EXPERIMENTAL STUDY OF EFFECTIVE FLANGE WIDTH ON SYMMETRICAL CROSS-SECTION WALLS

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ABSTRACT

In the February 27, 2010 Chile Earthquake many medium height buildings with structural wall elements collapsed. According to damage surveys one of the factors associated with this structural failure was high flexural compression stress in flange walls. The objectives of this study are to evaluate the provision in the current standard for effective flange width in tension and compression, to clarify high compression stress in flange walls, and clarify the effect of porous sub-standard concrete on effective width. The effective flange width is the width of the flange that influences the lateral forces acting in the plane of the web wall. It is related to stress and strain distribution. As stress and strain distribution is nonlinear, to avoid nonlinearity used uniform distribution of stress and strain.

This study is based on experimental testing of three specimens of symmetrical cross-sections walls (H-shaped). The Specimens are designed in accordance with Japanese standard at 1/3 scale acting monotonic or cyclic lateral and axial force. The output the tests is strain distribution in flange walls from each side of each specimen. Data was obtained by installing reinforcement strain gauges in all three specimens, as well as concrete strain gauges in specimen H2 to observe compression. Mechanical properties also analyzed in this study to determine stress-strain relationship models. Bilinear model for steel and trilinear model for concrete used to obtain stress. Effective flange width is calculated by divided the area of stress distribution with the maximum stress.

From these tests it is concluded that effective width should be greater than standard provisions for both tension and compression. In cyclic tests, effective flange width for compression is greater than for tension, before compression is neglected. In general, it is indicated that the use of sub-standard concrete does not significant effect to effective flange width.

Keywords: experimental, flange, wall, cross-section, stress-strain

1. INTRODUCTION

Construction in many countries prone to earthquakes use walls as a structural element sometimes with an additional frame. This structural element have excellent seismic performance good fire resistance, due to the use of reinforced concrete, and they are also economical, as load-bearing walls are as thick as wall girders but allow for greater internal space, as columns and beams are not necessary.

In the February 27, 2010 The Maule earthquake in Chile caused many medium height buildings to collapse or suffer sufficiently heavy damage to merit being demolished, while other buildings suffered only non-structural, or reparable structural damage. Most of the medium height buildings in Chile are constructed using structural walls. One of the factors commonly associated with the structural failure of this type of element is compression failure, apparently related to high flexural compression stress in flange walls [Moehle, 2010][1]. The question research background is why compression has caused damage to the flange wall.

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[1] Moehle, Wallace, *et. al.*, February 27, 2010 Chile Earthquake Reconnaissance Team Investigations, EERI,2010

Earthquake force assumed as lateral load acting on the in-plane direction of wall will produce tension force on one side and compression force on the other side. If the wall is flanged wall, the flanged will contribute to resisting the force. The width of the flange that influences the lateral forces acting in the plane of the web wall is called the effective flange width. The important aspect of behavior is the shape of the stress and strain distribution, as the distribution of strain and corresponding stress in flange walls is nonlinear. This highly complicates design and analysis, and to avoid this, a uniform distribution of stress and strainis used, as effective flange portion contributes to structure behavior. Some variables that influence effective flange width and dominant parameters are: drift level, geometry of the wall, material and axial load level.

When axial force acts on a wall with a cross-section the flange wall will be subjected to compression. One side of wall will act in an opposite to tension force and same direction to compression force; these conditions make compression force become higher than pure flexural force. The stress distribution produce by tension, compression forces and axial force is nonlinear; to simplify the representation of nonlinear stress and strain distribution a fictitious geometrical shape like a square with a total area of the same proportions of strain or stress distribution. Effective flange width is the area of stress distribution (A) divided by maximum stress of stress distribution (σ_{max}).

Effective flange width is different in some standards; the US standard for effective flange width for a single wing (right or left side flange) is the minimum between one-four height of the wall (h) and half of distance between an adjacent walls web (L). In Japan the standard effective flange width for a single wing depends on minimum of the six time wall thickness (t) and one-four distance between an adjacent walls web (l').

