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DETERMINATION OF APPROPRIATE
RAILING HEIGHTS FOR BICYCLISTS
-FINAL-

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**DETERMINATION OF APPROPRIATE
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-FINAL-**

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Chapter 1 - Introduction

Background

The land characteristics and environment surrounding a traveling surface can pose hazards to users. Specific hazardous conditions consist of bodies of water, steep drop-offs, or hazardous terrain adjacent to roadways, sidewalks, bikeways, or bridges. To protect motorists, bicyclists, and pedestrians, railings are often installed along the traveling surface.

The identification of these and other hazardous conditions adjacent to travel surfaces influenced a collective consensus among highway officials to develop national railing height guidelines and specifications. Various railing height recommendations were subsequently established for multiple users, including motorists, bicyclists, and pedestrians. However, professionals in the transportation field never reached a common determination regarding the most appropriate railing heights for all users.

This study focuses on railings along shared use paths and bridges. A bikeway is defined as a road, path, or way that is specifically designated (in some manner) as being open to bicycle travel. Bikeways can consist of paths that are exclusively designated for bicycle travel only, or roads that allow both vehicles and bicycles (i.e., shared-use facility). A bridge is defined as a structure that allows people or vehicles to cross an obstacle, such as a river, canal, or railway.

The American Association of State Highway Transportation Officials (AASHTO) is at the forefront of adopting an appropriate railing height for bicyclists. AASHTO's goal is to foster the development, operation, and maintenance of an integrated national transportation system. To accomplish this goal, AASHTO established several committees to provide a forum for consideration of transportation issues. The Standing Committee on Highways oversees the Subcommittee on Bridges and Structures and the Highway Subcommittee on Design. The Subcommittee on Bridges and Structures developed the AASHTO "*Bridge Specifications*," while the Highway Subcommittee on Design developed the "*Guide for the Development of Bicycle Facilities*."

Currently, the AASHTO "*Bridge Specifications*" require a 1.4-meter (54-inch) bicycle railing height¹ on bridges. Alternatively, the current AASHTO "*Guide for the Development of Bicycle Facilities*" specifies a minimum bicycle railing height of 1.1 meters (42 inches) on bridges, which is consistent with the height required for pedestrian railings. The difference in recommended railing heights is a point of discrepancy between bicycle facility designers and bridge designers. Many bicycle facility designers prefer the lower height, while bridge designers feel they must specify the higher height to adequately protect the public. The higher height involves higher costs, requires additional hardware, and impacts the view and sight distance. However, no empirical data exists to support the selection of either height for bicycle railing.

¹ Railing height consists of the distance from the travel surface to the top of the railing.

Evaluating and determining criteria for appropriate bicycle railing heights is challenging since the issue is not straightforward, and environments and applications vary. Different heights are appropriate for different conditions along the landscape. For example, a higher railing height may be needed to protect bicyclists from serious injury or death in areas with steep terrain, high wind exposure, and/or water bodies. Lower railing heights may be adequate in scenic areas where a simple fall over the railing may result in only minor injury.

Purpose of Study

This study summarizes the bicycle railing height guidelines and specifications used by AASHTO, state departments of transportation (DOTs), international transportation agencies, and local governments. The objectives of this study include the following:

- Research the history of the adoption of bicycle railing heights
- Survey state DOTs to identify practices regarding the use of bicycle rails and any history of incidents involving bicycles and rails
- Survey European countries with significant bicycle usage to identify railing height practices
- Survey bicycle advocacy groups to determine opinions and concerns of constituents
- Outline the relative benefits and liabilities of a 1.1-meter (42-inch) versus a 1.4-meter (54-inch) railing height
- Determine the critical heights for bicycle railings
- Develop criteria for using the determined appropriate bicycle railing height

This report provides documentation for the design of bicycle railings, and facilitates the resolution of the inconsistency between the two AASHTO publications.

Organization of Study

This study was conducted in three tasks. The first involved a literature review of documented research regarding the height of bicycle and pedestrian rails, and any relevant crash data. The study does not include active crash testing or other laboratory experiments regarding appropriate railing heights. Testing and experimentation are beyond the scope of this research project.

The second task involved a preference survey of state departments of transportation, international transportation agencies, and bicycle advocacy groups to identify practices, as well as opinions and concerns, regarding bicycle railing heights. The survey also requested information regarding bicycle crash events involving a railing.

The third task involved compilation and documentation of the results of the first two tasks. Recommendations for updating the AASHTO guides were subsequently identified.

Results of the Literature Review

Literature relevant to appropriate railing heights for bicyclists is limited. As such, research and communication with committee members involved in the adoption of AASHTO bicycle railing height guidelines was performed. This effort determined that no scientific analysis was conducted to warrant the degree of safety of a 1.1-meter (42-inch) versus a 1.4-meter (54-inch) railing height. The lack of available AASHTO Committee meeting minutes and documentation outlining the adoption process creates a challenge for researchers. Due to the lack of empirical data, supplemental resources were consulted to aid in the determination of an appropriate railing height for bicyclists. The supplemental resources included documents on bridge design aesthetics, dimensions of the human body, center of gravity issues, and bicycle crash data.

Several resources discuss the effects of inappropriately introducing a man-made object, such as a railing, into the foreground of a scenic view. Affected parties include bicyclists, motorists, and residents of the surrounding area. The Federal Highway Administration (FHWA) recommends conducting a visual impact analysis (VIA) to study the change in continuity of a scenic view due to the introduction of a man-made object. Visual transparency was also identified as an important factor in railing design guidelines.

Other research material identified the importance of context sensitive design and studying the surrounding landscape when implementing a bridge project. Good design and engineering judgment should be used to blend the bridge into the landscape in all environments. Recommendations include maximizing the view from the bridge through flexibility in railing design. The design should take into consideration the varying amount of time required for bicyclists to cross the bridge. Chapter 5 provides a more-detailed summary of aesthetics and railing design.

Additional resources listed average heights of adult males and females and children, including eye-level heights of motorists, and heights of bicyclists and pedestrians. These heights help determine the ability to see over a railing along a bikeway or traffic barrier within mountainous terrain. Chapter 3, “The Design Bicyclist,” summarizes human dimensions and provides center-of-gravity analyses.

The literature review revealed that bicycle crash data involving railings is not a widely-reported event. Crash surveillance systems and informational guides were investigated, including the National Center for Statistics and Analysis (NCSA) Fatality Analysis Reporting System (FARS), North Carolina Department of Transportation’s Division of Bicycle and Pedestrian Transportation Bicycle and Pedestrian Crash Web-database, and the FHWA “*Bicycle Crash Types Information Guide*.” Chapter 5 discusses the limitations of available crash data in greater detail.

To supplement the literature review, a bicycle railing height survey was provided to state bicycle coordinators, bicycle advocates, and bridge engineers. The survey questioned respondents regarding railing height practices, and solicited information regarding crash

events and data. Chapter 4 provides a summary of the survey, and Appendix A presents the state and advocacy group bicycle survey and responses.

Chapter 2 - History of Railing Height Guidelines

Through interviews with state and federal transportation officials and data collection, the history of the establishment of railing height guidelines was reviewed. As shown in Figure 1, the process began in the early 1970s and continues today.

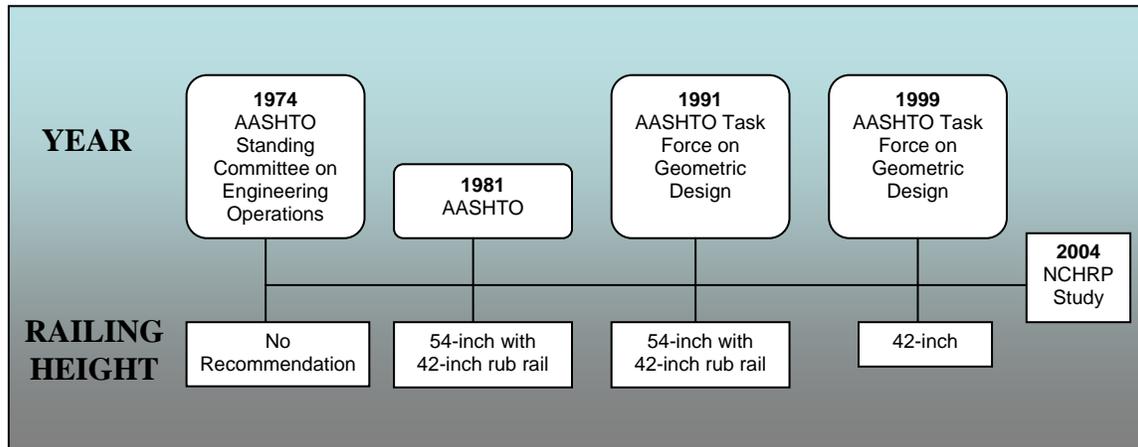


Figure 1 - Timeline of Bicycle Railing Heights Guidelines

In 1974, the Standing Committee on Engineering Operations prepared the first AASHTO “*Guide for Bicycle Routes*.” The guide’s purpose was to outline steps and technical details for development of bicycle facilities on public roadways. However, the guide failed to recommend a specific railing height for bicyclists. During this same time period, the California Department of Transportation (CalTrans) developed state bicycle guidelines. A member of the State Bicycle Guide Committee, John Forester, recommended railing heights between 1.1 meters (42 inches) and 1.4 meters (54 inches). As a result, CalTrans conservatively adopted the higher railing height of 1.4 meters (54 inches) for safety purposes.²

In 1981, AASHTO updated the 1974 “*Guide for Bicycle Routes*” to include recommendations for railing heights, and changed the document’s name to “*Guide for Development of New Bicycle Facilities*.” The 1981 guide referenced the CalTrans bicycle guide for railing height specifications, and adopted the minimum railing height of 1.4 meters (54 inches). The 1981 guide also introduced the use of smooth rub rails at a height of 1.1 meters (42 inches). Smooth rub rails are horizontal rails, which prevent a bicyclist’s handlebar from coming into contact with a fence or barrier.

² Conversation and correspondence with John LaPlante, Chair of Committee on Geometric Design for the 1999 AASHTO Guide for the Development of Bicycle Facilities.

In 1991, the AASHTO Task Force on Geometric Design expanded the “*Guide for Development of Bicycle Facilities*,” but maintained the 1.4-meter (54-inch) minimum railing height recommendation.

In preparation for the 1999 update of the “*Guide for Development of Bicycle Facilities*,” the AASHTO Task Force on Geometric Design researched the history of the 1.4-meter (54-inch) railing height requirement. The Task Force’s research efforts found that the 1970’s CalTrans railing height recommendation was chosen arbitrarily, with no empirical evidence for its defense. The Task Force’s research also discovered that several bicycle path structures were constructed with the standard 1.1-meter (42-inch) pedestrian railing height, and the lower railing height did not affect the safety of the structures.³

During the preparation of the 1999 update, the Task Force received several public complaints stating that the 1.4-meter (54-inch) railing height obstructs scenic views along bike trails, and does not appear to increase safety. Public sentiment, research findings, and lack of crash evidence convinced the Task Force to change the minimum railing height to 1.1 meters (42 inches).⁴

Following their findings, the Task Force asked the AASHTO Bridges and Structures Subcommittee to specify the reduced minimum railing height in the AASHTO bridge specifications. However, the Subcommittee declined to reduce the 1.4-meter (54-inch) railing height specification, stating that the Task Force only provided a lack of adverse crash data, rather than positive safety data, for the 1.1-meter (42-inch) railing height.

³ Ibid.

⁴ Ibid.

Chapter 3 - Existing State of Art of Bicycle Railing Design

Existing Policy

In 1998, the Federal Highway Administration (FHWA) adopted a policy to improve conditions and safety for bicycling and walking and create an integrated, intermodal transportation system, which provides travelers with a real choice of transportation modes. This policy was adopted under the passing of legislation for the Transportation Equity Act for the 21st Century (TEA-21). The FHWA guidance paper, “Bicycle and Pedestrian Provisions of Federal Transportation Legislation” (1999) provides the agency’s position on the matter:

“TEA-21 confirms and continues the principle that the safe accommodation of non-motorized users shall be considered during the planning, development, and construction of all Federal-aid transportation projects and programs. To varying extents, bicyclists and pedestrians will be present on all highways and transportation facilities where they are permitted and it is clearly the intent of TEA-21 that all new and improved transportation facilities be planned, designed, and constructed with this fact in mind”.

As such, this policy statement provides guidance to transportation facility designers that they should not disregard the importance of bicycling as a transportation mode, and transportation facilities should be designed with their accommodation in mind.

Existing Guidelines

Guidelines exist at the federal, international, state, and local levels for the design of railings for bicyclists.

AASHTO Guidelines for Bridges

During the design of a highway bridge, designers typically select a railing based on the type of traffic that is anticipated for the bridge. For guidance, designers use the 1989 AASHTO “*Standard Specifications for Highway Bridges*,” combined with any state policies or guidelines. In 2007, the AASHTO “*Load Resistance Factor Design (LRFD) Bridge Design Specifications*” will become the national standard for guidance.

On bridges that serve primarily vehicular traffic, such as a bridge along a limited access highway, designers generally select a bridge railing that is designed for vehicular applications. If a sidewalk or designated bicycle facility is included in the design of a bridge, designers select the most appropriate railing design for the multi-modal environment.

Determination of Railing Requirements

There are three types of railings that are routinely specified on bridges that are designed for vehicle loadings:

- Vehicular or traffic railing – Designed to protect only vehicles

- Combination pedestrian railing – Designed to protect vehicles and pedestrians
- Combination bicycle railings – Designed to protect vehicles, pedestrians and bicyclists

Bicycle and pedestrian railings (non-vehicular) are only design for pedestrian and bicycle loadings. These types of railings would only be installed on a bridge if they were protected by a vehicular railing. An example would be a bridge with a vehicular railing installed between the travel lanes and a shared use path, and a bicycle railing installed at the edge of the structure next to the shared use path.

The structure owner determines the type of railing (i.e., vehicular, combination pedestrian, combination bicycle) installed on the structure. Little guidance is available at the federal level for the selection of the appropriate railing on bridges that service “occasional” bicycle and pedestrian traffic.

The AASHTO “*Standard Specifications for Highway Bridges*” does not give a set criterion outlining how to choose a particular type of railing. AASHTO recommends the use of good judgment when choosing a railing type for each structure. Typically, if the structure contains a sidewalk, combination pedestrian railing (at a minimum) should be installed. If the structure experiences heavy levels of bicycle traffic, a combination bicycle railing should be considered. On a high-speed limited access expressway, a vehicular railing is usually sufficient due to the lack of heavy pedestrian and bicycle traffic.

Vehicular Railing Design

The primary purpose of vehicular bridge railings is to contain the average vehicle during a collision. Other considerations in the design of vehicular railings are the protection of a vehicle’s occupants in the event of a collision, the location of other vehicles near the collision, and traffic and pedestrians crossing under the structure. Aesthetics and freedom of view from passing vehicles are also important factors. Section 2.7.1.2 of the AASHTO “*Standard Specifications for Highway Bridges*” states, “Traffic railings and traffic portions of combination railings shall not be less than 2 feet 3 inches from the top of the reference surface.”



Figure 2 - Wyoming Vehicular Railing

Another important factor in the design of a vehicular railing is the transition of the rail off of the structure, either terminating off the structure or transitioning with the continuing

highway rail. A smooth termination or transition should be provided to reduce the possibility of the vehicle “going” onto the end of the rail. The railing should also be smooth on the structure, with no protruding materials that could potentially snag the vehicle during a collision.

