TESTING THE GUARDRAIL POST TO DECK CONNECTION

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Every deck builder knows full well the risks inherent in their occupation. Most injuries are related to builders getting cut, smashing body parts, getting nicked with saws, or stepping on nails. These are the daily risks that we try to guard against. However, the injuries that are most likely to take our business, home, livelihood, and everything we have worked so hard for occur after we have packed up our tools, turned our work over to the homeowner, and are working on our next job. These are the catastrophic injuries that occur due to deck railing failures. They occur years later, after we have moved on, timber has shrunk and settled and, connections have loosened. A deck railing fails, giving way and spilling the occupants from the deck. There is no warning; there is no indication of risk, or of imminent danger. Wedding receptions and graduations turn from festive occasions into tragic news events. A few years will pass, court depositions will be taken, and the contractor risks losing everything.

Why? Because deck railings are hard pressed to handle the loads placed on them during their service life. Railings are built by the carpenter with only a vague idea of the future demands that will be placed on his work. Will a sports team enjoy a picnic on this deck and have eleven men lean or sit on the top rail? Will partygoers begin wrestling and fall into it? Who decides what the appropriate load is and what is an acceptable margin of safety?

Structural safety decisions are under the purview of the building code officials and their code writers. These officials quantify the load that a guardrail and handrail must carry with a reasonable safety margin. Code provisions for deck guardrails can be found in the International Residential Code (IRC, 2000 and 2003). IRC Tables R301.4 and R301.5 define the minimum concentrated live load for guardrails and handrails as 200lbf (pounds of force). The application of that load is described in Footnote “d”, Table R301.4: “A single concentrated load applied in any direction at any point along the top”.

In acknowledgment that guardrails and railings in use may be subjected to conditions that are more demanding then those experienced in the testing process, the IRC employs an appropriate “safety factor”. Extreme conditions and variables such as improper installation, variation in material properties, weathering, and excessive "in-use" loading require that a safety factor be applied to the minimum design load. The International Building Code, Section 1714, employs a safety factor of 2.5 for test units as described in Section 1712.1, "the structural unit and connections." Since this safety factor has been used for many years, we believe it is appropriate for the tests described herein.

Each guardrail design must successfully withstand a load of 500 lbf (200 lbf x 2.5 = 500 lbf), applied at the top in any direction, to be considered as a code compliant assembly.

<u>A Stronger Connection is Needed:</u>

Forensic examination of guardrail failures reveals the weak link in the design to be the guardrail post attachment to the deck band board. When an occupant of a deck leans against the guardrail, their weight stresses the post connection at the base of the post. This force, along with others, weakens and ultimately can cause the connection to fail. Because of this scenario, research has been conducted to understand and improve this connection.

In an effort to address this problem, Morse Technologies examined the construction details of deck connections, defined the various modes of connection failure, and developed practical mechanisms to reinforce components in ways that resist the most prevalent modes of failure.

Historically, the guardrail post has been attached to the deck using one of two types of fasteners; lag screws or carriage bolts. The process for installing each fastener type is similar; both require two fasteners installed near the bottom of the post and connected to the deck band board. However, the lag screw and bolt connections exhibit different modes of failure.

Lag bolts are installed by drilling through the post and into the band board and then screwing the lag screw into the band board. The threads of the lag bolt are intended to grip the timber fibers of the band board. Ideally, the holes in the post and in the band board are made with different drill bits; one sized to allow the lag bolt to pass through the post and the other sized to allow the threads to grip the band board. Although this connection has a rather large capacity to resist vertical (shear type) loads, its ability to resist lateral loads applied to the post is limited. This limitation is the relatively low capacity of lag bolts in tension due to pullout of the lag bolts through the timber bandboard.

Carriage bolts are installed in a similar fashion. Holes are drilled in the same location as with lag screws, but the holes are sized to allow the carriage bolt to pass through both the guardrail post and the band board. The connection is achieved by the installation of a washer and retaining nut on the carriage bolt. When tightened, the assembly provides a through-bolted connection between the post and the band board of the deck. As with the lag bolt, this connection does well resisting vertical loads but its ability to resist lateral loads applied to the post is limited. The limitation of this design is related to the connection of the band board to the joists of the deck. While the connection of the post and band board generally remains intact, the load applied to the post causes the band board to be peeled off the ends of the deck joists. This is due to the method of connection typically used for band boards. Band boards are affixed to the deck with 16-penny nails installed in the end grain of the deck joists. This method possesses a surprisingly low resistance in tension, allowing pullout with relatively little force.

