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Between the Posts: Research on the Cap and Top Rail to Guardrail Post Connection

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Between the Posts: Research on the Cap and Top Rail to Guardrail Post Connection

A thesis submitted in partial fulfillment of the requirements of the Honors Program of the
Department of Landscape Architecture in the Fay Jones School of Architecture,
University of Arkansas

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Fall 2013

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Introduction

Between 2003 and 2007, an estimated 11,120 Americans went to the emergency room as a direct result of a structural failure or collapse of wood deck railings. This is an average of 2,224 people each year. Furthermore, estimates show there are over 40 million decks in the United States and about half of these are more than fifteen years old, which is past their expected lifespan (Legacy Services, 2012). Decks are exterior structures susceptible to the elements that degrade over time, making the need for proper, safe construction techniques even more important. The safety of unsuspecting people who use decks and rely on the deck's safety components is at stake.

The 2012 International Residential Code states that guardrails and handrails must withstand a 200-pound "single concentrated load applied in any direction at any point along the top." (Table R301.5). A fair amount of research and testing has been done to ensure that guardrail *posts* meet this requirement but not the rest of the guardrail system. Two studies, one at Virginia Tech (Loferski et al., 2005) and the other at the University of Maryland (Morse, 2005), have been pretty widely disseminated online and through *Professional Deck Builder Magazine*, which has had follow-up articles as well ("Question & Answers", 2011). These studies found that all of the traditional guardrail post to joist connections failed to meet the code requirement but that the use of certain brackets, such as the Simpson StrongTie™ HD2A and the DeckLok bracket would make the posts code-compliant. These studies have certainly helped to make decks safer, but what about the space between the guardrail posts? There is typically at least six feet between posts, obviously comprising the vast majority of the guardrail system of a deck. This space between the posts relies mainly on the

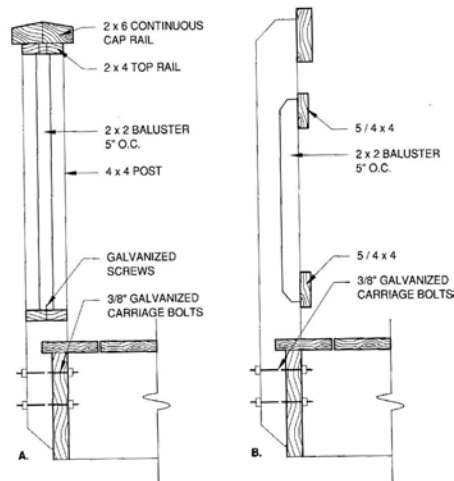
cap rail and top rails to keep people from falling through and they also need to meet the 200-pound concentrated load safety requirement, but do they? That is the main question and area of research for this paper as there has been practically no testing done on this subject.

Literature Review

When searching for common methods of cap and top rail attachment, two things became apparent: the sheer variety of possible connections but also the ambiguity as to how they are actually achieved. With a focus solely on the most common guardrail system, wood, a search through professional reference books, Do-It-Yourself books, websites, on-line videos, and real world examples revealed many different connections and methods of construction. Research also focused on materials that would be available to the average contractor or “weekend warrior,” except for possibly the professional reference books.

A look at professional reference books revealed little about the cap and top rail to guardrail post connection. The only one that showed details of this connection was the Landscape Architectural Graphic Standards (Hopper, 2007). It gives two details for an exclusively wood guardrail system (Fig. 1). Example A has a horizontal, continuous 2x6 cap rail running centered over the tops of the guardrail posts with horizontal 2x4 top rails directly beneath, which can be assumed to only run between the posts. The bottom rail mimics the top rail and galvanized screws are shown going through the top and bottom rails into the ends of the 2x2 balusters held centered between them. Nothing is mentioned as to how the cap, top, and bottom rails are fastened to the guardrail posts

or each other. The other detail, example B, shows an independent, continuous 2x6 cap rail on edge, attached to the upper inside surface of the guardrail posts. The 5/4x4 top and bottom rails are attached to the posts in the same way with 2x2 balusters attached



to their outside surfaces. There is no mention of fasteners.

Figure 1. Landscape Architectural Graphic Standards, pg. 591

Example A, on the left, shows a continuous cap rail running over the posts with discontinuous top and bottom rails between the posts. Example B, on the right, is quite unique with the cap, top, and bottom rails all attached flush to the inside surface of the posts. Another version of this example was not seen again.

A search through Do-It-Yourself books was much more fruitful in terms of variety, but the ambiguity was still there. The local home improvement stores had only one DIY book that went into detail on the cap/top rail to guardrail post connection. This was a Black & Decker book: *The Complete Guide to Decks*, Updated 5th Edition (Creative Publishing international, 2012). It provides pretty good step-by-step instructions, and in essence it calls for a continuous, 2x4 top rail on edge that is attached flush to the inside surface of the guardrail posts with two-and-a-half inch deck screws or 10d nails at scarf joint splices. A continuous 2x6 cap rail is laid flat atop the top rail and the posts, also attached with two-and-a-half inch deck screws or 10d nails at scarf joints (Fig. 2). There is no bottom rail, as the balusters extend down to attach to the joists (the guardrail posts are not notched), with two two-and-a-half inch deck screws at the top and bottom.

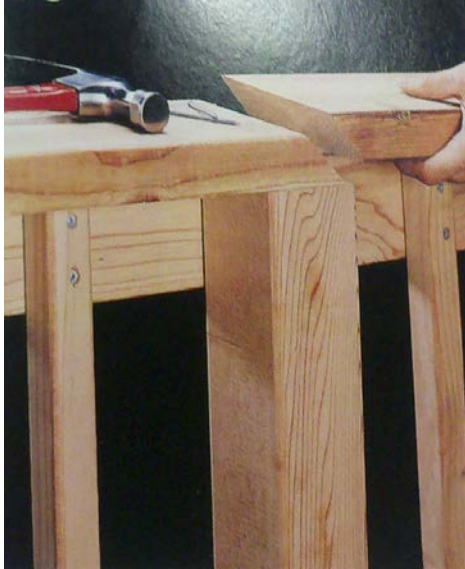
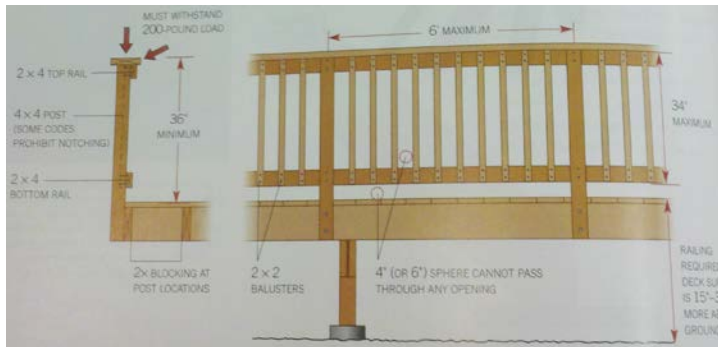


Figure 2. Black & Decker: The Complete Guide to Decks, pg. 169. This image shows how all the rails are continuous, except where scarf joints are needed. The cap rails run over the posts and the top and bottom rails attach flush to the inside surface of the posts.

Various other Do-It-Yourself books were available at local bookstores. The Complete Deck Book: Everything You Need to Plan, Build, or Buy the Perfect Deck for Your Home, a Sunset Book (Beneke, 2002), called for something very similar to what Black & Decker recommended except with a bottom rail for the balusters to end on with



a sweep space below (Fig. 3).

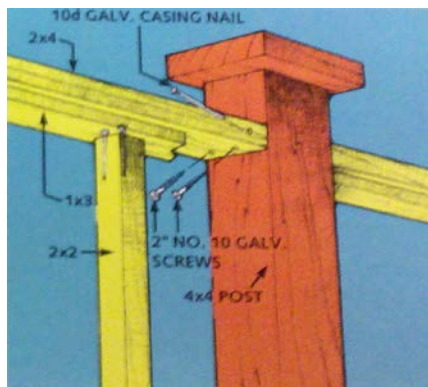
The fasteners were not specified.

Figure 3. Complete Deck Book pg. 152

This example is very similar to the Black & Decker guardrail example shown

above, except lacks detail on what fasteners to use. A maximum post spacing of six feet is also specified.

A Reader's Digest book, *The Family Handyman: Decks, Patios, and Porches* detailed quite an interesting connection (Reader's Digest Association, 2002). Figure 4 shows how the guardrail posts extend past the top of the cap rail so it calls for a discontinuous, horizontal 2x4 cap rail that is toe-nailed on the short sides to the posts with a 10d galvanized casing nail and from underneath with two, two inch No. 10 galvanized screws at an upward angle. Centered directly beneath the 2x4 is a horizontal 1x3 which is somehow attached to the cap rail and/or posts but is not shown. What is

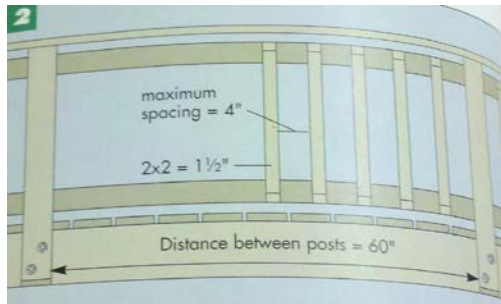


shown are two nails going through either just the horizontal top rail or both the cap and top rail to the tops of the balusters to hold them in place. The bottom rail is a horizontal 2x4, just like the cap rail.