Pedestrian and Bicycle Railing Design

The 2002 AASHTO “*Standard Specifications for Highway Bridges*” has imposed more stringent requirements for railing height. Section 2.7.2.2.1 of the specifications states, “The minimum height of a railing used to protect a bicyclist shall be 54-inches, measured from the top of the surface on which the bicycle rides to the top of the top rail.” Section 2.7.3.2.1 states, “The minimum height of a pedestrian railing shall be 42-inches measured from the top of the walkway to the top of the upper rail member.”

s opposed to the “*Guide for the Development of Bicycle Facilities*,” the “*Standard Specifications for Highway Bridges*” and “*LRFD Bridge Design Specifications*” use the word “shall” instead of “should” when specifying the minimum height requirement for bicycle and pedestrian railing (1.4 meters (54 inches) and 1.1 meters (42 inches) respectively). The use of the word “shall” signifies that the heights represent requirements rather than design guidelines.

The 1989 AASHTO “*Guide Specification for Bridge Railing*” also requires a height of 1.4 meters (54 inches) for bicycle railing and a height of 1.1 meters (42 inches) for pedestrian railing. Section G2.7.2.2.1 states, “The minimum height of a railing used to protect a bicyclist shall be 54 inches, measured from the top of the surface on which the bicycle rides to the top of the top rail.” Additionally, Section G2.7.3.2.1 states, “The minimum height of a pedestrian railing shall be 3 feet 6 inches measured from the top of the walkway to the top of the upper rail member.” The use of the word “shall” signifies that the heights represent requirements rather than design guidelines.



Figure 3 - Golden Gate Bridge Railings
Source: John Allen.

According to the guide specification, the design of the rail shall include “consideration to safety, appearance, and freedom of view.” These considerations are similar to those in the *Standard Specification for Highway Bridges*, with the latter providing more detail: “when the bridge carries mixed traffic freedom of view from passing vehicles.”

Both specifications indicate that the critical requirement for bicycle railing is providing a height that protects the bicyclist. Aesthetics and providing a view from the travel lanes represent secondary requirements. The project engineer can use his/her discretion when meeting these last two requirements. The height specifications for pedestrian and bicycle railings are consistent with the AASHTO “*LRFD Bridge Design Specifications*.”

Requirements also exist that limit the size of the openings between horizontal and vertical elements. In accordance with the “*LRFD Bridge Design Specifications*,” the requirements prevent objects from falling or being pushed through the railing onto the travel way below. Section 2.7.2.2 of the 2002 “*Standard Specifications for Highway Bridges*,” which supercedes all other bridge guidelines, states “Within a band bordered by the bikeway surface and a line 27 inches above it, all elements of the railing assembly shall be spaced such that a 6-inch sphere will not pass through any opening. Within a band bordered by lines 27 and 54-inches, elements shall be spaced such that an 8-inch sphere will not pass through any opening.”

AASHTO Guidelines for the Development of Bicycle Facilities

The 1999 AASHTO “*Guide for the Development of Bicycle Facilities*” addresses three conditions where railings should be installed. The conditions include: structures (i.e., bridges), two-way shared-use paths adjacent to a roadway, and shared-use paths adjacent to slopes and/or waterways.

The “*Guide for the Development of Bicycle Facilities*” was not intended to set forth strict standards, but to provide sound guidelines for the planning and design of bicycle facilities. As such, planners, engineers, and designers will not find the word “shall” when reviewing the recommendations for designing bicycle facilities. The word “shall” implies a mandatory condition. Traditionally, when certain requirements in design or application are described with the word “shall,” it is mandatory that these requirements be met. Conversely, the word “should” is used when certain design or application recommendations are intended for guidance or directional purposes.

Chapter 2 of the 1999 AASHTO bicycle guide states, “Railings, fences or barriers on both sides of a path on a structure should be a minimum of 1.1 meters (42 inches) high.” The chapter provides no guidance regarding the conditions adjacent to the structure, such as the distance of the drop-offs. It is assumed that every



Figure 4 - Bicycle Railing - 1.1 Meter High Railing
Crossings of Colonie Park, Town of Colonie, New York

structure, regardless of drop-off distance, requires a minimum railing height of 1.1 meters (42 inches).

Chapter 2 recommends a physical barrier of 1.1 meters (42 inches) between the roadway shoulder edge and the shared-use path edge when the distance between the two edges is less than five feet. A physical barrier serves to identify the path as an independent facility, and protects path users from traveling on the roadway shoulder.

Additionally, the “Width and Clearance” section of Chapter 2 recommends, “A minimum 1.5-m (5-foot) separation from the edge of the path pavement to the top of the slope is desirable when the path is adjacent to canals, ditches, or slopes steeper than 1:3. Depending on the height of embankment and condition at the bottom, a physical barrier, such as dense shrubbery, railing or chain link fence may need to be provided.” The section does not provide guidance regarding the height of the railing or barrier.

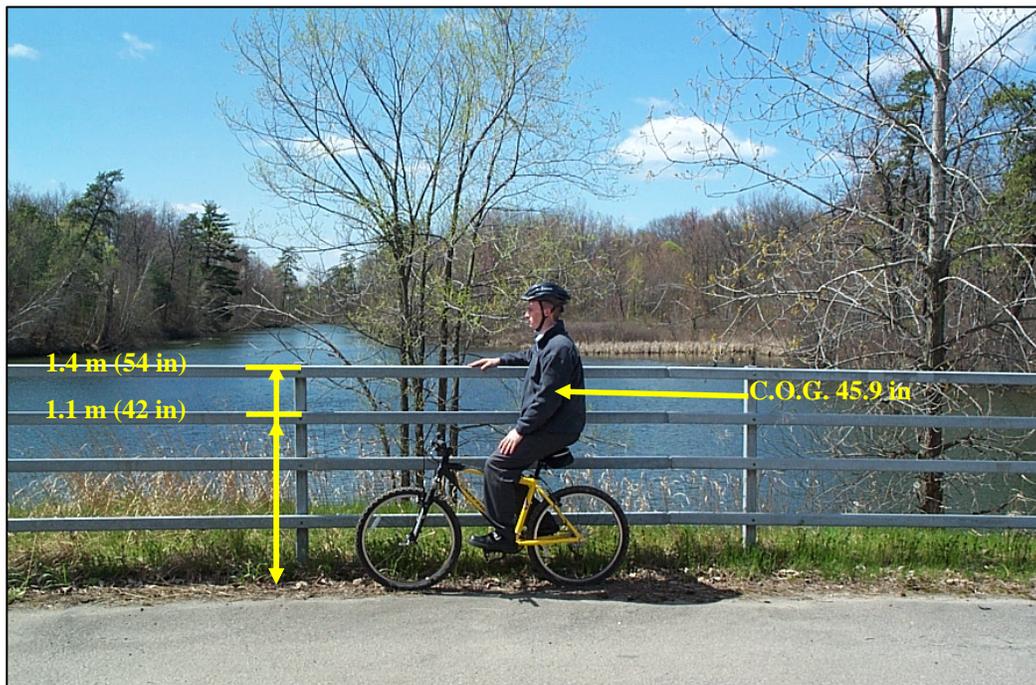


Figure 5- Bicyclist Center of Gravity - The bicyclist above represents the 95th percentile human height, which has a center of gravity on a bicycle of 45.9 inches.

European and Foreign Guidelines

A comprehensive study should include a review of international guidelines for the adoption of bicycle railing heights. As such, European and other foreign countries with significant bicycle usage were contacted and surveyed to determine their state of practice.

Correspondence and survey responses were received from Canada, Australia, Netherlands, and England. Their adopted bicycle railing heights include:

- Canada’s “*Highway Bridge Design Code*” recommends a 1.4-meter (55-inch) railing height on bridges for bicyclists.
- Australia’s “*Guide to Traffic Engineering Practice – Part 14 Bicycles*” recommends a bicycle railing height of 1.4 meters (55 inches).
- Danish Road Directorate’s “*Collection of Cycling Concepts*” contains guidelines for a bicycle railing height of 1.2 meters (47 inches).
- Hampshire, England’s recommended minimum railing height for barriers on a bridge is 1.5 meters (59 inches).

State and Local Guidelines

An analysis of the survey revealed that some states do not strictly adhere to the AASHTO Bridge Guidelines requirement for a 1.4-meter (54-inch) high bicycle railing. Of the 28 states responding, 68% (19 states) indicated that they use a 1.4-meter (54-inch) bicycle railing height on bridges, while 18% (5 states) indicated that they use a 1.1-meter (42-inch) bicycle railing height. Four states (14%) indicated that their selection varies depending on project conditions. Heights of 32 inches (0.8 meters) and 45 inches (1.15 meters) were also identified.

The survey revealed that out of the 28 states responding, 25% use a bicycle railing height of 1.4 meters (54 inches) along a bicycle path, while 61% use a bicycle railing height of 1.1 meters (42 inches). Two states indicated that the heights of bicycle railings are project-driven or determined by environmental conditions.

Table 1 lists the state-adopted bicycle and bridge railing heights of the 28 responding states. Some states noted that bicycle railing heights were determined based on the physical conditions surrounding the bicycle facility, such terrain, snow conditions (shared use paths use by skiers in the winter), drop-off height, etc. A complete listing of the comments received can be found in Appendix A.

The “Design Bicyclist”

Bicycle railing height design decisions in the 1970s were based on the theory that railing heights must be higher than a bicyclist’s center of gravity (COG). As such, highway officials conservatively adopted a 1.4-meter (54-inch) height. However, this approach and theory is widely disputed since, to date, no scientific study has concluded that the COG of a bicyclist is the key factor in railing height determination.

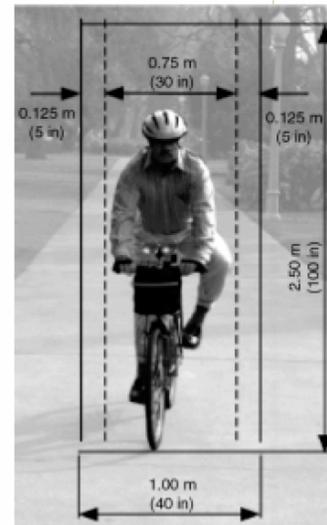


Figure 6 - Bicyclist Operating Space

Source: AASHTO, “*Guide for the Development of Bicycle Facilities*,” 1999

The COG of a body is defined as the center of the gravitational attraction experienced by the body, also known as the body’s balance point. Anthropometrics is the description of the dimensions of the human body, which are measured using landmarks on the human body.

Table 1- State Adopted Railing Heights

State	Bridge Railing Height (inches)	Shared use path Railing Height (inches)
Arkansas	N/A	N/A
California	54	54
Florida	54*	54*
Hawaii	54	42
Idaho	54	42
Illinois	54	42
Indiana	54	N/A
Iowa	54	Both
Louisiana	54	N/A
Maine	**	42
Maryland	54	42
Massachusetts	N/A	N/A
Missouri	42	42
Montana	42	42
Nevada	42	42
New Hampshire	N/A	N/A
New York	54	54
North Carolina	54	54
Oklahoma	54	42
Oregon	54	42
Pennsylvania	42	42
Rhode Island	**	54
South Carolina	54	54
South Dakota	54	54
Tennessee	N/A	N/A
Texas	42	42
Utah	Project-Driven	
Vermont	54	42
Virginia	54	42
Washington	54	42
Wisconsin	**	42
Wyoming	54	42
*Note that the actual use of bicycle railing is infrequent on state road bridges in Florida. FDOT roadway bridges in rural areas only rarely provide bicycle railings; urban roadway bridges seldom provide bicycle railings.		
**Based on the physical conditions surrounding the roadway		

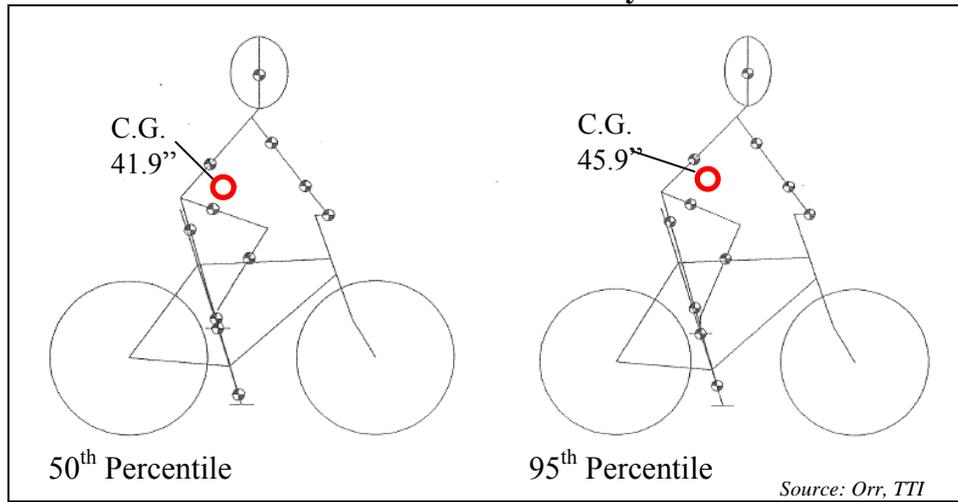
David Orr of Texas A&M University, Texas Transportation Institute, documented the COG of a 50th and 95th percentile person in “*A Study on the Required Height of a Bridge Railing to Accommodate Bicycle Impacts*,” for his Master of Engineering degree research paper. Orr’s paper was initiated based on discussion of the height requirement for bicycle railings on bridges at a conference of state transportation officials in 1993. In the engineering paper, Orr determined the COG of a 50th percentile and 95th percentile adult male on a bicycle. A “percentile” is the point on a distribution curve for a specified variable where that percent of the measured (or calculated) values would be less. For example, if the 95th percentile test score were 80 points, then 95% of the total population would have scored less than 80 points.

A mountain bicycle was selected for the study because the proper posture of a mountain bicycle rider has a higher center of gravity, regardless of saddle height. Using a Giant ATX 760 mountain bike, Orr determined the appropriate railing height through two crash scenarios. The first scenario assumed that the railing height must be at least as high as the COG of the person on the bicycle. This scenario assumed that if a lateral force were applied to a rider, half the rider’s mass would attempt to topple over the railing, while the other half would attempt to prevent the rider from toppling over the railing. This scenario is similar to a crash event where a bicyclist is traveling parallel to a railing and collides with the railing in a glancing fashion. The bicyclist’s body collides with the railing because of a lateral force caused by a collision with an object or another bicyclist, an evasive action to avoid a collision, a sudden cross wind, or other incident that causes a lateral force on a moving bicyclist.

The second scenario rotated the bicyclist about the center of the front wheel to illustrate the maximum height of a bicyclist above the ground. This scenario simulated the worst-case event of a bicyclist impacting a railing from a perpendicular or 90-degree angle. This scenario is similar to a crash event where a bicyclist loses control on a curve as a result of high speed and collides “head on” or at an angle with a railing. The bicycle’s front wheel strikes the railing or a vertical post and the momentum causes the bicyclist to rotate up and around the center of the front wheel and over the railing.