The objectives of this study are to evaluate the provision in the current standard for effective flange width in tension and compression, to clarify high compression stress in flange walls, and clarify the effect of porous sub-standard concrete on effective width

2. EXPERIMENTAL METHODS

Symmetrical cross-section reinforced concrete walls used in this study are H-shaped. This form factor has good stability when subjected to tension and compression forces, as the wall has the same flange on both sides. H-shaped walls are designed according to the Japanese standard. Specimen are three symmetrical cross-section H-shaped type wall with the same reinforcement steel bar design and geometry used in this study (H1, H2 and Hx) which have length of web wall 1000 mm, height 1000 mm with a thickness of 80 mm. Connected to both edges are flange walls, both with dimensions of length 1250 mm, height 1000 mm and thickness 80 mm. Two specimens are of similar concrete quality, and one specimen is of different concrete quality. Specimen H1 is subjected to static cyclic lateral and axial load, specimens H2 and Hx are subjected to static monotonic lateral and axial load. The purpose of using different types of load is to facilitate the use of different types of stress-strain relationship model. Hx is porous sub-standard concrete specimen.

The samples of concrete and reinforcement steel bars collect for mechanical properties test as unconfined concrete compression strength test, concrete shear test and reinforcement steel bars tension strength test. Mechanical properties test use to develop stress-strain relationship model.

The specimens are 1/3 scale and use a customized 5 mm reinforcing bars diameter as longitudinal reinforcement and tensile reinforcement. Transverse reinforcement is 4 mm in diameter. Longitudinal reinforcement put in every 50 mm with a total of 19 rows. Longitudinal reinforcement spacing in the web and flange walls is the same. Transversal reinforcement is spaced every 100 mm with a total of 10 columns in the flange wall and 7 columns in the web wall. Tension reinforcement is mounted in both. Tensile reinforcement is installed in each end wall, 2 lines for the web wall and one for flange wall. The specimen reinforcement steel bars design and location of steel and concrete strain gauges is shown in Figure 1. The specimens have a slit (clearance) 10 mm between upper stab (beam for loading) and wall develop concentration force in the tension reinforcement.

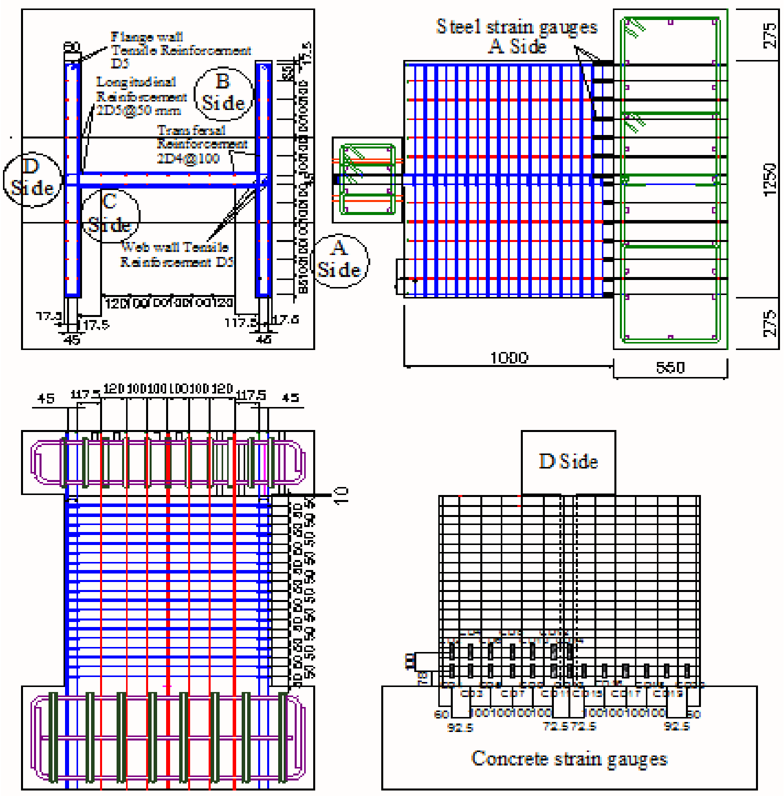

Figure 1. The specimen reinforcement steel bars design and location of steel and concrete strain gauges

A lateral static cyclic load and lateral monotonic load were applied to the top of the specimen. Constant axial load acts in the web wall is 0.07AgFc. Two loading protocol models were used. For specimen H1 a static cyclic lateral load and for specimens H2 and Hx a static monotonic lateral load.

