

CRASHWORTHY RAILING FOR TIMBER BRIDGES

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SUMMARY

Bridge railing systems in the United States have *historically been* designed based on static load criteria given in the American Association of State Highway and Transportation Officials (AASHTO) *Standard Specifications for Highway Bridges*. In the past decade, full-scale vehicle crash testing has been recognized as a more appropriate and reliable method of evaluating bridge railing acceptability. In 1993, the National Cooperative Highway Research Program published *Report 350, Recommended Procedures for the Safety Performance Evaluation of Highway Features*, which provides new criteria for evaluating longitudinal barriers. Based on these specifications, a cooperative research program is continuing between the USDA Forest Service, Forest Products Laboratory, the Midwest Roadside Safety Facility of the University of Nebraska-Lincoln; and the Federal Highway Administration to develop and crash test bridge railings for wood bridge decks. This paper describes research that resulted in the successful development and testing of several bridge railings for longitudinal and transverse wood decks in accordance with *NCHRP Report 350* requirements.

1 INTRODUCTION

The primary purpose of bridge railing is to safely contain errant vehicles crossing a bridge. To meet this objective, railings must be designed to withstand the force of an impacting vehicle without endangering the occupants. In designing railing systems for highway bridges, engineers have traditionally assumed that vehicle impact forces can be approximated by equivalent static loads that are applied to railing elements. Although railing loads are actually dynamic, the equivalent static load method has been used for many years as a simplified approach to standardized railing design.

Despite the widespread use of design requirements based primarily on static load criteria, the need for more appropriate full-scale vehicle crash test criteria has long been recognized. In 1981, the National Cooperative Highway Research Program (NCHRP) published *Report 230, Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances* [1]. This comprehensive report provided recommendations relative to crash testing and evaluation of longitudinal barriers and served as the basis for future bridge railing crash testing requirements. The first recognition of full-scale crash testing in a national bridge specification came in 1989 when the American Association of State Highway and Transportation Officials (AASHTO) published *Guide Specifications for Bridge Railings* [2]. This specification presents recommendations for the development, testing, and use of crash-tested bridge railings and refers extensively to *NCHRP Report 230* for crash testing procedures and requirements. In 1993, NCHRP published *Report 350, Recommended Procedure for the Safety*

Performance Evaluation of Highway Features [3]. This publication is currently the accepted standard for evaluating longitudinal barriers in the United States and is the basis for railing evaluation discussed in this paper.

A primary concept of *NCHRP Report 350* is that bridge railing performance needs differ greatly from site to site, and railing designs and costs should match site needs. Thus, evaluation criteria are based on six performance levels: Test Level 1 (TL-1) through Test Level 6 (TL-6). Although *NCHRP Report 350* does not include objective criteria for relating a test level to a specific roadway type, the lower test levels are generally intended for use on lower service level roadways and certain types of work zones, while the higher test levels are intended for use on higher service level roadways.

Emphasis on the use of crash-tested railings for new Federally funded projects has significantly increased the role of full-scale crash testing as a means of evaluating railing performance. Recently, the Federal Highway Administration (FHWA) officially adopted *NCHRP Report 350* and has strongly suggested that AASHTO adopt the same requirements and make crash-tested railings mandatory. Most highways on which wood bridges are installed will require railings that meet TL-1 through TL-4 requirements. A railing that meets either TL-5 or TL-6 requirements currently has a very limited application for wood bridges because of the high traffic volumes and speeds associated with these levels.

2 BACKGROUND

For wood bridges to be viable and competitive with other bridges in the future, a range of crash-tested bridge railings for different wood bridge types is required. To meet the need for crashworthy railings for wood bridges, the USDA Forest Service, Forest Products Laboratory (FPL), in cooperation with the Midwest Roadside Safety Facility (MwRSF) of the University of Nebraska-Lincoln, the FHWA, and the wood products industry initiated a program to develop crash-tested bridge railings for longitudinal wood decks and transverse glued-laminated timber (glulam). Additionally, a project was initiated to adapt crash-tested wood railings to concrete decks.