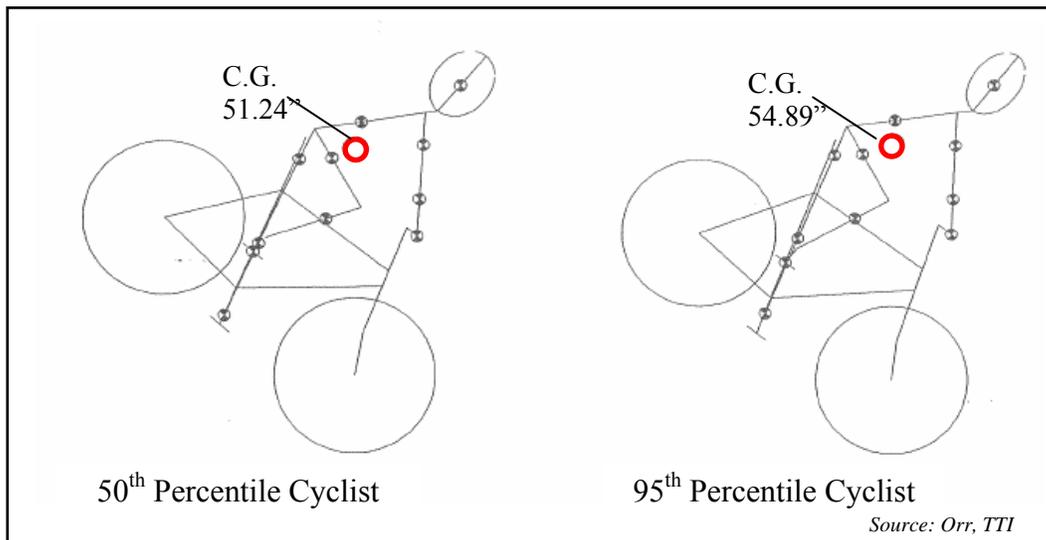
Orr’s first scenario revealed that the COG of a 50th percentile adult male on a bicycle, as estimated by a 50th percentile anthropometric dummy, is located 1.1 meters (41.9 inches) above the ground. The height of the COG of the 95th percentile person on a bicycle, as estimated by a 95th percentile anthropometric dummy, is 1.2 meters (45.9 inches). The 95th percentile height of an adult human male is 1.8 meters (72.8 inches). The first scenario concluded that the COG for both percentiles is well below the 1.4-meter (54-inch) recommended railing height in the AASHTO “*Standard Specification for Highway Bridges*.” Figure 7 illustrates the 50th and 95th percentile COG of a male bicyclist.

Figure 7
Center of Gravity



The second scenario rotated the bicyclist's COG above the center of the front wheel to maximize the COG height. This simulation revealed that the 50th percentile dummy's COG is located 1.3 meters (51.24 inches) above the ground. The 95th percentile dummy's COG is located 1.4 meters (54.89 inches) above the ground. Orr concludes that AASHTO's 1.4-meter (54-inch) railing height limit is inadequate, and should be increased to accommodate the simulation event. Figure 8 illustrates the 50th and 95th percentile's COG under this simulation.

Figure 8
Simulation Center of Gravity



Orr's findings are based on the simple theory that the bicyclist's COG must be below the height of the railing to prevent a bicyclist from falling over the railing. This theory does not take into account any of the other dynamics of a collision with a railing. For example, when a bicyclist is traveling parallel with a railing, a lateral force must be

applied for the bicyclist to fall over the railing. A lateral force most likely would result from a redirection of the bicyclist's momentum due to loss of control of the bicycle or a collision with an object prior to the collision with the railing. The lateral force of the collision with a railing is directly related to the sideways momentum of the bicyclist or the angle of the collision with the railing.

As the COG represents the center of a much larger mass, the point of contact of the body with the railing would not likely occur at the COG, but at a distance equal to approximately one-half the width of the body away from the COG. The lateral force applied to the body must be adequate to rotate the COG over and around the point of contact. Therefore, it is possible that a railing lower than the height of the bicyclist's COG would prevent the bicyclist from falling over the railing. This is the same phenomenon that often prevents a large vehicle or truck from vaulting over a 0.7-meter (27-inch) high railing during a crash event. A simulation or modeling of the lateral force necessary to vault a bicyclist over a railing lower than the bicyclist's COG would be difficult to accomplish without crash testing to verify or calibrate the assumptions and variables.

Chapter 4 - Survey Results

A preference survey was conducted during January and February 2004. The survey was posted on the internet, and state bicycle and pedestrian coordinators and advocacy groups were asked (via regular and electronic mail) to participate. The Association of Pedestrian and Bicycle Professionals (APBP) list serve was also monitored for opinions and information relative to bicycle railings.

Survey Respondents

The primary purpose of the survey was to identify height preferences, and determine real and perceived issues related to the height of bicycle railings. Two bicycle railing height surveys were created: one for state representatives and one for bicycle advocacy groups. Appendix A provides the state and advocacy bicycle railing height surveys.

The state bicycle railing height survey questioned respondents as to their state of practice regarding railing heights, and solicited information on crash events and data. The advocacy bicycle railing height survey questioned respondents as to their group's preference of railing height, and also solicited information on crash events.

Thirty-four (34) individual respondents provided their professional title (i.e., bicycle coordinator or bridge/design engineer) in the state bicycle survey, as outlined below.

- 24 bicycle coordinators and transportation/trail planners completed the survey, which represented 71% of those respondents who provided their titles.
- 10 bridge/design engineers completed the survey, which represented 29% of those respondents who provided their titles.

Twenty-seven (27) representatives of advocacy groups and international transportation agencies provided their professional titles for the advocacy bicycle survey. The titles included presidents, directors, and planners.

The bicycle surveys also solicited the opinions of bicycle users and facility designers regarding the advantages and disadvantages of a 1.4-meter (54-inch) versus a 1.1-meter (42-inch) railing height. State bicycle coordinators and bicycle advocates expressed similar sentiment regarding the advantages and disadvantages of each height.

Issues and Preferences

Advantages and Disadvantages of a 1.4-meter (54-inch) Railing Height

Respondents indicated that the 1.4-meter (54-inch) railing height provided protection from high falls and steep slopes, therefore creating a greater feeling of security. However, respondents also indicated that the 1.4-meter (54-inch) railing height reduced the viewshed, sight distance, and aesthetics of a trail or bridge, created a feeling of confinement, and required a greater expense. Respondents also indicated that a 1.4-meter (54-inch) railing height:

- Prevented bridge users from tossing debris off the bridge
- Protected bicyclists from strong winds on coastal areas
- Created difficulty for exiting a bicycle path in the event of an assault.

Advantages and Disadvantages of a 1.1-meter (42-inch) Railing Height

State bicycle coordinators, bicycle advocates, and bridge engineers indicated that the 1.1-meter (42-inch) railing height provided a proper viewshed and sight distance, but reduced the feeling of security, and inadequately protected bicyclists from drop-offs. Respondents also indicated that a lower railing height would be less expensive than a higher railing height.

Preference

The results of the preference survey indicated that:

- 43% of advocacy groups prefer a 1.1-meter (42-inch) railing height.
- 46% of state bicycle coordinators and bridge designers prefer a 1.1-meter (42-inch) railing height.

The remaining advocacy and state respondents (50%+) were divided on their preferred railing height. The remaining respondents either indicated a preference for a 1.4-meter (54-inch) high railing or selected the “other” response. Those who chose the “other” response provided discussion, opinions, and sentiment, ranging from personal bicycling experiences to the inability to reach a conclusion due to multiple factors. Appendix A provides the responses from the surveys.

Figure 9 shows the preferred railing height of advocacy groups, while Figure 10 shows the preferred heights from the state bicycle survey.

Figure 9 - Preferred Railing Height of Advocacy Groups

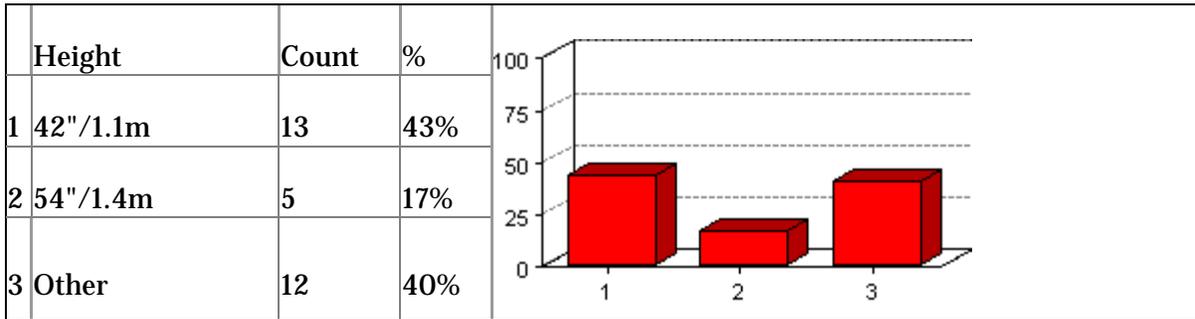
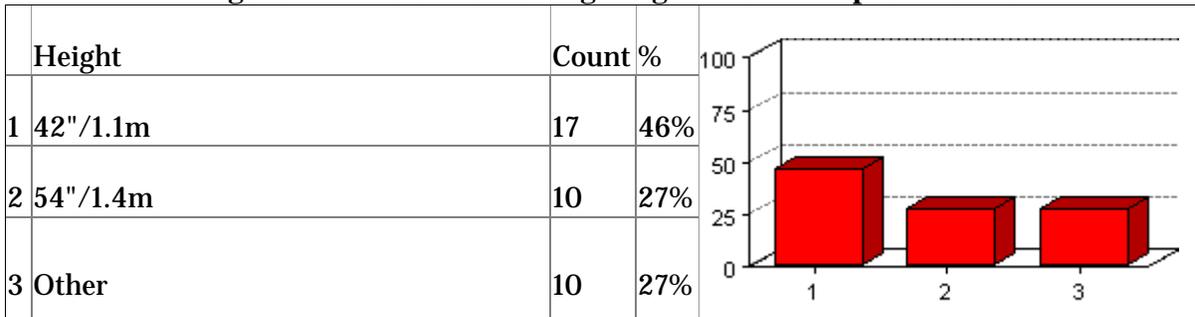


Figure 10 - Preferred Railing Height of State Representatives



Crash History

Bicycle crash studies and crash surveillance systems were investigated to acquire information related to bicyclist crashes with railings. In addition to existing records, information regarding bicycle/railing crashes was researched and solicited as part of the survey.

Limitations of Available Crash Data

The first study investigated for this study was the landmark research report FHWA-RD-95-163 entitled “*Pedestrian and Bicycle Crash Types of the early 1990’s*” (Hunter, Stutts Pein and Cox, 1995). The informational guide (“*Bicycle Crash Types: A 1990’s Information Guide*,” Hunter, Pein and Stutts, 1997) was reviewed for relevant crash data. The informational guide was prepared as a supplement to initial study, and presented the findings of coding 3,000 bicycle-motor vehicle crashes from six states. Although some of the coded crashes may have involved a bicyclist colliding with a railing as an action leading to a collision with a motor vehicle, or as a result of a motor vehicle collision, the coding methodology did not allow the retrieval of this information without reviewing the crash reports.

The North Carolina Department of Transportation’s Division of Bicycle and Pedestrian Transportation Statewide Bicycle and Pedestrian Crash Web-Database was examined. The database includes information for approximately 20,000 bicycle and pedestrian crashes with motor vehicles in North Carolina, as reported through local police departments between 1997 and 2002. The website permits database queries that include roadway features, crash type, bicyclist position, and operator liability. Roadway features are characterized through intersection type, highway ramps, and railroad and bridge crossings. However, a crash event on a bridge does not provide information regarding bridge railing height, or the bicyclist’s interaction with the bridge (i.e., approaching the railing head on or at an angle). Between 1997 and 2002, 27 bicycle crash incidents occurred on bridges in North Carolina. Over the six-year period, these incidents represented 0.45% of the total bicycle crashes (6,037) in North Carolina. Incidents with bridge railings represent an extremely small percentage of the total number of incidents.

The Fatality Analysis Reporting System (FARS) web-based encyclopedia, developed and administered by the National Highway Traffic Safety Administration and the National Center for Statistics and Analysis, provides a database for retrieving fatal crash information. The vehicle classification includes “pedalcyclists,” which represent persons on vehicles that are powered solely by pedals, including bicycles. However, the crash data for pedalcyclists do not indicate whether the event involved a railing or occurred on a bridge.

The research described above illustrates the difficulties of acquiring relevant crash data from motor vehicle crash surveillance systems. State and national crash surveillance systems managed by state transportation departments or state motor vehicle departments generally record only crashes that occur between a motor vehicle and bicyclist. Although

many states require that serious bicyclist crashes not involving a motor vehicle be reported, research indicates that these types of crashes are underreported.⁵

Reporting systems do allow retrieval of crash data involving road features, such as guide rails or bridges; however, it is difficult to retrieve specific information involving a bicyclist crash with a railing. Additionally, motor vehicle crash surveillance systems generally provide only information for crashes between vehicles and bicyclists that involve a serious injury. Overall, these systems are not reliable sources of information for bicycle/railing crashes not involving motor vehicles. Data retrieval from the systems for crashes involving railings is difficult, and would require review of the actual crash reports to determine if the crash involved a railing.

Crashes Reported Through the Survey and Outreach Process

The state and advocacy surveys solicited information regarding specific bicycle crashes. If a respondent indicated that he/she possessed knowledge regarding a crash, an additional survey form would appear at the end of the standard survey. This additional survey form solicited basic information about the crash, and requested permission for a follow-up phone call.

The survey reported a total of six bicycle crashes involving a railing. Three crashes occurred in the United States, two occurred in England, and one occurred in Canada. Overall, statistical analysis of six crashes would not be reliable. However, information from these crashes provided characteristics of bicycle railing crashes, and offered useful information related to the design of bicycle railings. Follow-up phone calls were made to acquire specific information about the details of the crash.

Additional crash information related to railings was acquired through the outreach process. During one crash, a bicyclist lost control on a shared-use path on a bridge after colliding with a pedestrian. With no railing separating the path from traffic lanes, the bicyclist fell into the path of motor vehicle traffic. During another crash, two bicyclists collided with a motor vehicle on a bridge. The bicyclists were thrown over the bridge's railing. The type and size of the railing were not reported. Finally, another bicyclist collided with an object in the road and fell over a vehicular railing.

The bicycle crashes are summarized in Table 2 below. Of the nine crashes, five occurred on roadway bridges, two occurred on a shared use path and two occurred on a shared use path on a bridge. In four of the five roadway bridge crashes, the railing consisted of a vehicular railing less than 1.1 meters (42 inches) high (the height of the railing in the fifth crash is unknown). Two of the six crashes involved a motor vehicle (bicyclists were hit by an overtaking motor vehicle).

Two of the crashes involved a 1.4-meter (54-inch) high railing. During both of these crashes, the bicyclists were traveling at excessive speeds. One of the bicyclists lost

⁵ R. Brustman, "An Analysis of Available Bicycle and Pedestrian Accident Data," New York Cycling Coalition, 1999, p.4.

control while turning into a curve, collided with the railing, and fell or vaulted over the 1.4-meter (54-inch) railing. In the other crash, the bicyclist collided with part of the bridge structure. The railing was not involved in this crash.

