COMPARING THE SEISMIC PERFORMANCE OF UNIBODY AND CONVENTIONAL CONSTRUCTION ON A TWO-STORY WOOD-FRAME HOUSE

C. Acevedo¹, G. Deierlein², E. Miranda², B. Fell³, S. Swensen⁴, E. Jampole⁵

ABSTRACT

A two-story wood light-frame house was designed and analyzed using two design approaches. The first design followed the current practice (conventional) approach, where only shear wall panels were considered using the typical response modification factor (R = 6.5). The second design followed an innovative approach, known as the “unibody”, where non-structural walls were considered and no response modification factor (R = 1.0). This paper presents the results of these two structures and discusses the advantages of the “unibody” approach over current practice in terms of damage performance. The models were created with OpenSees and the house layout was obtained from a full-scale specimen tested at the University of California, San Diego outdoor shake table constructed using the unibody approach. For the conventional house, the structure was modeled two ways: 1) with shear panels only and 2) with shear panels and non-structural sheathing (i.e., gypsum and stucco). Meanwhile, for the unibody house, non-structural sheathing was considered for the lateral resistance system. The house designed with the unibody approach was virtually undamaged at the desing level, with mean drift of 0.18%, while the conventional saw a mean drift of 2.39%. As a result, the unibody design is less susceptible to damage for the design earthquake than the conventional house. Future work will further investigate how vulnerable the conventional structure is when considering all the non-structural elements in the analysis.

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A two-story wood light-frame house was designed and analyzed using two design approaches. The first design followed the current practice (conventional) approach, where only shear wall panels were considered using the typical response modification factor ($R = 6.5$). The second design followed an innovative approach, known as the “unibody”, where non-structural walls were considered and no response modification factor ($R = 1.0$). This paper presents the results of these two structures and discusses the advantages of the “unibody” approach over current practice in terms of damage performance. The models were created with Opensees and the house layout was obtained from a full-scale specimen tested at the University of California, San Diego outdoor shake table constructed using the unibody approach. For the conventional house, the structure was modeled two ways: 1) with shear panels only and 2) with shear panels and non-structural sheathing (i.e., gypsum and stucco). Meanwhile, for the unibody house, non-structural sheathing was considered for the lateral resistance system. The house designed with the unibody approach was virtually undamaged at the design level, with mean drift of 0.18%, while the conventional saw a mean drift of 2.39%. As a result, the unibody design is less susceptible to damage for the design earthquake than the conventional house. Future work will further investigate how vulnerable the conventional structure is when considering all the non-structural elements in the analysis.

Introduction

The majority of residential structures in countries such as the US, Canada, Japan, and New Zealand are made out of wood light-frame, especially in seismic areas. In general, wood structures have performed relatively well during earthquakes in terms of collapse. As codes and standards continue to improve the design guidelines, most of the focus is on collapse safety and little to prevent the structure from getting significantly damaged during a seismic event. The current design procedure for the lateral resisting system (i.e., shear walls) of a wood structure is through the use of response modifications factors ($R$-values). These $R$-values could be as large as 6.5 when sheathing the shear walls with oriented-strand board (OSB) or plywood, and as low as 2 when using other materials. The latter is restricted depending on the seismic category of the site \cite{1}. As a byproduct, these

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structure would undergo significant damage during earthquakes which may lead to economic losses and societal disruption as seen in past events such as the 1994 Northridge Earthquake, where there were billions of dollars in losses and thousands of displaced households [2]. To improve this vulnerability in our current design codes and standards, the authors of this paper have developed a low-cost design and construction approach, which significantly improves the seismic performance of wood light-frame structures, known as the “unibody” design methodology. This approach increases the strength and, particularly, the stiffness of the lateral resisting system by integrating architectural non-structural walls and finishes (e.g., gypsum wallboard, stucco) with structural framing elements, such as the wood studs, to work together as one unit to resist the lateral demands of an earthquake. Although non-structural elements are not accounted for seismic design, there have been many studies showing how these elements increase the strength and stiffness of the overall structure [3]. The unibody approach builds on these previous studies, but focused on ways to better engage these non-structural walls and finishes to the framing for improved performance. Several tests have been conducted by the authors in order to validate this new approach. Fig. 1 shows the road map to the development of the unibody methodology, from small-scale quasi-static to large-scale dynamic tests.

