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# CICLIC BEHAVIOR OF LOW DUCTILITY WALLS CONSIDERING PERPENDICULAR ACTION

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## SUMMARY

Low ductility wall buildings became part of the Peruvian construction boom of the first decade of the 21st century. Government promote under the Program named "Mi Vivienda" (My house in English), the construction of low rise buildings of 5 stories using walls with wire mesh reinforcement, provide part of a solution of an apartment, with reasonable cost. However, the height of the buildings started to grow and grow, reaching 12 to 16 stories. In the design of this walls, provisions recommend the confinement of the corners of the walls, due the action of the walls ensemble will provide a limited ductility under seismic behavior. In this paper the comparison of the action of perpendicular wall with a one plane wall is presented. Here 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 shape wall is higher than one plane wall. Also resistant of the H shape wall increase, however ductility remains almost similar in both walls.

## INTRODUCTION

On 1997 as initiative of Professor A. Galvez, his idea of replace the masonry wall bricks by a thin concrete wall, bring the opportunity to CISMID Structural Lab to start the study of low ductility walls. The purpose of study the behavior of this walls using low strength concrete (f'c=100 kg/cm$^2$) and the reinforce of a wire mesh Q62 became a benchmark of the study for walls to be used on 4 stories buildings. On that research the walls with very light reinforcement and low compressive stress, are considered a low limit for this kind of walls. Investigations like performed by UNICON-PRODAC at PUCP Structural Lab, were used as basic material for discussion among the members of the Peruvian Concrete Standards committee to fill the empty space for the design of this kinds of walls produced between 1997 to 2003. On 2003 Peruvian Concrete Standards committee publish an addenda that include recommendations for the design of low ductility walls. By that time new research on Wall and full scale test were performed on the study of Eng. Gabriela Medina at CISMID Structural Lab, under the support of UNICON-FORSA-PRODAC. This study produced parameters considered as a high limit of stress for this walls. Since that time low ductility walls are widely used on 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 empty space on the standards, buildings of 12, 14 and 16 stories were build under unknown criteria.

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One of the worries is to understand when flexural behavior will be predominant and under which number of stories. Also how is the influence in the stiffness of a perpendicular wall against one plane wall. In this paper the comparison of the action of perpendicular wall with a one plane wall is presented. Here experimental test is presented by a cyclic lateral loading considering the action of a constant axial load.

**Figure 1:** Low ductility wall

## MAIN DIFFERENCES OF A LOW DUCTILITY WALL AND STANDARD WALL

On Figure 2 two off the main differences between a low ductility wall and an standard concrete wall are presented. The first is the thickness of the wall, were low ductility wall could have 100 mm. or even 80 mm. against the 150 mm. which is minimum thickness of an standard concrete wall. The second difference is the reinforcement showing deformed ductile bars at the edges of the walls and electro welded wire mesh on the web of the wall, also connection with dowels tied to basement or connection between stories is produce using dowels, against the deformed bars on web of walls used in standard concrete wall.

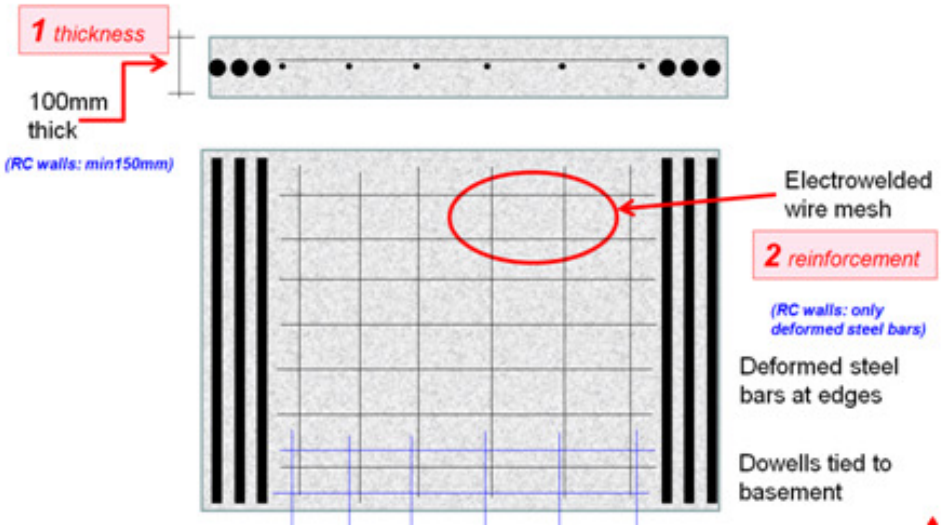



**Figure 2:** Low ductility wall reinforcement and configuration

Figure 3 presents the difference in the construction where builders offer one day one story and slab as an efficiency parameter. However this massive and continuous placement brings failures such cold joint at base of wall or hole air bags inside the concrete. It increase time in the construction process due to actions of repair this deficiencies. Some builders after a series of bad experiences propose the use of fluid concrete with fibers in order to reduce total time of construction.


**Figure 3:** Construction Process

During 1998 to 2003 non regulation was applied in the construction of this kind of wall due they were not consider shear walls. The application was on 5 story buildings, however many constructors started to build structures of 12, 14 and 16 stories, just like that, without confinement columns. On 2003 the NTE-060 Peruvian Concrete Standard include recommendations for construction of this kind of walls. Stiffness contribution of the perpendicular wall is need in order if this will contribute on the inelastic behavior under lateral load with and without perpendicular wall.