Table 2 - Documented Bicycle Crashes

Country	Location	Railing Height	Description
U.S.	Roadway Bridge	<1.1 m	Bicyclist hit by overtaking vehicle and fell over railing
U.S.	Roadway Bridge	<1.1 m	Bicyclist fell over bridge vehicular railing. (Cause unknown)
England	Roadway Bridge	<1.1 m	Bicyclist veered off course due to slippery surface and fell over railing
U.S.	Roadway Bridge	N/A	Motor vehicle collided with two bicyclists who were thrown over railing
U.S.	Roadway Bridge	Approx. 1m	Collided with obstruction and fell over railing
U.S.	Shared use path	1.4 m	Bicyclist traveling too fast lost control while turning into curve, collided with and vaulted over railing
England	Shared use path	N/A	Single vehicle incident. Details unknown
Canada	Shared use path on Bridge	1.4 m	Bicyclist traveling too fast collided with bridge structure (did not collide with railing)
Canada	Shared-use Path on Bridge	Not provided	Bicyclist collided with pedestrian and fell into path of motor vehicle traffic

Chapter 5 - Issues related to Bicycling Railing Heights

Information received from the railing height survey and communication with bridge engineers, transportation planners, and bicycle advocates revealed several issues pertinent to the determination of bicycle railing heights. Several survey respondents indicated that a 1.1-meter (42-inch) railing evokes a feeling of insecurity while riding. As such, the 1.4-meter (54-inch) railing height is perceived as providing greater protection in the event of a crash. However, some survey respondents also indicated that a 1.4-meter (54-inch) railing height reduces views of scenic landscapes, and diminishes bridge aesthetics. Furthermore, some survey respondents indicated that an additional 12 inches of railing substantially affects the cost of a bicycle facility or bridge project, without providing a proven increase in safety.

Perceived Safety of Falling

The primary purpose of a railing is to protect a bicyclist, pedestrian, or motorist from falling off a bridge or structure. As such, an important concern to a number of survey respondents was the perception of safety when traveling along a bridge.

Survey Responses

Several questions within the survey solicited opinions regarding the advantages and disadvantages of a 1.1-meter (42-inch) versus a 1.4-meter (54-inch) railing height. Some respondents expressed concern that a 1.1-meter (42-inch) railing height does not provide a feeling of security for bicyclists. As such, some feel that an advantage of the 1.4-meter (54-inch) railing height is that the higher height protects bicyclists from high falls and steep slopes, and provides a greater feeling of security.

Four respondents to the advocacy survey identified their stature as a six-foot frame, and expressed concern that a 1.1-meter (42-inch) high railing would not protect them in the event of a crash. Two of the four respondents indicated that they are forced to reach down to the 1.1-meter (42-inch) high rail to push off. These four individuals possess greater heights than the 95th percentile human adult male, whose center of gravity (COG) on a bicycle (according to Orr's first scenario) is 45.9 inches. A COG of 45.9 inches is approximately four inches above a 42-inch rail height. Overall, the perception of insecurity for these four respondents (and similar-sized bicyclists) may be warranted.

To accommodate bicyclists who expressed concern regarding the insecurity associated with a 1.1-meter (42-inch) railing, and those who believe the 1.4-meter (54-inch) height provides greater protection from falls, a railing height between 1.1 meters (42 inches) and 1.4 meters (54 inches) represents a compromise. Perhaps a 1.2-meter (48-inch) railing height could provide both protection from steep slopes and high falls and a feeling of security.

Acrophobia

The lack of empirical evidence supporting the need for the higher railing height leads to the possibility that the feeling of insecurity associated with the lower railing height may be due to a fear of heights. This disorder is known as acrophobia. In general, phobias (including acrophobia) affect about 9 to 10% of Americans.

Summary

Perception represents a strong force in an individual's determination of personal safety when traveling along a bicycle path adjacent to a steep slope or high drop-off. Despite the lack of empirical evidence proving that a 1.4-meter (54-inch) railing height provides added protection, many of the responses from the survey and outreach process indicated that a 1.1-meter (42-inch) high railing was inadequate, and that the additional height provides an added sense of security. There appears to be a consensus that an increased level of comfort is experienced when bicycling across a bridge with a 1.4-meter (54-inch) high railing.

Views and Aesthetics

The issue that appears to have had the greatest influence on lowering the recommended railing height from 1.4 meters (54 inches) to 1.1 meters (42 inches) is aesthetics. Most of the relevant survey responses and comments referred to the general term of "aesthetics" as the reason for preferring a 1.1-meter (42-inch) height railing. Some responses and comments specifically identify a desire to avoid obstructions to the view.

Railing Aesthetics

A number of documents related to bridge aesthetics were reviewed to determine aesthetic attributes or criteria that should be considered in the design of a railing. Most of the reviewed documents discuss the design attributes of a bridge, and outline how the attributes are seen in the context of the surrounding landscape. Typical design attributes of a bridge that relate to form and aesthetics include proportion, symmetry, order and rhythm, contrast and harmony, detail, simplicity, and unity of design. The specific bridge components that are viewed in the context of the surrounding landscape are the piers, side fascia, abutments, wing walls, and other fixtures, including railings or treatments on the side of the bridge.

Based on the available guidance on bridge and structure aesthetics, it is difficult to determine any general suggestions, principles, or guidelines regarding the size, scale, or form that would render a railing system aesthetically objectionable. Using conventional wisdom, bridge designers tend to design a shallow bridge section that would be visually unobtrusive, and maximize the vertical clearance. A higher bridge railing could appear disproportionate with the thin section of a bridge. However, the visual quality or beauty of a railing system would have to be judged based on its physical setting.

Impacts on Visual Quality

The greatest concern regarding aesthetics is presumed to be the deterioration of visual quality resulting from the introduction of a man-made object, such as a railing, into the foreground of a scenic view seen from users of a shared use path or from the surrounding area. When applying visual assessment criteria in accordance with the widely accepted Visual Impact Assessment (VIA) methodology, the construction of a railing would lower the visual quality of a view due to the change in intactness and unity of the view.⁶

A number of rhetorical incidents have occurred that tend to support a decrease in visual quality resulting from the introduction of a railing into the view from a bicycle path. The Town of Agawam, Massachusetts constructed a 1.4-meter (54-inch) high three-rail wood fence railing type along the Connecticut River Walkway at the top of a slope along the shoreline of the Connecticut River. The railing was designed before the 1999 AASHTO *Guidelines for Bicycle Facilities* was issued. Before the construction was complete, the Town received numerous complaints from neighboring residents that the railing would disrupt the view of the scenic river from their homes and from users of the walkway. Subsequently, the top rail was removed, and the height of the railing was lowered to 1.1 meters (42 inches), which seemed to satisfy the residents.⁷

The New York State Department of Transportation (NYSDOT) has received complaints regarding a 1.4-meter (54-inch) high metal tubular railing with a dark brown finish that was installed along a lakeside segment of a trail in the Adirondacks. The rail interrupts views of the lake from the trail and an adjacent state highway.⁸

Interruption of Views and Sight Lines

The view from a bridge by motorists and bicyclists is an important attribute that appears to be common to all bridge aesthetic considerations. Bridge designers are encouraged to consult the community, and consider open-bridge railings instead of concrete barriers to allow views to scenic landscapes.⁹ Many states have adopted policies to encourage the use of open-bridge railings to maintain scenic views, and to adopt railing designs that maximize the view.

Two conditions should be considered when assessing the impact of a railing on a surrounding view: the view from passing motorists and bicyclists on bridges, and the view from bicyclists and pedestrians on a shared use path or walkway.

Overall, the implication of the survey comments is that a 1.1-meter (42-inch) railing height has less of an impact on aesthetics and visibility than a 1.4-meter (54-inch) railing height.

⁶ Federal Highway Administration. US Dept. of Transportation. “*Visual Impact Assessment for Highway Projects*,” 1981. p.13.

⁷ Conversation with Jeffery McCollough, Pioneer Valley Planning Commission, March 25, 2004.

⁸ Conversation with Charles Nagle, Landscape Architecture Bureau, NYSDOT, March 24, 2004.

⁹ Federal Highway Administration, US Dept. of Transportation. “*Flexibility in Highway Design*,” 1997, p.104 - 105

The Effect of Railing Height on the View

The ability to see over a traffic barrier designed for bicyclists appears to be an issue for motorists in mountainous terrain or where the viewing subject is higher than the horizon line. For the purposes of calculating sight distance, the average height of a vehicle occupant's eye is 1,080 mm or 1.1 meters (42 inches),¹⁰ which corresponds to a 1.1-meter (42-inch) railing height. Theoretically, a person in a vehicle would have an uninterrupted view of objects above the horizon line if the railing height were 1.1 meters (42-inches). The view would ultimately depend on the cross slope of the roadway, the longitudinal slope of the roadway, and the vehicle occupant's cone of vision. The additional 0.3 meters (12 inches) of a 1.4-meter (54-inch) high railing would likely obscure a vehicle occupant's view of the horizon.

The ability to see over a railing along a bikeway is a function of the eye level height of the bicyclist or pedestrian. The average eye level of a bicyclist varies with the type of bicycle, riding stance, and seat height. For the purposes of illustrating the impact of railing height on the unobstructed view from a bikeway, the average height of pedestrians, rather than bicyclists, was used for this study. Data for pedestrians is more readily available and consistent.

The average standing eye level height is 65.4 inches for an adult male and 61.5 inches for an adult female. The average eye level height of a 12-year old child is 54.5 inches.¹¹ As illustrated in Table 3, the difference in eye height and railing height for a 1.1-meter (42-inch) high railing is much greater than that for a 1.4-meter (54-inch) high railing. The lower height can greatly increase the potential for an unobstructed view from a pedestrian on a bikeway.

The measure of the unobstructed view is determined by an individual's cone of vision angle. As shown in Figure 11, a 64.5-inch tall adult male, positioned three feet from a 1.1-meter (42-inch) railing, has a cone of vision angle of 33 degrees. Consequently, the same adult male positioned before a 1.4-meter (54-inch) railing has a smaller cone of vision angle (18 degrees), and therefore, experiences a greater obstructed view. Table 3 provides the cone of vision angles for an adult male, adult female, and child positioned before a 1.1-meter (42-inch) and 1.4-meter (54-inch) railing.

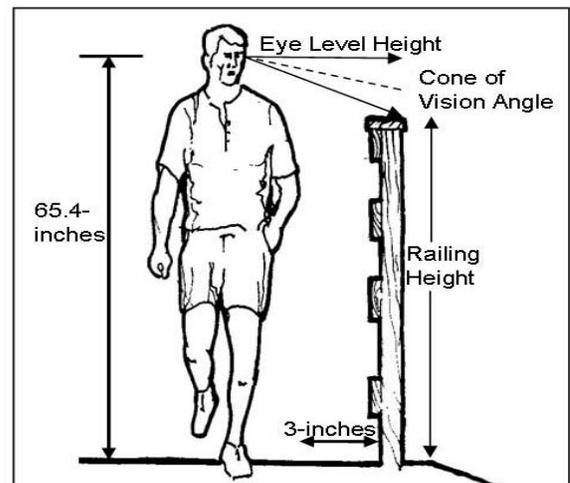


Figure 11 - Cone of Vision Angle

¹⁰ AASHTO, "A Policy on Geometric Design of Highways and Streets," 4th Ed., 2001, p. 127.

¹¹ Hoke, Jr., John R., American Institute of Architects, Ramsey/Sleeper, "Architectural Graphic Standards," 9th ed., 1994, p. 1.

Table 3 - Eye Level Height and Associated Cone of Vision Angle

Person	Avg. Eye Level Height (in.)	Difference from 42" rail (in.)	Cone of Vision Angle with 42" rail (degree)	Difference from 54" rail (in.)	Cone of Vision Angle with 54" rail (degree)
Adult Male	65.4	23.4	33°	11.4	18°
Adult Female	61.5	19.5	28°	7.5	11°
Child – 12 yrs.	54.5	12.5	19°	0.5	0.8°

The Effect of Railing Transparency on the View

Another consideration is the visual transparency of the railing. The structure of the posts and rails on a combination traffic and bicycle railing is much heavier than a bicycle railing due to the vehicle design loadings. The Standard Specifications for Highway Bridges specifies that all assembly elements of railings 27 inches above the bikeway must be spaced such that a six-inch sphere will not pass through any opening. Additionally, all assembly elements of railings between 27 and 54 inches in height must be spaced such that an 8-inch sphere will not pass through any opening. However, the design of these openings is often reduced by state design guidelines to prevent large objects from passing through the barrier. For example, for railings designed for bicyclists or pedestrians, CalTrans requires bridge elements to be spaced such that a four-inch sphere will not pass through any opening between the road surface and to 27 inches above it. For subsequent heights, the spacing must prevent an eight-inch sphere from passing through the elements.¹² These more restrictive specifications create a greater visual obstruction to the view beyond the railing.

¹² California Department of Transportation, “*Bridge Design Specifications*,” April, 2000, p. 2-4.

Summary

A reference to “aesthetics” is used extensively in the preference of a 1.1-meter (42-inch) height railing over a 1.4-meter (54-inch) railing. However, no attributes related to form or scale have been identified as the determining factor in the objection to the 1.4-meter (54-inch) height. It would be difficult to assess the aesthetics of a railing system without understanding the setting and surrounding visual environment.

The more pertinent issue of visual impact occurs when a railing is placed within a scenic view, and man-made objects can be visually offensive. In this regard, the smaller 1.1-meter (42-inch) railing height may have less of an impact than the higher 1.4-meter (54-inch) railing height.

Additionally, a 1.4-meter (54-inch) high railing would have a greater impact on the sight line of users of a bikeway than a 1.1-meter (42-inch) high railing.

Cost

During the study process, the cost of bicycle railing was cited as a reason supporting a lower railing height. However, no cost figures or cost thresholds were received from the information acquired during the survey or telephone outreach. As such, a cost comparison was conducted to assess the costs associated with the different railing heights.

Due to the heavier materials necessary for vehicular loadings, the cost of railing designed to withstand vehicular crashes on bridges is greater than the cost of a railing designed for pedestrian and bicyclist loading. Therefore, separate cost comparisons were conducted for bridge railing and shared use path railing. The primary source of cost information for the cost comparison was the 2004 RSMMeans “*Heavy Construction Data*,” which provides national averaged unit prices for various construction materials. The unit prices include the costs of material, labor, overhead, and profit.

The source of cost information for bridge railings was the New York State Average Weighted bid prices. These prices can vary greatly from one state to the next depending on labor and material costs, and the design of the state’s standard bridge railing systems. New York has developed a system of similar standard bridge railings that vary in size, height, and number of rails depending on the intended use. Two- and three-rail systems are used for bridges that accommodate only vehicular traffic. Four-rail (42-inch high) systems are used for bridges that accommodate pedestrian traffic. Five-rail (56-inch high) systems are used on bridges that require added protection for bicyclists. The use of a similar rail system with multiple rails allows for an easy cost comparison. Although the bid prices are unique to New York, the relative costs are useful in illustrating the cost effect of adding an additional rail.

In addition to the cost difference between a 1.1-meter (42-inch) and a 1.4-meter (54-inch) railing height, the cost of railing compared with the rest of the facilities was also investigated.

Table 4 illustrates typical costs of railings that are routinely used along shared use paths. These costs are for similar railing systems, and are intended to show the relative differences in the cost of material and the cost of adding an additional rail. The costs of footings or deck connections are not included in these unit prices.

Table 4 - Bicycle Railing (non-vehicular loading)

Railing Type	Railing Size	Cost per meter	Cost difference
Aluminum Pipe Railing*	2 rail, 38mm diameter, satin finish	\$106	\$40
	3 rail, 38mm diameter, satin finish	\$146	
Galvanized Steel Pipe Railing*	2 rail, 38mm diameter	\$105	\$40
	3 rail, 38mm diameter	\$145	
Wood Board Railing	25 x 100mm, 50 x 100mm rails, 100 x 100mm posts, No. 1 grade cedar – 2 rail, 1.2 m high	\$63	\$7
	25 x 100mm, 50 x 100mm rails, 100 x 100mm posts, No. 1 grade cedar – 3 rail, 1.5 m high	\$70	
Chain Link Fence	9 ga. Aluminized steel, 50 mm line post 3m O.C., 40 mm top rail - 1.5 m high	\$55	--

* The costs shown are for a railing along stairs, and the height of the railing was not provided. The typical height of a railing on stairs is approximately 0.9 m (36") high. As most of the value is in the rails, the cost of 1.1-m and 1.4-m high railing would be slightly higher than the costs shown.