2.1 Longitudinal Wood Decks

Longitudinal wood decks are constructed of glulam, spike-laminated lumber, or stress-laminated lumber [4]. In each system the lumber laminations are placed edgewise and are oriented with the lumber length parallel to the direction of traffic. The objectives for longitudinal deck railing development originally focused on five railing systems at levels comparable to TL-2 and TL-4. These systems were all successfully tested and plans have been published [5]. The program was then expanded to include the development and testing of four railings for wood bridges located on low-volume roads. These included three railings for TL-1 and one at a level below TL-1 that was formulated specifically for very low volume forest roads. This was a departure from previous testing, which has historically focused only on railings at TL-2 and higher. However, because many wood bridges are located on low volume roads, the development of railings at the lower levels was considered both warranted and necessary.

2.2 Transverse Glulam Decks

Transverse glulam decks are constructed of panels that consist of individual lumber laminations glued together with waterproof structural adhesives. The panels are typically 1.22 m wide and are continuous across the bridge width. To form the bridge deck, panels are placed edge-to-edge and are supported by longitudinal glulam or steel beams. Crashworthy railing development for transverse glulam decks focused on the need to develop four railing systems: two to meet TL-4 and two to meet TL-2.

2.3 Concrete Decks

Concrete decks are constructed in a variety of configuration in both composite and non-composite applications. In recent years, there has been growing interest in using wood railings on concrete decks. To meet this need, a project to adapt the crash-tested wood railings to concrete decks was initiated. The objective of this project was not to test wood railings on concrete decks, but to adapt the wood railings tested on wood decks so that they could be attached to concrete decks without

compromising the railing strength or performance characteristics.

3 TEST REQUIREMENTS AND EVALUATION CRITERIA

The test requirements and evaluation criteria for this project followed procedures defined in *NCHRP Report 350* criteria. These procedures establish a uniform methodology for testing and evacuating railings so that the safety performance of different railing designs, tested and evaluated by different agencies, can be compared. It is impractical and impossible to test all railings for all possible vehicle and impact conditions. Therefore, the procedures specify a limited number of tests using severe vehicle impact conditions and a set of evaluation criteria against which test results may be evaluated.

3.1 Test Requirements

Vehicle impact requirements for railing crash testing depend on the railing test level and are specified as requirements for vehicle type, weight, impact speed, and impact angle relative to the longitudinal rail axis. Testing for TL-1 and TL-2 requires two vehicle impact tests, and testing for TL-4 requires three vehicle impact tests (Table 1). For the very low volume railing tests, representative criteria were formulated as a 2,000-kg pickup truck impacting the railing at 24 km/h at an impact angle of 15 deg.

Test Level	Impact Conditions		
	Small Car (820 kg)	Pickup Truck (2,000 kg)	Van Truck (8,000 kg)
1	50 km/h 20 deg	50 km/h 25 deg	
2	70 km/h 20 deg	70 km/h 25 deg	
4	100 km/h 20 deg	100 km/h 25 deg	80 km/h 15 deg

Table 1 - NCHRP Report 350 vehicle type and impact condition requirements.

In addition to vehicle impact requirements, the *NCHRP Report 350* criteria also specify requirements for data acquisition and construction of the test bridge and railing. Requirements for data acquisition include specific data collection parameters and techniques that must be completed before, during, and after the crash test. Construction requirements specify that the bridge railing be designed, constructed, erected, and tested in a manner representative of actual installations. To properly assess the performance of most bridge railings, they must also be evaluated as a system in combination with the bridge superstructure for which it is intended. This is very important when considering railings for wood bridges,

because the attachment of the railing to the bridge deck and the ability of the wood superstructure to resist applied railing loads may often be the controlling parameters.

3.2 Evaluation Criteria

Evaluation criteria for full-scale crash testing is based on three appraisal areas: (1) structural adequacy, (2) occupant risk, and (3) vehicle trajectory after the collision. Criteria for structural adequacy are intended to evaluate the ability of the railing to contain and redirect the vehicle. Occupant risk evaluates the degree of hazard to occupants of the impacting vehicle. Vehicle trajectory after collision is concerned with the path and final position of the impacting vehicle and the probable involvement of the impacting vehicle in secondary collisions. These criteria address only the safety and dynamic performance of the railing and do not include service criteria such as aesthetics, economics, bridge damage, or post-impact maintenance requirements.