Figure 4. *The Family Handyman: Decks, Patios, and Porches*, pg. 21. All of the rails are discontinuous between the posts and a curious system involving a laid flat 1x3 as the top rail is shown. The common method of toe-nailing to attach the rails to the posts is also shown.

The final *Do-It-Yourself* book is a bit older and depicts a guardrail system not seen much in more recent ones but is still not entirely uncommon (Beneke, 1998). It is an interesting detail because although the 2x6 cap rail is continuous and runs over the tops of the guardrail posts, it is entirely independent since the top rail sits an inch or two below (Fig. 5). This means the cap rail is only fastened at the posts and nowhere else. The top and bottom rails are 2x4s secured on edge, with 2x2 balusters running between them. There is no indication of whether the top and bottom rail are continuous and

mounted to the face of the posts or are discontinuous and mounted between the posts.

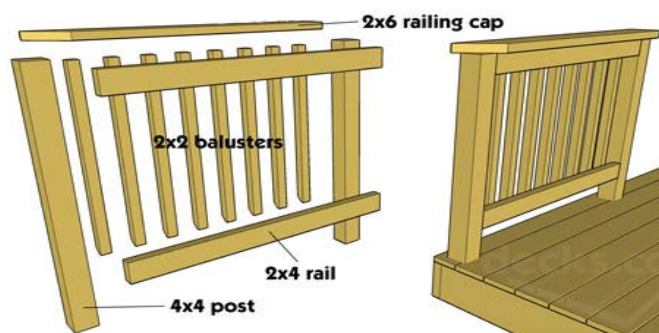


Fasteners were not specified.

Figure 5. Better Homes & Gardens: Deck Projects, pg. 54

And independent cap rail runs over the posts but whether the top and bottom rails are continuous or not is not clear.

The internet was slightly more rewarding than Do-It-Yourself books, offering a similar amount of variety but a bit more detail on the actual connections. Decks.com recommends a horizontal, continuous 2x6 cap rail, centered atop the guardrail posts with a vertical 2x4 top rail just beneath, flush with the inside surface of the posts (Fig. 6). The 2x4 bottom rail is installed the same as the top rail with 2x2 balusters attached to



their outer surface. There is no mention as to what type of fastener to use (Decks.com, 2012).

Figure 6. http://www.decks.com/Deckbuilding/Wood_Deck_Rail_Parts It is clear that the top and bottom rails are discontinuous between the posts but there is still no mention of fasteners.

Deckplans.com goes into more detail and switches up the dimensions of the cap and top rail while also extending the guardrails up past the 36 inch height of the cap rail (DekBrands, 2012). This website says to first attach a 2x6 top rail on edge between the posts, flush to their inside face with four deck screws toe-nailed from the top and bottom

at each end to hold it in place (Fig. 7). Then a 2x4 cap rail goes on top, discontinuous between the posts and attached with deck screws to the top rail every 16-20 inches (Fig. 8). There is no bottom rail as the posts are notched at the bottom and the 2x2 balusters go down to attach directly to the joists, fastened with one two-and-one-half inch deck screw at both the top and bottom (Fig. 9).

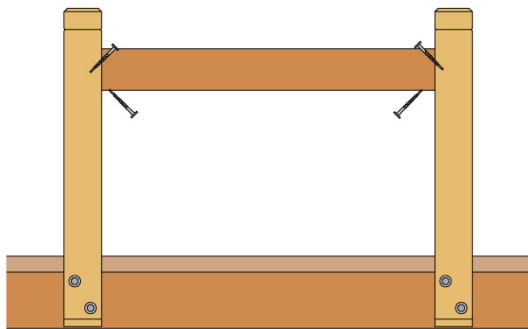


Figure 7. <http://www.deckplans.com/how-to-install-wood-handrail-posts/step-3> This figure shows how the deck screws are toe-nailed from the top and bottom to hold the top rail in place.

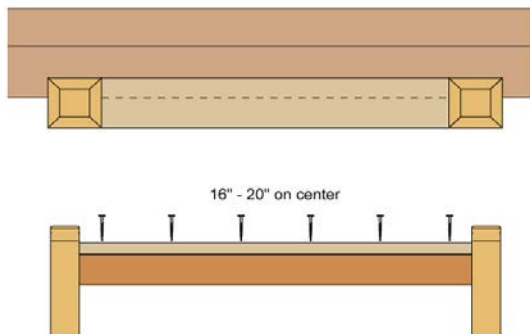


Figure 8. <http://www.deckplans.com/how-to-install-wood-handrail-posts/step-4> The cap rail is attached to the top rail through deck screws every 16-20 inches, with screws close to posts as well.

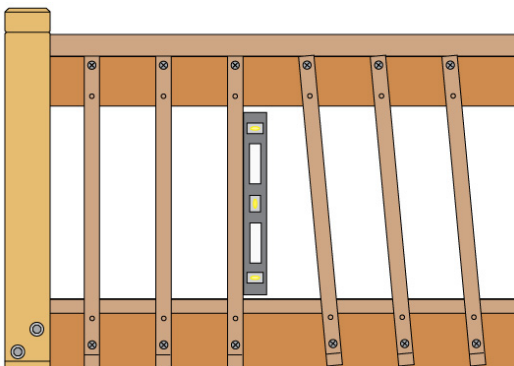
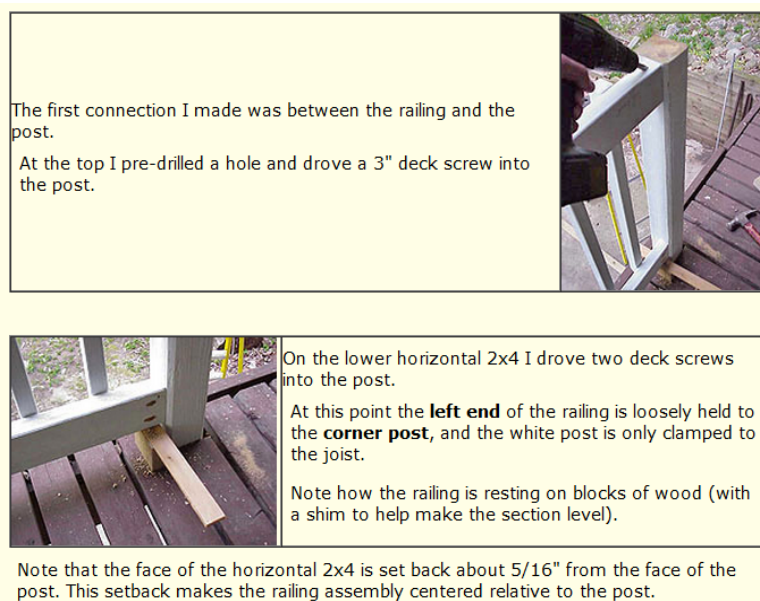


Figure 9. <http://www.deckplans.com/how-to-install-wood-handrail-posts/step-7> This figure shows how the balusters are attached with one screw per end.

There are two articles from the website HammerZone.com and they went into the most detail of all the websites mentioned here. In the first article, 2x4s were used for the cap, top, and bottom rails (Maki, 2003). Where possible the cap rail went over the guardrail posts but at some locations had to stop at posts which supported an overhead structure. The top rail was installed on edge, flush with the top of the posts, and nearly flush with the inside surface of the posts so that it and the 2x2 balusters would be centered on the posts. The top rails were fastened with four, three inch deck screws driven in at an angle at the tops and bottoms of each end (Figs 10 & 11). The bottom rail was installed essentially the same way except with two screws driven in diagonally at each end from the inner surface into the posts (Figs 10 & 11). The balusters were attached to the top and bottom rails' outer surface. Three-inch deck screws were also



used to fasten the cap rail, about every twelve inches or so to the top rail and two per location at posts and splices (Fig. 12).

Figure 10.

http://www.hammerzone.com/archives/decks/handrail/contemporary/basic1/painted_2x4.htm This figure

shows how three-inch deck screws were toe-nailed to attach the top and bottom rails to the posts.

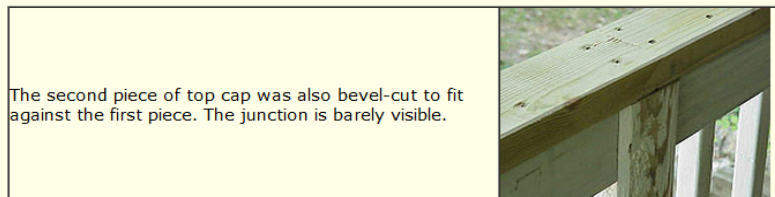
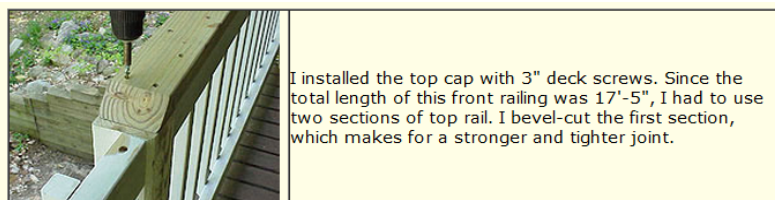
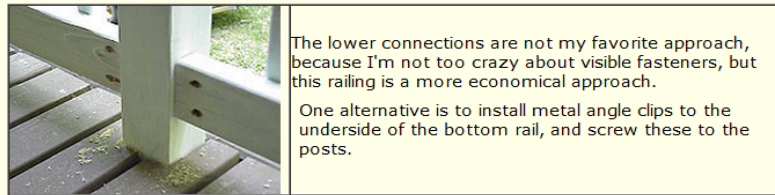
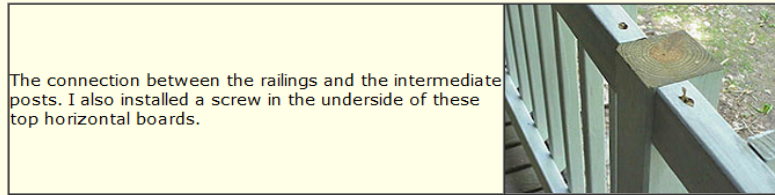


Figure 11.

http://www.hammerzone.com/archives/decks/handrail/contemporary/basic1/painted_2x4.htm Toe-nailed attachments are shown again with discontinuous top and bottom rails.

