TITLE: RESPONSE OF OPEN FLOOR AND ROOF FRAMING TO FORCES CAUSED BY ACCIDENTAL FALLS AND RECOMMENDATIONS FOR REGULATORY CHANGES TO IMPROVE WORKERS SAFETY

OBJECTIVES
To evaluate the response of open floor and roof framing to forces caused by a falling object under simulated conditions that are typical in residential construction.

To evaluate the performance of conventional Personal Fall Arrest Systems (PFAS) and their impact on worker safety.

To persuade safety regulatory agencies to change the way fall protection is currently regulated.

CONCLUSIONS
1. A six foot drop of a 250 pounds object, using PFAS consisting of a life line with a shock absorber connected to a harness, induces a force on the structural system in the range of 700 pounds to 1,100 pounds.

2. As expected, straight-down falls yield the highest force on the body and the structural system.

3. The response of our partially framed truss roof that was temporarily braced according to Wood Truss Council of America and Truss Plate Institute (WTCA/TPI) guidelines and exposed to various kinds of forces from a falling object with a personal fall arrest system (PAFS) was excellent.

4. The partially framed truss roof that was temporarily braced according to common construction practices, when exposed to similar forces from falls, the WTCA/TPI braced roof performed very well and exceeded expectations. The WTCA/TPI guidelines for temporary bracing were conservative for the building configuration and structural system used in this study.

5. Top chord bracing at mid-span only, was not sufficient to prevent lateral instability when the fall was perpendicular to the direction of the structural system and away from the line of bracing, even when PFAS was used to reduce the force exerted by the falling body.

6. Anchorage from a single truss using a tie-off strap was acceptable as long as the anchorage is near the line of continuous bracing and the whole system was adequately braced. Direct bracing of the wide face of the top chords prevents roof truss lateral instability when exposed to forces perpendicular to the span direction.

7. 2x4 lumber bracing connecting the narrow faces of top chords in a discontinuous manner was ineffective in maintaining lateral instability when the fall was over the gable end and away from the line of bracing.
8. A rigid steel bar that tied multiple trusses together was always preferred because it distributed the load from the fall to multiple trusses decreasing the stresses on any single member and thus increasing system reliability and safety.

9. In open floor framing, anchorage from a single I-joist using a tie-off strap worked well as long as the anchorage point was near a line of blocking, as was the case over an interior bearing wall. A rigid bar that tied off multiple I-joists was always preferred to distribute the load from a fall to adjacent members.

10. The force on the structural system and the human body after a fall can not be adequately predicted by basic principals. The predicted response was always higher than the actual measurement.

RECOMMENDATIONS

1. Cost-effective PFAS technologies are currently available to safeguard workers against injury and death. We recommend changing the OSHA interim fall prevention guidelines to include fall protection with PFAS.

2. Well-designed fall protection with PAFS, consisting of a shock absorber, harness and life line, performed well in a properly braced floor or roof framing system. The anchoring location should be at or near a continuous line of bracing to prevent system collapse caused by lateral instability.

3. Anchorage off a single truss or a single I-joist in a properly braced open roof or floor system is acceptable as long as the anchorage point is at or near a continuous line of bracing.

4. Fall protection with PFAS should be used only with properly braced roof or floor framing systems. A well braced gable end, along with the MiTek Stabilizer® 24 brace placed strategically along the length of the truss constitutes a properly braced roof system.

5. Anchorage from a rigid element that ties together multiple components of a partially framed floor or roof further improves system reliability and safety. More research is needed to identify light-weight and cost-effective options to encourage implementation in the field.
BACKGROUND/PURPOSE
Falls are the leading cause of death and serious injury in residential construction. OSHA regulation (Standard 1926.501) specifies fall protection for heights above six feet. In December of 1995 OSHA revised the regulation and published an interim fall protection compliance policy for fall protection for certain residential construction activities. Under this interim fall prevention guideline, workers are allowed to work at heights above six feet freely without utilizing conventional or personal fall arrest systems (PFAS). The leading argument has been that requiring conventional or PFAS is either not feasible or creates a greater hazard to the workers. Since the current interim guideline has been in place, the frequency and severity of falls in residential construction has been steadily increasing year after year.

According to the National Association of Home builders (NAHB), the residential construction fatality rate is 8.35 deaths per 100,000 full-time workers, approximately 2.2 times greater than private industry in the U.S.. From 2003-2006 there were 602 fatal falls in residential construction.

During the 13 years this interim guideline has been in place, innovation and technology have developed to a point where we no long need to expose our workers to unnecessary risks that lead to tragedy. Testing conducted elsewhere shows that it is feasible and reduces risks of serious injury and/or death if conventional fall prevention systems are utilized to include PFAS.