4 PROJECT DEVELOPMENT

Based on a fundamental understanding of the performance characteristics of each bridge type, designs for the longitudinal and transverse deck test bridges and the individual railing systems were developed. A brief description of the primary features of these designs follows.

4.1 Longitudinal Decks

From the standpoint of economics and time, it was considered impractical to develop and test different railing systems for each longitudinal deck type. Rather, a more feasible approach was undertaken to develop several railing systems that could be adapted to each of the three longitudinal deck types with little or no modification. To accomplish this, it was determined that railing development and testing should utilize the weakest deck type for resisting lateral impact forces.

In assessing the potential resistance of each longitudinal deck type, the glulam deck was considered to be the weakest in resisting transverse railing loads, because the glulam panels act as solid pieces of wood, without mechanical reinforcement. Loads applied transverse to the panel length are most likely to introduce tension perpendicular to grain and failure in the upper panel section. To be representative of typical installations and to provide a fictional lower bound to withstand vehicle impact loads without damage, a 273-mm glulam deck thickness was selected.

4.2 Transverse Decks

Highway bridges using transverse glulam decks are most commonly constructed using glulam deck panels that are 1.22 m wide and 127 to 171 mm thick. To be applicable in most applications, it was determined that the thinner 127-mm deck would be used for testing. It was also

determined that the railing post spacing should be 2.44 m so that it would easily match the 1.22-m panel widths with minimal panel fabrication.

The orientation of the wood grain for transverse decks is perpendicular to traffic and, unlike longitudinal decks, tension perpendicular to the wood grain due to railing loads is not a primary design consideration. However, the railing load distribution to the deck panels was a consideration, given the large lateral loads during vehicular impacts. To distribute loads as much as possible, it was determined that the railing post attachment should be placed at the deck panel joints, where loads could be distributed into two adjoining panels.

4.3 Bridge Railing Design

The primary emphasis of the railing design process was to develop railings that would meet the requirements of the *NCHRP Report 350*. Additionally, it was determined that consideration should be given to (1) the extent of probable damage to the structure after vehicle impact and the difficulty and cost of required repairs; (2) the adaptability of the railing to different wood deck types; (3) the railing system cost to the user, including material, fabrication and construction; (4) the ease of railing construction and maintenance; and (5) its aesthetics.

Selection and design of the final systems were based on a review of other railings that had been successfully crash tested as well as those that are currently used on wood bridges but had not been crash tested. To the extent possible, candidate designs were evaluated using BARRIER VII computer simulation modeling [6]. Although several proven computer models were used it was sometimes difficult to adapt the programs for wood components because the behavior and properties of the wood systems at ultimate loading were unknown. Data collected during the crash testing were used to refine input parameters and to more accurately predict railing performance in subsequent tests.

5 TEST METHODOLOGY

Testing of all bridge railings was conducted at the MwRSF outdoor test site located in Lincoln Nebraska. To perform the railing testing, two different test bridges were constructed. A brief description of the test decks, vehicle propulsion and guidance, and data acquisition follows.

5.1 Test Bridges

For the longitudinal deck a test bridge was constructed that measured approximately 2.44 m wide and 28.58 m long in five simply-supported spans measuring 5.72 m each. The deck was constructed of 273-mm-thick by 1.22-m-wide glulam panels. Two glulam panels were placed side by side to achieve the 2.44-m deck width, and transverse distributor beams were attached to the deck underside per AASHTO requirements [7]. The test bridge

was positioned on concrete supports that were placed in excavations so that the top of the test bridge was level with the concrete surface at the site. For previous longitudinal deck tests at TL-2 and TL-4, lateral reinforcement was necessary to resist impact loads [8-11]. For the TL-1 and very low volume testing, reinforcement was not considered necessary and was not placed in the deck.

For the transverse decks, a second test bridge was constructed that measured approximately 3.96 m wide and 36.58 m long, in three simply-supported spans measuring approximately 12.19 m each. The deck was constructed of 130-mm-thick by 1.22-m-wide glulam panels. Thirty panels were placed side by side to achieve the 36.58-m length and were attached to the longitudinal glulam beams with standard aluminum deck brackets [4]. This test bridge was positioned on concrete supports that were placed in a 2.13-m-deep excavated test pit. The concrete supports were placed so that the top of the test bridge was 51 mm beneath the concrete surface to allow for placement of the bridge deck wearing surface.