## THEORETICAL INFLUENCE OF THE PERPENDICULAR WALL EFFECT

For the theoretical investigation of the influence of the perpendicular wall against the in plane wall, we consider an H shape wall of 2500 mm. length, and 2600 mm. height and 100 mm. thickness. If we mentioned the H shape wall as steel shape, the in plane wall is the web, and the perpendicular walls are flange of the wall. Therefore, flange length is 2500 mm, with same height and thickness as the web. Theoretically speaking, walls under perpendicular action and combined load demands will experiment primary axial deformation, due to the axial forces, usually assigned as dead load and live load on the building design process, produced a pattern of axial stresses. Then, seismic action appears, lateral deformation will change the configuration of axial stresses and shear stresses will produce concentration and also dissipation of stress on the wall flange.

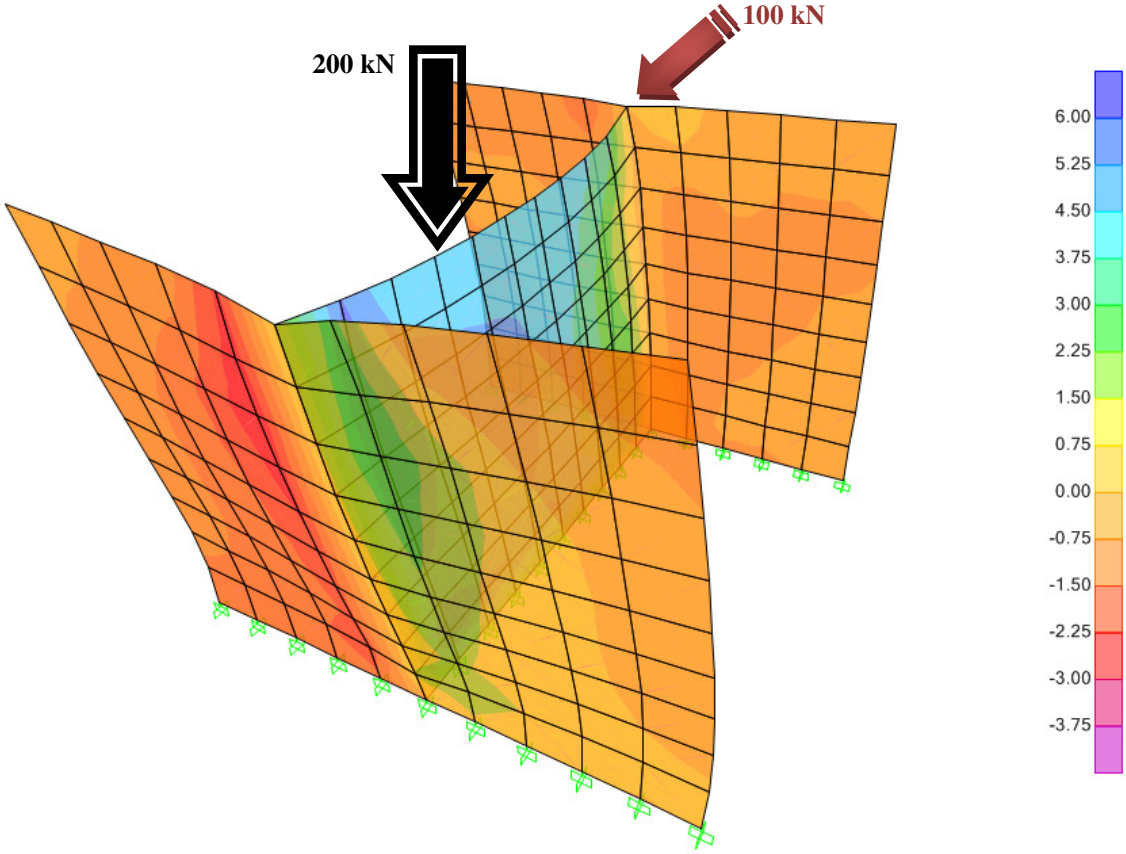
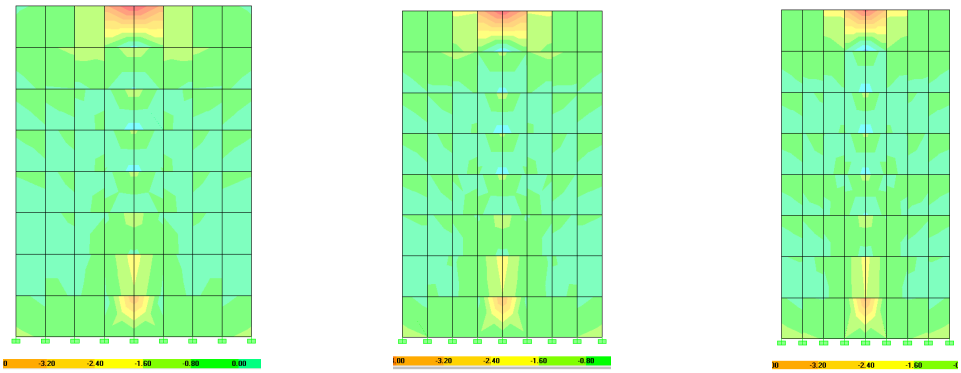



**Figure 4:** Load condition for H wall and deformation under shear stress component

As an example, load configuration and the deformation of the H wall under lateral load with a constant axial load is presented on Figure 4. Therefore if 200 kN axial load is applied, producing a confinement axial stress of 8kg/cm2. This axial stress is reduced by the application of the lateral load to a level till 7.2 kg/cm$^2$ on the web, and increase on the toe to 18 kg/cm$^2$ on the toe intersection of web and flange. Also horizontal stress on the flange wall shows average value of a level of 4.0 kg/cm$^2$. Let´s consider the variation on the geometrical parameter flange length, and produce the variation of the flange length and web length ratio for the component of the horizontal stress. Results of the investigation are presented on Figure 5.