The use of joist hangers at the joist to band board connection does very little to improve resistance to pullout. The contribution of the decking material to the structural integrity of the band board to joist connection is also very minimal, as the deck materials commonly used today are either 5/4, or less, pressure treated pine with the fasteners placed very close to the board edge, or man made composite material with no structural contribution.

To counter these shortcomings, Morse Technologies developed DeckLok, a metal bracket system that, among other things, greatly increases the lateral load-carrying capacity of the guardrail post to deck connection. DeckLok replaces the lag bolt, carriage bolt or through-bolt connection with a much stronger connection that directs the force into the contiguous deck members, absorbing and distributing the energy of the load with reduced risk of injury to the deck occupants. The effect of this distribution is evidenced during load testing through bending of the timber post, twisting of the timber band board, and most importantly, deformation of the metal bracket. These distortions not only increase the ability of the railing system to accommodate lateral load, they also provide a warning to the occupants of the deck that something is amiss.

** picture and description of bracket

The Testing Process:

During research performed at the in the Civil Engineering Department at a local University, test units were assessed that replicated five different configurations. These test units simulated the current industry-standard methods for connecting timber deck guardrail rail posts to deck structures. For each of the five configurations, three samples were tested to eliminate anomalies and for comparison of results.

All of the test units were constructed using pressure-treated No. 2 Southern Pine 4x4s attached to No. 2 Southern Pine 2x8 band boards using ½" hex-bolts with flat washers, simulating the common practice of attaching posts with carriage bolts and retaining nuts. The band boards were then connected to the deck joists using four 16-penny nails. 5/4x6 deck boards were screwed to the deck joists using two 2", No. 8 galvanized decking screws at each joist. Due to the introduction of multiple decking products being used in place of solid-sawn lumber decking, we did not rely on the decking to provide structural support to the tested post assembly. Therefore, the decking installed on the test units did not contact the band board being tested and thus was not allowed to provide support for the band board and post rail connection. Each unit was then tested on a fabricated steel load frame. An increasing lateral load was applied to the 4x4 at a point 36" above the deck surface to measure resistance, to record the necessary data, and to assess the safety code compliance of each Test Unit.

These tests did not take into account the effects of weathering. Deck components and their connections deteriorate over time. The load capacity of screws, nails, hardware, and wood products diminish with use and age. The test units were constructed with new lumber and fasteners. It is most probable that the load capacity of these, or any connections, would diminish with the effects of time and weathering. As stated earlier in this paper, the factor of safety is used by the safety code to compensate for these factors.

Test Load Frame:

To compare the effectiveness of the test units, a fabricated steel load frame was constructed. The purpose of the load frame was twofold: to support the test units to simulate real life conditions, and to provide a mechanism with which load could be applied and quantified as the test units were stressed to failure.

Our load frame was fabricated from 2" angle steel, welded into a 4´x5´ rectangular test bed. By welding angle steel legs to the frame, slots were created to confine the deck joists. Holes were drilled through the steel slots where ½" pins would be inserted to lock the test units into the load frame. Steel risers were welded to the load frame to hold the test units above the frame. This allowed the guardrail post and the deck band board that was being tested to react and move independently without contacting or binding on the load frame itself. See photo 1.

Photo 1: Test Load Frame

Load was applied by means of a "come along" type cable puller with one end hooked to a calibrated and certified dynamometer and the other to a steel ring, affixed to the 4x4 timber post being tested. The ring was positioned at a height of 36" above the deck surface, the minimum height of a residential guardrail as required by IRC.

This series of tests assumed that, in railing failure, the deck joists remain in place. Our tests simulated this condition by affixing the deck joist to our steel frame such that only the joists were anchored. Lateral force was applied to the top of the 4x4 until failure occurred, or until the force exceeded that which our equipment could safely withstand (1,350 lbs. to 1,500 lbs.). For this series of tests, guardrail post failure was defined as a condition where deck occupants would no longer be safely corralled by the guardrail. As long as the post remained in a somewhat vertical position and retained structural integrity, the test was continued.

The tests were stopped by catastrophic events, such as post failure or excessive movement of the post. Each of the five configurations was tested with three separate samples (A, B, and C) to allow results to be averaged.

Test Unit Configurations

In each series of tests, the Control Test Unit represents the common industry accepted standard construction practice and method of attachment. The Bracket Test Unit is the alternative attachment method provided by the use of the DeckLok metal bracket system.

Test 1

For Test 1, the 4x4 post was mounted outside of the band board, equidistant from each of the two deck joists. The 2x8 deck joists were set at 16" O.C. The 4x4 post is mounted with two ½" by 8" hex-bolts with flat washers on each end. The holes were pre-drilled, 5½" O.C. apart, 1½" from the bottom. The 4x4 was mounted perpendicular to the band board.