Relative to the overall cost of a shared use path, the cost of adding railing can be significant. A linear cost estimate of a 10-foot wide asphalt paved shared use path through a wooded area with an average existing cross slope of 10% was prepared using the RSMeans cost data. The cost per linear meter is approximately \$150, approximately the same cost as a three-rail metal railing. The addition of a two-rail metal railing with a height of 1.1 meters (42 inches) to one side of a shared use path may increase the cost approximately 70% to \$255 per linear meter.

If the railing was increased to a three rail metal railing that was 1.4 meters (54 inches) high, the linear cost of the shared use path could increase by 95% to approximately \$295 per linear meter. The difference in cost between the two height railing is approximately \$40 per linear meter or approximately 15% of the cost of a shared use path with a 1.1 meter (42 inch) high railing.

The cost of vehicular bridge railing is substantially higher than bicycle railing due to the higher loadings necessary for vehicular traffic. For example, RSMeans provides a cost of \$299 per linear meter for a two-line galvanized steel pipe bridge railing, and a cost of \$755 for a four-line galvanized steel pipe bridge railing.

The average bid price of New York State Department of Transportation (NYSDOT) vehicular railings was investigated. The vehicular railing investigated was NYSDOT Item No. 568M50, which consists of a two-rail, steel bridge railing. The combination vehicular-pedestrian railing investigated was NYSDOT Item No. 568M51, which consists of a four-rail, steel bridge railing. Finally, the combination vehicular-bicycle railing investigated was NYSDOT Item No. 568M52, which consists of a five-rail, steel bridge railing. Table 5 compares the average bid price cost for all vehicular type railings in New York State over a two-year period.

Table 5 - Comparison of Average Bid Price in New York (2002-2003)

NYSDOT Item	2002 (Linear Meter Cost)				2003 (Linear Meter Cost)				2002 and 2003 (Linear Meter Cost)	
	No. of Bids	Low	High	Weighted Average	No. of Bids	Low	High	Weighted Average	No. of Bids	2 Year Average
568M50 (V)	10	\$195	\$340	\$252.53	7	\$150	\$303	\$286.41	17	\$269.47
568M51 (P)	21	\$344	\$600	\$397.34	23	\$261	\$600	\$299.09	44	\$348.22
568M52 (B)	2	\$410	\$600	\$477.85	4	\$435	\$600	\$465.80	6	\$471.83

Note: (V) = Vehicular, (P) = combination Pedestrian, (B) = Combination Bicycle

It would be reasonable to assume that the additional cost of adding a fifth rail to a four rail system would be about 25% of the four-rail system. However, As illustrated in Table 5, the difference in cost between a combination pedestrian railing (four rails) with a height of 1.1 meters (42 inches) and combination bicycle railing (five rails) with a height of 1.4 meters (54 inches) is approximately \$125 per meter, or approximately a 35% increase in cost. The increase in height would affect the fabrication costs by requiring more material and labor for assembly. The increased weight would create an increase in transportation costs from the fabrication plant to the site. Also, the increased height could create a longer moment arm during a collision, which would require a stronger anchorage system and subsequently, more labor and material for installation. Finally, the large increase in price bid for the 1.4-meter (54 inch) railing may be related to the smaller number of contracts and quantities.

The additional cost of installing a 1.4-meter (54-inch) high combination bicycle railing on both sides of a 90-meter (approximately 300-foot) long bridge instead of a typical two-rail vehicular railing is approximately \$200 per meter or a total of \$36,000.

The additional cost of installing a 1.4-meter (54-inch) high combination bicycle railing on a 90-meter (approximately 300-foot) long bridge instead of a 1.1-meter (42-inch) high combination pedestrian railing is approximately \$125 per meter or \$22,500. However, the additional cost can be considered negligible to minor when compared to the overall cost of a bridge. The percentage difference in cost depends on the type of structure, overall

length of the project, and vertical clearance under the structure. For example, an increase in rail height creating a cost difference of \$125 per linear meter (\$22,500 total) on a 90-meter (approximately 300-foot) long multi-span steel multi-girder bridge with an overall price of \$3,000,000 only represents 0.8% of the total project cost.

In summary, the difference in cost between a 1.1 meter (42 inch) and a 1.4-meter (54-inch) high railing along one side of a shared use path is approximately \$40 per linear meter which represents approximately 15% of the cost of a shared use path.

The difference in cost of a four-rail 1.1 meter (42 inch) and a five-rail 1.4-meter (54-inch) high combination railing on both sides of a bridge is approximately \$125 per linear meter, or less than one percent of the total cost of the bridge.

It is interesting to note here that the increase in cost of installing a combination pedestrian railing instead of a bicycle railing is only an increase of approximately 80\$ per linear meter.

Additional Issues Related to Railings

Respondents to the survey introduced several additional issues for consideration when determining appropriate railing heights for bridges and bicycle paths. Additional factors to consider include the affects of wind on the bicycle facility and the use of the facility by equestrians and cross-country skiers.

Wind

In many coastal areas, bridges are key links in creating continuous paths. Bridges provide bicyclists and pedestrians with the opportunity to experience spectacular land and water views. However, bridges in coastal areas are exposed to different weather elements (mainly related to wind exposure) than those located inland. Several respondents indicated that a 1.4-meter (54-inch) high railing on coastal bridges protects bicyclists from strong winds.

Equestrians and Cross Country Skiers

Railings on shared-use paths could be inadequate for the needs of equestrians and cross-country skiers. An equestrian mounted on a horse is above the normal height of a bicycle railing. Additionally, individuals who participate in cross-country skiing in areas of high snowfall tend to encounter undersized or snow-buried railings. Respondents indicated that the 1.4-meter (54-inch) railing was more practical than a 1.1-meter (42-inch) railing on shared-use paths that experience high snowfall accumulations and active cross-country skiing use. Figure 12 depicts a 1.2-meter (48-inch) railing in Stowe, VT, reduced to 0.8 meters (30 inches) due to



Figure 12 - Bridge with Snow Accumulation *Source: Bruce Burgess*

0.5 meters (18 inches) of snow accumulation along the trail surface.

Vehicle Side Crashes (“Head Slap”)

A follow-up conversation with a representative of the Texas Department of Transportation’s Bridge Division¹³ revealed the potential for severe head injury resulting from a sideways collision of a vehicle with a high bridge railing. This type of crash event is referred to as “head slap.” A bridge railing installed at a height of 1.1 meters (42 inches) or 1.4 meters (54 inches) to protect bicyclists and pedestrians could possibly cause a serious head injury to an occupant of a motor vehicle upon impact.

Although this issue does not affect the critical height of bicycle railing, it may have an impact on the decision to specify bicycle railing instead of vehicular railing on bridges that do not have designated bicycle facilities, but experience bicycle traffic.

¹³ Conversation with Mark Bloschock, Texas Dept. of Transportation, March 30, 2004

Chapter 6 - Findings and Recommendations

In the absence of scientific study, empirical data, and actual or simulated crash data, the first AASHTO guideline for the height of a bicycle railing was based solely on the theory that a railing should be equal to or higher than a bicyclist's center of gravity (COG) to prevent the bicyclist from vaulting or falling over the railing. In the absence of a thorough analysis of the height of the COG of a bicyclist, the difference in height of the COG of a pedestrian and a person on a bicycle was estimated. A conservative estimate of an additional 12 inches was applied to the 1.1-meter (42-inch) pedestrian railing height, and a 1.4-meter (54-inch) high bicycle railing height was established.

No other considerations or variables have been applied to the prevailing theory that the COG must be lower than the railing to prevent falling over the railing. For instance, the lateral force necessary to rotate the bicyclist's COG over the railing has not been considered in the height of the railing. The speeds of the bicyclist, direction of travel, and angle of collision with the railing have also not been considered.

Crash records are few and inconclusive. In the only reported crash involving a fall over a 1.4-meter (54-inch) railing, the bicyclist was traveling at a high rate of speed, and collided with the railing at an angle.

The survey and outreach process revealed a sense of insecurity regarding a 1.1-meter (42-inch) railing height. This is especially true for tall bicyclists crossing long bridges with high winds.

A real concern also exists regarding the obstruction of views associated with high railings. This concern has, in some cases, resulted in the reduction of railing height after the railing was installed.

Finally, survey respondents identified cost as a concern, especially when compared with the linear cost of a separate shared-use path.

It is reasonable to conclude that the "one size fits all" approach to bicycle railing design is not adequate. In many locations, especially along shared-use paths at the top of slopes in a scenic corridor, the theoretical additional degree of safety afforded to bicyclists by a 1.4-meter (54-inch) high railing would not likely offset the associated aesthetic and cost impacts. However, locations exist, especially on high, wind-prone bridges or on high speed curves, where a higher railing would lend a greater degree of comfort to a bicyclist, and could prevent a bicyclist from vaulting over a railing as a result of a high speed crash.

Recommended Bicycling Railing Heights

In locations where a bicyclist should be protected from a severe hazard, a minimum bicycle railing height of 1.2 meters (48 inches) is recommended. The Orr study revealed that the center of gravity of a 95th percentile adult male on a bicycle, as estimated by a 95th percentile anthropometric dummy, is located at a height of 45.9 inches. The 95th percentile height of an adult human male is 72.8 inches.

When a bicyclist is traveling parallel with a railing on a facility with a straight alignment, the chance of a collision or loss of control that would result in a lateral force great enough to propel the bicyclist over the railing is minimal. When applying the theory that the center of gravity should be equal to or less than the railing height, a 1.2-meter (48-inch) high railing would be adequate for these types of minor collisions for more than 95% of adult male bicyclists, and approximately 98% of all cyclists when women, children and different types of bicycles are considered.

A 1.2 meter (48 inch) high bicycle railing designed to prevent a bicyclist from falling over the railing is recommended in the following locations:

- Along a bicycle lane, shared use path or signed shared roadway (bicycle route) immediately adjacent to the edge of a highway bridge.
- Between a shared use path and a travel lane on a bridge or highway where a bicyclist may fall over a railing into the path of oncoming traffic. If the edge of the travel lane is greater than 1.5 m (5 feet) from the edge of the shared use path, a vehicular barrier would be sufficient.
- A bikeway bridge with a drop off of 0.6 meters (2 feet) or greater
- A shared use path adjacent to a hazard where the bicyclist would be severely injured if they were to fall over the top of the railing. Typical hazards would include cliffs, water bodies or rocks.

An example of an existing 1.2-meter (48-inch) high bicycle railing consists of the outside railing of the Golden Gate Bridge. This bridge is used extensively by bicyclists and pedestrians, and no serious collisions with the railing of the bridge have been reported. Figure 13 shows the 1.2-meter (48-inch) high railing along the Golden Gate Bridge.

The 1.2-meter (48-inch) height would have less of a potential to obstruct the vision of shared-use path users, would cost slightly less than a 1.4-meter (54-inch) high railing, and would provide a greater perception of comfort and safety for bicyclists.



Figure 13 - Golden Gate Bridge

Source: John Allen.

Exceptions

Designers should have different size railings available for application under unique conditions. The following two criteria related to the safety of the bicyclist should be considered when specifying a bicycle railing height other than 1.2 meters (48 inches):

- The potential for vaulting over a railing caused by a high speed collision at an angle to the railing
- The use of a railing as a physical barrier to prevent collisions with hazards

The Potential for Vaulting Over a Railing

A bicyclist may vault over a 1.2-meter (48-inch) railing if the force and angle of the collision is enough to lift the body of the bicyclist over the top rail. Vaulting over a railing could occur if the bicyclist is traveling at a high rate of speed and collides with the railing at a sharp angle. In this instance, the COG of the bicyclist may rotate over the axle of the front wheel, which would project the COG of the bicyclist higher than 1.2 meters (48 inches).

The exact threshold of vaulting over the railing is a function of the momentum of the bicyclist, the angle of the collision that results in a force perpendicular to the railing, and the difference in heights of the bicyclist's center of gravity and railing.



Figure 14 - Application of a 1.4 m (54-inch) High Railing

Where a 1.2-meter (48-inch) high railing is recommended as described previously, the height of the railing should be increased to 1.4-meters (54-inches) at the following locations to prevent a bicyclist from vaulting over a railing as a result of a high speed angular collision with the railing:

- On a shared use path or the approach to a bridge where the radius of a curve adjacent to a hazard is not adequate for the design speed or anticipated speed. The relationship between speed and minimum curvature is described in the AASHTO Guide for the Development of Bicycle Facilities, 1999 edition.
- On a shared use path on the outside of curves where inadequate sight distance or large volume of users could cause a bicyclist to take evasive action and collide with a railing at a sharp angle.
- On a shared use path or bridge at the end of a long descent where speeds of bicyclists are greater.

Figure 14 illustrates a shared use path where the downhill approach leads to a curve under the bridge. A higher 1.4-meter (54-inch) railing is recommended for this location.

Railing Used as a Physical Barrier

Railings are often used as a physical barrier to protect a bicyclist from descending a slope or from colliding with an adjacent hazard when insufficient space is available to separate a bicycle facility from the hazard. According to the AASHTO “*Guide for the Development of Bicycle Facilities*”, a 1.5-meter (5-foot) separation between the pavement and the top of a slope or hazard is desirable. The guide states, “Depending on the height of the embankment and condition at the bottom, a physical barrier, such as dense shrubbery, railing or chain link fence, may need to be provided.” The recommended height of the barrier is not specified.

A railing that is used as physical barrier is not intended to keep a bicyclist from falling or vaulting over the barrier. Its intent is to prevent the bicyclist from colliding with the hazard. For example, a bicyclist riding on a shared use path built on an embankment with a steep slope could possibly lose control and descend down the slope on the bicycle. The high speed collision or fall at the bottom of the slope could result in severe injury. If the out-of-control bicyclist were to collide with a barrier, a hedge or railing, and fall at the top of the slope, the resulting injury would not be as severe and the high speed collision at the bottom of the slope would have been prevented.

Many states have provided additional guidance for the requirement for a railing on top of slopes. The need for a railing or barrier is usually a function of degree of slope and height of embankment. These guidelines do not appear to be based on scientific or empirical data. The condition at the bottom of slope may be a better indicator of the need for a barrier.

Where a slope is not steep (not greater than 1:3) and sufficient clearance from the path and the top of slope cannot be achieved, a 1.2-meter (48-inch) bicycle railing would not be necessary because there is no need to keep a bicyclist from falling over the railing. In these locations a barrier of sufficient height that could keep the bicyclist from an out-of-control descent down the slope would be adequate. The aesthetics and ability to see over the barrier by all users should be a consideration when establishing the height of the railing or other physical barrier.

Other Design Considerations

The visual impact of a bicycle railing is a real consideration, especially along scenic corridors. The primary concern in these conditions is the transparency of the railing system.

Steel and aluminum structural elements of a railing system can be visually thinner than wood elements, allowing individuals to see through a railing system. However, a typical “rustic” wood post and wood board railing system may be more visually compatible in a natural setting. Yet, wood boards can greatly obstruct a view.