**Bf= 1750 mm. Bf/L=0.7** **Bf = 1500 mm. Bf/L= 0.6** **Bf=1250 mm. Bf/L= 0.5**

$\sigma_{11}$ = 4.02 kg/cm$^2$ $\sigma_{11}$ = 4.15 kg/cm$^2$ $\sigma_{11}$ = 4.32 kg/cm$^2$

**Figure 5:** Horizontal stress on perpendicular wall for different flange length - web length ratio.

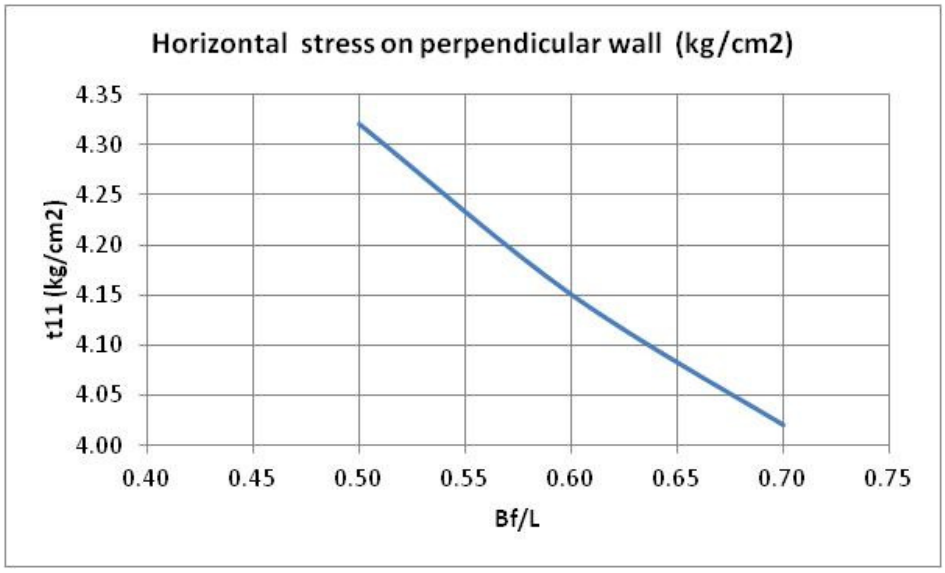



**Figure 6:** Horizontal stress variation for Bf/L ratio

If the example is repeated to investigate the change of stress in the axial component on the H wall, considering that this kind of stress will have an initial level of axial stress of 18 kg/cm$^2$, from this point, the stress change function with the Bf/L ratio is presented on Figure 8. Also Figure 7 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.