Figure 12.

http://www.hammerzone.com/archives/decks/handrail/contemporary/basic1/painted_2x4.htm This figure shows a continuous 2x4 cap rail that utilizes scarf joint splices when needed.

The other article (Maki, 2005) didn't have quite as much information (Fig. 13). A 2x4 was used for the top rail, secured on edge and flush to the *outside* surface of the guardrail posts. The fastener was not specified. The 2x6 cap rail was then attached as a continuous, horizontal member, centered over the posts and top rail and possibly attached with three-inch deck screws. The balusters were 2x2s fastened with two, two-and-one-half inch deck screws at both ends, with the bottom ends attached to the joists.

Building The Hand Rail:

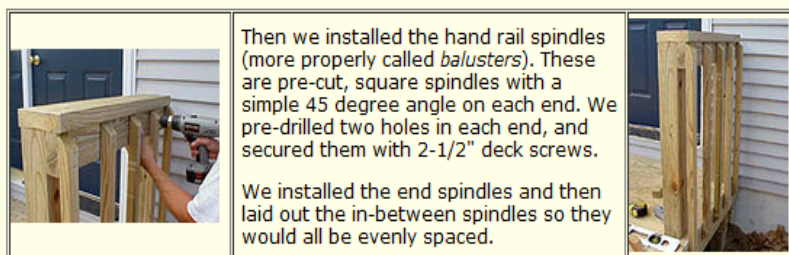
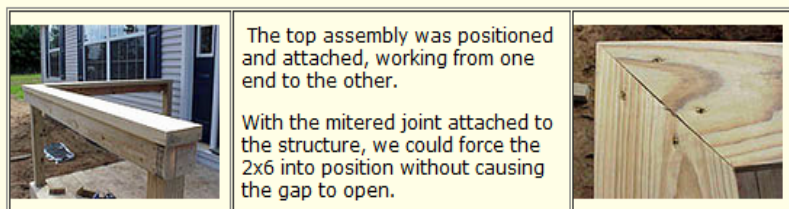
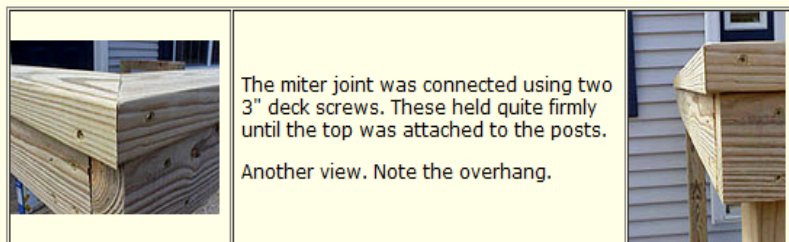
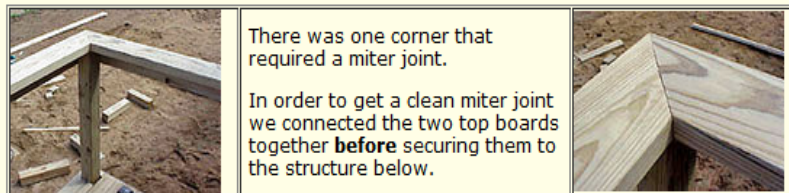
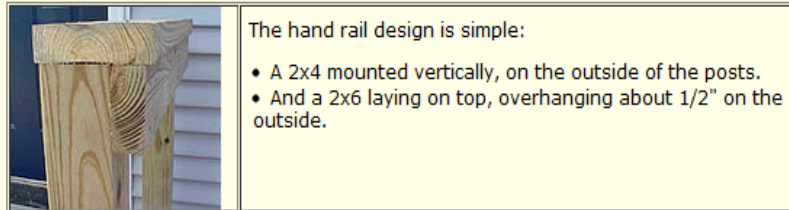
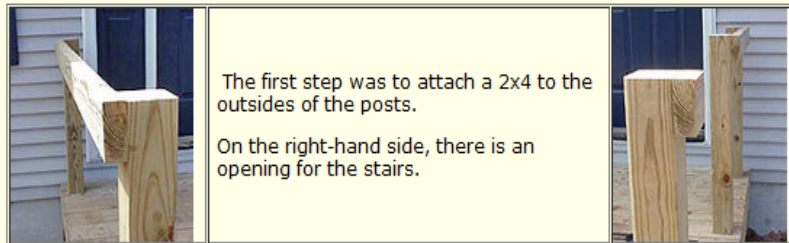


Figure 13.

<http://www.hammerzone.com/archives/decks/basicp2/build6p2.html> Top and bottom rails are continuous and attached to the *outside* surface of the posts.

Two-and-one-half, and three inch deck screws are mentioned as fasteners.

Also somewhat informative were online videos, provided by Lowe's, Home Depot, and Decks.com. In the Lowe's video they notched the inside top of the guardrail posts for a 2x4 top rail to fit and fastened it with screws (Lowe's, 2009). The cap rail was continuous 5/4x6 decking material, laid flat, and centered over the posts. 2x2 balusters were attached to the top rail and joists at the bottom (the bottom of the guardrail posts were notched), with just one screw per location, two screws seemed to be used at every



other attachment location (Fig 14).

Figure 14.

<http://www.youtube.com/watch?v=RwNsJ5sFjHc>

Completed deck with continuous cap rail and discontinuous top and bottom

rails. Screws seemed to be used exclusively as fasteners. There was no mention of post spacing.

Whereas the Lowe's video used all screws, the Home Depot video used almost all nails (even to attach the guardrail posts to the joists!). The top rails were 2x4s but simply installed on edge, with nails, to the inside surface of the guardrail posts, without notching. There was a bottom rail that mimicked the top rail with 2x2 balusters nailed to it and the top rail (Fig. 15), with 5/4x6 continuous decking running atop the top rail and posts, this time fastened with decking screws (The Home Depot, 2008).



Figure 15.

<http://www.youtube.com/watch?v=9y9560S5a0Q> A nail gun was used liberally during this video. Balusters are being attached with nails in this figure.

The Decks.com video used 2x4 top and bottom rails installed between guardrail posts attached with four, three-and-one-half inch trim screws driven in diagonally, two per end (“How to Build Deck Railings”, 2012). 2x2 balusters run between, fastened with two-and-one-half inch trim screws, one at each top and bottom. A 2x6 or 5/4x6 (they used 2x6) horizontal cap rail is suggested, screwed in place and discontinuous since

the posts extend up past it (Fig. 16).



Figure 16.

<http://www.youtube.com/watch?v=c84wb8Z660c> All of the rails were discontinuous in this video as the posts extend past the cap rail. Screws

seemed to be used exclusively as fasteners and there was no mention of post spacing.

The final area of research was real world examples in Fayetteville, Arkansas. About ten locations were visited, most of them being wood walkways for lower-income/student apartment buildings near Leverett and Deane Streets because they were semi-public and access was possible. Again, there was a surprising amount of variety, but one thing that was noticeable was that nails were used more often than screws. However, this could be attributable to the generally older construction of these decks. The first example (Fig. 17) is actually a bit different than the others since it is a private deck located just outside of city limits, almost fifteen years old. Galvanized nails are the only fasteners and the guardrail posts are curiously notched on the outside for



the 2x4 top rail. A 2x6 continuous cap rail is centered above the posts and the balusters attach to the outside surface of the top rail and the joists below.

Figure 17. Residential deck with the tops of the posts notched to receive the top rails.

The next example is from apartments across from the Lewis Soccer Fields (Fig. 18). This example also used all nails with a continuous 2x6 cap rail centered above the guardrail posts with 2x4 top rails running directly beneath, discontinuous between, and flush with the inside of the posts. 2x2 balusters extend down to attach to the joists.

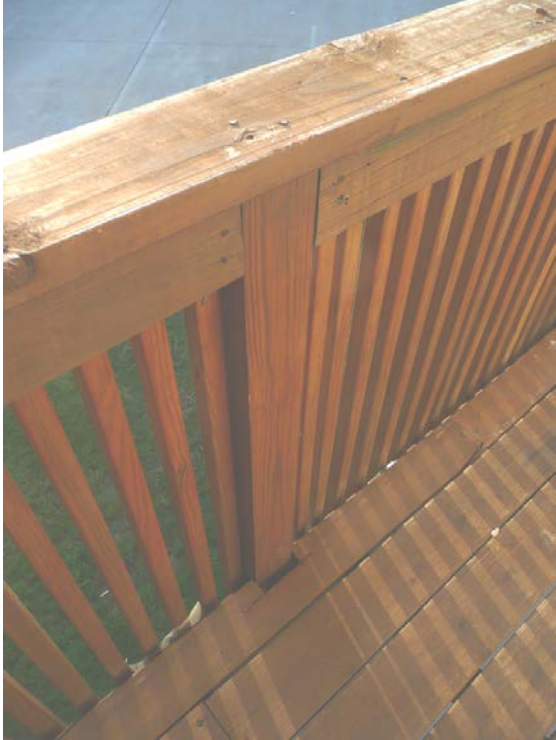


Figure 18. Apartments on Lewis Avenue with a continuous cap rail and discontinuous top rails. Nails were the only fasteners used.

