SUMMARY

It is well known that wood frame structures perform well during seismic event, but damage assessments after actual earthquake have shown that most of the shear wall failure was due to cracking and tearing of GWB. In modern design the contribution of GWB in terms of strength and stiffness is not incorporated probably because there is a paucity of literature on role of GWB during seismic event. This study addresses specifically this aspect and shall present results from destructive testing of wood frame shear wall under monotonic and cyclic loading to describe load sharing between GWB and structural wood sheathing. This paper presents preliminary result of testing a standard prescriptive shear wall. The strain profiles and general load strain curve for both sheathings reveal that at 20 kN GWB fails with almost no strains in it whereas OSB shows high magnitude of strain. No apparent change in slope of load strain curve for OSB side is observed at the time when GWB fails.

INTRODUCTION

Majority of the buildings built in United States are wood structures. Traditionally wood structures have performed well during seismic events. However, damage assessment after 1994 Northridge earthquake suggested that the most of the shear wall failure was due to cracking and tearing of GWB. Pulling out of nails was also contributed to the failure. The total estimated damage worth was $ 40 billion and more than half of that amount was attributed to wood frame structures damages. 48000 housing units were rendered uninhabitable (Schierle, 2002). The question raised from this was how to improve existing code provisions and retrofit the existing structures to resist earthquake damages in future.

One school of thought attributes these losses to the fact that the contribution of GWB is not incorporated in design (AF&PA 2001). As shown in Table 1 GWB is slightly stiffer
Table 1. Stiffness for various sheathing materials used in wood frame shear wall construction

<table>
<thead>
<tr>
<th>Material</th>
<th>Modulus of Elasticity</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>OSB</td>
<td>6-8 G Pa</td>
<td><a href="http://www.fpl.fs.fed.us">www.fpl.fs.fed.us</a></td>
</tr>
<tr>
<td>PLYWOOD</td>
<td>7-10 G Pa</td>
<td><a href="http://www.fpl.fs.fed.us">www.fpl.fs.fed.us</a></td>
</tr>
<tr>
<td>GWB</td>
<td>11-13 G Pa</td>
<td><a href="http://www.modulararts.com">www.modulararts.com</a></td>
</tr>
</tbody>
</table>

than OSB or other sheathing material, but it is brittle. Since stiffness attracts load, in high probability major part of the load goes to the gypsum wallboard at time of the seismic event. But being brittle it cannot withstand the load after failure and subsequently cracks. In modern design this aspect is completely overlooked.

Propelled by the enormity of damages during the 1994 Northridge Earthquake, CUREE [http://curee.org/projects/woodframe/index.html] conducted rigorous testing and exhaustive study to come up with reasoning for the amount of damage. CUREE quantified the effect of GWB (McMullin and Merrick 2002) on the shear wall. But the extent of load sharing between different components of shear wall at the time of seismic event and how load shifts when GWB fails during a seismic event is not known. This study addresses specifically this aspect and will test shear walls under monotonic and cyclic loadings to try and answer the mystery of load sharing in wood frame shear wall assembly under various loading conditions. However, this paper presents preliminary results and discussion from monotonic tests.

LITERATURE REVIEW

As wood shear wall is the major lateral force resisting system in majority of the buildings, it has been the subject of various studies and research (Filiatrault 2001). However, there are a very few studies which described the contribution of GWB during a seismic event.

Wolfe (1983) tested 13 different types of wall, 30 walls in total, under monotonic loading using ASTM E 564 standard to study the contribution of GWB to the racking resistance of light-frame walls. Tests were conducted with varying wall lengths, GWB orientation and wind bracings. Wolfe concluded that GWB has a significant contribution in to racking resistance of the wall, which varies with panel orientation and wall length. Racking resistance of the walls with GWB and wind bracing were found to be the linear sum of resistance provided by each element. Horizontal orientation of panels was found to provide 40% greater strength and stiffness than the vertical oriented panels. The relationship between wall length ultimate shear strength was approximately linear, but wall stiffness was found to be a power function of length. The one failure mechanism consistent with all types of wall was the nail tearing and bending through paper surface. GWB had fastener failure at the bottom plate.

Karacabeyli and Ceccotti (1996) tested contribution of GWB on shear wall capacity of 2.44 x 4.88 m (8’ x 16’) walls. The tests concluded that GWB on one side and OSB on other increased the peak load but decreased ductility when compared to only OSB as sheathing. Also observed was that till small deflection of about 25 mm the law of superposition is valid to determine the lateral resistance but after that the relationship becomes complex.
Johnson (1997) performed monotonic testing on different type of walls with different opening ratios. On one side sheathing was of plywood and other side GWB. Observation about failure of GWB revealed that as drift increases tape joints around the opening begin to crack. At large displacements nail starts to pull out on the edges and tear the edges. Field nails also encounter some pull and lateral displacement.