5.2 Vehicle Propulsion and Guidance

Vehicle propulsion and guidance were provided by steel cable configurations. For propulsion a reverse cable tow with a 1:2 mechanical advantage was used. A cable was attached to the front of the vehicle, routed through a series of pulleys, and connected to a tow vehicle that traveled in a direction opposite to the test vehicle. The unoccupied test vehicle was then pulled by the tow vehicle and released from the tow cable a prescribed distance prior to impact. A vehicle guidance system developed by Hinch was used to steer the test vehicle [12]. Using this system, the left-front wheel hub is attached to a tensioned steel cable that maintains the vehicle's direction along a designated straight path. Prior to impact, the guidance connection is sheared off and the vehicle separates from the guidance cable.

5.3 Data Acquisition

Data acquisition parameters and techniques for the crash testing program were based on *NCHRP Report 350* and followed three testing phases: pretest, test, and post-test. In the pretest phase, the as-built bridge railing and vehicle were documented using photography and drawings that indicated the applicable configuration, dimensions, and vehicle weight. During the test phase, data regarding the vehicle impact speed, impact angle, trajectory, and accelerations were collected primarily through the use of high-speed motion picture photography and accelerometers mounted on the vehicle. Additional instrumentation was placed on some railings to assess vehicle impact forces transmitted to the bridge rail and superstructure. In the post-test phase, the condition of the railing, bridge superstructure, and vehicle were documented using photography and standardized damage assessment methods.

6 CRASH TESTED RAILINGS

As a result of the development and testing program, several bridge railings employing both wood and steel railings were constructed and successfully crash tested. Overall, no significant damage to the test bridge was evident from any of the vehicle impact tests. For the railing systems with wood rails, damage to the railing was primarily gouging and scraping from vehicle impact. All wood railing remained intact and serviceable after the tests and replacement was not considered necessary. For steel railings, there was permanent deformation in the rail and post in the vicinity of the vehicle impact location. This would necessitate replacement of specific rail and post members, but damage was relatively minor considering the severity of the impact.

A detailed discussion of the testing and results for each railing system is beyond the scope of this paper and has been presented elsewhere [13, 14]. A brief summary of the tested railings follows.

6.1 Longitudinal Decks

Testing for the longitudinal decks involved three TL-1 railings and one very low volume railing [15]. The three TL-1 railings included a flexible steel rail, a semi-rigid steel rail, and a curb-type timber rail. Drawings and photographs of the TL-1 railings are shown in Figures 1 and 2, respectively. The flexible steel railing consisted of a 12-gauge W-beam rail mounted to nominal 102-by 52-mm breakaway sawn lumber posts spaced 1.91 m on-center. The bottom of the post was placed between two steel angles that were connected to the deck edge with lag screws. The semi-rigid steel railing consisted of a 12-gauge W-beam rail mounted to steel posts spaced 1.91 m on-center. The posts were bolted to a steel plate that was bolted to the bridge deck surface. The low-height curb-type wood railing was constructed with a glulam rail supported with scupper blocks spaced 3.05 m on-center and bolted to the deck.

The very low-volume railing consisted of a low-height, wood curb rail. Three geometrics were considered for the curb railing including a square, rectangular, and trapezoidal shape (Figure 3). The curb rail was constructed with sawn lumber and supported with scupper blocks spaced 2.90 m on-center and bolted to the deck.

6.2 Transverse Decks

Development and testing of railings for transverse glulam decks involved a total of four railings: two for TL-4 and two for TL-2. Testing of the TL-4 railings has been successfully completed. Testing of the TL-2 railings is scheduled to be completed in 1999. A brief description of the TL-4 system follows.