The top railing of a bicycle railing should be rigid. A steel mesh or tension cable system that replaces the intermediate rails may be considered to allow a more transparent look, as illustrated in Figures 15 and 16.



Figure 15 - Tension Cable Railing



Figure 16 - Steel Mesh Railing

If the height of a railing is a serious consideration in the obstruction of a view, the top railing can be lowered by adding an extended top rail at a retracted angle on the outside of the railing, thus maintaining the effective height of the railing. This type of railing has been specified for the Clinton River Trail Master Plan in Michigan, and is illustrated in Figure 17.¹⁴ If a bicyclist were to rotate over the top rail, the extended rail would restrain the center of gravity. The “effective” height in Figure 17 is a sum of the height of the railing and the extended railing, which totals 1.4 meters (54 inches).

The design of the bottom rail is another important consideration. One of the crashes reported in the survey involved a bicyclist losing control and sliding under the railing. A railing system should have adequate bottom protection to prevent a fallen bicyclist from sliding underneath the railing.

Another important consideration is the location of railings relative to the path of travel. AASHTO “*Guidelines for Bicycle Facilities*” recommends that, “a minimum 0.6-m (2-foot) wide graded area with a maximum 1:6 slope be maintained adjacent to both sides of the path; however, 0.9 m (3 feet) or more is desirable to provide clearance from trees, poles, walls, fences, guardrails or other lateral obstructions.”¹⁵ Bicycle railings are frequently placed too close to the travel path, thereby reducing the effective width of the path. Bicyclists will tend to “shy” away from the railing, which increases the risk of a collision with another path user.

¹⁴ The Greenway Collaborative, Inc. “*Clinton River Trail Master Plan, Michigan.*” November 2003.

¹⁵ AASHTO. “*Guide for the Development of Bicycle Facilities,*” 1999.

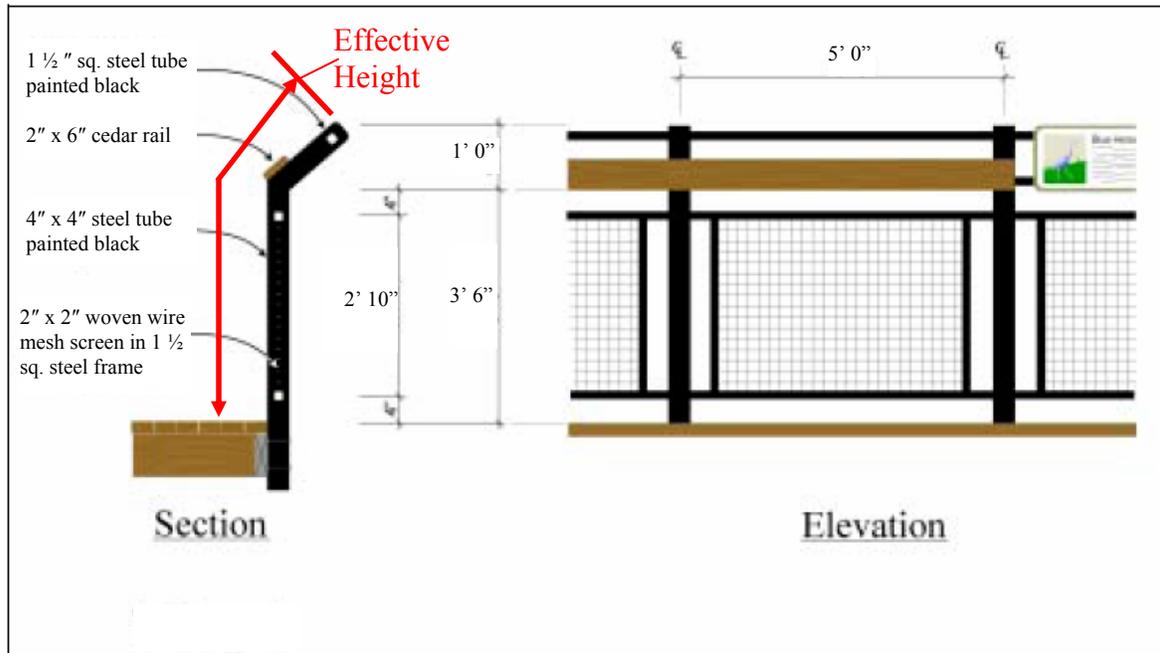


Figure 17 - Bicycle Railing with Extended Top Rail

A head-on collision on the Burke-Gilman Trail in Seattle was reported where one bicyclist was overtaking another cyclist as they entered one end of a bridge along the trail. The bicyclist being overtaken steered away from the railing, and collided with the other bicyclist who lost control and fell. A third bicyclist approaching from the opposite direction collided with the fallen bicyclist and was killed.¹⁶

Figure 18 illustrates a shared-use path with railings immediately adjacent to the pavement. The location of these railings reduces the effective width of the pavement, and could cause conflicts between bicyclists using the path, especially on hills.



Figure 18 - Railings too close to Path

When the full width of the path and clear areas cannot be maintained across a structure, a visual transition should be provided from the pathway to the narrow bridge. This visual transition could be accomplished with a transition of the railing from the full width to a narrower width, or by striping the clear area on the bridge.

¹⁶Communication with John S. Allen, April 19, 2004

Additional Recommendations

The following issues are recommended for further consideration or study.

Criteria for determining when Bicycle Railing should be specified

During the course of the research and outreach effort, it became clear that one of the major concerns of transportation planners and designers is the lack of guidance relative to specifying bicycle railing on bridges that do not have designated bicycle facilities, but that experience bicycle traffic. This issue and the current guidance from AASHTO documents is discussed in Chapter 3.

Although this issue was not part of the problem statement or project objective, and the survey was not designed to solicit information or preferences regarding the need for bicycle railing, numerous questions and comments were received relative to the need for guidance in this area. Indeed, three of the six crashes that occurred on roadway bridges involved vehicular railing that was less than 1.4 m (54 inch) bicycle railing. It appears that criteria addressing the need for bicycle railing on bridges may have a greater impact on the safety of bicyclists than the critical height of bicycle railing.

Some of the questions that have been raised that will need further analysis are:

- What is considered “occasional” bicycle traffic?
- How much “shy” distance from a vehicular barrier is necessary for a bicyclist to safely travel on a bridge?
- What bridge length or duration of exposure is acceptable for bicycle traffic next to vehicular railing?
- Should geometric conditions such as grade or environmental conditions such as crosswinds be considered?

Railing spacing on a 1.2 meter (48 inch) high combination bicycle railing

The AASHTO Standard Specifications for Highway Bridges limits the spacing between rails on combination pedestrian and bicycle railings. The documents states “Within a band bordered by the bikeway surface and a line 27 inches above it, all elements of the railing assembly shall be spaced such that a 6-inch sphere will not pass through any opening. Within a band bordered by lines 27 and 54-inches, elements shall be spaced such that an 8-inch sphere will not pass through any opening.”

The spacing appears to be very conservative. In fact, the 1989 AASHTO Guide Specification for Bridge Railing specifies “a maximum clear spacing of 15 inches.”

If the top rail of a 1.1 m (42 inch) combination pedestrian railing was raised an additional 150 mm (6 inches) to a 1.2 (48 inch) height combination bicycle railing, the need for an additional rail would not be necessary. The cost of a combination bicycle railing would be substantially reduced with the elimination of the additional rail that a 1.4 m (54 inch) high railing currently requires. The opening between the two top rails would be 360 mm (14 inches) if the top rail was raised.

The opening between rails as specified in the AASHTO Standard Specifications for Highway Bridges should be reassessed so that the additional rail necessary on a combination bicycle railing can be eliminated.

Summary of Researched Sources and Individual Contacts

Provided below is list of researched sources and a brief summary of the information that they offer.

RESEARCH SOURCES

AASHTO. Guide for Bicycle Routes. Prepared by the Standing Committee on Engineering Operations. 1974.- *Does not specify minimum railing height.*

AASHTO. Guide for Development of New Bicycle Facilities. Executive Committee. 1981.- *Specifies minimum railing height of 4.5 feet (1.4m).*

AASHTO. Guide for the Development of Bicycle Facilities. Prepared by the Task Force on Geometric Design. 1991.- *Specifies minimum railing height of 4.5 feet (1.4m).*

AASHTO. Guide for the Development of Bicycle Facilities. Prepared by the Task Force on Geometric Design. 1999.- *Specifies minimum railing height of 3.5 feet (1.1m).*

AASHTO. Guide Specifications for Bridge Railings. 1989.- *Requires a minimum railing height of 54 inches for bicycle railing and 42 inches for pedestrian railing.*

AASHTO. Guide Specification for the Design of Pedestrian Bridges. 1997.- *Gives no specifications relating to railings.*

AASHTO. Standard Specifications for Highway Bridges. 2002.- *Requires minimum railing height of 54 inches for bicycle railing and 42 inches for pedestrian railing.*

AASHT., Roadside Design Guide, 2002.- *Provides guidance on the selection and design of bridge railing.*

AASHTO. A Policy on Geometric Design of Highways and Streets 2001, 4th Ed.

Australian Road Research Board. <http://www.arrb.org.au>. - *Provides information regarding the "Guide to Traffic Engineering Practice - Part 14 Bicycles", published by Austroads and Standards Australia. This manual recommends that barriers should be 1.4 metres or 55" (min 1.2 metres) high, measured from the riding surface.*

Bicycling Info. <http://www.bicyclinginfo.org/> - *Bicycling Info is a clearinghouse for information about health and safety, engineering, advocacy, education, enforcement and access and mobility. Recommends bicycle railing heights on both sides of structure to be a minimum of 3.5 feet.*

California Department of Transportation, Bridge Design Specifications, April, 2000.

Danish Road Directorate. <http://www.vd.dk/dokument.asp>. Collection of Cycling Concepts. -*Contains guidelines for a bicycle railing height of 1.2m high.*

Federal Highway Administration. US Dept. of Transportation. "National Bicycling and Walking Study. Case Study No.2: Current Planning Guidelines and Design Standards Being Use by State and Local Agencies for Bicycle and Pedestrian Facilities."

Federal Highway Administration. US Dept. of Transportation. "National Bicycling and Walking Study". August 1992.- *Recommends bicycle railing heights to be 4.5 feet high.*

Federal Highway Administration. US Dept. of Transportation. "Visual Impact Assessment for Highway Projects," 1981.- *Provides the Visual Impact Assessment methodology.*

Federal Highway Administration, US Dept. of Transportation. "Flexibility in Highway Design," Publication No. FHWA-PD-97-062, 1997

Ferrara, Dr. Thomas C. Statewide Safety Study of Bicycles and Pedestrians on Freeways, Expressways, Toll Bridges, and Tunnels. MTI Report 01-01. September 2001. Mineta Transportation Institute, College of Business, San José State University- *Recommends where cyclists ride adjacent to bridge railings, the railing shall be at least 48 inches high. The authors feel lower railing heights contact the cyclist below his or her center of gravity, causing the rider to topple over the railing rather than being prevented from going over. At the same time, the report states that bicycle collisions on bridges are rare events, and where the bicycle will be a reasonable distance from the railing and pose no danger to the bicyclist, there should be exceptions to the rail height.*

Flink, Charles., Kristine Olka and Robert M. Sears. Trails for the Twenty-First Century. 2001. Island Press. Washington. – *Recommends a bicycle railing height of 54 inches.*

Forester, John. <http://www.johnforester.com/Articles/Safety/NatBSFacilities.htm>- *Provides a brief history into the adoption of the AASHTO Bicycle Facilities Guide.*

Hirsch, T.J., and C.E. Buth. 1992. Aesthetically pleasing combination pedestrian-traffic bridge rail. Transportation Research Board. no. 1367, 26-

National Highway Traffic Safety Administration. USDOT . National Center for Statistics and Analysis. Traffic Safety Facts 2001. A Compilation of Motor Vehicle Crash Data from the Fatality Analysis Reporting System and the General Estimates System. 2002. - *A Compilation of Motor Vehicle Crash Data from the Fatality Analysis Reporting System and the General Estimates System*

Oregon Department of Transportation. Oregon Bicycle and Pedestrian Plan. 1995. – *Recommends railing height of 53”.*

Orr, David W. A Study on the Required Height of a Bridge Railing to Accommodate Bicycle Impacts: A Master of Engineering Paper. Texas A&M University, Texas Transportation Institute.- *Provides an analysis for determining the appropriate railing height for bicyclists using such variables as anthropometrics, center of gravity, and bicycle frame sizes. The paper concludes that the AASHTO adopted height of 54" is not sufficient.*

Portland, Oregon. Bikeway Design and Engineering Guidelines. <http://www.trans.ci.portland.or.us/designreferences/bicycle/appenda.htm> - *Warns against adding too high (6 ft.) of a chain link fence on top of a concrete barrier. This creates a "cattle chute" effect, where the bicyclist experiences a confined environment.*

RS Means, Heavy Construction Cost Data, 18th Annual Edition. 2004.

San Francisco Bay Conservation and Development Commission. San Francisco Bay Conservation and Development Commission permit for San Francisco-Oakland Bay Bridge East Span Seismic Safety Project. November 2001.-*Includes brief history of how 54-inch railing height came about. (i.e. Cal DOT)*

Transportation Alternatives. [http:// www.transalt.org](http://www.transalt.org) - *Similar to chain link fence guidelines in Portland, OR, Transportation Alternatives recommends minimal impact to a view shed, and is currently challenging the placement of a 7' chain link fence along the Queensboro Bridge. They believe the 7' fence will affect the bridges historic aesthetics, and decrease usage of the bicycle path due to an intimidating experience for cyclists (i.e. cattle chute effect).*

USDOT Federal Highway Administration. Implementing Bicycle Improvements at the Local Level. USDOT Federal Highway Administration Publication No. FHWA-98-105 1998- *Recommends bridge railings to be a minimum of 1.4m (4.5 ft) high to keep bicyclists from pitching over the top in case of a crash.*

USDOT Bureau of Transportation Statistics. Transportation Statistics Annual Report 2000. – *General information regarding national bicycle crashes and fatalities.*

USDOT Federal Highway Administration. Injury to Pedestrians and Bicyclists: An Analysis based on emergency department data. FHWA-RD-99-078- *Provides information of pedestrian and bicycle injuries based on emergency department data. Limited as to railing height induced injuries.*

W.W. Hunter, W.E. Pein and J.C. Stutts, Bicycle Crash Types: A 1990's Informational Guide, Tech. Report FHWA-RD-96-104, FHWA, 1997 – *A study of various crash types for bicyclists. No railing information available.*

STATE GUIDELINES FOR BICYCLE FACILITIES

California
New York
New Jersey
Virginia
Washington
Oregon
Minnesota
Florida
Texas

Local Bicycle Plans

Bay Bridge Bike/Pedestrian Path
Naperville's Bike Plan
Clinton River Trail Master Plan
Berkeley I-80 Bicycle/Pedestrian Bridge Design Guidelines

INTERNATIONAL RESEARCH

Research and correspondence with international bicycle advocacy groups revealed the following adopted bicycle railing heights:

- Canada's *Highway Bridge Design Code* recommends 55" or 1.4m railing height on bridges for cyclists.
- Australia's *Guide to Traffic Engineering Practice – Part 14 Bicycles* recommends a bicycle railing height of 1.4m high.
- Danish Road Directorate's *Collection of Cycling Concepts* contains guidelines for a bicycle railing height of 1.2m high.
- A survey respondent from Hampshire, England informed CHA that their minimum recommended railing height for barriers on a bridge is 1.5m.

