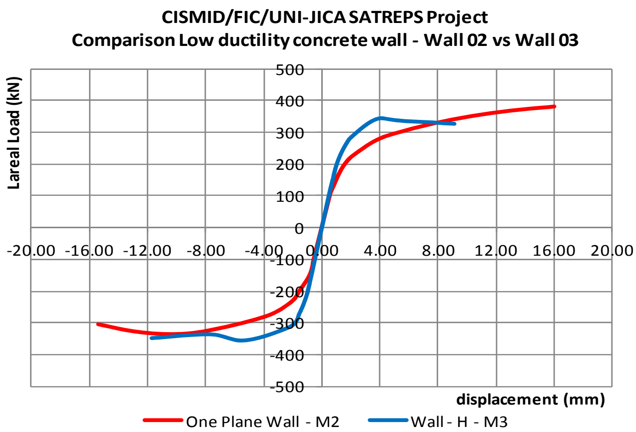

Fig. 17. Comparison of behavior curves of low ductility walls.

Fig. 18. Final stage of one-plane wall and H-shaped walls.

Table 1. Test results on walls.

Specimen	Initial Stiffness (kN/mm)	End Elastic Drift	Limit Drift	τ_{max} Stress (kg/cm^2)
One Plane Wall	185.2	0.00034	0.0040	14.5
Wall - H	192.0	0.00040	0.0015	14.5

application of the axial load and lateral load simultaneously specially in the case of the H-shaped wall where space is quite narrow to apply both loads. In the case of H-shaped wall the perpendicular wall (flange wall) has three lines of sensors in order to investigate the displacement at those locations and dissipation of the stress. Strain gauges were also set for the same purpose.

6. Test Results

The cyclic displacement versus base shear on the experimented walls is presented in **Fig. 16**, where hysteresis curves of the development of each test are presented. Both specimens had almost the same level of maximum stress, but in different failure modes. The reason for this similarity in stress level is due to an slip on the foundation occurs after 4 mm displacement. In the case of the one-plane wall, shear cracking appears at the base of specimen. Then flexural cracks then start to appear in both borders elements, propagating horizontally. Finally diagonal cracks finally appear and a combination of shear failure and slip failure at the base, is the final failure pattern. Comparison of behavior curves is presented on **Fig. 17**.

In the case of the H-shaped wall, the starting crack was a diagonal crack that appeared at the intersection between both walls. A shear cut of the basement appears, together with an up light of the toe. Final stage of both specimens is presented in **Fig. 18**.

A summary of the results of both tests is summarized in **Table 1**. Here in the case of the H-shaped wall stiffness is increased due to the perpendicular wall action. Also the end of the elastic zone in the specimens is also presented in **Table 1**. Here, the stiffer is the wall, lower the ductility. The maximum drift value for one-plane walls is 0.004 against the maximum drift on the H-shaped wall of 0.0015. Therefore, more rigider the wall, the lower the ductility.

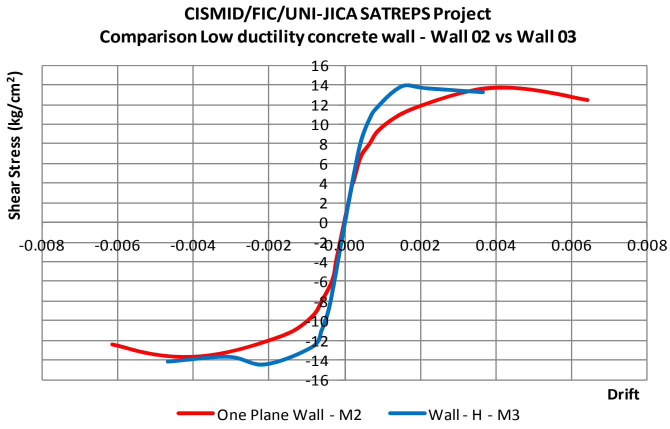

Fig. 19. Comparison of shear stress on low ductility walls.

Figure 19 presents a comparison of shear stress behavior in terms of drift and shear stress in the web wall on both specimens. The H-shaped wall has a elastic drift limit smaller than the one-plane wall specimen, where the values are presented in **Table 1**. Both walls reach the same level of maximum shear stress but with different drift.

7. Conclusions

- The contribution of the perpendicular action of a wall to one-plane wall has been presented theoretically in this paper. The influence of the flange size of the wall shows the spreading of the stress for $L/4$ to low levels. It is necessary to continue the study using experimental tests of different flange lengths.
- One case of flange length has been studied experimentally with the execution of two test: the first test with a one-plane wall and second test with an H-shape wall with a flange length of 250 mm. The height of the walls is 2600 mm and 100 mm in thickness. Both walls have been reinforced on the corners with 3 bars #4. Wire mesh appears as reinforcement for the web and flange with electro welded mesh Q-158 (5.5 mm diameter 0.15 m $As = 1.58$ cm^2/m).
- Test results are summarized in **Table 1**. In the case of H-shaped wall, stiffness is increases due to the perpendicular wall action. Maximum drift value for one-plane walls is 0.004 against the maximum drift for the H-shaped wall of 0.0015. Therefore, the rigider the wall, the lower the ductility.
- We need to continue the study in order to verify the spread of stress in the perpendicular flange wall and web wall. At this time we need to process data from strain gauges to investigate this spread of stress.

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