The TL-4 railings included a glulam railing with curb and a steel railing. Drawings and photographs of the railings

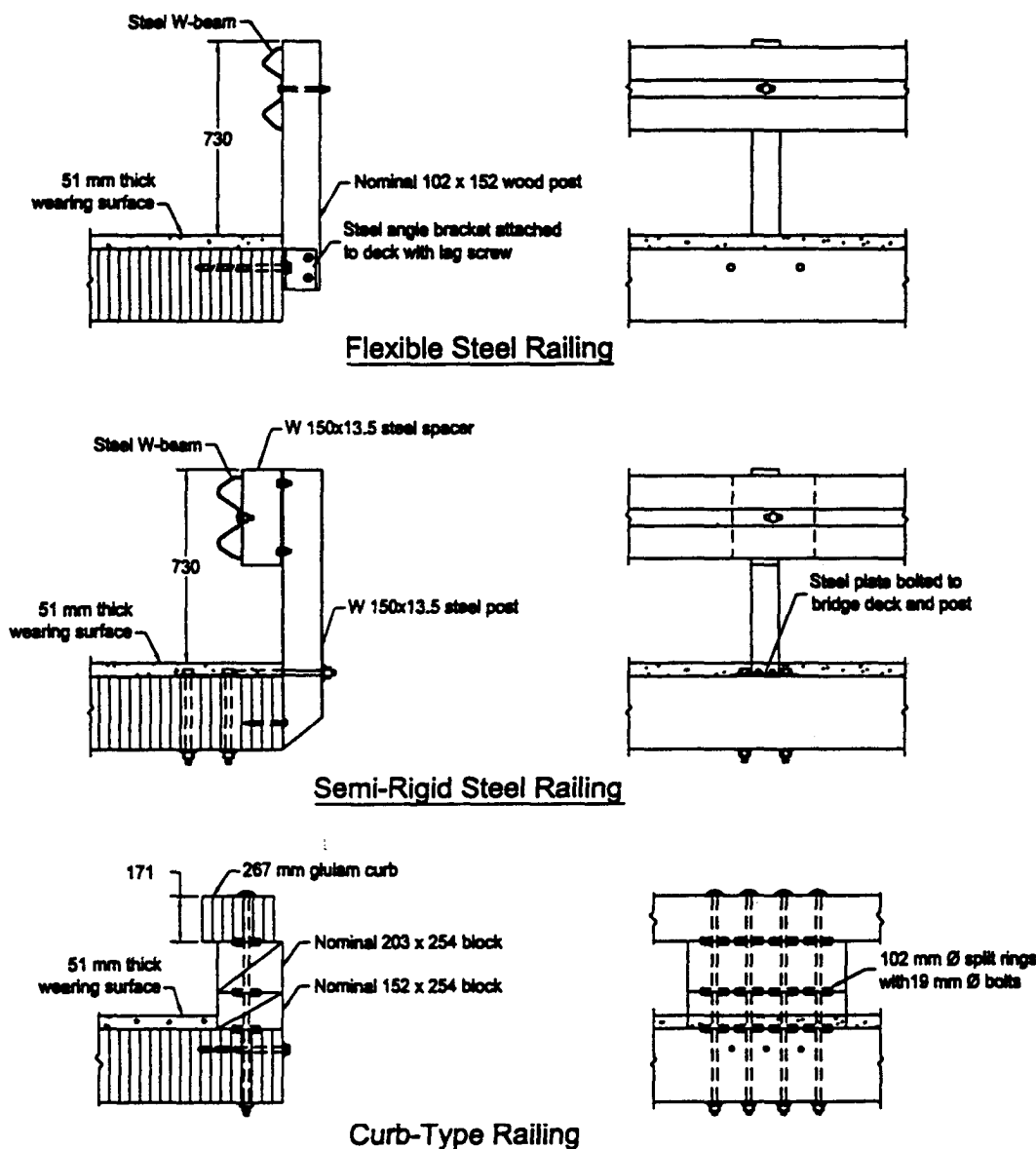


Figure 1- TL-1 railings for longitudinal wood decks (all units are in mm).

arc shown in Figures 4 and 5, respectively. Design of both railings was based on similar designs that were previously tested for longitudinal decks [5, 8-11], but the post spacing was increased from 1.91 to 2.44 m so that posts could be attached at the deck panel joint. The glulam railing was constructed entirely of glulam and consisted of a curb supported by blocks that were interconnected with 102-mm-diameter split rings and bolted to the deck with 19-mm-diameter bolts. The railing was supported by a post attached to the curb with a single 32-mm-diameter bolt. Small steel angles were attached to the curb blocks on each side of the post to prevent post rotation at impact.