The development sequence of the unibody methodology began with small connector and wall tests, where [4, 5] showed how using off-the-shelf connectors such as construction adhesive and stronger fasteners could increase the lateral resistance strength by up to two times and the stiffness by up to three times. Furthermore, at the large scale level, [6, 7] corroborated the findings of the small connector tests by testing full-sized walls and room assemblies. These large-scale tests showed that using construction adhesive can increase the stiffness by up to 2.6 times and the strength by 2 times for interior walls (i.e., gypsum on both sides). As for exterior walls, only using non-structural elements (i.e., stucco and fiberglass mat-board on exterior side, and gypsum type-X on the interior) the stiffness can increase by at least 3.9 times and the strength by at least 1.5 times when compared to a typical exterior shear wall (i.e., stucco and wood structural panel on exterior side, and gypsum on the interior). Finally, [8] conducted a shake table test of a two-story wood-frame house using the unibody methodology to verify the proof of concept. The results showed great performance with virtually no damage when subjected to the Capitola 000 record (PGA = 0.56 g, as achieved by the table) scaled up three times. This paper investigates the performance of a two-story house designed with the unibody approach compared to one designed using the current conventional method.
Two-Story House Design Summary

The layout chosen for this numerical comparison, was the same as the house tested by [8] as seen in Fig. 2. The design followed ASCE7-10 guidelines [1] and the International Residential Code [9]. The conventional house was designed with an R-factor of 6.5, while the unibody house used an R-factor of 1, Table 1 shows the design base shear for each structure. The house was assumed to be located in Palo Alto, on site class D soil. The lateral resisting system considered for the conventional wall consisted of 11.9 mm thick structural panel with 10d nails spaced at 102 mm on edges and 305 mm in field. Although the the gypsum was not considered in the design, it was included in the analysis. On the other hand, the unibody’s lateral resisting system included all of the exterior and interior walls. The exterior walls consisted of 22.2 mm stucco and 15.9 mm fiberglass mat-board on exterior side and 15.9 mm gypsum type-X on the interior side. The interior walls were sheathed with 15.9 mm gypsum type-X on both sides. All sheathing in the unibody was attached with #6 screws spaced 178 mm at edges and 305 mm field. The stucco mesh was attached to the wood framing with 6.4 mm Dia x 64 mm screws spaced at 102 mm at edges and 178 mm field. Both houses were subjected to 12 pairs of ground motions with Sa conditioned at T1, applied bi-directionally using OpenSees.

![Figure 2. Two-story house floor layout.](image)

<table>
<thead>
<tr>
<th>Structure</th>
<th>$V_{\text{base}}$ [kN]</th>
<th>T1 [s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>37</td>
<td>0.607 (0.519)*</td>
</tr>
<tr>
<td>Unibody</td>
<td>259</td>
<td>0.105</td>
</tr>
</tbody>
</table>

*With 12.7 mm gypsum on the opposite side

Preliminary Results and Conclusions

A multiple stripe analysis was performed for both cases. Table 2 shows the preliminary results of the two houses. As can be seen, the unibody house is on average virtually undamaged at the design level (where damage is typically visible at 0.2% drift). On the other hand, the conventional house, considering only the wood structural panel in the design and accounting for gypsum in the analysis,
does not perform well in terms of damage. At the MCE\textsubscript{R}, the unibody gets damaged while the conventional goes to collapse. For future work the conventional structure will be analyzed considering stucco and interior non-structural walls for better comparison.

Table 2. Mean Peak Story Drift from 12 Ground Motion Pairs

<table>
<thead>
<tr>
<th>Structure</th>
<th>Mean Peak Story Drift [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DLE</td>
</tr>
<tr>
<td>Conventional</td>
<td>2.37*</td>
</tr>
<tr>
<td>Unibody</td>
<td>0.18</td>
</tr>
</tbody>
</table>

*Nearly all ground motions caused collapsed

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