Control Test Unit:

The band board was attached to the ends of the joists using sixteen-penny nails, three on each joist, installed with a pneumatic nail gun.   No DeckLok brackets were used in this test.

Results:

The nails pulled out of the deck joists, dislodging the band board and the attached post at a load of 150 lbs. Since the band board was attached to 3 joists, each connection provided approximately 50 lbs resistance to pullout.

DeckLok Bracket Test Units:

The configuration with DeckLok brackets is shown in Diagram T-1. The 4x4 post is mounted in identical fashion to the Control Test Unit.   The DeckLok brackets were located with their base against the inside of the band board and their long side flush against a deck joist. The brackets were attached to the deck joists by two, 2½" long, ½" hex-bolts and nuts, with ½" flat washers on each side. A 2½" long, ½" hex-bolt, with flat washers and retaining nut secured the brackets to the band board. All nuts were tightened to approximately 30 lbs/ft of torque.

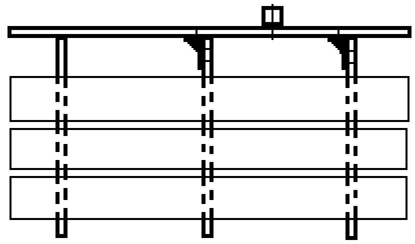

Diagram T-1

Test 1, DeckLok Bracket Results:

1A Timber failure of the 4x4 post at 700lbs

1B Timber failure of the band board at 525lbs

1C Timber failure of the band board at 600lbs

Test 1: Test units 1A, 1B, and 1C following test

Test 2

For Test 2, the 4x4 post was mounted <u>inside</u> the band board, equidistant from the two deck joists. The 2x8 deck joists were set at 16" O.C. The 4x4 is mounted with two ½" by 8" hex-bolts with flat washers on each end. The holes were pre-drilled, 5½" O.C. apart, 1½" from the bottom. The 4x4 was mounted perpendicular to the band board.

Control Test Units:

The band board was attached to the ends of the deck joists using sixteen-penny nails, three on each joist, installed with a pneumatic nail gun. No brackets were used in this test.

Results:

The nails pulled out of the deck joists, dislodging the band board and the attached 4x4 post at a load of 100 lbs. Since the band board was attached to each of the three deck joists, each connection provided approximately 33 lbs resistance to pullout.

DeckLok Bracket Test Units:

The DeckLok Bracket configuration for Test 2 is shown in Diagram T-2. The DeckLok brackets were located with their base against the inside of the band board and their long side flush against a deck joist. The brackets were attached to the deck joists by two 2½" long, ½" hex-bolts and nuts, utilizing ½" flat washers on each side. A 2½" long, ½" hex-bolt, with flat washers and retaining nut secured the brackets to the band board. All nuts were tightened to approximately 30 lbs/ft of torque.

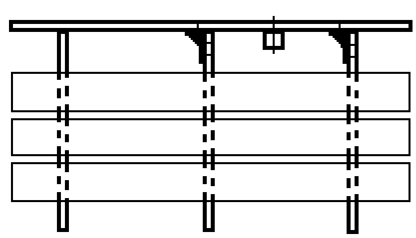

Diagram T-2

Test 2, DeckLok Bracket Results:

2A Timber failure of the 4x4 post at 525lbs

2B Timber failure of the band board at 525lbs

2C Timber failure of the band board at 500lbs

Test 2: Test units 2A, 2B, and 2C following test

Test 3

For Test 3, the 4x4 was mounted <u>outside</u> of the band board, located adjacent to the point of connection of a single deck joist. The 2x8 deck joists were set at 16" O.C. The 4x4 is mounted with two ½" by 8" hex-bolts with flat washers on each end. The holes were pre-drilled, 5½" O.C. apart, 1½" from the bottom. The 4x4 was mounted perpendicular to the band board.

Control Test Unit:

The band board was attached to the ends of the deck joists using sixteen-penny nails, three on each joist, installed with a pneumatic nail gun. No brackets were used in this test.

Results:

The nails pulled out of the deck joists, dislodging the band board and the attached 4x4 post at a load of 75 lbs. Since the band board was attached to each of the three deck joists, each connection provided approximately 25 lbs resistance to pullout.

