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Forensic Engineering Investigation of Lumber Temporary Guardrails

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Abstract

During intermediate stages of building construction, temporary guardrails are required for unfinished openings on balconies, decks, elevated walkways, pits, and excavations. OSHA requires that these temporary guardrails be able to withstand 200 pounds of load, but does not specify guardrail mounting methods. A forensic case involved failure of a 2x4 lumber guardrail nailed to a wood-frame building, where it was alleged that the mounting method was inadequate. Full-scale testing was conducted to analyze the adequacy of this fastening method and its reliability when subjected to the repeated removal and replacement that commonly occurs on worksites.

Keywords

forensic engineering, OSHA, temporary, guardrail, fall, lumber, construction

Introduction

The forensic case involved a worker who was working on the third floor of a multi-unit condominium building under construction. A large man, he was leaning against a temporary guardrail covering a 9 foot wide opening across a balcony. The temporary guardrail was a 12 foot long spruce/pine/fir (SPF) 2x4, nailed into oriented strand board (OSB) wall sheathing and underlying studs. The nails were 12 penny plain-shank resin-coated nails. According to some of the testimony, there were two nails in each end, though others reported more nails in each end. As the worker was leaning on the rail while on break, one end pulled out of the wall, and the worker fell to his death. The client in this case was the insurance company for the framing subcontractor.

Briefly, the US Occupational Safety and Health Administration (OSHA) regulations are found in Code of Federal Regulations Title 29. Construction-specific regulations are found under subheading 1926, and “Fall Protection Systems Criteria and Practices” are under 1926.502. A requirement of this regulation is that unprotected openings must have guardrails able to withstand a 200 pound load applied anywhere along the rail. This loading strength is the key requirement; a non-mandatory appendix to 1926.502 allows that temporary guardrails may be made of many different materials, including 2x4 lumber. Another non-mandatory element is that the maximum span between guardrail vertical supports should be 8 feet. As such, the subject guardrail (which did not have an intermediate support across the 9 foot opening) covered too wide a distance, which was a point of interest for various parties in the case.

As to the attachment method, OSHA regulations do not preclude the use of simple nailing to attach lumber guardrails, and such a method is commonly used. One area of concern is that temporary guardrails may be taken down and replaced frequently by the various trades involved in the construction project, in their efforts to bring materials or equipment into the structure. When guardrails are attached by nails, such removal is likely facilitated by hammering or prying against the inner surface of the guardrail, forcing the nails axially out of their holes. There are at least three scenarios that are foreseeable for a subsequent reinstallation:

1. The worker has left the existing nails in place in the 2x4 board and attempts to reinsert the nails into the existing holes and hammer the guardrail back into its original position.
2. The worker has left the existing nails in place and hammers them back into a different area of the building exterior.
3. The worker uses new nails to fasten the guardrail into a different area of the building exterior.

It can be anticipated that the least durable of these scenarios involves reuse of the existing nails in the existing holes. Research did not reveal any existing studies of nailed-guardrail pullout strength, so it was determined that testing was necessary.

Testing setup

Though each building structure will have its own particular combination of materials and stiffness, it was decided that duplicating the wooden structure of the third floor balcony was impractical as well as unnecessary. A framework concept was envisioned that would hold panels of OSB sheathing 9 feet apart from each other, to simulate the sidewalls to which the subject guardrail had been attached. A sample guardrail would then be nailed to these panels, and loading would be applied. The issue of size, portability (as a potential trial exhibit), and the need for rigidity dictated the use of a welded steel framework.

One of the authors designed a framework using 3D CAD, and also used finite element analysis to predict deformation under the testing loads. The CAD model confirmed that the design would not experience undue deflection, and the framework was fabricated by the designer. See Figures 1 & 2.