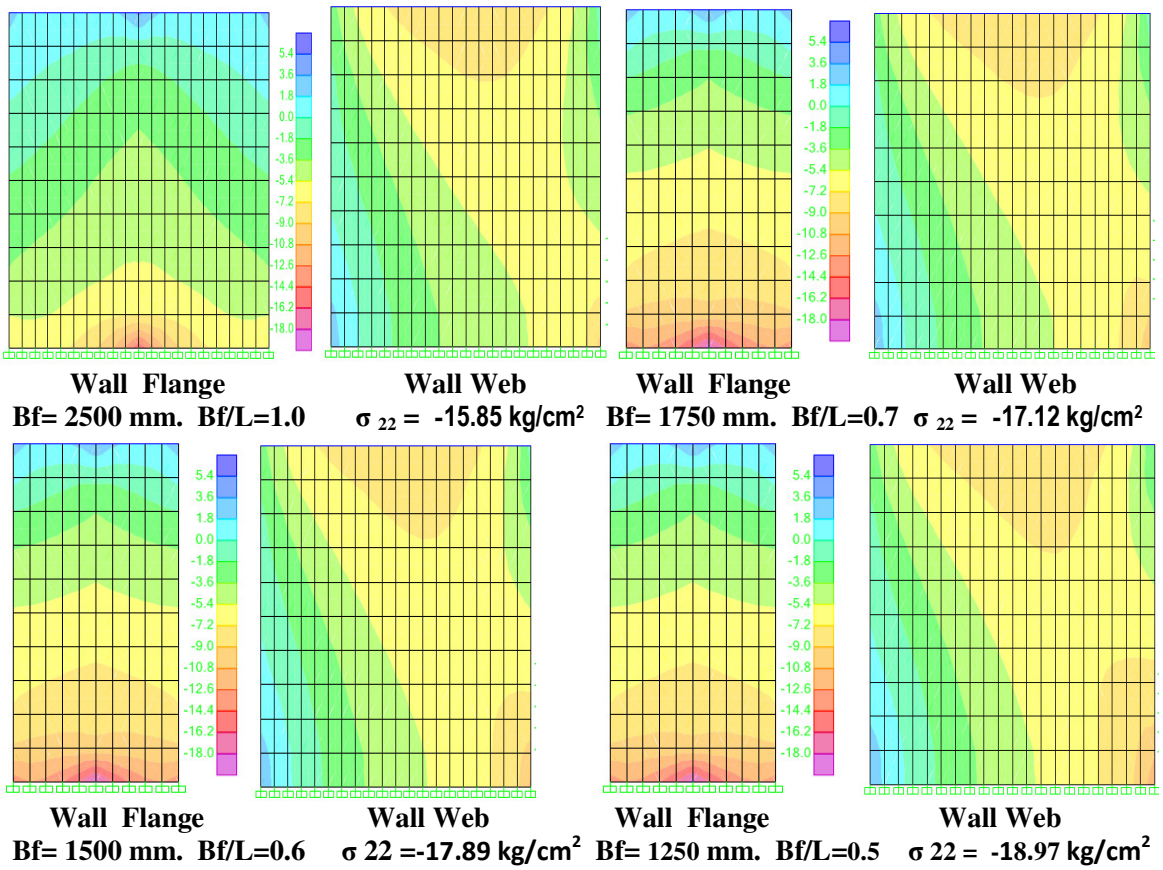



**Figure 7:** Axial stress on perpendicular wall for different flange length - web length ratio.

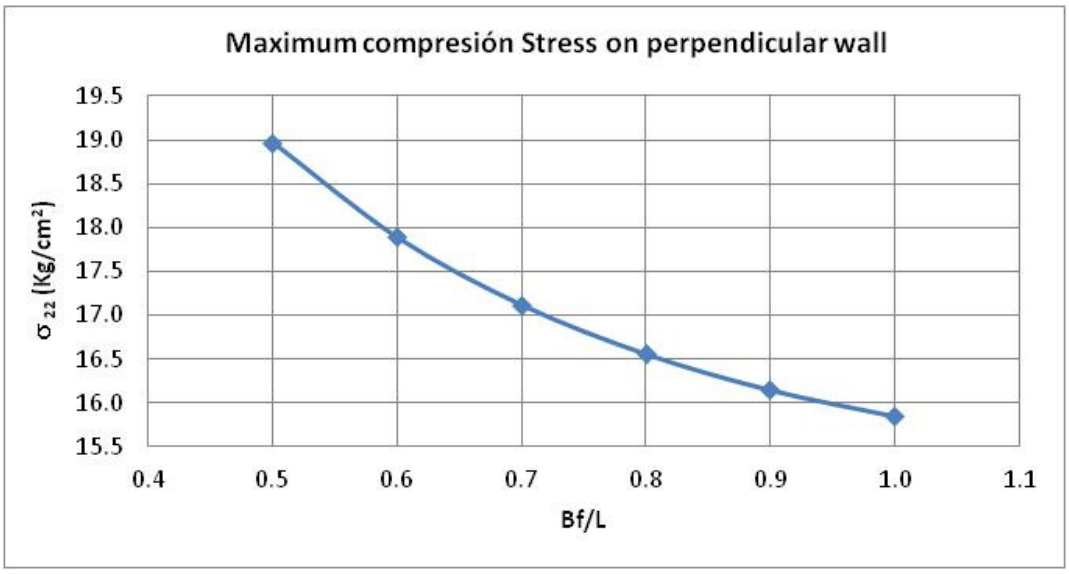
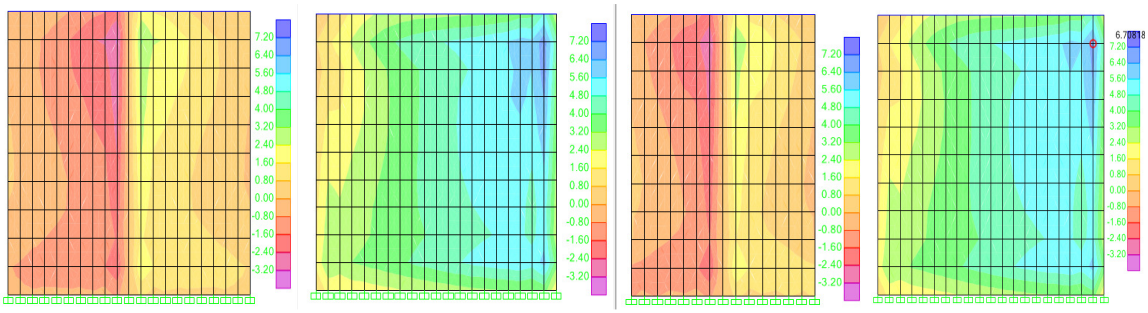