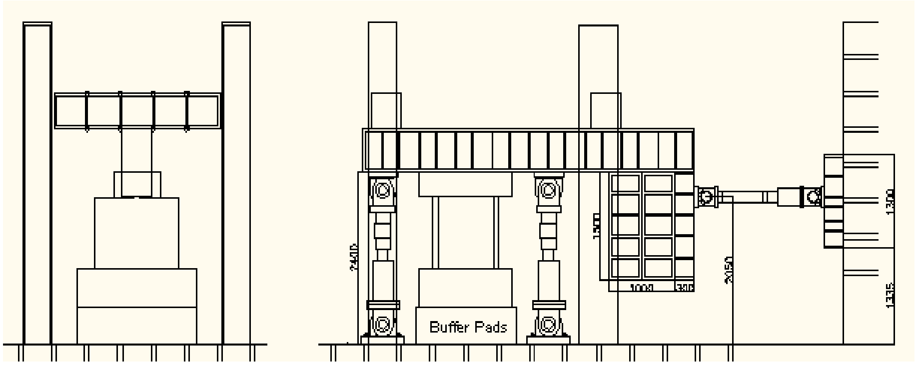

Figure 1 H-shape shear wall testing setup

The loading protocol consists of the following drift level: 1/6400, 1/3200, 1/1600, 1/800, 1/6400, 1/400, 1/200, 1/100, 1/66, and 1/50. For Cyclic each drift level is performed twice to see the deterioration. H-shape walls testing setup shown in Figure 1.

3. RESULT AND ANALYSIS

Figure 2. shown test result for all specimen. Specimen H1 and H2 had good performance and ductility when subjected to lateral force and Hx specimen lower than ultimate shear design capacity.

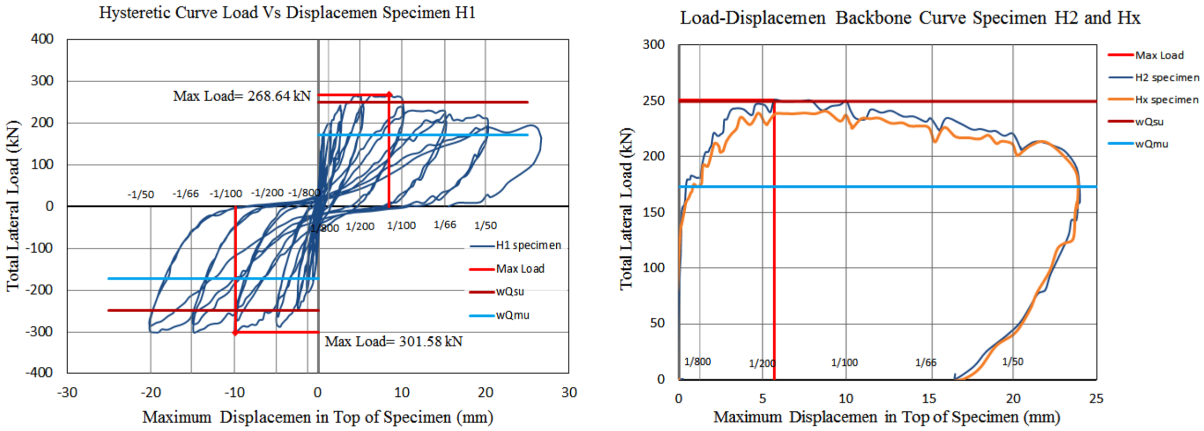

Figure 2. Hysteretic curve load vs. displacement, specimen H1and Backbone Curve H2 and Hx

Reinforcement strain distribution is one of the data outputs of the H-shaped wall testing. This data is required to obtain the stress distribution area (A) and maximum stress of stress distribution (σ_{max}) and to calculate effective flange width.

The mechanical properties testing materials is a very important part of this study. The output of this testing is used to making a stress-strain relationship model for stress-strain conversion. The results of steel reinforcement bars strength test is shown in Table 1.