The framework design features lever-based mechanisms that work through a digital force gauge to apply horizontal, vertical, and 45 degree angled loading to the lumber guardrail at any point along its 9 foot long unsupported span. See Figures 3 through 5. The digital force gauge was

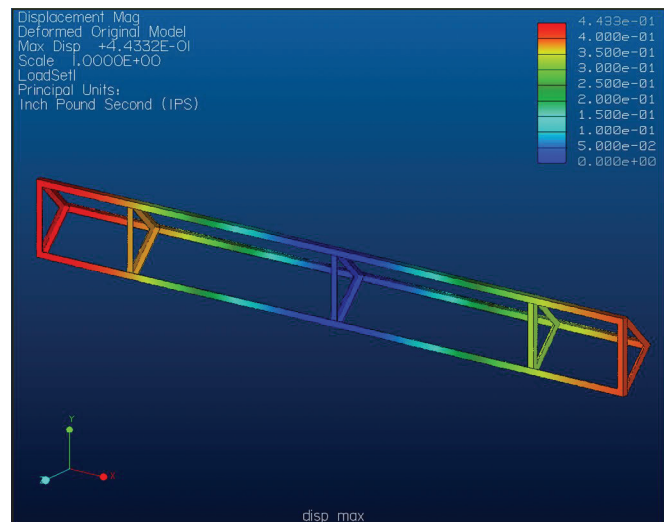


Figure 1
finite element analysis of CAD design



Figure 2
assembled test jig

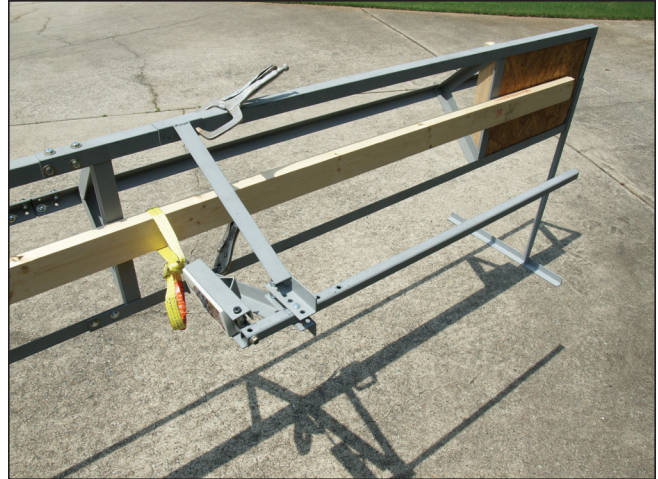


Figure 3
horizontal loading linkage



Figure 4
45° angled loading linkage



Figure 5
vertical loading linkage

a Chatillon model DFE-500 with a 500-pound capacity. Force was applied through a cargo strap looped around the test guardrail, which provided a measure of self-alignment to the load application.

Commercially available 12 foot SPF 2x4 boards were obtained. As is commonly known, 2x4 boards actually have a rectangular cross-section that is nominally 1½ inches by 3½ inches in dimension. In the interests of consistency, nominally straight boards without large knots were selected – this was reasonable since the subject failure did not occur due to a board fracture. The OSB sheathing selected had an advertised thickness of 19/32 inches, and it was cut into 17 x 24 inch panels for use in the test framework.

Installation test procedure

The OSB panels were mounted in the framework. A 2x4 board was centered vertically and horizontally across the 9 foot wide opening in the framework. The board was nailed through the OSB panels and into 2x4 blocking meant to represent building framing. Two nails were installed in each end and were adjacent to the 9 foot wide opening – see Figures 6 and 7.

Loading was applied in horizontal, 45° angled, and vertical directions, at the ends and center of each board. In each case, a load of approximately 220 pounds was applied and held for 2 minutes. The drop in load tension during this interval was monitored to track any significant pullout of the nails. The testing results showed a maximum of 12% reduction in load tension after 2 minutes. This phase of testing concluded the work done in conjunction with the subject forensic case.



Figure 6
OSB panel with 2x4 blocking



Figure 7
nailed installation of guardrail

Legal and other aspects of the forensic case

This case relied on the experience of both of the authors – a mechanical engineer to construct the test apparatus, and a structural engineer with experience in building construction.

The above-mentioned testing demonstrated that when using materials, proportions, and fasteners comparable to those of the subject forensic case, the tested guardrails met the OSHA requirements for loading. And as a common means of installing temporary guardrails on building exteriors, it is reasonable to conclude that this method (properly done) is sound for initial installation.

The construction project at issue in this case was a three-story condominium development with dozens of units (and balconies) per building. The framing subcontractor for the project had specific contract verbiage calling for them to install temporary guardrails, which they subcontracted to another company. There was no specific contractual requirement to maintain these guardrails, however, after installation. All subcontractors had contractual requirements to replace guardrails if they removed them, though the means of replacing them was not specified. Safety meetings were conducted periodically and a frequent topic of discussion was the failure of subcontractor workers to replace the temporary guardrails after completing the work that necessitated their removal.