Weyerhaeuser Real Estate Company (WRECO) is leading an effort to improve safety practices amongst its various home building divisions and currently has cautious support from key entities involved in home building and building safety. The path chosen is to demonstrate through science and testing that doing away with the current interim guideline and implementing enforceable fall protection technologies will improve safety in residential construction and drastically reduce or eliminate injuries resulting from falls.

The Weyerhaeuser Technology Center (WTC) was chosen to develop and carry out a test program to evaluate conventional fall protection technologies under controlled conditions and recommend options for implementation.

1.0 APPROACH
To evaluate the effectiveness of conventional fall protection with PFAS under various construction situations, the team involved in the project agreed to build a typical one-story, 20-foot by 24-foot building with open floor and roof framing. Sponsorship for the project and guidance was provided by WRECO. Prefabricated components, including walls and trusses, were donated by Woodinville Lumber. A Woodinville Lumber framing crew, with a boom truck operator, assisted with the erection of the building and the implementation of the test program. PFAS was provided by Super Anchor, a manufacturer and advocate of fall protection systems, along with support and guidance during the various phases of the project.

It was decided early on that it was prudent and desirable to use a fall arrest protection system that was practical and cost-effective with a high likelihood of being used on the job site. The system consisted of a harness and a lanyard with a shock absorber attached to a rigid object that emulated a 250 pound worker falling from a height of six feet. Two types of open framing construction were chosen to conduct the tests: roof trusses and floor I-joists. Key variables in the test program included: alternatives in temporary bracing, fall variations and anchorage options.
1.1 Building Construction
Woodinville Lumber designed and fabricated the walls and roof trusses. Drawings of the prefab walls are displayed in Appendix B. The prefab walls were assembled on a level wooden foundation with the help of a boom truck. The perimeter walls were 10 feet high and consisted of 2x6 studs and 7/16 inch OSB sheathing. A 10-foot high, 2x4 interior wall without sheeting, connected the west and east sides of the building. Stud spacing was 16 inches on-center (o.c.), unless otherwise noted on the plan.

A typical 24-foot Fink truss with a 4:12 top chord slope and with a 16-inch overhang was used to frame the roof. Top and bottom chords were made from Hem-fir (HF) 2x4 lumber grade No 2. Truss webs were made from 2x3 Spruce Pine Fir (SPF) stud/std grade. Appendix A displays the truss configuration and design information. Five trusses were used in total. All trusses were of similar design, except the gable-end truss which was delivered to the site with sheeting on its outside face.

The partial roof with the five trusses was assembled on the ground and lifted in place with the help of the boom truck. Bird blocks were used to tie the truss tails together and a MiTek Stabilizer® 24 to brace the top chords of the trusses at the quarter point along the span, as commonly done in the field. The truss bottom chord was secured to the top plates of the wall with 2-10d (3-inch) box nails.

In addition to open roof framing, partial open floor framing consisted of five TJI’s and was assembled on the ground and then lifted into place with the assistance of the boom truck. The TJI’s were of grade 110 with a depth of 9-1/2 inches spaced at 19.2 inches o.c. They were designed to span 13 feet in a two-span continuous condition under a typical design load. Blocking was provided over the bearing wall and the top flanges were braced at midspan per the manufacturer’s specification. The bottom flange of each I-joist was secured to the top plate of the wall with 2-10d (3-inch) box nails.

1.2 Open Roof Framing - Temporary Truss Bracing
Two methods were used to temporarily brace the trusses. Method 1 was based on the Building Component Safety Information (BCSI) guide, BCSI-B1, that was developed jointly by the Wood Truss Council of America (WTCA), and the Truss Plate Institute (TPI) published in October of 2006. Method 2 was more representative of “real world” construction and depicts how roof framers in the Northwest normally secure the gable end truss and laterally support roof trusses as they are rolled from one end to the other end of the building.

Figure 1 shows the temporary bracing scheme for the gable-end truss based on the WTCA/TPI temporary bracing guidelines. It shows that the gable-end truss is solidly braced from the ground level up. The top and bottom chords of the remaining four trusses that make the partial open framing roof were also braced accordingly. The WTCA/TPI bracing guidelines allow alternative uses of bracing for the top chord. The MiTek Stabilizer® 24 metal brace is such an alternative to 2x4 lumber and was used in this case to space the trusses and laterally support the top chords at two locations on either side of the peak.
Figure 1. Temporary bracing scheme according to WTCA/TPI guidelines.

Figure 2 shows the temporary bracing scheme according to method 2 (common construction practice). The gable-end truss is secured in place with one 2x4 vertical brace from the outside and a diagonal 2x4 brace that spans from the top of the gable-end truss to the top plate of the interior wall. The truss top chords are braced with the MiTek Stabilizer® metal braces at mid-span near the peak.

Figure 2. Temporary bracing scheme according to “common construction practices”.