**Figure 8:** Maximum axial stress variation for Bf/L ratio

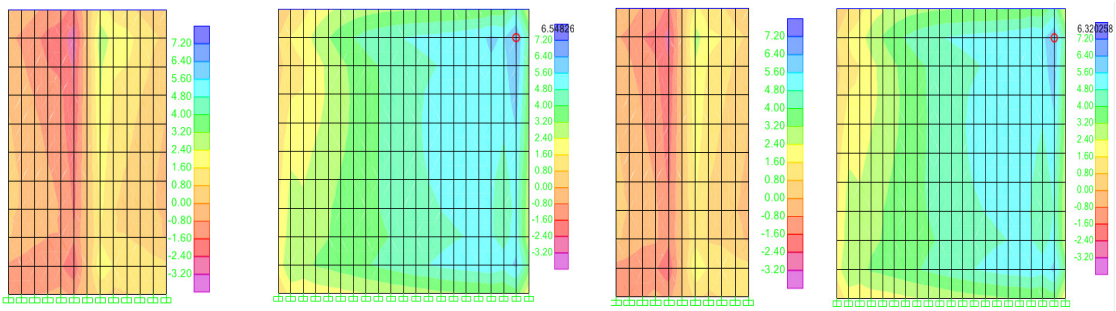


**Wall Flange** $\tau_{12}$ = 3.30 kg/cm² Bf = 2500 mm

**Wall Web** $\tau_{12}$ = 6.96 kg/cm² Bf/L= 1.0

**Wall Flange** $\tau_{12}$ = 3.07 kg/cm² Bf = 1750 mm

**Wall Web** $\tau_{12}$ = 6.70 kg/cm² Bf/L= 0.7



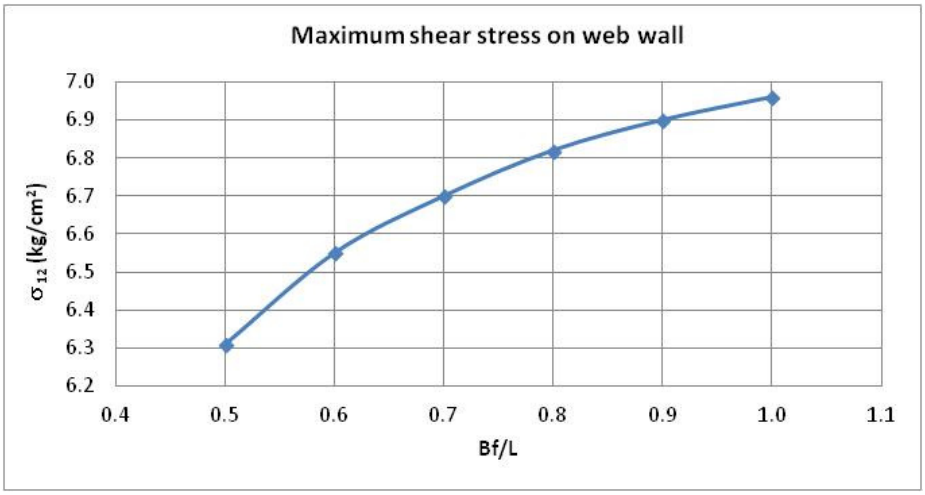
**Wall Flange** $\tau_{12}$ = 2.93 kg/cm² Bf = 1500 mm

**Wall Web** $\tau_{12}$ = 6.55 kg/cm² Bf/L= 0.6

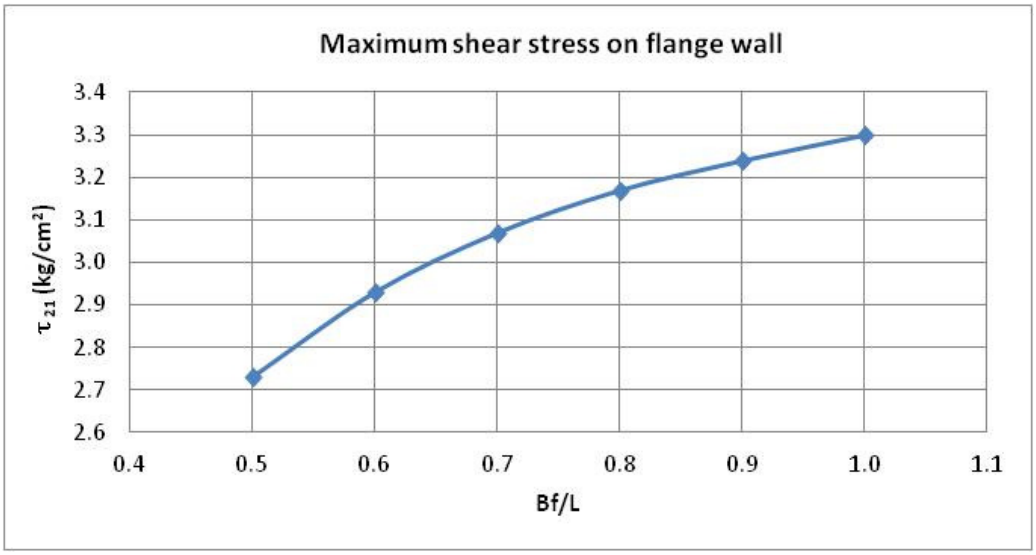
**Wall Flange** $\tau_{12}$ = 2.73 kg/cm² Bf = 1250 mm

**Wall Web** $\tau_{12}$ = 6.31 kg/cm² Bf/L= 0.5

**Figure 9:** Shear stress on wall and web walls




**(a)**




**(b)**

**Figure 10:** Shear stress variation for Bf/L ratio

In the opposition of the case of axial stress, let´s consider the variation on the shear stress under constant axial and shear force. Figure 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 value will decrease as the Bf/L ratio decrease as is presented at Figure 10a.
Also the ratio between Bf/L and shear stress for the web wall is presented on Figure 10b, where the level of shear stress on the flange wall are almost have of the shear stress of the web stress. Tendency of the stress are almost the same, stress decrease as Bf/L ratio decrease. It means less flange less stress.