Table 1. Result of steel tensile strength test

Steel bars	Fracture strain (%)	Maximum load (kN)	Yield strength (N/mm^2)	Yield strain (%)	Tensile strength (N/mm^2)	Yield ratio	Young's modulus (N/mm^2)	2nd Stifness (N/mm^2)
D4	23.11	11.30	354.02	0.194	514.06	1.45	182763	3315.5
D5	17.48	7.00	374.12	0.216	498.03	1.33	173005	2691.6

Table 2 shown unconfined concrete compression strength test result. Analysis of specimen testing results in order to calculate effective flange width for symmetrical cross-section walls is based on modeling mechanical properties of the materials. Each material will employ a different model and each reinforcement diameter will have another model, also model for different types of loading.

Table 2. Results of unconfined concrete compression strength test

Specimen	Height (mm)	Maximum Load (kN)	Young's modulus	Strain when maximum (%)	Compressive strength (N/mm2)
H2	201.6	240.6	26886.29	0.184	30.587

This study has been divided effective flange width into tension and compression. The tension effective width is all from steel strain gauge. Total data of tension effective width from these studies is ten sides. The maximum effective flange width in H1 specimen A side is 1154.2 mm drift 1/50(1) and load level 211.06 kN, B side is 1136.9 mm drift 1/66(2) and load level 222.77 kN, C side is 1094.7 mm drift -1/100(2) and load level -271.57 kN, D side is 1105.3 mm drift -1/100(2) and load level -271.57 kN. The maximum effective flange width in H2 specimen A side is 1201.2 mm drift 1/100 and load level 249.86 kN, B side is 1200.9 mm drift 1/100 and load level 249.86 kN, C side is 1201.6 mm drift 1/50 and load level 220.58 kN. The maximum effective flange width in Hx specimen A side is 1201.1 mm drift 1/400 and load level 220.09 kN, B side is 1200.2 mm drift 1/100 and load level 237.17 kN, C side is 1201.4 mm drift 1/100 and load level 237.17 kN.

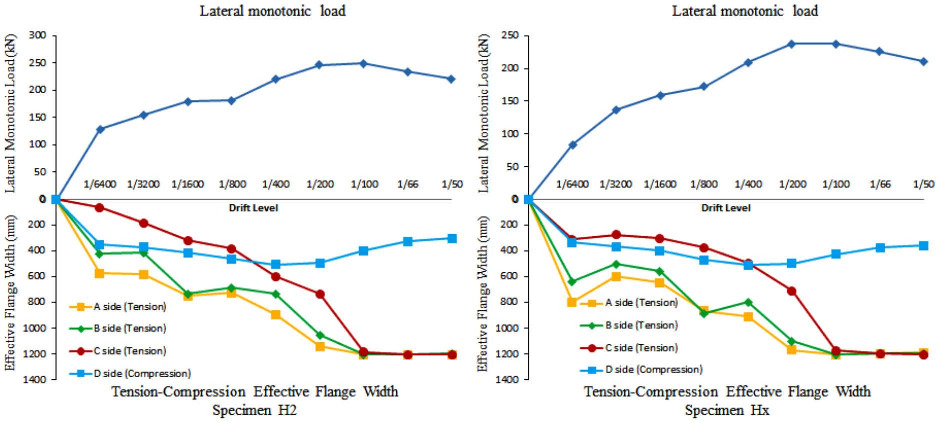

Figure 3. Effective flange width both wings for specimen H2 and Hx (different concrete quality)