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1.3 Open Floor Framing - Temporary I-Joist Bracing

The open floor framing consisting of 9-½ inch TJI 110 joists at 19.2 inches o.c. was temporarily braced with 2x4 lumber according to the TJI joist installation specification. Figure 3 shows the bracing scheme that was used for the I-joist floor to laterally support the top flange of each I-joist and the blocking over the interior bearing wall.

Figure 3. Temporary bracing of the top I-joist flange in open floor framing.
1.4 Fall Protection Equipment
The PFAS that was deployed in this study is displayed in Figure 4 below.

Figure 4. Equipment for fall arrestor protection system.

A. Fall Arestor® Body Harness model 6008-5, rated for 6,000 pounds, meets ANSI A10.14.9 and OSHA 1926.502; 300 pounds capacity, single user

B. Fall Arestor® Life line with snap hook, 300 pounds maximum capacity single user

C. Fall Arestor® shock absorber, maximum 42 inches travel, meets ANSI A.10.14.91 and OSHA 1926:502
1.5 Anchorage Systems

Figure 4 also displays the various anchorage systems that were used in our test program.

D. Fall Arestor® Tie-Off Strap, maximum 5,000 pounds load, complies with OSHA 1926:502, not to exceed 300 pounds user weight. Use only locking snap hooks or locking carabiners for connection hardware

E. Super Anchor™ Safety Bar, one-person rated

F. Super Anchor® ARS 2x4, 14 galvanized stainless steel; rated for 5,000 pounds, complies with OSHA 1926 (Subpart M), maximum user weight of 300 pounds.

1.6 Instrumentation

Force data from the falling 250-pound dummy was captured via a 5,000-pound capacity, Omega LCCA-5K, load cell transducer. The device was positioned directly in-line between the structural member and the fall protection lanyard attached to the dummy. The load cell signal was hardwired to a Daytronic 3230 signal conditioner (+5V) and a National Instruments NI SCXI 1600 16-bit digitizer and a SCXI 1120 isolated analog input module. Data was collected utilizing a USB interface with a National Instruments Labview program on a laptop to capture 2,000 samples per second with a total collection size of 15 seconds. The start of each test was initiated by an electronic trigger attached to the data acquisition system. A few moments later, the dummy was dropped using a quick release mechanism attached to an overhead crane.

1.7 Test Program

The test matrix for the Fall Protection program is displayed in Table 1 on the next page. There are two types of framing systems: open roof framing using a fink truss with 4:12 top chord slope spaced at 24 inches o.c. and open floor framing using 9-½ inch TJI’s 110 at 19.2 inches o.c.. There were four different variations of falls: straight down, over the gable end, over the eave, and over the truss tail (for truss roof system only). The temporary bracing requirements were as described above in sections 1.2 and 1.3 for open roof framing and open floor framing, respectively. The anchorage options ranged from the simple tie-off strap from a single truss to the load distributing steel bar. Not all variations of the full factorial were carried out in this test program, but enough testing was done to cover the practical range of outlined variables.

Figure 5 on page 10 displays a simple diagram indicating the open roof framing set up and the anchorage locations. The fourth truss from the west gable end was used for all open roof framing falls and the fourth I-joist from the east gable end was used for all open floor framing falls.
<table>
<thead>
<tr>
<th>Fall type</th>
<th>WTCA/TPI bracing guidelines</th>
<th>Open Floor Framing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straight down</td>
<td>Test 1 (Fall Arestor® Tie-Off Strap on truss #4)</td>
<td>Test 5 (Fall Arestor® Tie-Off Strap on truss #4)</td>
</tr>
<tr>
<td></td>
<td>Test 1a (Super Anchor™ Safety Bar on trusses 3,4,5)</td>
<td>Test 12 (Fall Arestor® Tie-Off Strap on I-joist #4 near mid-span)</td>
</tr>
<tr>
<td>Over gable end</td>
<td>Test 2 (Fall Arestor® Tie-Off Strap on truss #4)</td>
<td>Test #6 (Fall Arestor® Tie-Off Strap on truss #4)</td>
</tr>
<tr>
<td></td>
<td>Test 2a (Super Anchor™ Safety Bar on trusses 3,4,5)</td>
<td>Test #9 (Fall Arestor® Tie-Off Strap on truss #4 at 1/4 point)</td>
</tr>
<tr>
<td></td>
<td>Test #8 (Fall Arestor® Tie-Off Strap on I-joist #4 near blocking)</td>
<td>Test #10 (Fall Arestor® Tie-Off Strap on I-joist #4 at 1/4 point - Replace)</td>
</tr>
<tr>
<td></td>
<td>Test #11 (Mitek stabilizer® brace w/ 2x4 shorts at mid-span)</td>
<td>Test #16 (Repeat test #10)</td>
</tr>
<tr>
<td></td>
<td>Test #15 (Super Anchor® ARS 2x4 on truss #4)</td>
<td></td>
</tr>
<tr>
<td>Over eave</td>
<td>Test 3 (Fall Arestor® Tie-Off Strap on truss #4)</td>
<td>Test #7 (Strap off truss #4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Test #13 (Fall Arestor® Tie-Off Strap on I-joist #4 near mid-span)</td>
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<tr>
<td></td>
<td></td>
<td>Test #14 (Fall Arestor® Tie-Off Strap on I-joist #4 near blocking)</td>
</tr>
<tr>
<td>Over truss tail</td>
<td>Test #16 (Repeat test #10)</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Test matrix for Fall Protection program.
Figure 5. Schematic of roof and floor open framing structural systems and anchorage locations.
2.0 TEST RESULTS