## EXPERIMENTAL TEST CONSIDERING PERPENDICULAR WALL EFFECT

In order to investigate in experimentally the influence of the perpendicular wall on and H shape configuration against one plane wall, two experiments were performed: an experiment on a one plane wall, and an experiment with a perpendicular wall that produce an H shape wall.

### *About The Specimens*

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

The walls have a reinforce on the corners as confinement 3 bars #4. Wire mesh appears as reinforcement of the web and flange with electro welded mesh Q-158 (5.5 mm. diameter @ 0.15m As=1.58 cm2/m). Is common use of 600 mm. dowels between stories on buildings, but in the case of the specimens dowels are same growing from the footing base. Figure 11 presents the configuration of both specimens, one plane and H shape wall, notice 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.

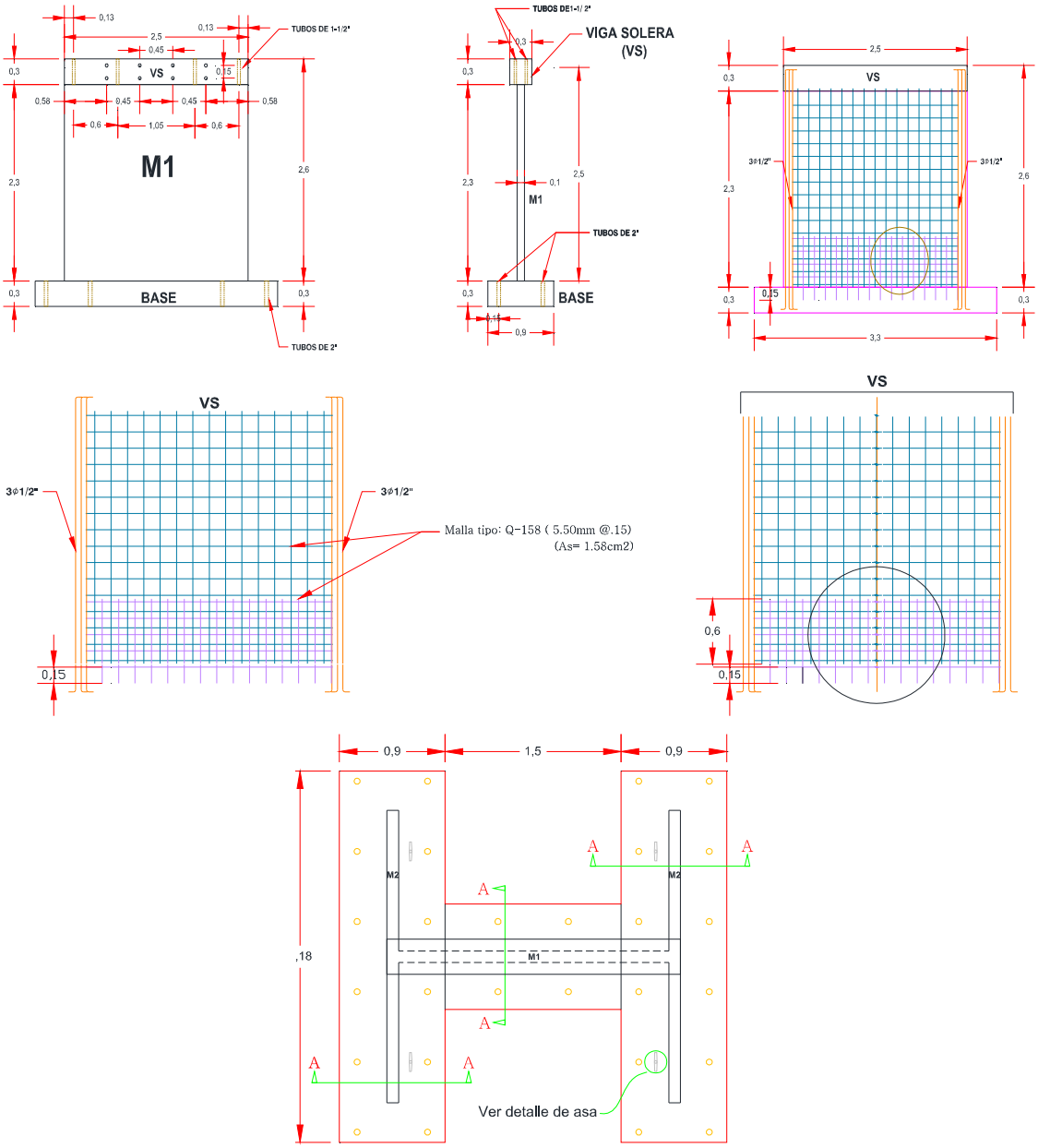



**Figure 11:** Test specimen configuration for H shape wall

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 and set the fluid mix of concrete inside to produce the concrete wall. On the top of each wall a loading beam is build to be use for setting of the loading steel frame. Figure 12 presents four stage of the constructions of the specimens.

**Figure 12:** Four stages on the construction of the specimens

## 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 approximately 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 the lateral action such a earthquake movement, an increasing cyclic displacement will be applied to the specimen in order to start the movement of the wall and measure in each step the load. Figure 13 present the history of the cyclic displacement applied on the wall. The displacement were applied using the new jack system provided by JICA under the SATREPS project. This jacks (Rikken System) had capacity of 500 kN and 400 mm. stroke.