The final example, or at least some variation on it, was fairly common because the guardrail posts often extended up to support an overhanging roof or more walkways (Fig. 19). This makes the cap, top, and bottom rails discontinuous. Here a 2x6 is used for the cap rail, 2x4s for the top and bottom rails, and 2x2s for the balusters. The top and bottom rails are flush with the inside surface of the posts and the balusters are attached to their outside surface. Nails were mostly used at this location but some screws were used to attach the cap rail to the top rail and posts.



Figure 19. Apartments near Cleveland and Storer with all rails discontinuous. Nails were used to attach the bottom rails to the posts and some separation can be seen in this figure where the nails have completely pulled out or sheared off.

The literature search also focused on guardrail post spacings since a maximum is not stated by code. A six foot spacing was the most-recommended in the literature. Although only one real world example had the posts six feet on center and the average spacing from a sample of eight different locations was just under nine feet, the literature is pretty clear about calling for a six foot maximum spacing. In fact, the only specified spacing length for wood deck guardrail posts besides six feet was one for five feet and another for four feet. The previously mentioned Complete Deck Book (Beneke, 2002), the Deckplans.com website (DekBrands, 2012), and the Decks.com video (“How to Build Deck Railings” 2010) specify a six foot maximum spacing while the Better Homes and Gardens book specified five feet (Beneke, 1998). Other resources, such as the American Wood Council’s “Prescriptive Residential Wood Deck Construction Guide”, recommends a six foot maximum spacing, while Portland, Oregon’s “Deck Design Guide” specifies a four feet maximum spacing. There appears to be nothing in the local

(Fayetteville's), national, or international building codes which specifies wood deck guardrail post spacing maximums. A six foot spacing was therefore chosen to represent the most common, but also largest, spacing specified by the literature.

Fastener use was the last final area researched. In the real world examples, nails appeared more frequently than screws. However, all of the real world examples visited looked to be at least a decade old and did not reflect what was found in the literature, especially the newer literature. With the exception of the Home Depot video, the oldest Do-It-Yourself book (Beneke, 1998), and the Black & Decker book (Creative Publishing international, 2012), nails were not used. It should also be noted that nails were only specified for use at splices or scarf joints in the Black & Decker book. Therefore, a large majority of the literature specifies screws rather than nails. Even though they take more time and labor, a good contractor should use screws rather than nails to construct decks because of nails' tendency to pull out and weaken connections over time. For these reasons, it seems that screws rather than nails should be used to construct wood deck guardrails.

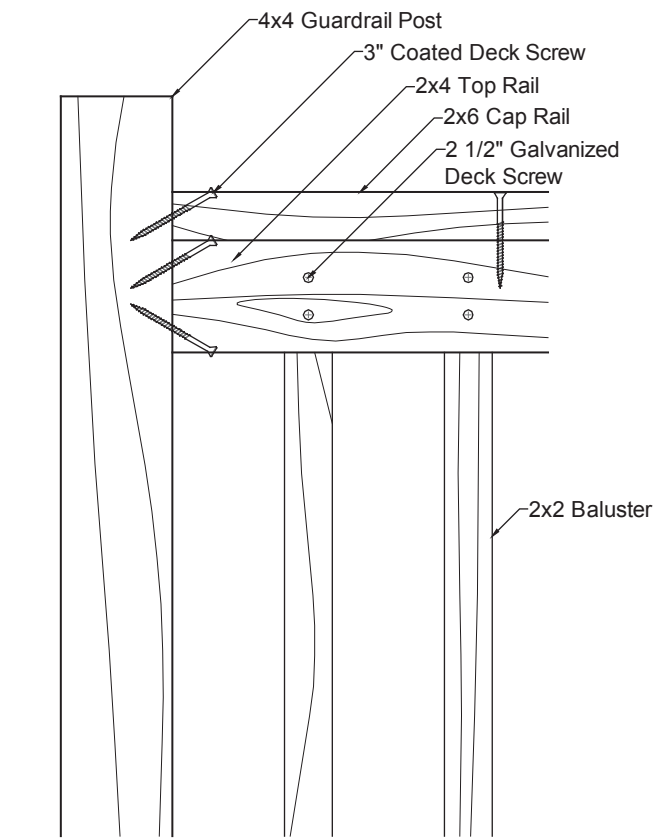
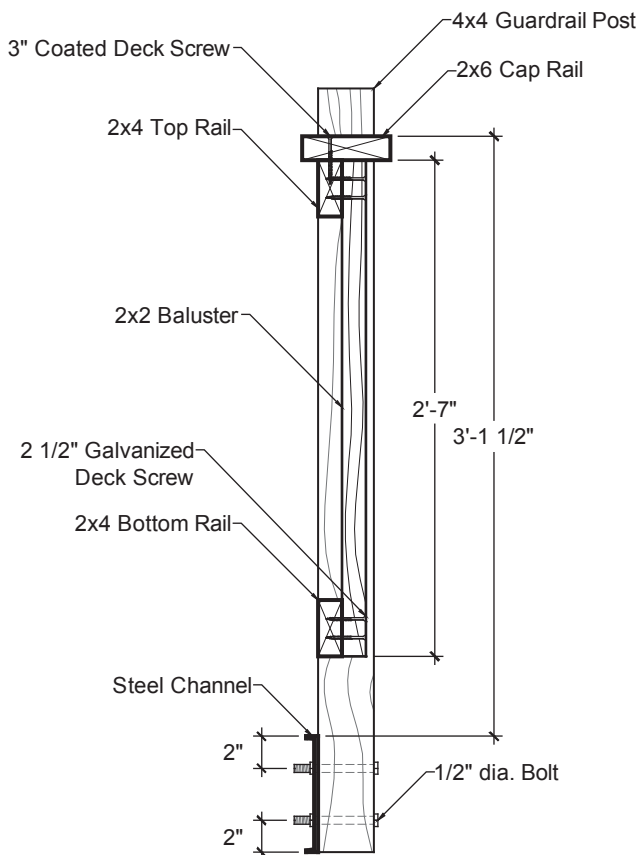
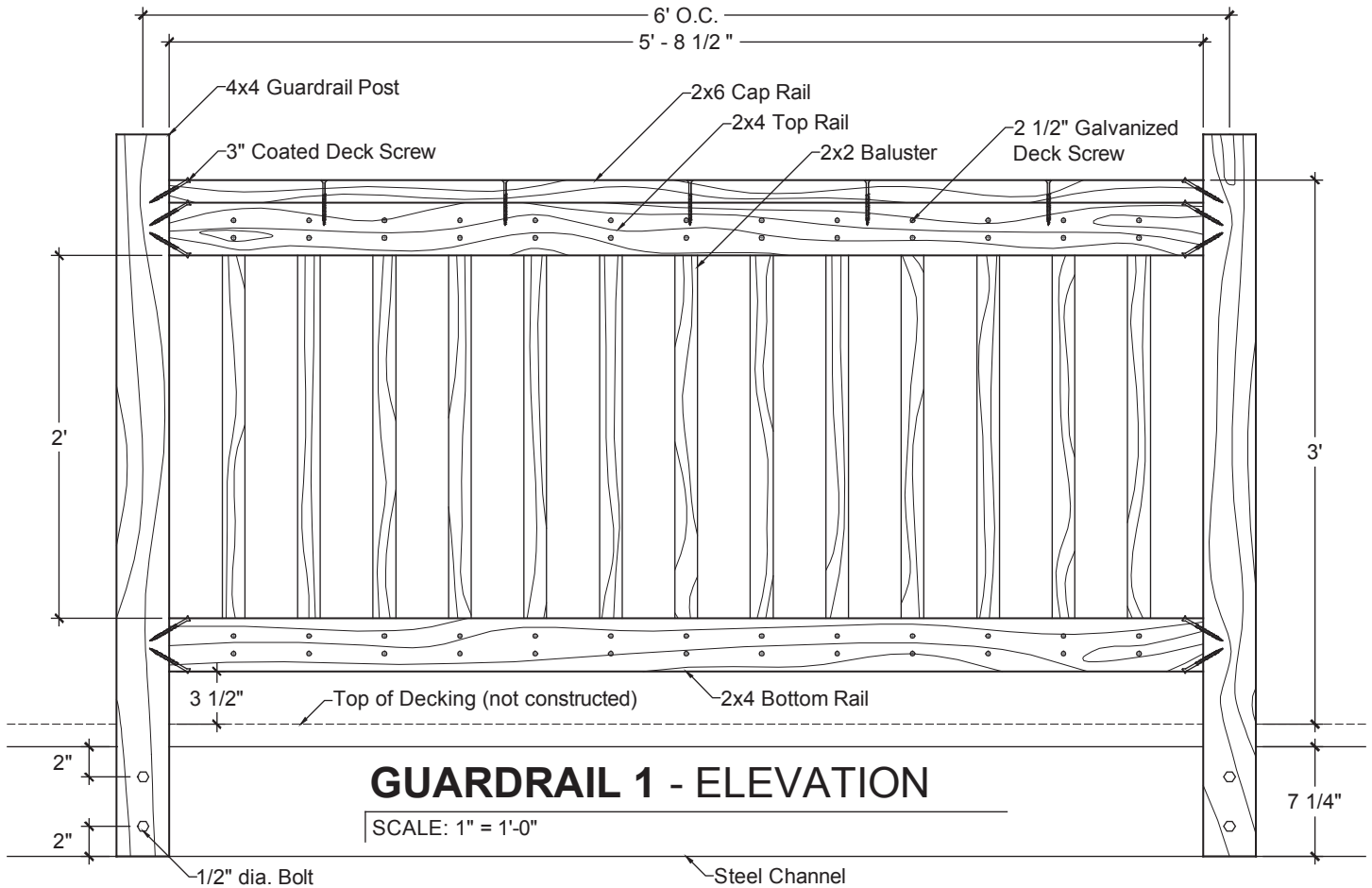
All in all, the strongest of the examples found in the literature review generally rely on eight (two per cap and top rail per end) toe-nailed screws to hold everything between the posts in place and resist 200 pounds of force. In a laboratory setting, the 200 pounds is magnified by 2.5 as a safety factor for a 500 pound total load as per the 2012 International Building Code instructions: "the test specimen shall be subjected to an increasing superimposed load until structural failure occurs or the load is equal to two and one-half times the desired superimposed design load" (1710.3.1). Furthermore, apply this 500-pound force three or more feet from where the cap and top rails connect