2.1 Results Summary
Table 2 on page 12 displays the test results from the test program. There were 17 tests in total. Five of the tests were conducted on open roof truss framing with temporary bracing per WTCA/TPI guidelines, eight of the tests were carried out on open roof truss framing with temporary bracing that emulates common construction practices and the remaining four tests were carried out on open floor I-joint framing with temporary bracing per TJI installation specification. All connections complied with the structural requirements of the applicable standards.

The data displays the peak force for each test condition along with the travel distance of the shock absorber. It is worth noting that the “straight down” drop yielded the maximum force on the structural system and that the force was higher for the condition where the WTCA/TPI temporary bracing was used for more rigid of bracing conditions. All other conditions yielded forces on the structural system near or below the 900 pounds threshold value.

The shock absorber worked extremely well and in no case full unzipping (travel length) was observed. The particular shock absorber used in this test had a maximum unzipping capacity of 42 inches. The initial length of the shock absorber was 16 inches. Table 2 shows that maximum shock absorber length, as measured after the completion of the test, ranged from 28 inches to 54.8 inches (straight down drop) resulting in travel distance after initial impact from 12 inches to 38.8 inches, respectively. There was good correlation between travel distance and force on the structural system.

2.2 Physical Observations
- Although the top chord of truss number four (that was used to conduct all drops) had couple big knots near the anchorage point, the truss performed very well and was used repeatedly for the majority of the tests.

- The MiTek Stabilizer® 24 metal brace system was used as a spacer, as well as to laterally brace the top chords, performed very well and prevented structural collapse of the partially framed system in the case where the fall was over the gable end.

- The 2x4 lumber shorts that were used to laterally brace the top chords of the five trusses at the peak location were ineffective when the load was applied perpendicular to the direction of the trusses (over gable end) and away from the line of bracing.

- The 9-½ inch I-joint buckled laterally when exposed to forces perpendicular to its direction (drop over gable end) and applied away from the line of blocking. On the contrary, however, the I-joint floor system performed well when the anchorage was near the blocking over the interior bearing wall.

- Although, the rigidity of the overall open roof framing system decreased somewhat when the WTCA/TPI temporary bracing was removed, the physical response of the system to similar types of forces resulting from falls did not change significantly and did not result in a local or global collapse.
Straight down falls resulted in higher induced forces on the structural system, but falls over the gable end were more critical because they test the lateral stability of the partially framed floor or roof system.

PAFS drastically reduces the force exerted on the body or structural system.

The unzipping of the shock absorber resulted in additional travel after first impact and was somewhat inconsistent depending primarily on the type of fall. As expected, straight down falls resulted in longer travel after initial impact.

Travel after initial impact, for falls over the eave in the partially framed roof truss and in all cases of the partially framed I-joist floor, was limited due to building height limitations, but in all cases the peak force that occurred just prior to the unzipping of the shock absorber was captured by the data acquisition system.

Table 2. Test results from 18 falls under various construction conditions and anchorage options.
3.0 ANALYTICAL PREDICTION

The force exerted on the structural system depends on the total energy in the body just before the shock absorber activation (equals work done on the body) and the total distance traveled after the shock absorber is activated. The distance traveled includes the unzipping length of the shock absorber, the extension of the harness, the stretch in the line and the deflection of the structural system in the direction of the fall.

The total energy of the system just before the shock absorber activation is the sum of the kinetic energy \((1/2 * m * v^2)\) and the potential energy \((m * g * h)\) where “m” and “v” are the mass and velocity of the falling object, respectively, “h” is the distance above ground and “g” is the acceleration of gravity.

The extension of the harness was approximately one foot when the falling object came to rest. The deflection of the structural system in the case of a straight down fall can be approximated from the force exerted on the structural member and the stiffness and geometry of the structural system. The deflection of the structural subassembly resulting from falls over the eave or gable end was harder to predict. The stretch in the line can be calculated from the force exerted on the line and its stiffness.