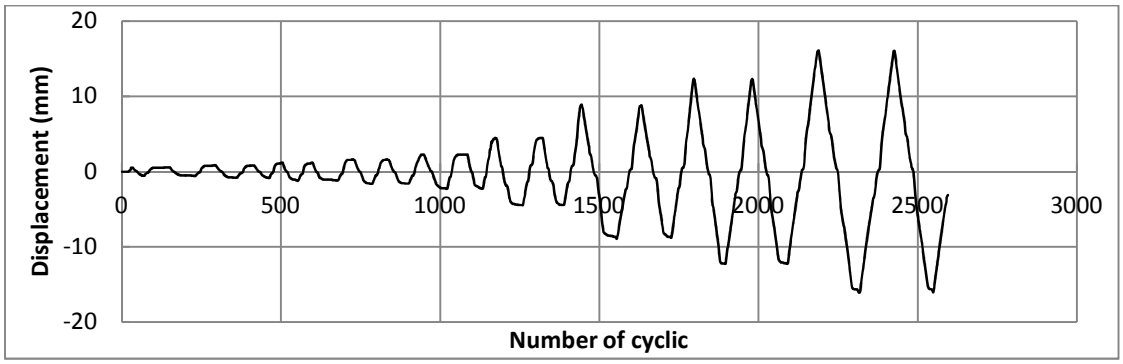



**Figure 13:** History of cyclic displacement on test

For the measure of the displacements a set of transducer were placed to measure displacement in different locations on the walls. In the one plane wall and web wall (on H shape specimen), displacements transducers were set on the positions presented on Figure 14, here sensors on the body of the wall were setting on the diagonal, vertical and horizontal in order to reproduce the displacement on all directions. For the measure of the stress on 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 data logger Tokyo Sokki TDS 530.

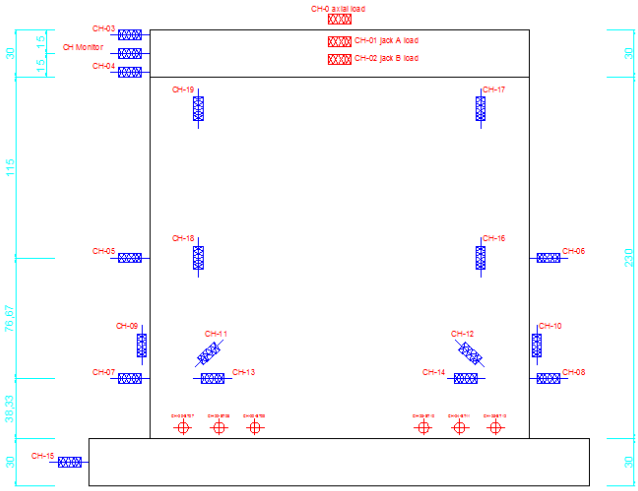



**Figure 14:** Displacement transducer setting

**Figure 15:** Test set up for one plane wall and H shape wall.

On Figure 15 the test setup of both specimens are presented. Here is possible to notice the difference on the setup due to need of application of the axial load and lateral load simultaneously in special in the case of the H shape wall were space is quite narrow to applied both loads. In the case of H shape wall the perpendicular wall (flange wall) has three lines of sensors in order to investigated the displacement on that positions and the dissipation of the stress. Also strain gages were set for the same purpose.

## TEST RESULTS

The cyclic displacement versus base shear on the experimented walls are presented on Figure 16, where hysteresis curves of the development of each test are present. It is possible to read that both specimens had almost the same level of maximum stress, but in different failure mode. In the case of the one plane wall, shear cracking appears on the base of the experiment. Then flexural cracks starts to appear on both borders elements, propagation horizontally. Finally diagonal cracks appear and a combination of shear failure with slip failure of the base, is the final failure pattern.