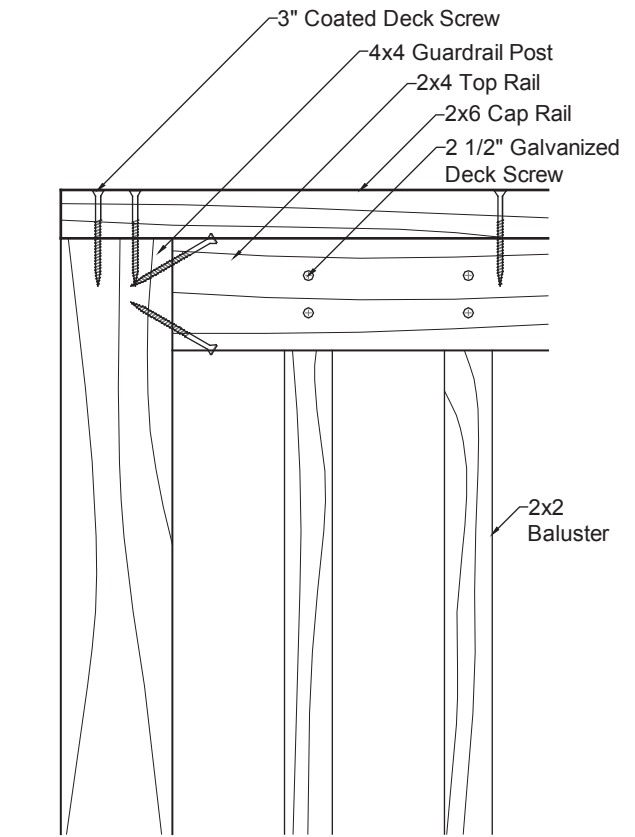
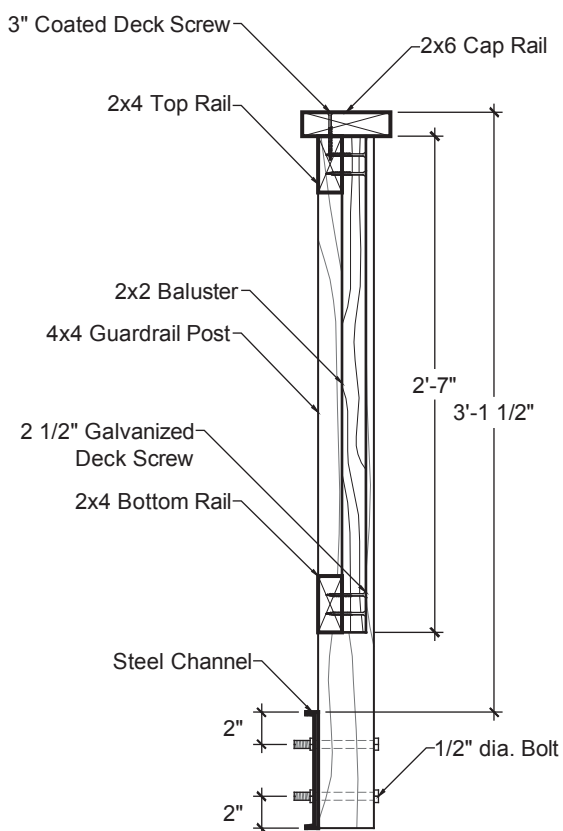
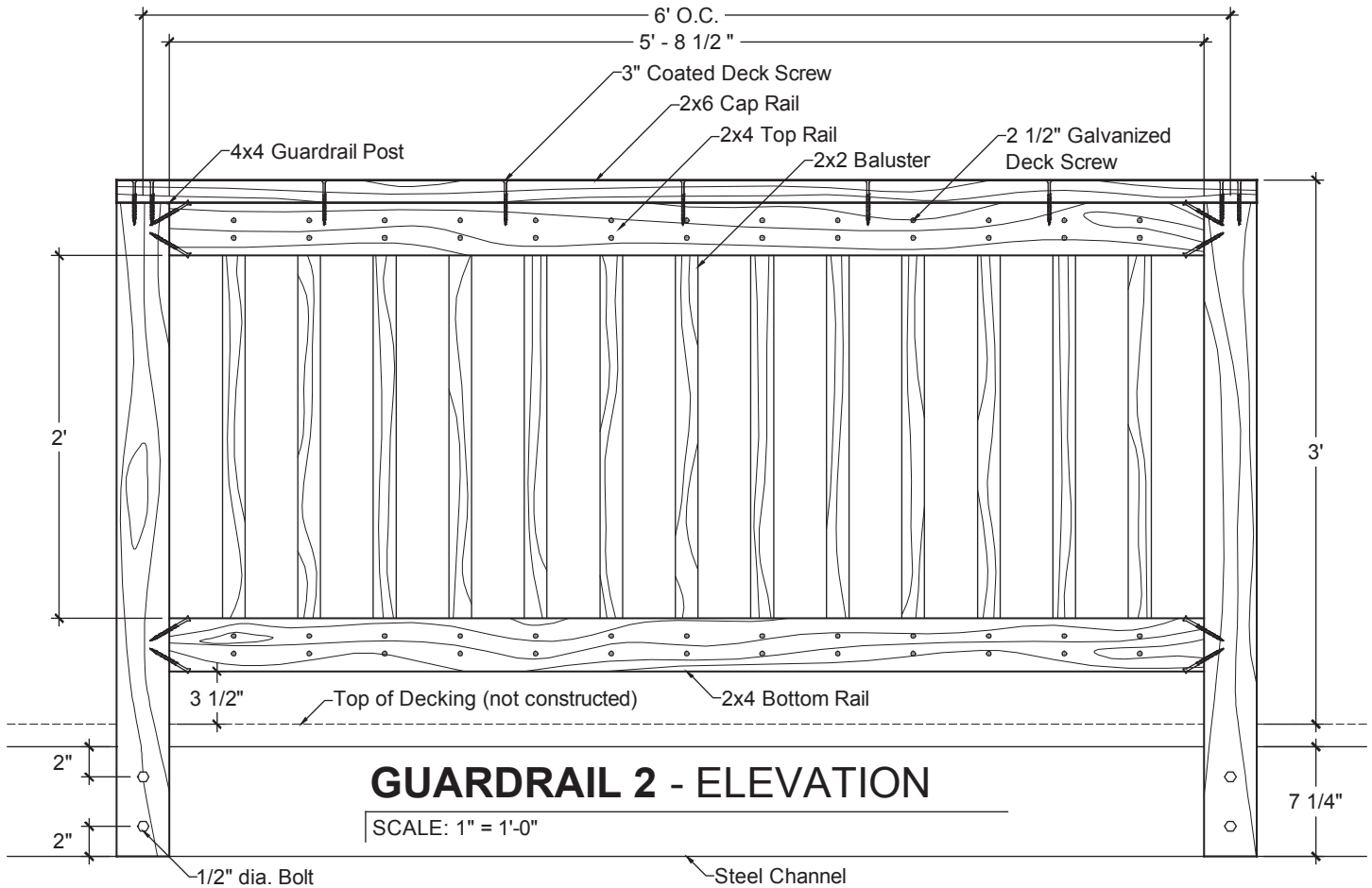
to the guardrail post and this becomes a minimum of a 1,500 pound moment force, certainly a lot to overcome. Especially after seeing the real world examples, it was doubtful that any of the above-mentioned examples would pass this test, which would render almost all deck guardrails not code-compliant and likely dangerous. Testing and research needed to be done to make the space between the posts safe as well.

Methodology

When looking at all of the sources in the literature review and taking commonalities from them all, three main types, or simply “Guardrails,” emerged that seemed to encompass nearly all of the most common modes of construction. Guardrail 1 is where the cap, top, and bottom rails are discontinuous because the guardrail posts extend up past them (Fig. 4, 7-9, 16, and 19). This is somewhat common for either aesthetic or functional purposes such as supporting an overhead structure or even other wooden walkways or balconies above, as witnessed at several of the apartment buildings. This Guardrail relies solely on toe-nailed fasteners to hold the guardrail system in place between the posts (page 20).