An attempt was made to predict the force on the structural system considering the above assumptions and actual measurements without good results. The prediction is always higher than the measured response. Additional measurements are needed and with higher accuracy to develop a model that can be used to predict the actual force on the body or structural system. Prediction of the force on the structural system or the human body is outside the scope of this program.
4.0 TEST DESCRIPTION AND KEY OUTCOME

4.1 Test No. 1a

- Construction condition: Open Roof Framing
- Anchorage: Super Anchor™ Safety Bar on trusses 3, 4, 5
- Temporary Bracing: WTCA/TPI bracing guidelines
- Fall type: Straight down between trusses 4 and 5 three feet from the peak

Key outcome and physical observations
The structural system performed well with no sign of physical damage on the three trusses sharing the load. The steel safety bar was effective in distributing the load to adjacent trusses. The anchorage plate was bent out of shape requiring the safety bar to be replaced after a single use. The peak force on the structural system was 1,133 pounds. Travel after initial impact was 38.8 inches. Open roof framing that was braced according to WTCA/TPI temporary bracing guidelines was extremely rigid and provided the best platform for anchorage. Figure 6 displays the status of the open roof framing system before and after the fall.

Figure 6 on the next page compares the status of the framing before and after the fall indicating no physical damage.

Figure 6. Comparison of open roof framing before and after Test No. 1a. No physical damage is observed.
4.2 Test No. 2a

- Construction condition: Open Roof Framing
- Anchorage: Super Anchor™ Safety Bar on trusses 3, 4, 5
- Temporary Bracing: WTCA/TPI bracing guidelines
- Fall type: Drop over gable end

Key outcome and physical observations
The structural system performed well although there was no direct lateral bracing of truss No. 2 near midspan where the load was applied. There was no sign of lateral instability and all trusses remained in the vertical position after the impact. There was visual damage of the anchorage plate requiring replacement after one drop. The maximum force recorded was 813 pounds and travel after impact was 26 inches.

Figure 7 compares the status of the framing before and after the fall. Close observations of the framing after the fall did not indicate any physical damage to any of the structural components of the roof assembly.

![Figure 7. Comparison of open roof framing before and after Test No. 2a. No physical damage observed.](image)

Overall, the Super Anchor™ Safety Bar provided an effective mechanism to distribute the load from the fall to multiple trusses. For the two types of tests conducted, the system performed extremely well. The team did not find it necessary to carry out the remaining tests with drops over the eave or over the truss tail having confidence that the system would have performed equally well under those conditions.
4.3 Test No. 1

- Construction condition: Open Roof Framing
- Anchorage: Arestor® Tie-Off Strap on truss #4
- Temporary Bracing: WTCA/TPI bracing guidelines
- Fall type: Drop straight down between trusses 4 and 5

**Key outcome and physical observations**
The structural system performed very well under the force resulting from the “straight down” fall. There was no sign of physical damage. Anchorage from a single truss using the tie-off strap is acceptable in a properly braced open roof system. The peak force and travel after initial impact was 1,165 pounds and 38.8 inches, respectively. The peak force and travel after initial impact was near those realized in test No. 1a.

Figure 8 displays the set-up for the test and provides a comparison of framing integrity before and after the fall.

![Comparison of open roof framing before and after Test No.1 (fall straight down). No physical damage is observed.](image-url)
4.4 Test No. 2
- Construction condition: Open Roof Framing
- Anchorage: Arestor® Tie-Off Strap on truss #4
- Temporary Bracing: WTCA/TPI bracing guidelines
- Fall type: Drop over gable end

**Key outcome and physical observations**
The structural system performed well under the lateral load. There was no sign of lateral instability and all trusses remained in the vertical position after the impact. Anchorage from a single truss in a properly braced roof system is acceptable. The peak force just before the activation of the shock absorber was 767 pounds and the maximum distance of travel after initial impact is 22 inches. The force was considerably lower than the force on the structural system from a “straight down” fall.

Figure 9 compares the integrity of the framing before and after the fall. Close observation of the framing indicates no physical damage.

Figure 9. Comparison of open roof framing before and after Test No.2 (fall over gable end). No physical damage is observed.
4.5 Test No. 3
- Construction condition: Open Roof Framing
- Anchorage: Arestor® Tie-Off Strap on truss #4
- Temporary Bracing: WTCA/TPI bracing guidelines
- Fall type: Drop over eave

Key outcome and physical observations
The structural system performed very well under the load along the direction of the span. No physical damage was observed. The peak force and distance traveled after initial impact was 820 pounds and 24.3 inches, respectively. Note that the travel distance was limited by the building height.

Figure 10 displays the framing integrity before and after the fall. All trusses remain in good shape.

Figure 10. Comparison of open roof framing before and after Test No. 3 (fall over eave). No physical damage is observed.
4.6 Test No. 5

- Construction condition: Open Roof Framing
- Anchorage: Arestor® Tie-Off Strap on truss #4
- Temporary Bracing: Based on common “real world” construction practices
- Fall type: Drop straight down

**Key outcome and physical observations**

In this test, most temporary bracing was removed except one 2x4 brace that supported the outside face of the gable end and was left in place. In addition, MiTek Stabilizer® 24 metal braces were added to provide lateral support to the five trusses near the peak and a diagonal brace was added to laterally brace the gable end truss to the top plate of the interior wall. This type of bracing was defined herein as “real world” construction.