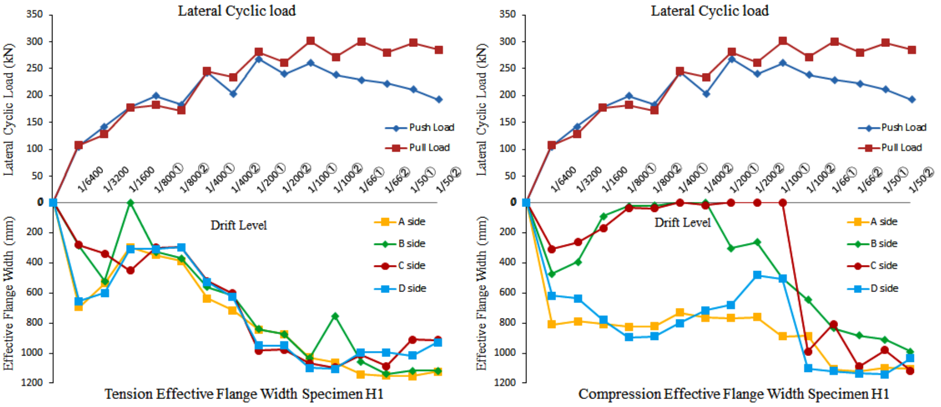

Figure 4. Tension and compression Effective flange width both wings specimen H1

The compression effective width is from steel and concrete strain gauge. Total data of compression effective width from these studies is seven sides. The maximum effective flange width in H1 specimen A side is 1120.4 mm drift 1/50(2) and load level 192.52 kN, B side is 987.8 mm drift 1/50(1) and load level 211.06 kN, C side is 1120 mm drift -1/66(2) and load level -280.60 kN, D side is 1140.3 mm drift -1/50(2) and load level -285.48 kN all data from steel strain gauges.

The maximum effective flange width in H2 specimen from steel strain gauges in D side is 909.1 mm drift 1/400 and load level 220.09 kN, and from concrete strain gauges in C side is 1080.23 mm drift 1/50 and load level 220.58 kN. The maximum effective flange width in Hx specimen from steel strain gauges in D side is 912.5 mm drift 1/400 and load level 209.35 kN.

The difference between the widest and narrowest values is very small. This proves the validity of the results, as they are derived from many different types of data. The average maximum tension effective flange width is 1169.75 mm and compression is 1132.6 mm.

Figure 3 shows effective width of both wings is quite similar in specimens H2 and Hx have same design and type of loading. The difference is specimen Hx made from substandard concrete; however, it indicated that the concrete quality does not have significant effect on the results. Figure 4 shows the cyclic load compression is greater than tension. The cyclic loading results are different from monotonic loading. It is possible that this is because, in the cyclic load, walls experience alternating tension and compression that mean in the flange wall not just acting one type of force. This is increasing the potential high compression force occurred in the wall. These results have answered that in the design earthquake force building compression effective width have dominant contribution.

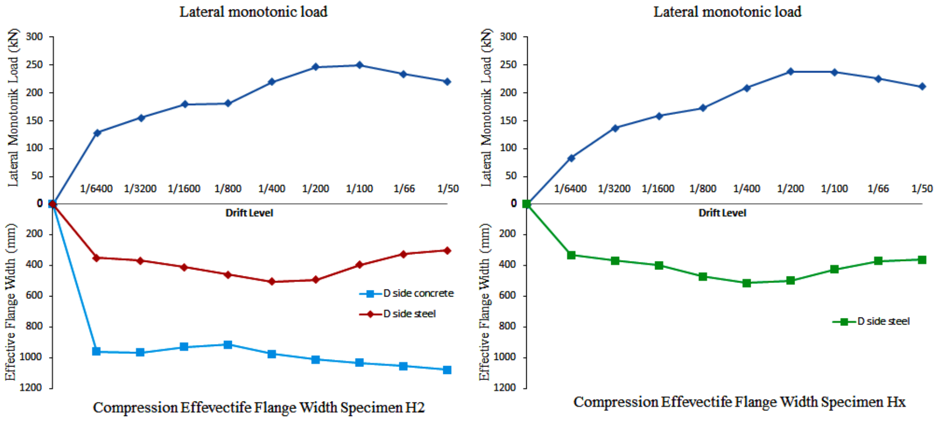

Figure 5. Compression effective flange width both wings concrete H2, steel H2 and Hx

Figure 5 shows the compression stress in reinforcement is about half of compression stress in concrete. The difference with the cyclic test is that compression stress in the reinforcement is almost the same as with monotonic compression stress in concrete.

So these mean compression stress must observe from concrete and reinforcement with cyclic force.

4. CONCLUSIONS

The conclusion of the study, in terms of verifying the standard provisions suggest that effective width for tension is larger than that currently proposed by the standard, indicating that the standard provisions would be inadequate for resisting flexural force. In terms of compression, standard provisions also need to be more conservative. Effective flange width provision in the Japanese standard is at slight variance with the test results, which suggest that 7 times wall thickness (7t) would be adequate. In this study the compression stress was greater than the tension stress. Compression was greater that tension stress in cyclic lateral load tests and almost similar in concrete. This indicates that in symmetrical cross-section walls with axial load the compression side must be considered as significant. The conclusion in terms of clarifying the effect of sub-standard porous concrete is that, in general, the quality of the concrete does not have a significant effect on the effective flange width.

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