NATIONAL CORRESPONDENCE

Correspondence with individuals who were members of the committees charged with developing design guidelines for bicycle facilities, and those who are aware of guideline issues and adoption history include:

Bill Wilkinson-involved in AASHTO bicycle guide updates

Richard Lemeiux- Member of 1981 AASHTO Guide for Development of New Bicycle Facilities

Andy Clark- League of American Wheelman- assisted with identification of outreach efforts

Michael Ronkin- ODOT-assisted with the identification of outreach efforts, and individuals involved in writing the AASHTO bicycle guidelines

Noah Budnick- Transportation Alternatives

John LaPlante- Chair of Committee on Geometric Design for the 1999 AASHTO Guide for the Development of Bicycle Facilities. Supplied substantial information on the history of AASHTO bicycle railing height guidelines.

Phil Clark-NYSDOT- Member of AASHTO Committee on Geometric Design, 1999

Jennifer O'Toole-APBP- assisted with the identification of survey recipients

Aida Berkovitch-FHWA- assisted with the identification of survey recipients

Howard Mann- NYMTC- assisted with the identification of outreach efforts

Mark Bloschock- TDOT Bridge Division- raised the issue of “head slap” effect

APPENDIX A



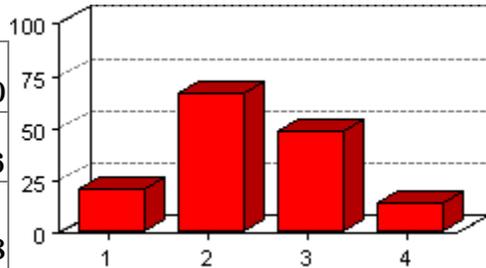
National Cooperative Highway Research Program

**BICYCLE RAILING HEIGHT SURVEY
STATE RESULTS**

Total Responses: 50

1. What guidelines do you use for bicycle railing heights? (Check all that apply)

	Count	%
1 State Bicycle Facility Design Guidelines	10	20
2 AASHTO Guidelines for Bicycle Facilities	33	66
3 AASHTO Standard Specifications for Highway Bridges	24	48
4 Other	7	14



OTHER RESPONSES:

I'm not involved in design

State Bridge Design Guidance

state Bridge Design Guidance

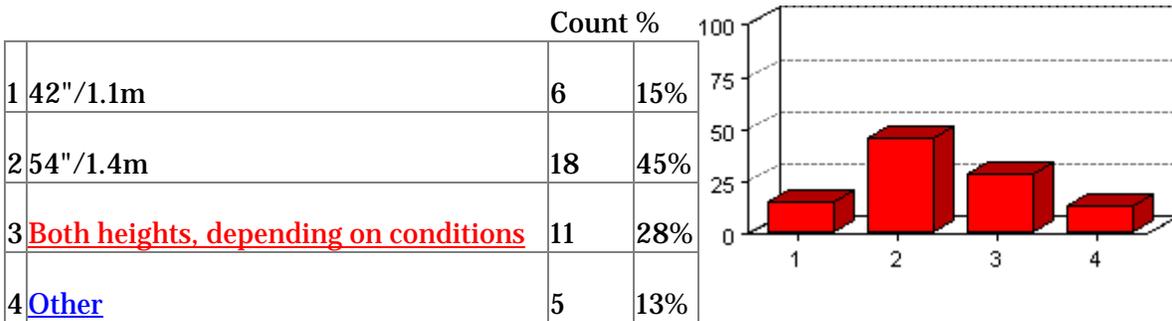
Virginia Bicycle Facility Resource Guide

NYSDOT Bridge Manual

Virginia Bicycle Facility Resource Guide

Jhon Forester, Handbook for Cycling Transportation Engineers

2. What bicycle railing height does your agency routinely use on bridges?



BOTH HEIGHTS RESPONSES:

On highway bridges the AASHTO Bridge manual holds, on trail bridges the AASHTO Guidelines for Bicycle Facilities hold.

54" was routinely used up to a few years ago. Now the engineer looks at the situation more critically (width of shoulder, drop-off below, etc) and makes a determination on railing height

The AASHTO Guidelines for Bicycle Facilities mentions a 42

The AASHTO Guidelines for Bicycle Facilities mentions a 42

We lobby for 42", bridge designers insist on 54"

Different administrative and/or design units (local highway district design, central office bridge design, consultants) may be responsible for a project

42" min. ped only, 54" if designed as bike trail

54

For pedestrian accommodation the Department uses the 42" height. If the bridge features a bicycle facility, we currently use 54" even if it is to be shared by both types of users.

Determined by Structures Designers

depending on height of fall and facility located below

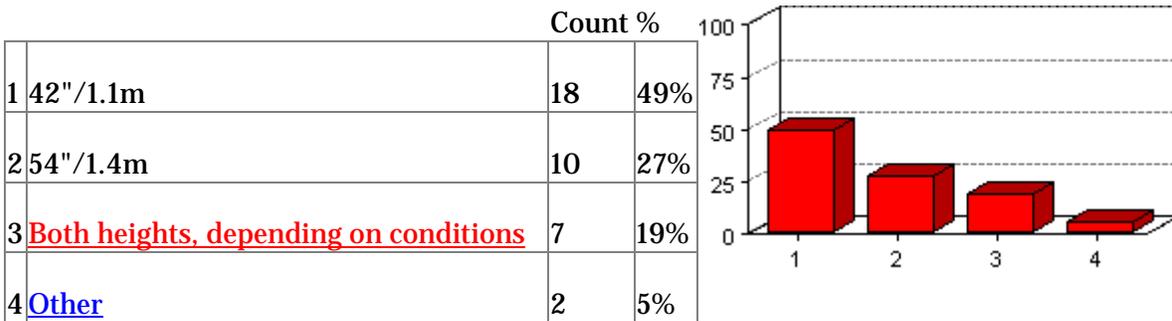
OTHER RESPONSES:

Our single stanWe basically used what is appropriate for a specific project, so neither of these is "routinely" used. We have not used railing on a specific bike/ped path, and would need to identify the appropriate height in the planning & design process.

Have not used 42" "routinely". Standard single slope for bridges is 45". Design is what is appropriate for project.

Assuming you are referring to roadway bridges, 36"

3. What bicycle railing height does your agency routinely use on bike paths?



BOTH HEIGHTS RESPONSES:

It depends if the bridge used by the path also accommodates motor vehicles. If yes then we use 54". If not we use 42".

AASHTO changed the height for railings when it updated the Bicycling Greenbook in 1999. Railing heights for bikepaths already in design at that time continued to use the taller rails. All new bikepath (& multi-use trails) under design since that time have adopted the lower railing standard of the 1999 AASHTO Guide for Development of Bicycle Facilities. It is worth noting that there was much discussion at the time of the revision regarding the railing height and proposed changes. Also: The taller 54" railing is practical on multi-use trails that are in "high snowfall" parts of the country where trails are not plowed. The shorter railings can quickly become buried. Also: The last bikepath that was constructed in our region with the tall (54") railing ran into a great deal of opposition and had to be lowered. The bikepath was a 3 mile stretch (with railings along much of this length) along a scenic river. The tall railings obscured the view of users as well as nearby residents

We use 42" on all shared use paths except in those areas which experience significant winter snow accumulation and where significant winter time eg. snowmobile and cross country use is anticipated. This is primarily limited to rail trails.

The 42" height has been used on some enhancement projects.

I cannot be certain. It is possible that heights described in the 99 AASHTO Guide are used for separated bike paths, except on highway bridges, where highway bridge specifications are deemed to take precedence.

Determined by Structures Designers

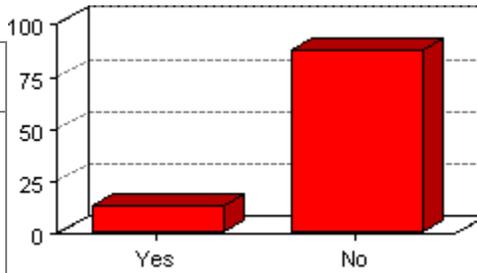
OTHER RESPONSES:

We haven't done that many specific bike/ped paths. Done on a project specific basis. Mountainous terrain can make it difficult to use one standard.

We recommend for two and one way paths; and between traffic lanes.

4. Are you aware of any accident data or accident studies relative to railings on bicycle facilities or bridges? If yes, please explain, or provide source of documentation.

	Count	%
Yes	5	13%
No	33	87%



YES RESPONSES:

Contact the AASHTO review board that worked on the revised AASHTO guidebook. There was quite a bit of debate regarding the change at the time.

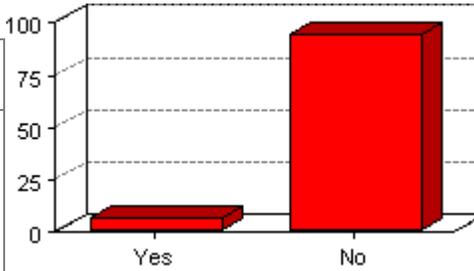
The Virginia Department of Motor Vehicles annually publishes statistics on all types of injuries on state roadways. "Virginia Traffic Crash Facts" publication includes data on accidents involving bicycles.

The Virginia Department of Motor Vehicles annually publishes statistics on all types of injuries on state roadways. "Virginia Traffic Crash Facts" publication includes data on accidents involving bicycles.

Not aware of any systematic collection of data or studies pertaining to this question (prior to this study) but, like other state coordinators, I have a small file of reports/discussions of bicycle railing accidents relative to the height question.

5. Do you have any knowledge of specific bicycle crash event(s) involving a railing?

	Count	%
Yes	3	6%
No	47	94%

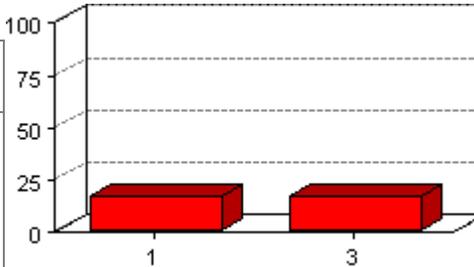


YES RESPONSES

Total Responses: **3**

5-1. Did the accident occur on a bridge or bikeway?

	Count	%
1 Bridge	1	17%
3 Other	1	17%

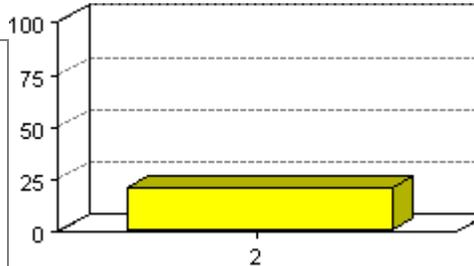


OTHER RESPONSE:

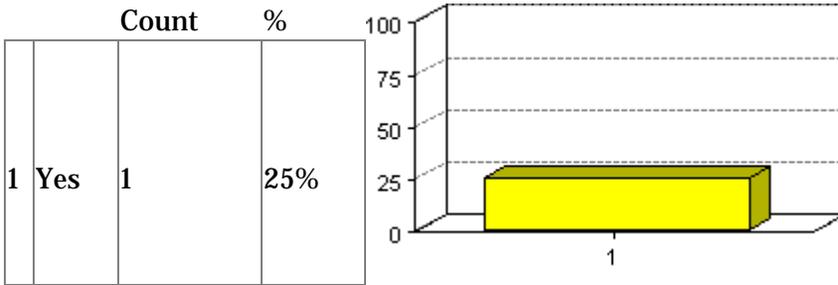
This one crash was reviewed by Mark Bloschock in our Bridge Division. He is the only person familiar enough to discuss. He can be contacted at (512) 416-2178.

5-2. What was the action leading to the crash?

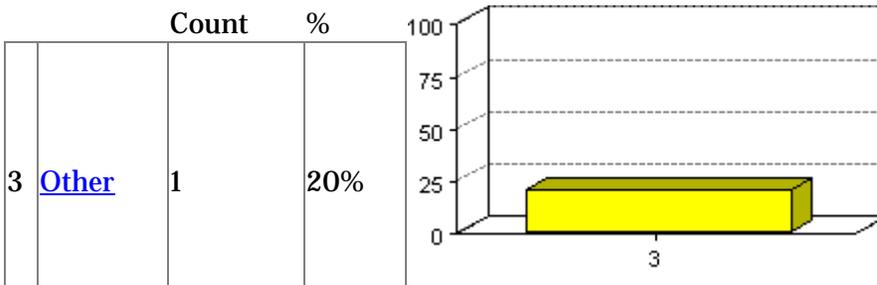
	Count	%
2 Car Overtook Bicyclists	1	20%



5-3. Did the bicyclist fall over the top of the railing?



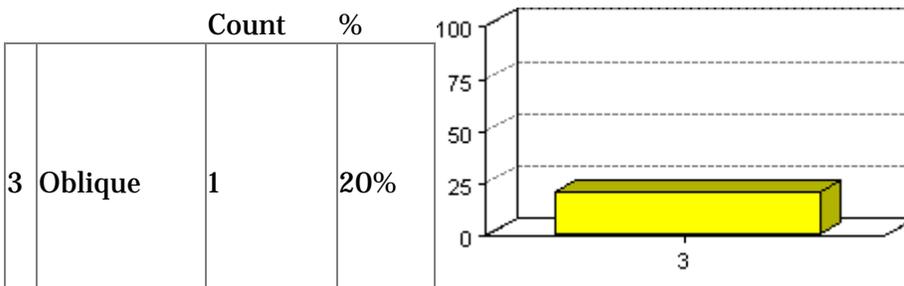
5-4. What was the height of the railing?



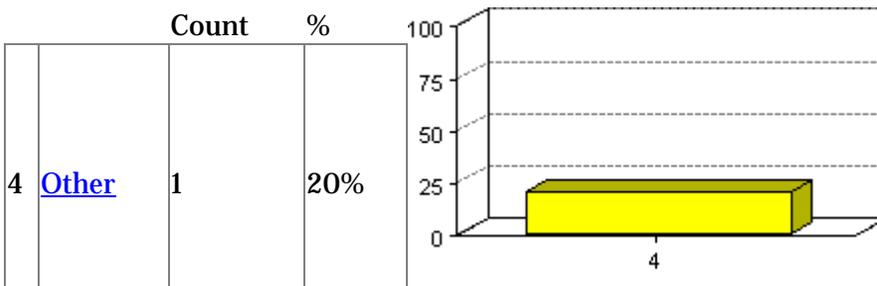
OTHER RESPONSE:

Would estimate about 26" above curb/ledge; ~32" above roadway

5-5. At what angle did the bicyclist approach the railing?



5-6. What was the servery of the bicyclist's injuries?