The partially framed roof system performed well without any visual sign of damage after impact. The peak force resulting from the “straight down” fall was 951 pounds and the distance traveled after initial impact was 24 inches. Note that the peak force was considerably lower than the force resulting from the same type of fall in a more rigid roof system using temporary bracing that complies with the WTCA/TPI bracing guidelines.

Figure 11 provides a comparison of the framing before and after the fall. There is no physical damage on the trusses resulting from the “straight down” fall.

![Image of framing before and after Test No. 5](image-url)
4.7 Test No. 6
- Construction condition: Open Roof Framing
- Anchorage: Arestor® Tie-Off Strap on truss #4
- Temporary Bracing: Based on common “real world” construction practices
- Fall type: Drop over gable end

Key outcome and physical observations
The performance of the partially framed roof system was very good with no signs of lateral instability. All trusses remained vertical after the fall with no physical damage observed. The peak force resulting from the fall over the gable end was 730 pounds and the distance traveled after initial impact was 29.5 inches.

Figure 12 displays the integrity of the structural system before and after the fall. Close physical observation of the trusses indicate no physical damage.

Figure 12. Comparison of open roof framing before and after Test No. 6 (fall over gable end). No physical damage is observed.
4.8 Test No. 7

- Construction condition: Open Roof Framing
- Anchorage: Arestor® Tie-Off Strap on truss #4
- Temporary Bracing: Based on common “real world” construction practices
- Fall type: Drop over eave

**Key outcome and physical observations**

The drop over the eave was uneventful without any physical damage to the structural system. The peak force resulting from the fall over the eave was 958 pounds and the distance traveled after initial impact was 18.5 inches. Note that travel distance was limited by the building height, but the peak force was recorded properly.

Figure 13 shows that all trusses remain vertical after the gable end fall with no physical damage observed.

![Figure 13. Comparison of open roof framing before and after Test No. 7 (fall over eave). No physical damage is observed.](image-url)
4.9 Test No. 8

- Construction condition: Open Roof Framing
- Anchorage: Arestor® Tie-Off Strap on truss #4
- Temporary Bracing: Based on common “real world” construction practices
- Fall type: Drop over truss tail

**Key outcome and physical observations**

The drop over the truss tail did not yield any damage to the truss directly involved or any other trusses in the partially framed roof. The peak force resulting from the fall over the truss tail was 855 pounds and the distance traveled after initial impact was 12 inches. Note that travel was limited by the building height but the peak force was recorded properly.

Figure 14 shows that there is no damage to the trusses resulting from a six foot fall over the truss tail.

![Figure 14. Comparison of open roof framing before and after Test No. 8 (fall over truss tail). No physical damage is observed.](image-url)
4.10 Test No. 9

- Construction condition: Open Roof Framing
- Anchorage: Arestor® Tie-Off Strap on truss #4
- Temporary Bracing: Based on common “real world” construction practices
- Fall type: Drop over gable end away from the line of bracing

**Key outcome and physical observations**

The key difference in this test was the location of the fall which was away from the continuous line of bracing. The MiTek Stabilizer® 24 metal brace was used to laterally brace the five trusses near the peak.

The performance of the structural system was surprisingly good indicating that the MiTek Stabilizer® 24 metal brace performed adequately to keep the partially framed roof from collapsing. Video of the event showed a much more flexible system during the fall than experienced in other tests, and the pictures in Figure 15 indicate lateral buckling of the truss that was directly involved in anchoring the falling object in the line of the pulling force.

The peak force and travel distance after the initial impact was 900 pounds and 28 inches, respectively.

![Figure 15. Comparison of open roof framing before and after Test No. 9 (fall over gable end away from the line of bracing). Lateral instability of the truss directly involved in the anchoring of the falling object was observed.](image-url)
4.11 Test No. 10

- Construction condition: Open Roof Framing
- Anchorage: Arestor® Tie-Off Strap on truss #4
- Temporary Bracing: Based on common “real world” construction practices
- Fall type: Drop over gable end away from the line of bracing

Key outcome and physical observations
The key difference in this test from test No. 9 was the replacement of the MiTek Stabilizer® 24 metal braces with 2x4 lumber braces, 24 inches in length. The 2x4 lumber braces connected the narrow faces of the top chord with 2-10d (3-inch) common nails near the peak as shown in Figure 16.

This type of bracing was not adequate to prevent the total collapse of the partially framed roof system when the fall was over the gable end and away from the line of bracing. Unlike the MiTek Stabilizer® 24 brace that was connected to the wide face of the top cord to provide direct lateral bracing to the roof system, the 2x4 bracing connected the top narrow face of each truss top chord in a discontinuous manner and was inadequate in protecting the system from complete collapse.