DeckLok Bracket Test Units:

The DeckLok Bracket configuration for Test 3 is shown in Diagram T-3. One DeckLok bracket was utilized to anchor the 4x4, through the band board, to the deck joist by slipping the bracket over the top bolt and installing a flat washer and retaining nut. The DeckLok bracket was located with its base against the inside of the band board and the long side flush against a deck joist. The bracket was attached to the deck joist by two 2½ " long, ½" hex-bolts and nuts, utilizing ½" flat washers on each side. All nuts were tightened to approximately 30 lbs/ft of torque.

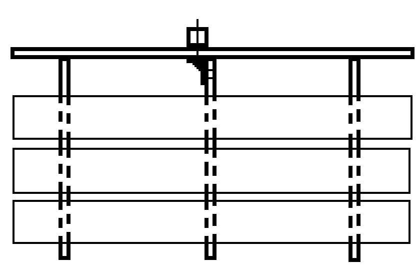

Diagram T-3

Test 3, DeckLok Bracket Results:

3A Timber failure of the 4x4 post at 600lbs

3B NO FAILURE Test stopped at 1,500 lbs to avoid damage to testing equipment.

3C NO FAILURE Test stopped at 1,350 lbs to avoid damage to testing equipment.

Test 3: Test units 3A, 3B, and 3C following test

Test 4

For Test 4, the 4x4 was mounted inside of the band board, located adjacent and contiguous to a single deck joist. The 2x8 deck joists were set at 16" O.C. The 4x4 is mounted with two ½" by 8" hex-bolts with flat washers on each end. The holes were pre-drilled, 5½" O.C. apart, 1½ " from the bottom. The 4x4 was mounted perpendicular to the band board.

Control Test Unit:

The band board was attached to the ends of the deck joists using sixteen-penny nails, three on each joist, installed with a pneumatic nail gun. No brackets were used in this test.

Results:

The nails pulled out of the deck joists, dislodging the band board and the attached 4x4 post at a load of 65 lbs. Since the band board was attached to each of the three deck joists, each connection provided approximately 22 lbs resistance to pullout.

DeckLok Test Units:

The DeckLok Bracket configuration for Test 4 is shown in Diagram T-4. One DeckLok bracket was utilized to anchor the 4x4 and band board to the deck joist by slipping the bracket over the top bolt and installing a flat washer and retaining nut. The DeckLok bracket was located with its base against the inside of the 4x4 and the long side flush against a deck joist. The bracket was attached to the deck joist by two 2½" long, ½" hex-bolts and nuts, utilizing ½" flat washers on each side. The base of the bracket slipped over the end of the upper 2x8 ½" hex bolt that secured the post. All nuts were tightened to approximately 30 lbs/ft of torque.

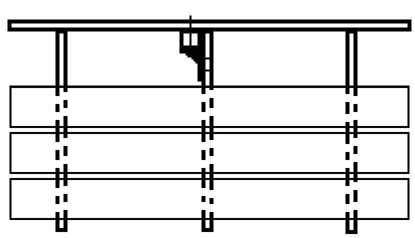

Diagram T-4

Test 4, DeckLok Bracket Results:

4A NO FAILURE Test stopped at 1,350 lbs to avoid damage to testing equipment.

4B Timber failure of the 4x4 post at 900 lbs. The dynamometer jumped to 1,400 lbs indicated when 4x4 broke.

4C Timber failure of the 4x4 post at 525 lbs.

Test 4: Test units 4A, 4B, and 4C following test

Test 5

For Test 5, the 4x4 was mounted on the inside of the terminal deck joist to replicate the mounting of a rail post along the side of the deck. The 2x8 deck joists were set at 16" O.C. The 4x4 is mounted with two ½" by 8" hex-bolts with flat washers on each end. The holes were pre-drilled, 5½" O.C. apart, 1½" from the bottom. The 4x4 was mounted perpendicular to the terminal deck joist.

Control Test Unit:

The band board and the ledger boards were attached to the ends of the deck joists using both sixteen-penny nails, three on each joist, installed with a pneumatic nail gun, and 3½" deck screws, three on each deck joist. No brackets were used in this test.

Results:

The nails and the screws pulled through the ends of the terminal deck joist, splintering the timber at each end, dislodging the band board and the attached 4x4 post at a load of 220 lbs.

DeckLok Test Units:

The DeckLok Bracket configuration for Test 5 is shown in Diagram T-5. One DeckLok bracket was located with its base against the inside of the 4x4 and the long side flush against the 2x8 blocking. The second bracket was located with its base against the deck joist and the long side flush against the 2x8 blocking. The brackets were attached to the 2x8 blocking by two, 2½" long, ½" hex-bolts and nuts, utilizing ½" flat washers on each side. A 2½" long, ½" hex-bolt, with flat washers and retaining nut secured the brackets to the deck joist and the 4x4. All nuts were tightened to approximately 30 lbs/ft of torque. As in the other tests, the 5/4" board deck tread was screwed to the deck joists that were not in contact with the 4x4 post.