The steel rail consisted of a 10-gauge steel thrie beam mounted to a wide-flange steel spacer and post. The lower end of the post was bolted to two steel plates that were connected to the top and bottom surfaces of the bridge deck with 102-mm-diameter shear plates and 19-mm-

diameter bolts. A steel tube section was attached to the top of each rail post and extended along the entire bridge length. Given the 2.44-m post spacing, the tube was necessary to provide increased load distribution and stiffness to the railing.

6.3 Concrete Decks

The railings adapted for use on concrete docks included two TL-2 and one TL-4 railing that had been previously tested [5, 8-11], and the TL-1 curb-type railing. Because the railing geometry and materials were unchanged from the systems crash tested on the wood decks, design for the concrete decks focused on the railing deck attachment. Suitable attachments were developed based on loads obtained from instrumentation during previous testing or from the ultimate capacity of the wood deck attachments.

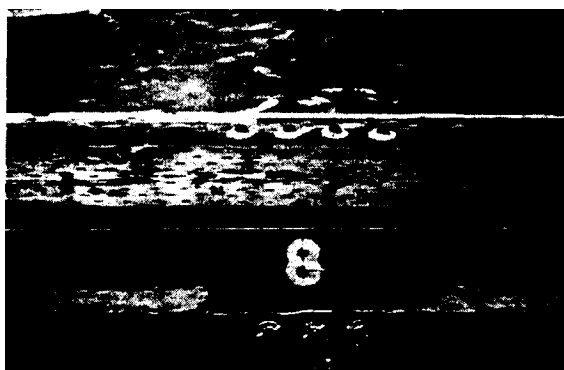
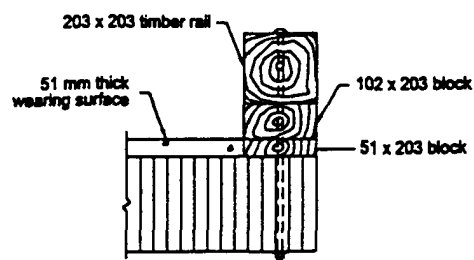


Figure 2- TL-1 railings for longitudinal wood decks: flexible steel railing (top); semi-rigid steel railing (middle); curb-type railing (bottom).

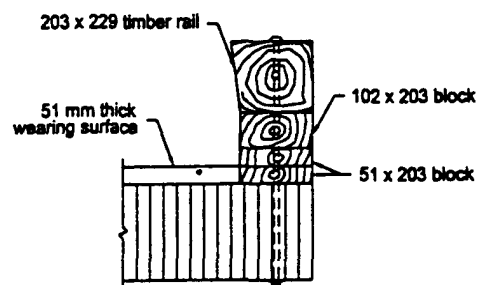
Complete plans for the concrete deck railings have been published and are currently available [16].

7 CONCLUDING REMARKS

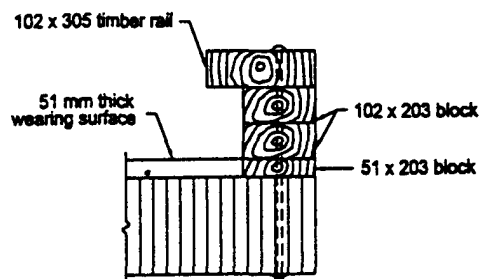
This program clearly demonstrates that crashworthy railing systems are feasible for both longitudinal and transverse wood decks. Even at high-impact conditions required by TL-4, the railing systems performed well with no significant damage to the bridge superstructure. With the development of crashworthy railing systems, a significant barrier to the use of longitudinal and transverse wood deck bridges has been overcome.