The peak force and distance traveled after the initial impact was 675 pounds and 13.5 inches, respectively.

Figure 16. Comparison of open roof framing before and after Test No. 10 (fall over gable end away from the line of bracing). Total collapse of roof system observed. The fall was over the gable end and away from the line of bracing in a poorly braced partially framed roof system.
4.12 Test No. 11

- Construction condition: Open Roof Framing
- Anchorage: Arestor® Tie-Off Strap on truss #4
- Temporary Bracing: Based on common “real world” construction practices
- Fall type: Drop over gable end away from the line of bracing (repeat of test No. 10)

**Key outcome and physical observations**

A new roof system consisting of five new trusses was constructed on the ground and lifted in to place. Test number 10 was then repeated on the new system with the same results. The partially framed roof system partially collapsed when exposed to forces perpendicular to the direction of the span away from the bracing line.

The peak force and distance traveled after initial impact was 843 pounds and 15.5 inches, respectively.

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Figure 17. Comparison of open roof framing before and after Test No. 11 (fall over gable end away from the line of bracing). Partial collapse of roof system observed. The fall is over the gable end and away from the line of bracing in a poorly braced partially framed roof system.
4.13 Test No. 16

- Construction condition: Open Roof Framing
- Anchorage: Super Anchor® ARS 2x4 on truss #4
- Temporary Bracing: Based on common “real world” construction practices
- Fall type: Drop over gable end away from the line of bracing

**Key outcome and physical observations**

This test was carried out to test a metal anchor (Super Anchor® ARS 2x4) connected to a single truss in line with the top chord bracing. Bracing of the top chords near the peak was provided by the MiTek Stabilizer® 24 metal brace.

The roof system performed well indicating the effectiveness of the MiTek Stabilizer® 24 brace.

The peak force and distance traveled after initial impact was 851 pounds and 30.5 inches, respectively.

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Figure 18. Comparison of open roof framing before and after Test No. 16 (fall over gable end away from the line of bracing). Slight lateral buckling of the truss directly involved in the anchoring of the falling object was observed.
4.14 Test No. 12

- Construction condition: Open Floor Framing
- Anchorage: Arestor® Tie-Off Strap on I-joist #4
- Temporary Bracing: Based on TJI installation specification
- Fall type: Drop straight down

**Key outcome and physical observations**

The partially framed I-joist floor performed well when exposed to forces from a straight down fall. The anchorage location was only a few feet away from the interior wall where blocking was used to laterally support the I-joist over the bearing wall.

The peak force and distance traveled by the falling body after the initial impact was 1,024 pounds and 30 inches, respectively. Note that the distance traveled by the falling body was limited by the building height, but the peak force was recorded accurately.

![Figure 19](image_url)

Figure 19. Comparison of open floor framing before and after Test No. 12 (fall straight down). No physical damage observed.
4.15 Test No. 13

- Construction condition: Open Floor Framing
- Anchorage: Arestor® Tie-Off Strap on I-joist #4
- Temporary Bracing: Based on TJI installation specification
- Fall type: Drop over gable end

**Key outcome and physical observations**

In this test, the anchorage point was several feet away from the location where blocking laterally supports the I-joist over the bearing wall. Lateral instability of the I-joist directly involved in anchoring the falling body was observed.

The peak force and distance traveled by the falling body after the initial impact was 748 pounds and 22.3 inches, respectively. Note that the distance traveled by the falling body was limited by the building height. The peak force was recorded accurately.

![Figure 20. Comparison of open floor framing before and after Test No. 13 (fall over gable end). Lateral buckling of the I-joist used to anchor the falling body observed.](image_url)
4.16 Test No. 14

- Construction condition: Open Floor Framing
- Anchorage: Arestor® Tie-Off Strap on I-joist #4
- Temporary Bracing: Based on TJI installation specification
- Fall type: Drop over gable near the bearing wall where blocking provides lateral support to I-joists

**Key outcome and physical observations**
In this test, the anchorage point was near the bearing wall where blocking provides lateral support to I-joists. The partially framed I-joist floor performed well with no physical damage observed.

The peak force and distance traveled by the falling body after the initial impact was 709 pounds and 27.8 inches, respectively. Note that the distance traveled by the falling body was limited by the building height. The peak force was recorded accurately.

![Figure 21. Comparison of open floor framing before and after Test No. 14 (fall over gable end). No physical damage observed.](image)
4.17 Test No. 15

- Construction condition: Open Floor Framing
- Anchorage: Arestor® Tie-Off Strap on I-joist #4
- Temporary Bracing: Based on TJI installation specification
- Fall type: Drop over eave

Key outcome and physical observations
The partially framed floor system performed well with no sign of physical damage (see Figure 9 below).