Toothman (2003) tested shear walls under monotonic loading, with structural sheathing on one side and GWB on other and concluded that the contribution of Gypsum is not additive. For GWB sheathed walls the failure of nails started along the bottom plate and continued around the perimeter of the wall. The ductility of the walls sheathed on one side with GWB and on other side material such as OSB or plywood, increased by a substantial amount as compared to the sheathing material alone. When failure pattern was observed for walls sheathed on both sides, gypsum panels were always first to fail. This is because of the relative ease with which nail could tear the sheathing. Toothman concluded that by adding gypsum panel in the structure there is an increase in overall strength, elastic stiffness and energy dissipation before failure of the structure also GWB provides a substantial amount of shear resistance.

Gatto and Uang (2002) tested walls with different structural sheathing (OSB, plywood, GWB) using different protocols namely Monotonic, CUREE, ISO and Sequential Phased displacement protocols and quantified the differences in parameters such as peak strength, initial stiffness etc. They also analyzed the effect of GWB on peak strength, initial stiffness, absorbed energy and deformation capacity and observed 12% increase in shear wall strength and 31% decrease in shear wall deformation capacity. As GWB is stiff so it was expected that it increased the initial stiffness by 60%. One kip average strength increase corresponded well with one kip peak strength of GWB which was one kip justified the superposition of GWB and the structural sheathing as reasonable. But Toothman 2003, found similar results but concluded that principle of superposition is not valid.

**METHODS AND MATERIAL**

The test frame is shown in Fig 1. Specimens were bolted to a fabricated steel beam solidly attached to the strong floor to simulate a fixed foundation. Specimens were loaded using a 490 KN (110 kip) servo controlled hydraulic actuator with a 254 mm total stroke, and controlled by an MTS 406 servo controller. The hydraulic actuator is attached to the strong wall and supported by a 102 mm hydraulic cylinder. The 102 mm cylinder charged with oil over air accumulator with a pressure of approximately 690 kPa. This allows the actuator to raise and lower freely during the test without creating additional vertical loading on the wall.

*Fig 1. Test set up (Seaders 2004)*
WALL SPECIMEN

The schematic of the wall is shown in figure 2. The details are as follows:

**Studs:** 2 x 4, stud grade, Douglas fir, 610 mm (16") o.c.

**Structural Sheathing:** 12 mm (15/32"), exposure 1, OSB

**Nail edge spacing:** top, bottom, outer edges - 19 mm (3/4"), inner edge - 13 mm (1/2").

**End Posts:** Two 2x4s, nailed 16 d common nails at 610 mm o.c.

**Bottom plate:** One 2 x 4.

**Top plates:** Two 2 x 4s, nailed 16d common nails at 305mm (1') o.c.

**Stud to plates:** Two 16 d common nails

**Anchorage:** Four 16 mm (5/8") A307 bolts 64 x 64 x 6.5 mm (2.5" x 2.5" x 0.25") washers

**Hold downs:** Two Simpson’s PHT 16 Tie-down with sixteen 16d sinkers and 15.9 mm (5/8") A307 bolts to foundation (at corners)

![Fig 2. Schematic of wall (Seaders 2004)](image1)

**DATA ACQUISITION**

Digital Image Correlation (DIC) is a full-field, non-contact technique for measurement of displacements and strains. The set up consist of a pair of cameras arranged at an angle to take stereoscopic images of the scene. The system returns full field 3D displacement and strain data measured over the visible specimen surfaces. It allows measurement of large deformations and strains, far beyond elastic limits of materials, so failure initiating events and post failure strain development may be observed and analyzed.

It works on the principle that surface deformation is same as the image deformation. So by measuring displacement by matching any point between two images of specimen at different state of deformation the strains can be calculated with the help of software. Required is therefore a texture in the area of interest. This texture could be applied or naturally occurring. The set up consist of a pair of camera mounted on a tripod as shown
in Fig 3. The camera is focused on the shear wall and triggered by an external signal. To calculate displacement at any point, a small subset of pixels is used. This subset has a unique light intensity pattern and the DIC software searches the best matching subset in deformed image using mathematical correlation of intensity patterns.

The subset that gives the highest coefficient of correlation is located on that point of interest. Strain is calculated from the gradient of displacement. The data hence acquired is in the form of images, which are translated into data series and plotted against load. The software also gives us the advantage to calculate strain any where in the sheathing and hence we are not limited to just a few points. One essential aspect is the quality of the images and light intensity. A good balance and exposure is essential to allow the computer algorithm to track the random texture reliably.

RESULTS AND DISCUSSION

Results from one wall tested to failure are hereby discussed. The loading was monotonic and the typical load deflection curve of the wall is shown in Fig 4. The load deflection curve shows the deflection of the top of the wall as load increases.

The results are presented for the bottom middle of the wall where the corners of two panels meet and focused on four fasteners on either side. Strains local to fastener for both the panels (OSB and GWB) were analyzed and strain profile for corresponding areas extracted.