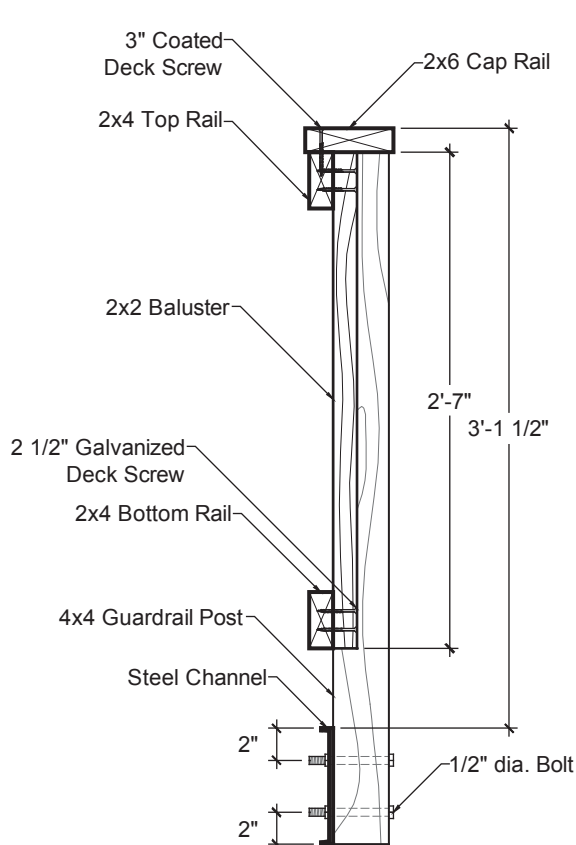
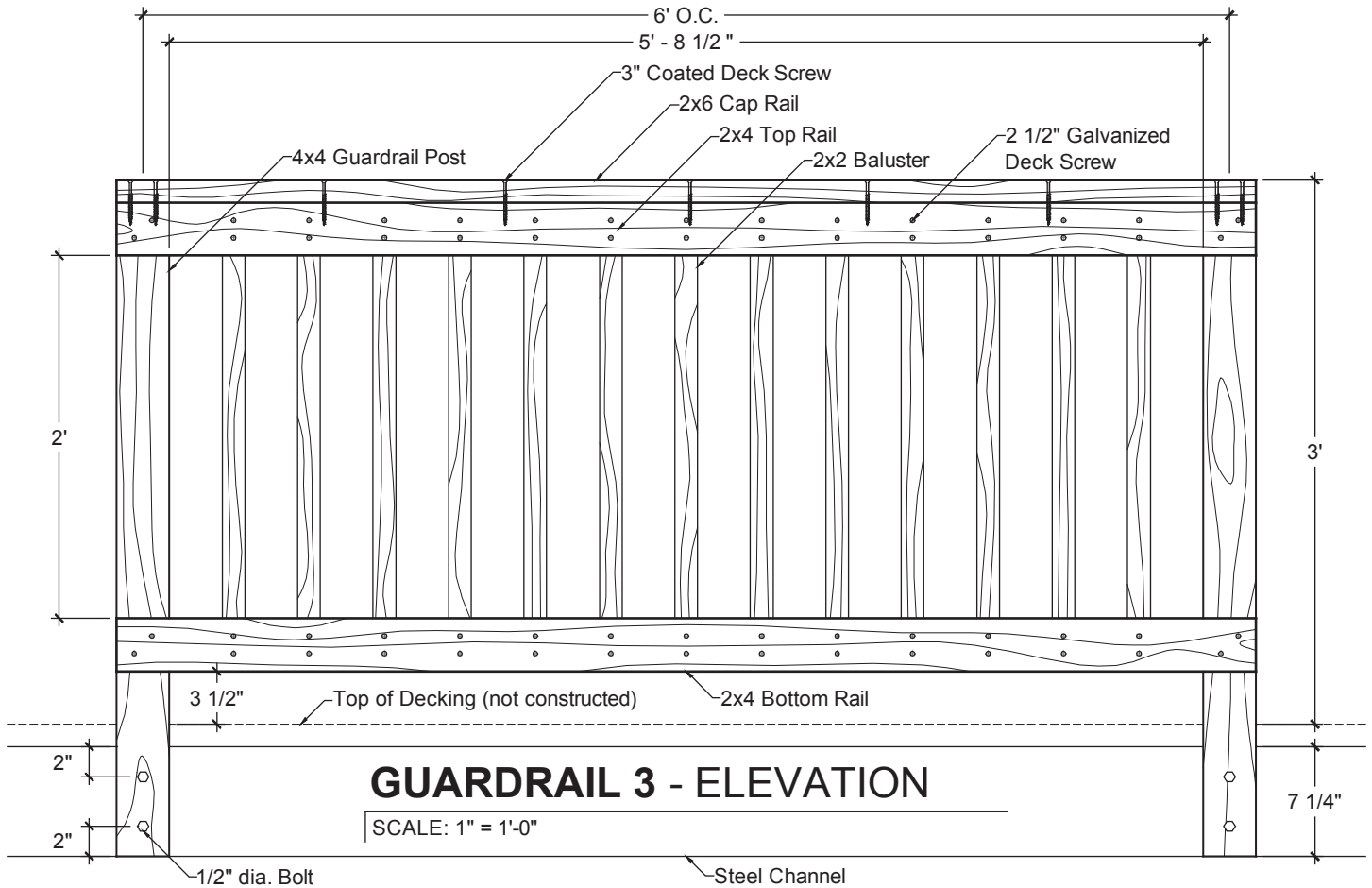
The next system, Guardrail 2, is where the top and bottom rails are discontinuous but the cap rail runs continuously over the tops of the guardrail posts (Fig. 5, 6, 10-12, 18, and example A in Fig. 1). This is quite common but the top and bottom rails still rely on toe-nailed fasteners and although the cap rail is no longer toe-nailed, it is fastened into the end-grain of the guardrail posts which is about half as strong as fastening to the edges of the posts (page 21).





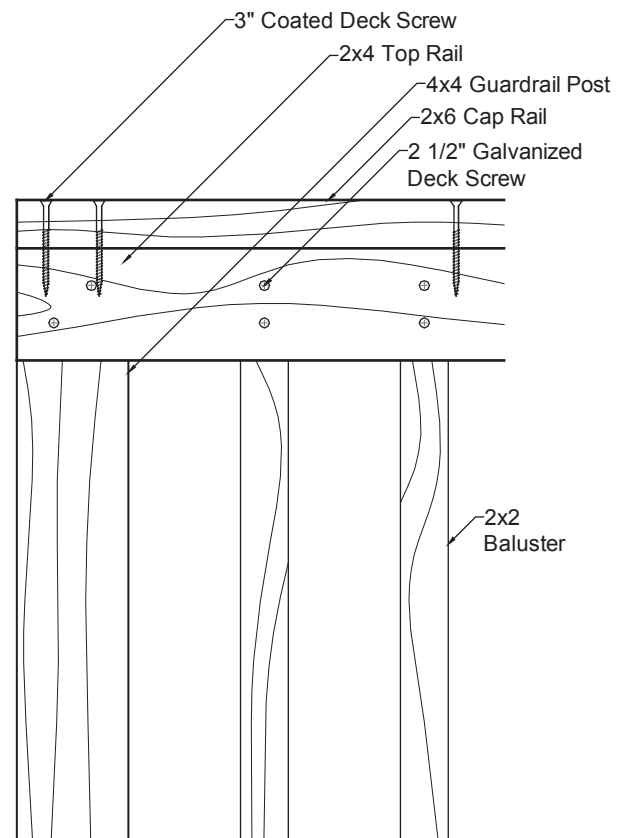
The last common mode of construction, Guardrail 3 uses continuous cap, top, and bottom rails by having the cap rail run over the tops of the guardrail posts and the top and bottom rails fastened flush to their inside surface (Fig. 2, 3, 13-15, and 17). The top and bottom rails could be fastened to the outside surface of the posts instead, but this configuration was not tested since it was not seen as often and its opposite, which should theoretically better resist forces from the usable side of the deck, could be specified just as easily. Here the top and bottom rails are attached straight to the guardrail posts and not into the end-grain (page 23). Also, if the force is directed away from the deck, the top and bottom rails would probably have to snap in order for this system to completely fail. This is unlikely to occur but is still a possibility.

One more system, Guardrail 4, seemed like it should also be tested (Fig. 20-21). This system is very similar to Guardrail 1 or 2 except that it uses “rail-set brackets” by the manufacturer Tehk (DecksDirect.com, 2012). The top and bottom rails are attached using powder-coated steel brackets on each end that are fastened to the guardrails posts with four, one-and-one-half inch square drive stainless steel screws. One more screw going up from the bottom attaches the bracket to the top or bottom rail. This system should be quite strong since the steel brackets cover a decent amount of the top or bottom rail on both sides of their ends. Again they are also attached with four screws driven straight into the guardrail post which doesn't seem likely to pull out. Testing this system should mimic Guardrail 1 so as to determine if the brackets will hold up with the supposedly weakest system (page 24). It still remains to be seen if it will be stronger than Guardrail 3 with its lack of brackets, however.