The peak force and distance traveled by the falling body after the initial impact was 730 pounds and 1.5 inches, respectively. The extremely small travel time after initial impact was due to the slip of the tie-off strap along the flange of the I-joist. The observed slip most likely did not affect the accuracy of the peak force significantly.

Figure 22. Comparison of open floor framing before and after Test No. 15 (fall over eave). No physical damage observed.
Appendix A – Truss design

Table: FALL PROTECTION TEST

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Scale = 1/43.3

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LUMBER:
TOP CHORD: 2 x 4 HF No.2
BOT CHORD: 2 x 4 HF No.2
MEMBERS: 2 x 3 SPF Studwall

BRACING:
TOP CHORD: Structural wood sheathing directly applied or 3/8-10cc purins.
BOT CHORD: Right side directly applied or 1½-0-0 cc bracing.

REACTIONS (lbs): 210800-5.8, 3.6-10550-5.4
Max Hr (2.4) = 30.0, G (6)
Max Up (2.7, 75, C (3), 9, 75, C (4))

FORCES (fl): Maximum Compression/Maximum Tension
TOP CHORD: 1.0-10627, 2.3-20680, 3.4-20680, 4.0-20680, 5.6-20680, 6.7-426
BOT CHORD: 2.1-10621, 2.5-17143, 3.6-17143, 4.0-17143, 4.9-482123
MEMBERS: 3.1-20677, 4.0-20677, 4.8-20677, 5.8-40677

NOTES:
1) Unbalanced roof live loads have been considered for this design.
2) ASCE 7.50: (Sec. 1.7) for: TCE = 4,000; SDC = 3,000; Category II, Exp B, enclosed, MW88B; cantilever left and right exposed; pent roof left and right exposed; and vertical left and right exposed. Lumber DDL1.00 data on DDL1.00.
3) This truss has been designed for a 5.1-gal bottom chord live load consisting with any other live loads.
4) This truss has been designed for a live load of 10.2 psf on the bottom chord in all areas where a rectangle 3.6-10.0 ft wide by 2.0-0.0 will be between the bottom chord and any other member.

LOAD CASES:
Blanket

WARNING: Verify design parameters and READ NOTES ON THIS AND COV/I PAGE BEFORE USE. This design is based on the parameters shown, and is for individual building components to be tested and loaded in the plane of the truss. Applicability of design parameters and proper incorporation of component is the responsibility of the building designer. The loading requirements shown are for lateral stability of individual trusses. The moment design is the responsibility of the building designer. Additional temporary bracing to insure stability during construction is the responsibility of the contractor. For general guidance regarding fabrication, quality control, storage, delivery, erection, and bracing, consult ANSI/TPI Truss Design Specification, and RII Building Component Safety Information available from Truss Plate Institute, 583 D'Orchile Drive, Madison, WI 53711 and Wood Truss Council of America (woodtruss.com).
### Appendix A continued – Truss Design

#### TRUSS QUOTE/OFFER

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**LOT NO.** PLAN NO. L-R

- FALL
- SUBDIVISION: DONATION

**QUOTE #: B8033061**

**INVOICE #:**

- CUST: WDNVLBR
- PO NO. 798556
- TERMS P.O. # REQD

**WOODINVILLE LBR**

**Bid By:** / /  
**Layout:** / /  
**Design By:** / /  

### FALL PROTECTION TEST

#### DONATION

- 32901 Weyerhaeuser Way
- Federal Way, WA

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Quoted price subject to change after 30 days. Price includes delivery to plate line. Single set and/or additional boomtime must be prescheduled and is billed @ $150/hr. Tri-County Truss reserves the right to ground drop product due to unsafe or impractical jobsite conditions. Tri-County Truss is not responsible for delays due to circumstances beyond our control. Sales subject to credit terms & conditions as determined by Tri-County Truss, Inc.

**DATE**

AUTHORIZED SIGNATURE FOR Woodinville Lumber

ALL SALES SUBJECT TO CREDIT POLICY/TERMS/APPROVAL AS DETERMINED BY TRI-COUNTY TRUSS INC.

**WOODINVILLE LUMBER**

**FALL PROTECTION TEST**

**BID #** B8033061
Appendix B – Fall Protection building layout
Appendix B continued – Prefab wall design

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FALL RESTRAINT BUILDING

Woodinville 425-488-1818
Longview 360-501-8500

March 07, 2008

Weyerhaeuser
Appendix B continued – Prefab wall design

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2'
9'-7 1/2
10'
5 1/2
Panel
Width
Height
Stud Lgth
OC Spacing
A-103
FALL RESTRAINT BUILDING
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March 07, 2008Woodinville 425-488-1818
Longview 360-501-8500
Appendix B continued – Prefab wall design
Appendix B continued – Prefab wall design
Appendix B continued – Prefab wall design

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Panel B-101

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Woodinville 425-488-1818
Longview 360-501-8500
Appendix B continued – Prefab wall design

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