![Fig.4. Load Deflection Curve.](image)

![Fig 5. Load Vs Strain (e_{xx}) in GWB & OSB](image)

Figs 5 show the Load Vs Strain curve for GWB and OSB for areas shown (box) in Fig. 6 (A1-A2). The particular areas were chosen after analysis as most of the strain was found to be in these areas. The strain in the area of interest was averaged for 25 x 25 mm square area and then plotted against load. As shown in Fig. 5, the strains in GWB till 20 kN are very small (e_{xx} 0-1000) and after that point the panel starts to deform significantly. OSB, on the other hand encounters higher strain than GWB during the initial stage of loading. However because GWB is stiff the strain is low till 20 kN and then there is a drastic increase in strain indicating failure of GWB panel. After GWB fails at 20 kN, the strain keeps on increasing progressively in OSB (Fig 5) till wall fails at 35 kN.

Some key observations from fig 5 are:

- The strain in GWB side is small (steep slope of curve) as compared to OSB during initial stages of the test. As shown in Table 1 it is clearly seen that GWB is twice as stiff as OSB, small strain during initial loading in GWB was expected.
- The progression of strain in OSB is uniform and there is no apparent kink at 20 kN mark where GWB failed. However, there is a change in slope around 20 kN in the OSB strain load curve indicating more load taken by OSB.
• After the failure of GWB (20 kN) the strain in the area of interest increases rapidly. This is mainly due to the tearing of paper cover after which the material crumbles and ruptures essentially falling apart increasing the magnitude of localized strain. The strain in GWB at failure of wall (35kN) is almost double than that of strain in OSB.

Figure 6 (A1 through G2) shows the progressive distribution of strain with respect to each fastener for the two panels till failure on either side. The dark green color shows the strain in that area is below the detection limit of the system and all the various color contours show the tensile and compressive strain in accordance with contour scale shown in Fig. 6. The negative sign depicts tensile strain while the positive strain refers to compressive strain. Table 2 is the numeric interpretation for the photographs in Fig 6.

At 5 kN (A1 & A2) there is hardly any strain in GWB while very little strain in OSB. Most of the panel is colored in shades of green, hence very small amount of strain in that area. Similarly for 10 kN the GWB (B1) does not experience any strain while there is a little bit compressive strain developing (light green color) in the area of interest (B2). As the load increases to 15 kN the strain near the fastener 2 on the GWB side increases in magnitude (C1) but no strain in the area of interest. On the OSB side (C2) the strain near fastener 1 now starts to increase. At 20 kN marked area show some strain in GWB panel and in OSB the strain is increasing progressively. The compression and tension areas along the side of the fastener 1 on both GWB and OSB side are clearly visible (D1 & D2) and the strains concentrated along the fastener creating a high strain zone localized to the fastener. The strain in the area of interest also increases for both OSB and GWB side significantly. At 25 kN Figure 6-E1 shows that GWB side has failed by now and the corner is experiencing high tensile strain and high compressive strain in the marked area. As the load increased past 20 kN the tearing of paper caused the material inside to rupture and fall out. On the other hand the strain around the fastener 1 on OSB side (Fig 6-E2) is increasing and there are no detectable strains in the field but significant compressive strain in the area of interest. The left panel for GWB is in high tension near the corner (F1) of the panel whereas on either side of the fastener 1 there is tension and compression area on the OSB side (F2) at 30 kN and high strains over the area of interest. At failure of the wall at 35 kN the marked areas show high magnitude of strains and the corner of left panel of GWB which was in high tension has totally ruptured and parts of material have fallen of from the corner (G1) and hence a high tension strain value is recorded. On the OSB side (G2) the strain has increased in magnitude and area around the fastener 1, 2 and 3 while nothing is recorded in the field of the panel.

Table 2 also supports the fact that strain in GWB is in the range of 200-1100 micro strains till 60% of failure load whereas the strain in the OSB panel varies from 200-2000 micro strain for the same period. But after 20 kN mark the strains in GWB increases rapidly, which leads to six time as much strain at failure in GWB than in OSB in the horizontal direction.

Table 2. Strains at various stages of loading.

<table>
<thead>
<tr>
<th>Strain</th>
<th>Material</th>
<th>0</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>30</th>
<th>35</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e_{xx}$</td>
<td>OSB</td>
<td>728</td>
<td>801</td>
<td>1090</td>
<td>1490</td>
<td>1927</td>
<td>2281</td>
<td>3068</td>
<td>4059</td>
</tr>
<tr>
<td></td>
<td>GWB</td>
<td>0</td>
<td>114</td>
<td>107</td>
<td>165</td>
<td>1141</td>
<td>12506</td>
<td>19785</td>
<td>24970</td>
</tr>
</tbody>
</table>
Fig 6. Progressive distribution of strain near the fastener.
CONCLUSIONS

As load is increased on the wall higher strain in the OSB side is seen as compared to GWB side until GWB fails at 20 kN which is expected because of stiffer nature of GWB. After GWB fails, it shows high magnitude of strain, which could be attributed to the tearing of paper cover of the GWB. Once the paper tears open the material within crumbles and ruptures which reflects higher value of strain. A change in slope of load strain curve for OSB side is observed at the time when GWB fails (20 KN). Given that the stiffness for GWB is twice as much of OSB, we observe smaller strain for initial period of loading and then after failure of GWB a sudden increase whereas in OSB there is steady build of strain till failure of the wall.

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REFERENCES