Square Curb



Trapezoidal Curb

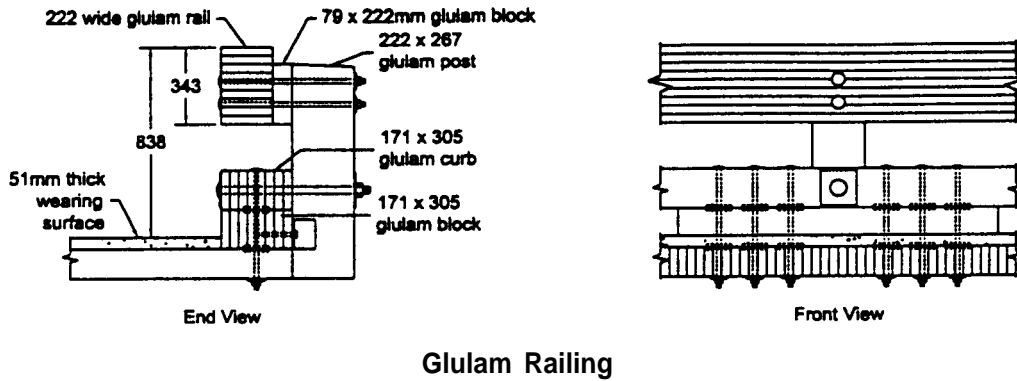


Rectangular Curb

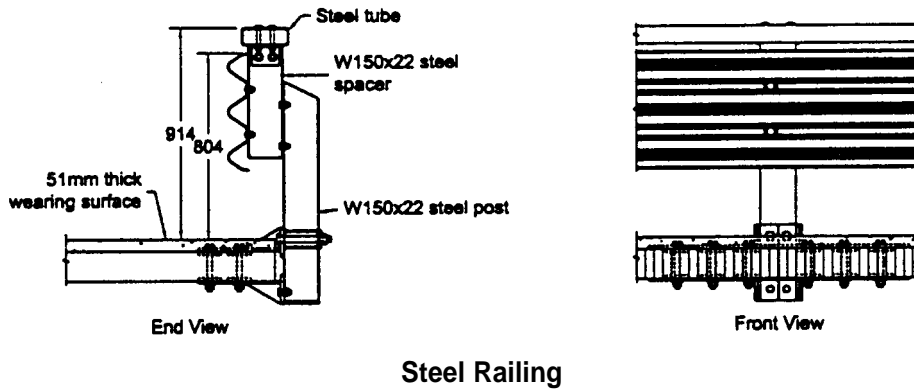
Figure 3- Very low-volume curb-railings for longitudinal wood decks (all units are in mm).

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Glulam Railing



Steel Railing

Figure 4 - TL-4 railings for transverse glulam decks (all units are in mm).



Figure 5 - TL-4 railings for transverse glulam decks: glulam railing (top); steel railing (bottom).

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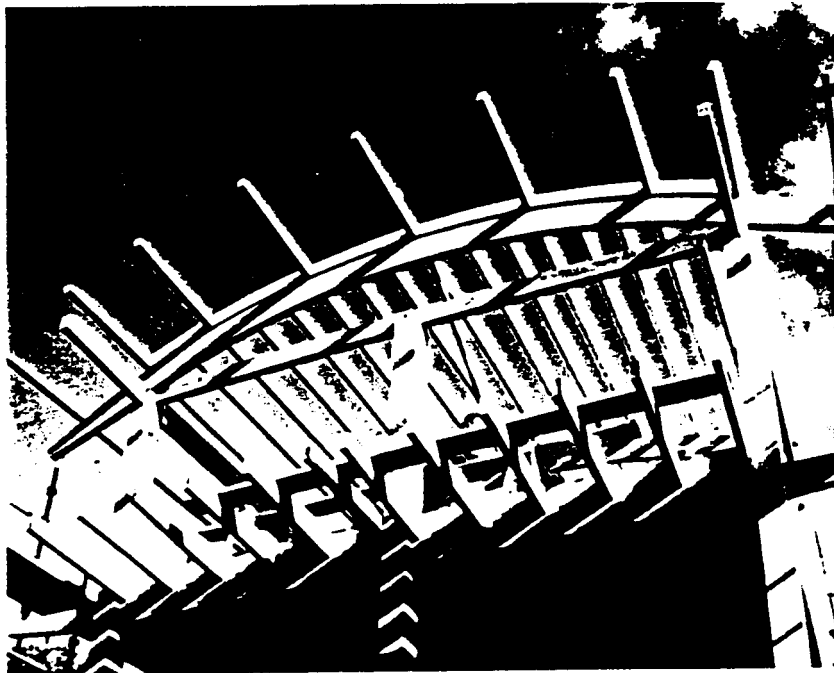


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