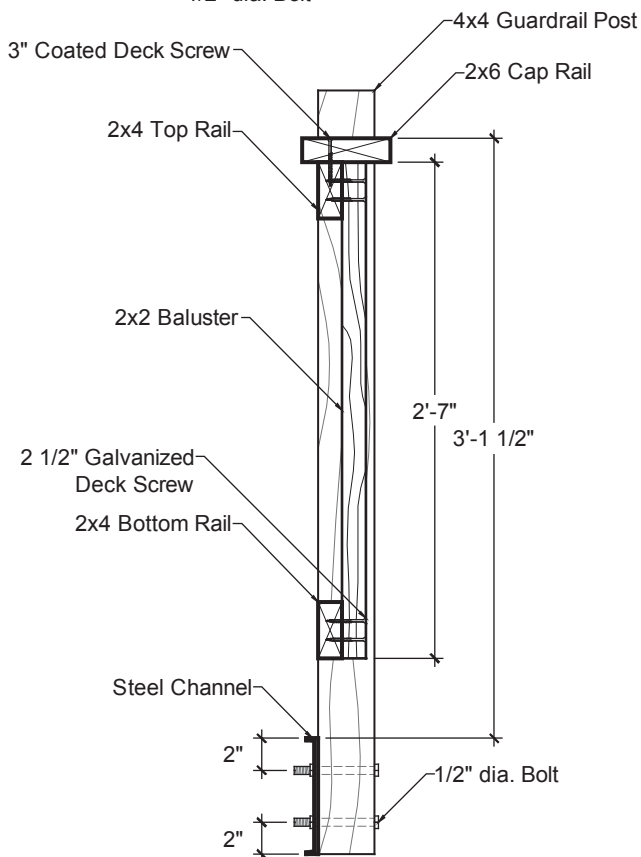
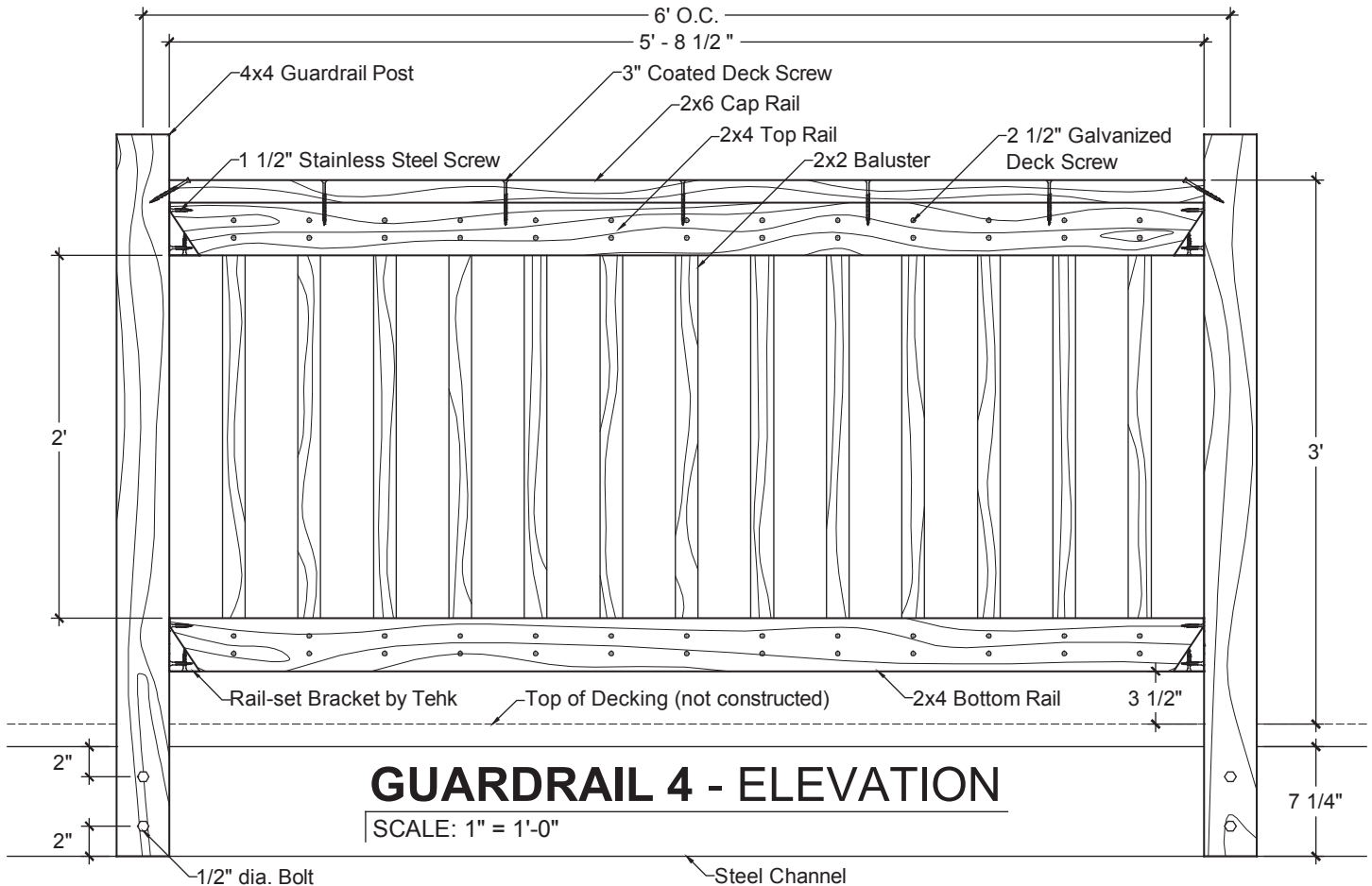
CROSS SECTION

SCALE: 1" = 1'-0"



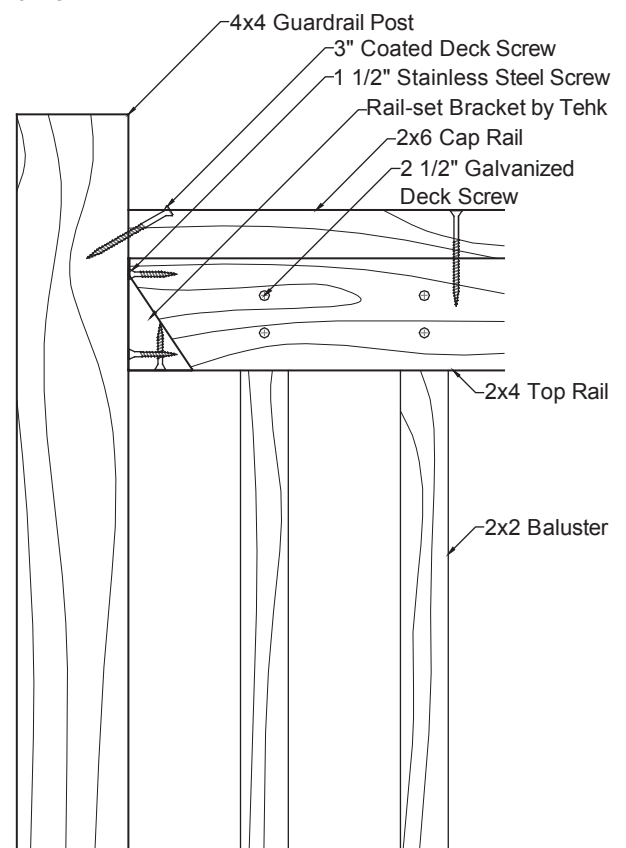
CAP/TOP RAIL DETAIL

SCALE: 1/2" = 1'-0"



CROSS SECTION

SCALE: 1" = 1'-0"



CAP/TOP RAIL DETAIL

SCALE: 1/2" = 1'-0"



Figure 20.

<http://www.decksdirect.com/catalog/product/gallery/id/7244/image/3729/> Tehk Rail-Set

Bracket and the screws used to fasten it to the post and rail.



Figure 21.

<http://www.decksdirect.com/catalog/product/gallery/id/7244/image/3730/> Tehk Rail-Set

Bracket as it is installed.

As mentioned in the literature review, all Guardrails were constructed with the posts six feet on center and screws rather than nails were used as the fasteners.

Materials:

All of the lumber used to construct the Guardrails was purchased from City Lumber, a local business in Fayetteville, Arkansas. The grade of the lumber varied some but all was Yellow Pine and MCA pressure-treated. All the 2x2s, 2x4s, and 2x6s were of the higher, #1 grade while the 4x4s were #2 grade. At every connection besides those involving the Tehk brackets and balusters, three inch long, #9, Phillips drive, coated deck screws were used. Where the balusters connected to the top and bottom rails, two-and-a-half inch long, #8, square drive, galvanized deck screws were used. To attach the Guardrails to the testing apparatus, five inch long, one-half inch diameter bolts and their corresponding nuts and washers were used. Two bolts per post were used and the attachment pattern mimicked actual connections to joists or band joists.

The lumber was delivered all at once and left outside until what was needed was brought inside to construct the Guardrails, which were left inside until they were tested. The amount of time each piece of lumber spent outside or inside varied, one could even say significantly, but moisture content readings on the lumber were taken right before each test (Table 2) and prove that the moisture content, and therefore strength, did not actually differ greatly. Three samples of each Guardrail were constructed and all the samples of one Guardrail were tested during the same testing period.

Testing Set-Up and Protocol:

Testing took place at the University of Arkansas' Engineering Research Center. The testing location had a long, linear "foundation" of reinforced concrete about six feet wide and four-feet deep with various locations of threaded holes four feet three-and-one-quarter inches on center for two-and-three-sixteenths inch diameter solid steel rods

to fit into. Since the test specimens are six feet wide, a MC8 x 8.5' steel channel was purchased and holes were drilled through it to attach it to the steel rods using two, two-and-one-quarter inch stainless steel U-bolts per location. Two, nine-sixteenths inch diameter holes were also drilled through the channel to accept the two bolts at each post connection (Fig. 22).



Figure 22. Steel channel leveled and attached to the solid steel rods via four U-bolts and holes drilled for the Guardrails to attach to.