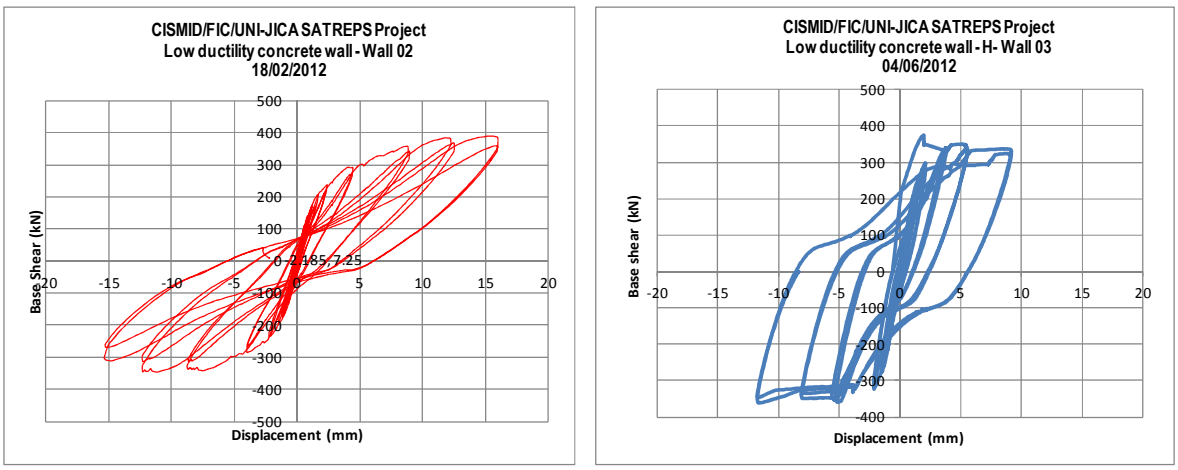



**Figure 16:** Hysteresis curves of one plane wall and H shape wall

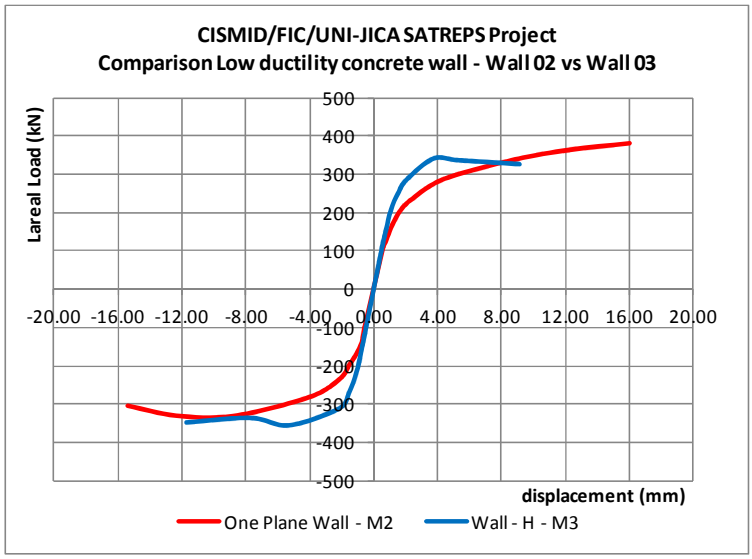



**Figure 17:** Comparison of behavior curves of low ductility walls.

In the case of the H shape wall, the starting crack was a diagonal crack that appears in the intersection zone between both walls. A continue diagonal shear cracks on the intersection of both walls appears during the test. Then shear cut of the basement appears, together with an up light of the toe. Final stage of both specimens are presented on Figure 18.

**Figure 18:** Final stage of one plane wall and H type wall

A resume of the results of both test is summarized on Table 1. Here we can read that in the case of wall-H stiffness is increased due to the perpendicular wall action. Also the end of the elastic zone in the specimens are presented on Table 1. Here is possible to read that as more stiff is the wall less is the ductility. Maximum drift value for one plane walls is 0.004 against the maximum drift on the H shape wall of 0.0015. Therefore, more rigid the wall less ductile is the wall.

**Table 1:** Test results on walls

| Specimen | Initial Stiffness (kN/mm) | End Elastic Drift | Limit Drift | $\tau_{max}$ 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 |

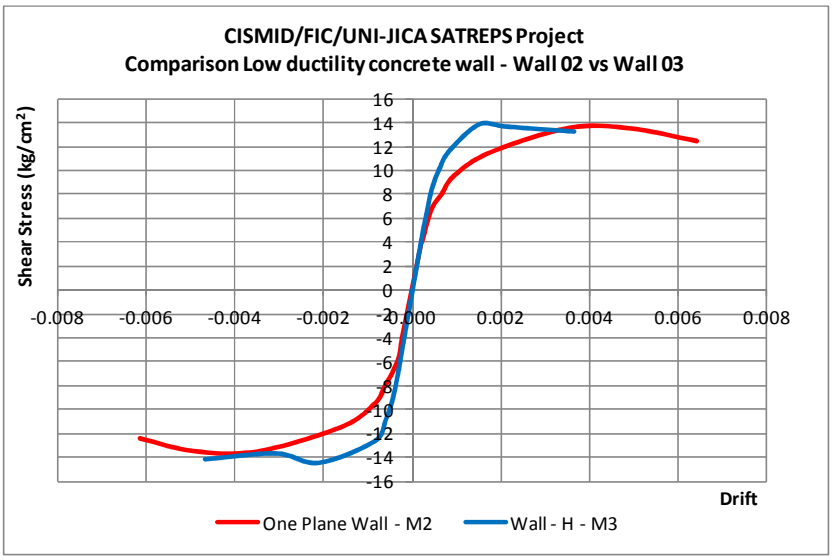



**Figure 19:** Comparison of shear stress on low ductility walls

On Figure 19 the comparison at shear stress behavior curves is presents in terms of drift and shear stress on the web wall on both specimens. Wall H has a limit drift prior the case of one wall specimen, where the values are presented on Table 1. Both walls reach the same level of maximum shear stress but with different drift.

## CONCLUSIONS.

- Contribution of the perpendicular action of a wall to one plane wall has been presented theoretically on this paper. The influence of the flange size of the wall shows and spreading of the stress for L/4 to low levels. It is necessary to continue the study using experimental test of different flange length.
- One case of flange length has been studied experimentally with the execution of two test: first test with one plane wall, and another test with and H shape wall with flange length of 250 mm. Height of the walls is 2600 mm. and 100 mm. thickness. Both walls have been reinforce on the corners as confinement 3 bars #4. Wire mesh appears as reinforcement of the web and flange with electro welded mesh Q-158 (5.5 mm. diameter @ 0.15m As=1.58 cm2/m).
- Test results are summarized on Table 1. Here we can read that in the case of wall-H stiffness is increased due to the perpendicular wall action. Maximum drift value for one plane walls is 0.004 against the maximum drift on the H shape wall of 0.0015. Therefore, more rigid the wall less ductile is the wall.
- We need to continue the study in order to verify the spread of stress on 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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