OSHA multi-employer worksite regulatory considerations

The OSHA Multi-employer Citation Policy (CPL 2-0.124) is a relevant discussion for this case. This will discuss whether the various parties would be considered *creating*, *exposing*, *correcting*, or *controlling* employers, in terms of potentially incurring OSHA citations. It is noted that an employer may have more than one of the above roles.

The *creating* employer: this was the (unknown) subcontractor entity that replaced the guardrail in a manner that did not withstand the loading applied by the decedent. The exact method used to re-attach the guardrail is not known. It may be beyond the knowledge of many construction workers as to which methods of re-attaching nailed-on guardrails are adequate and which are not – no published analysis of this topic was discovered in case research. It is important, however, for subcontractor supervisors to understand the standard of care necessary to meet contractual & safety requirements, and to reinforce this information with their subordinates. Even if unclear about the adequacy of re-installing nailed-on guardrails, subcontractor supervisors would not be likely to insist (to the general contractor) on a more “permanent” temporary guardrail attachment means, such as brackets or hinges. The subcontractor may have interaction with only a few of the dozens of balconies in the development, and the more permanent solutions are more expensive and would logically remain with the project after the subcontractor completes their phase of the work.

The *exposing* employer: this was the subcontractor entity that employed or supervised the decedent. This employer was responsible for exercising reasonable diligence to discover hazards, but there was no contractual language requiring subcontractors to verify the strength of already-installed temporary guardrails – nor would such a task be efficiently conducted at a worksite. There was also no evidence that the faulty condition was noticed in advance of the incident.

The *correcting* employer: this was the party that would have responsibility for correcting the hazard. At some worksites, there will be individuals or companies hired to inspect and maintain safety provisions, including temporary guardrails. Such an arrangement is not required, however. Though the framing subcontractor was contractually responsible for installing the guardrails, any subsequent subcontractors that removed them were contractually required to replace them – making the removing subcontractor the appropriate correcting employer. Though no specific replacement instructions were provided, it is common sense that they should be replaced in a manner that is not obviously deficient.

The *controlling* employer: this was the general contractor, who had general supervisory authority over the worksite and the power to correct safety hazards or compel subcontractors and subordinates to correct safety hazards. The level of control can be established by contract or by practice. The general contractor did not have contractual responsibility to replace guardrails but nevertheless frequently had to remind subcontractors to replace them, so there was a continual awareness of guardrail hazards in general. Ultimately, however, there are no OSHA requirements for periodic 200 pound load strength

inspections of temporary guardrails at worksites. Such inspections would not be efficient to conduct without specialized equipment, and there is no literature pointing to the need to question the strength of nailed-on guardrails.

Post-case re-installation testing

Of interest to the authors was the ability of the subject joint to withstand repeated re-installations of the guardrail in a worst-case scenario: re-use of the existing nail holes in the wall. It is noted that as a system that relies heavily on friction and on organic test materials, the results of this testing are not representative of other combinations of materials.

In this testing, the horizontal pull test was applied with an approximate load of 260 pounds, which represents a 30% “safety factor” over the OSHA-prescribed 200 pound loading. The load was maintained for one minute, and then the guardrail was pried away from the wall panels using a crowbar centered on the “inside” surface of the guardrail – see Figure 8.

This served to pull the nails axially from their holes. The nails were then re-inserted into the existing holes and the guardrail was re-installed using a hammer and wood block. The cycle of loading / removal / re-installation was repeated until the applied 260 pounds loading could not be achieved due to the nails pulling out of the wall panel holes. The number of cycles was recorded for 2 instances representing both ends of a sample guardrail – see Figure 9. The results showed that one installation was successfully re-installed 20 times, and the other installation was successfully re-installed 8 times.

Conclusions

The tested guardrail system materials, which were apparently comparable to those in use at the time of the incident, were found to be capable of withstanding the OSHA-specified loading both on initial installation and (as tested later) after several somewhat optimized re-installations.

The forensic case settled the day before trial.



Figure 8
crowbar removal of guardrail



Figure 9
left end of guardrail during pullout