Two different types of tests, on two different portions of the guardrail system were performed. The first was an “In-Fill Load Test” following the ASTM International D7032 (ASTM International 2010) and the ICC-ES AC273 (International Code Council

Evaluation Services, 2012) guidelines for testing the balusters of a guardrail system. All of the Guardrails utilized the same balustrade system with thirteen balusters each. The middle baluster was centered and about three-and-one-half inches separated all the balusters, which left the same distance between the first and last balusters and the 4x4 guardrail posts. To test the balustrade system, a one foot by one foot steel plate with a centered two-and-one-quarter inch stainless steel U-bolt placed in the very middle of the balustrade on the interior-facing side. A steel cable attached to this U-bolt and a load cell on the other side (Tacuna Systems, model STL with a 1,500 pound capacity). On the other side of the load cell, another steel cable attached it to a come-along (Maasdam Pow'r Pull, model 144S-6, patent no. 2506029 with a one-ton capacity). Using the come-along, a force was applied until the load cell read 125 pounds, which is a pass with a safety factor of 2.5 included (Fig. 23). This test was only performed three



times to get an average and on only one set of Guardrails (Guardrail 1), since they were all the same.

Figure 23. In-Fill Load Test being performed with a display of 273 pounds of force.

The “Concentrated Load Test for Guards” was the second and most important type of tests conducted and followed the same testing protocols referenced above. After

each Guardrail was connected to the testing apparatus, the moisture content was recorded. The moisture content close to the top of the posts, and near the middle of the cap, top, and bottom rails was recorded before each test and is shown in Table 2. After each Guardrail was bolted to the steel channel through its 4x4 posts, a custom “hook” manufactured from bent steel and with a J-bolt welded on top was placed over the cap rail, at the very top and middle of each guardrail. A steel cable connected this “hook” to the previously mentioned load cell which again had another steel cable on its other side attached to the come-along. A steady point of reference was established and placed on the interior-side of the Guardrails, just touching the steel “hook.” This was done to measure deflection as the Guardrails were pulled outwards during testing. A full view of



the testing set-up can be seen in Figures 24 and 25.

Figure 24. Full testing set-up with a Concentrated Load Test in progress.



Figure 25. Full testing set-up showing the custom “hook” made from bent steel and a J-bolt welded on top.

After the set-up and the moisture content was recorded, the come-along was ratcheted until the load cell displayed 200 pounds of force and the deflection was measured (Fig. 26). The come-along was ratcheted again until the load cell displayed 500 pounds of force and then the deflection was measured again (Table 1). Once a 500 pound force was applied to the Guardrail, it passed. The force would have been increased until the Guardrail broke but the testing equipment and set-up made this somewhat dangerous and the steel channel was looking like it would break or bend beyond repair before the Guardrails would break. The first test of Guardrail 1 also made it to 710 pounds without breaking so all following tests simply had 500 pounds of force applied.



Figure 26. How deflection was measured, with 200 pounds of force being applied in this example.

Results

In-Fill Load Test Results:

All three of the balustrades passed. Only when the force was increased to about 280 pounds did some pull-out of the screws begin to show, which would count as a fail according to the ASTM International D7032 guidelines, but this occurred at more than two-times the required testing limit (Fig. 27).



Figure 27. Only some evidence of slight pull-out when the testing force was exceeded.

Concentrated Load Test Results:

The concentrated load tests yielded some surprising results: every single test for all of the Guardrails passed. Not only did they pass but there was also no real noticeable damage or evidence of pull-out etc. where the cap, top, and bottom rails attach to the posts. This was not the case where the posts attached to the testing apparatus, however. Besides all of the Guardrails passing, the rest of the results lie in the deflection at the tops of their mid-span. Again, they were surprisingly similar, with variations of only a few tenths of inches. Guardrail 1 did deflect the most, which was expected, but not by much.

Table 1:

	Deflection at 200 lbs.	Deflection at 500 lbs.
GUARDRAIL 1		
Test 1	1 - 9/16"	4 - 3/4"
Test 2	1 - 11/16"	4 - 3/16"
Test 3	1 - 5/8"	4 - 5/8"
Average:	1.6417"	4.5375"
GUARDRAIL 2		
Test 1	1 - 3/8"	4 - 1/16"
Test 2	1 - 1/4"	4 - 9/16"
Test 3	1 - 3/8"	4 - 1/4"
Average:	1.3333"	4.2917"
GUARDRAIL 3		
Test 1	1 - 9/16"	5 - 3/16"
Test 2	1 - 1/4"	3 - 1/2"
Test 3	1 - 5/16"	3 - 3/4"
Average:	1.375"	4.1458"
GUARDRAIL 4		
Test 1	1 - 5/8"	4 - 11/16"
Test 2	1 - 1/4"	3 - 5/8"
Test 3	1 - 11/16"	4 - 11/16"
Average:	1.5375"	4.35"

Moisture Content:

The moisture content did not vary tremendously, with the overall averages between specimens only ranging from 8.3% as the lowest and 9.9% as the highest. Although the testing for Guardrail 1 occurred over a week before the rest of the tests, the extra wait time and varying amounts of time the lumber spent indoors and outdoors, does not appear to have affected the moisture content, which could have affected the strength of the wood.

Table 2:

	Moisture Content (%)					
	Left 4x4	Right 4x4	Cap Rail	Top Rail	Bottom Rail	Overall Average
GUARDRAIL 1						
Test 1	9.6	10.4	9.8	9.5	9.7	9.8
Test 2	8.7	10.2	9.6	9.8	7.7	9.2
Test 3	8.7	7.5	9.3	9.2	9.7	8.88
GUARDRAIL 2						
Test 1	8.1	10.3	9	8.7	8.8	8.98
Test 2	8.3	9.5	8.6	8.1	9.9	8.88
Test 3	9.8	9	7.7	8.6	8.2	8.66
GUARDRAIL 3						
Test 1	9.1	8.7	8.5	8.1	8.2	8.52
Test 2	8.8	8	7.4	8.2	9	8.28
Test 3	8.9	8.6	7.6	8.1	9	8.44
GUARDRAIL 4						
Test 1	13.2	10.9	7.8	9	8.6	9.9
Test 2	7.3	8.2	8.1	9.1	9.1	8.36
Test 3	8.8	8.7	8.1	9.2	10.3	9.02

Discussion

During the course of research for this paper, it could not be determined if any codes specify a maximum post spacing for wood deck guardrails. Neither the International Building Code, International Residential Code, Fayetteville's local building code, nor the ASTM International or ICC-ES testing guidelines specifically stated it. Even a call to a local building inspector only led to a recommendation of about an eight-foot maximum post spacing. That is why the literature and real world examples had to be relied upon to determine a likely spacing distance. This fact, and especially the real world examples, raise some concerns about there not being any guiding code. The literature, which does not give a maximum post spacing beyond six feet, seems quite reasonable. The real world examples, on the other hand, averaged a nine foot spacing

and one example had a spacing of eleven-and-a-half feet. A shortcoming of the research, however, is that more recently constructed real world examples were not visited. As stated in the literature review, all the real world examples visited appeared to be at least a decade old so current methods of construction, which could differ, were not analyzed. There is still clearly a lot of variation out there and more needs to be done to determine what is safe and could be added to the codes.

The expectation was that at least one Guardrail, if not most of them, would fail. That is why the results were surprising. But if at least one of the Guardrails was thought to fail, why didn't they? Although not definitively proven by the experiments, it appears that all of the forces which could have acted on the cap/top rail to post connection and



Figure 28. Notice the bending of the steel channel

potentially made the Guardrails fail, were simply transferred through them to the posts and thence to the bolted connection at their lower ends. This can be evidenced by how much the steel channel deflected (Fig. 28 & 29) and of washers crushing into the posts (Fig. 30). In fact, the only visible damage occurred here. This might have happened due to a “double-lever arm effect” which occurred when the forces applied in the tests traveled three feet from the mid-span of the guardrail to

where the cap and top rails attach to the posts, and then down another three feet to where the posts attached to the testing apparatus. Instead of a nearly 1,500 pound moment acting at the cap and top rail connection occurring, possibly a 3,000 pound moment force acts upon the post connections and becomes much more important to overcome. This means that this connection is the crucial one in a guardrail system and reinforces the work of the Joseph Loferski and Michael G. Morse research groups. This is just speculation, however, and more testing needs to be done to determine if a larger span would impact the cap/top rail-to-post connection more or simply increase the



forces on the post-to-joist connection.

Figure 29. Bending and even twisting of the steel.

The tests did answer the main question, however. It appears that wood guardrails, or at least the portions of the guardrail system between the posts, *are* code-compliant. Although these tests only prove that guardrails constructed in the four ways detailed in this paper are

code-compliant, it seems that as long as three inch, #9 deck screws are used as the fasteners and the post spacing is limited to six feet or less, then practically all the common methods of guardrail construction *as represented in published literature* should be code-compliant. There was no catastrophic failure, no evidence of failure or damage



Figure 30. Seating of washers as the wood grain is crushed.

at the cap, top, and bottom rails, and the deflection limits were not exceeded. Furthermore, they all performed about the same. Guardrail 3, the one with continuous cap, top, and bottom rails, could be said to have performed the best with the least amount of average deflection at 500 pounds of force and second-least at 200 pounds. Guardrail 1, with discontinuous cap, top, and bottom rails, performed the worst with most deflection at both intervals.

Guardrail 2, with a continuous cap rail but discontinuous top and bottom rails, slightly outperformed Guardrail 4 which utilized the Tehk rail-set brackets. Although the different Guardrails can be “ranked,” there was no stark difference between them as the largest range less than four-tenths of an inch.

In summary, the final conclusions that can be made are that: testing needs to be done to determine a maximum post spacing for wood deck guardrails and this should be added to building codes; further testing should be performed to determine whether a larger post spacing could cause the cap and top rail-to-post connection to fail or if the post-to-joint connection is just more likely to fail; and lastly, most methods of guardrail

construction as represented in the *current, written* literature by the Guardrails tested in this study *are* code-compliant.

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