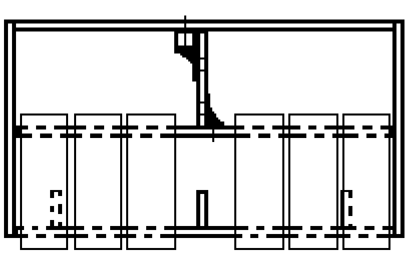

Diagram T-5

Results:

5A NO FAILURE Test stopped at 1,350 lbs to avoid damage to testing equipment

5B NO FAILURE Test stopped at 1,500 lbs to avoid damage to testing equipment.

5C NO FAILURE Test stopped at 1,350 lbs to avoid damage to testing equipment.

Test 5: Test units 5A, 5B, and 5C following test

Summary and Conclusion

Common, industry accepted practices for deck railing construction and attachment can lead to unsafe and potentially life threatening installations. Many of these installations may fail to meet the minimum IRC requirements for lateral loading. To address this condition, the DeckLok Bracket System has been developed by Morse Technologies. This system strengthens the connection of the rail post to the deck structure and causes the lateral force to be transferred to other deck components.

The DeckLok Bracket System was tested in many of the typical deck railing construction configurations and the test results were compared to the load resistance of the more common construction techniques. With every test that was run, a Control Test Unit was tested first to establish a baseline performance level that represents the current construction methods used in the deck building industry. In all cases, the deck railing system represented by the control test unit failed at the connection points and failed under lateral loads that were below the minimum IRC load requirements.

The addition of the DeckLok Bracket System (represented by the Bracket Test Units) to the Control Test Unit design resulted in significant increase in guardrail post capacity. All bracket tests resulted in load resistance that surpassed the minimum IRC lateral load requirements. Under continued loads, far beyond the minimum requirements, the primary failure was ductile, rather than timber failure. That is, the rail post (4x4) was allowed to shift gradually, transferring load to the deck structure and remaining substantially intact. This introduces a controlled, predictable mode of failure and moves catastrophic failure to a secondary failure position. The brackets exhibit excellent ductility and provide an effective warning that the restraint system (deck guardrail) is in danger of being overloaded and pushed to failure. That same ductility also allows for a realignment of the timber members of the deck to more effectively absorb energy.

It should be noted that there was an inconsistency in the load capacity of the 4x4 posts used in the testing. Each timber was examined carefully, picked for those with the fewest knots, cracks, or checking. However, the difference in their load strength was surprising. The 4x4 post from test 2A experienced total failure at 525 lbs, where a similar 4x4, bought from the same lot, on the same day, withstood 1325 lbs and did not fail. (the test was stopped to avoid damage to testing equipment and testing personnel).

Meeting building code requirements for load capacity of a deck rail post is challenging because of the geometry involved and the building materials typically used on residential decks. The leverage created by the 36" height of the post (above the deck surface) requires a substantial anchoring method to meet the 200 lbs x 2.5 = 500 lbs test load requirement. The test units replicating typical post-to-deck-structure connection details did not provide the required load capacity. It is necessary to tie into a much more substantial deck member than just the band board to achieve the necessary stability. By simply attaching the DeckLok bracket, the code required test load of 500 lbs was met or exceeded in each and every configuration tested.

These tests were performed using new timber, new connectors, and new fasteners. As with all things, exposure to the elements and time will likely weaken the components and reduce their load capacities. This is left for future research and testing.

The table below summarizes the test results. With the DeckLok brackets installed there is substantially improved lateral load capacity. The load capacities shown in the column titled "Guardrail Post Load Capacity with DeckLok" reflect the average of the three test units in each configuration. Please note that, in each bracket test, of every configuration, the minimum load requirement was met or exceeded.

SUMMARY OF TEST RESULTS

Configuration	Guardrail Post Load capacity w/out DeckLok	Guardrail Post Load capacity with DeckLok	Percentage increase	Mode of ultimate failure with DeckLok
Test Unit 1	150 lbs	608 lbs	405%	Timber
Test Unit 2	100 lbs	517 lbs	517%	Timber
Test Unit 3	75 lbs	1,150 lbs	1533%	Timber*
Test Unit 4	65 lbs	925 lbs	1423%	Timber*
Test Unit 5	220 lbs	1,400 lbs	636%	None

*Includes some or all units that did not fail.

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