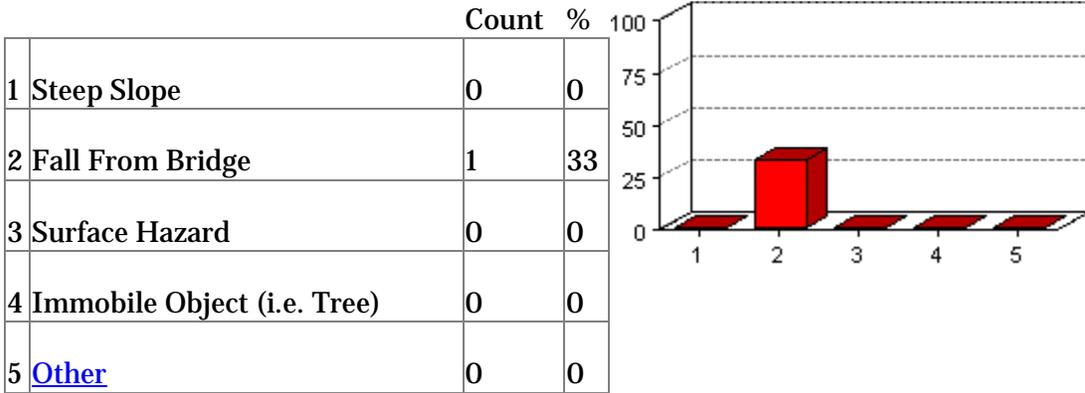


OTHER RESPONSE:

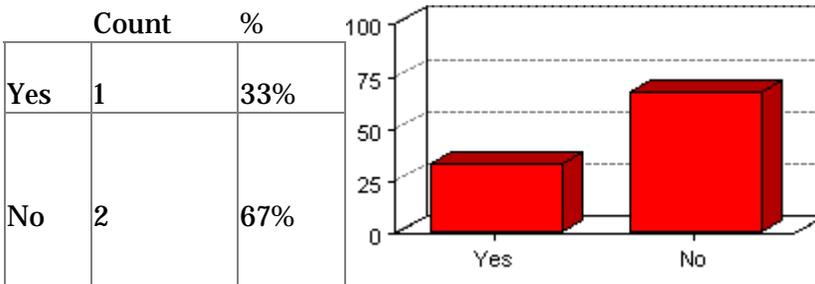
Killed

*BICYCLE RAILING HEIGHT SURVEY
STATE RESPONSES*

5-7. What type of hazard was the railing protecting the bicyclist from? (Choose all that apply)



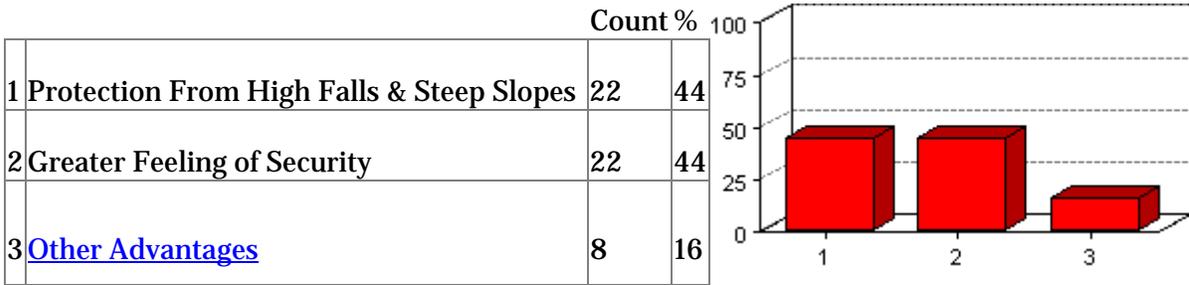
5-8. Would you be available for further discussion of this bicycle crash information?



Survey developed and hosted by [Clough, Harbour & Associates LLP](#).

*BICYCLE RAILING HEIGHT SURVEY
STATE RESPONSES*

6a. What are the advantages of a 54" railing height? (Check all that apply)



OTHER ADVANTAGES RESPONSES:

No advantage other than areas with high snowfall

Where bikeways are immediately adjacent to highways, a rail/barrier between the highway and the path can reduce hazards to path users by keeping vehicles and potentially hazardous objects off the path.

Where bikeways are immediately adjacent to highways, a rail/barrier between the highway and the path can reduce hazards to path users by keeping vehicles and potentially hazardous objects off the path.

As we don't use it, I'm unable to answer this question

N/A

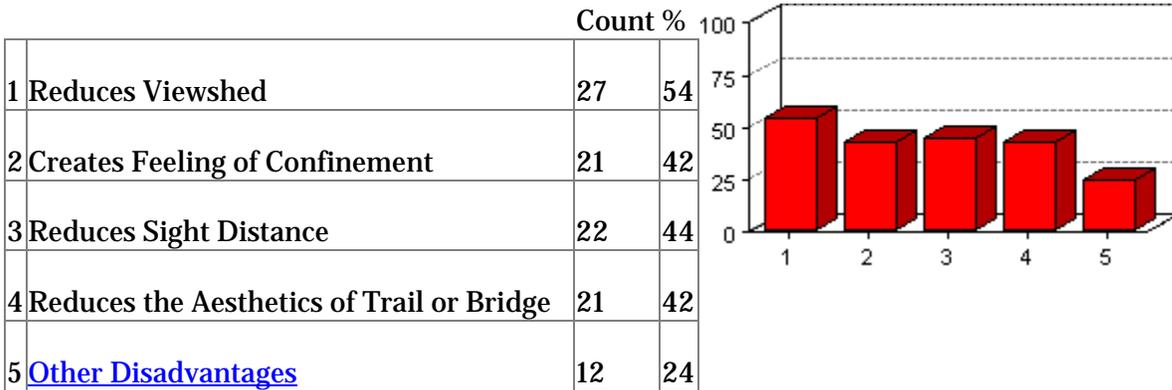
This height is recommend by Trail's for the 21st Century.

protection from strong wind on coastal bridges

Prevents bridge users from tossing debris off the bridge.

*BICYCLE RAILING HEIGHT SURVEY
STATE RESPONSES*

6b. What are the disadvantages of a 54" railing height? (Check all that apply)



OTHER DISADVANTAGES RESPONSES:

Cost, installation headaches, design of the three rails

Higher initial cost and greater long term maintenance cost

Can be a personal safety/security issue if path users are unable to leave the path in the event of an assault etc.

Can be a personal safety/security issue if path users are unable to leave the path in the event of an assault etc.

As we don't use it, I'm unable to answer this question

N/A

Costs more

requires a different rail design than is used for pedestrians

expense

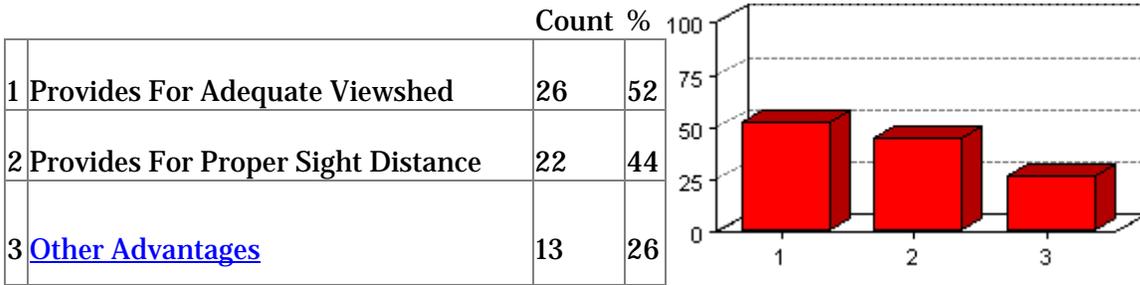
Any of these may be present based on the design used

*BICYCLE RAILING HEIGHT SURVEY
STATE RESPONSES*

Extra expense (significant issue where long railings used)

Expense

7a. What are the advantages of a 42" railing height? (Check all that apply)



OTHER ADVANTAGES RESPONSES:

cost, easier to design

reduced initial cost and long term maintenance

Improves view and sight distance, although I don't believe the difference is significant.

enhances trip experience

Sufficient for safety.

more economical

same rail as Pedestrian railing

Provides for adequate safety, protection, and security

No Comment

No comment

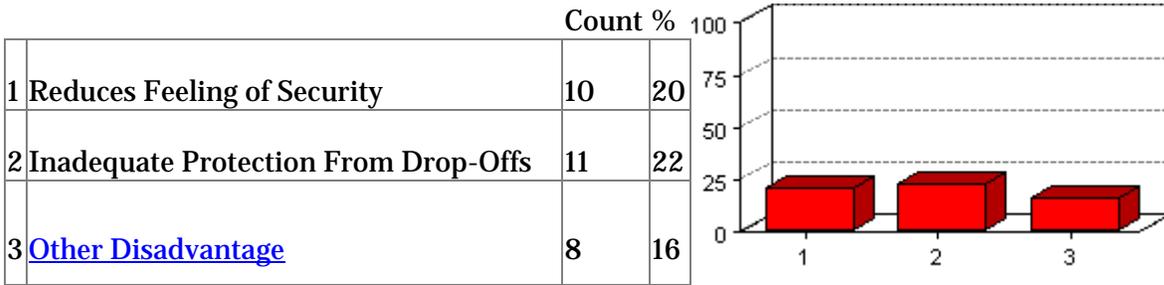
Less expensive

there is a bias built into the advantages listed above for 42" height.

Less expensive

*BICYCLE RAILING HEIGHT SURVEY
STATE RESPONSES*

7b. What are the disadvantages of a 42" railing height? (Check all that apply)



OTHER DISADVANTAGES RESPONSES:

42" is not a standard size for chainlink fence which is commonly used as a retrofit railing type on former railroad bridges

As noted above, I don't believe the advantages/disadvantages of 54" vs. 42" are significant.

None

none

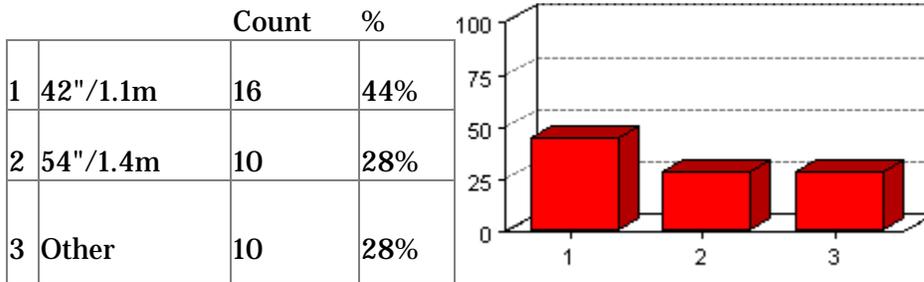
No Comment

No comment

Inadequate protection from drop-offs ex

Does not discourage debris tossed off bridges.

8. As an expert in the design of bicycle facilities, what is your preference for bicycle railing height? [Why?](#)



PREFERRED BICYCLE RAILING EXPLANATION:

In most cases the 42" is probably adequate, but in certain uses such as high bridges, the 54" does provide a greater sense of security. Although not needed on crossing a small creek, crossing the Mississippi River is another story.

I think this is a relatively easy thing to determine. In order to prevent a cyclist from being thrown over the top of a bridge railing, the top of the railing needs to be at least as high as the cyclist's center of gravity. Measure that on a relatively tall cyclist on a relatively tall bicycle, add a reasonable margin of safety, and you've got the minimum height, based on safety.

There is no empirical evidence that a 54" railing height provides added protection from falls. 42" has proven to be less costly, more aesthetically pleasing and can be more easily accommodate other uses eg. fishing from bridges. 54" railing height resulted in children and young adults climbing the railing to be able to fish from structures, where applicable. With 42" inch height we get far fewer complaints regarding perceived safety problems and less opposition to higher railing heights.

I don't have a strong preference for either height. A minimum of 42" sounds good.

The main concern here is safety. 42" is sufficient for safety.

I prefer 42" on non-motorized only facilities and 54" on highway facilities. The increased height should provide added safety if a bicyclist is hit by a motor vehicle.

42" would be easiest as it is the same as required for pedestrians. However, if there is some logic or data that supports a rail height that is higher, a rail height between 42" and 54" might be acceptable.

Have not seen enough data to support using a higher bridge railing.

This height meets the AASHTO Guide for the Development of Bicycle Facilities and seems sufficiently high for the intended purpose

This height meets the AASHTO Guide for the Development of Bicycle Facilities and seems sufficiently high for the intended purpose

Provides the height to protect from over-turning due to the elevation rider.

We have for too long made bicycling out to be dangerous - it isn't. High rails reinforce that view; plus they're ugly.

Provides better protection for bicycles.

Provides better protection for bicycles.

Provides better protection for bicycles.

48

Mountainous terrain is an issue. Past projects have used a standard of 36" with added chain link fencing.

You want to provide a sense of safety, while taking into consideration site distance and context sensitivity for design purposes.

Provides protection from fall off bridges.

North Carolina has numerous coastal bridges where strong winds are frequent. The western part of the state also has lengthy bridges over steep gorges. It is considered better to maintain 54" as the bicycle-safe rail height.

The MoDOT bridge unit prefers 54" because that is what is stated in the AASHTO manual. Districts think that 42" provides adequate safety, is less expensive and is the standard quoted in the other AASHTO manual. I suggest that we choose 42" as a minimum standard. State DOTs may always build higher.

Should be allowed to vary based on engineering conditions.

I never claim to be an expert; I'm not a designer. I prefer the 42" height for aesthetic reasons and for anticipated lower costs.

One that is needed for the facility it is designed to serve

confidence that the additional height improves safety

9. If you are familiar with any references of studies that are relevant to bicycle railing heights, please describe, provide a source, or forward a copy.

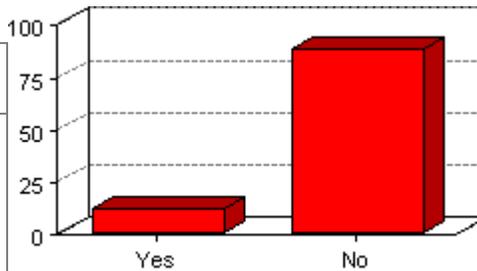


BICYCLE RAILING HEIGHT SURVEY ADVOCACY GROUP RESPONSES

Total Responses: 40

1. Are you aware of any accident data or accident studies relative to railings on bicycle facilities or bridges? If yes, please explain, or provide source of documentation.

	Count	%
Yes	4	12%
No	30	88%

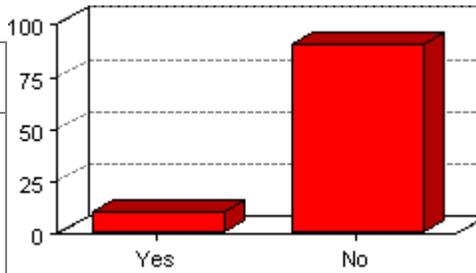


[YES RESPONSES:](#)

Yes, I have searched newspaper databases for accident reports. Such accidents are at best rare, and I could find no documented case of a railing overtopping accent on any reasonable height railing.

2. Do you have any knowledge of specific bicycle crash event(s) involving a railing?

	Count	%
Yes	4	10%
No	36	90%

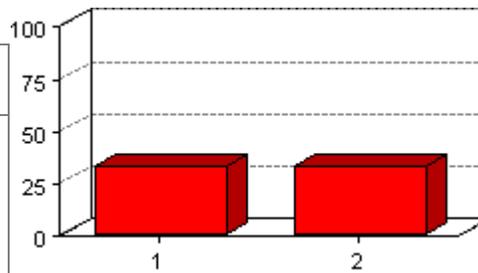


YES RESPONSES:

Total Responses: 4

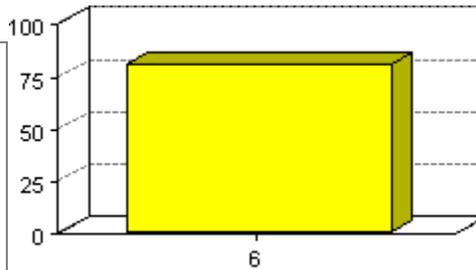
2-1. Did the accident occur on a bridge or bikeway?

	Count	%
1 Bridge	2	33%
2 Bikeway	2	33%



2-2. What was the action leading to the crash?

	Count	%
6 Other	4	80%



OTHER RESPONSES:

Cyclist veering off-course due to slippery surface

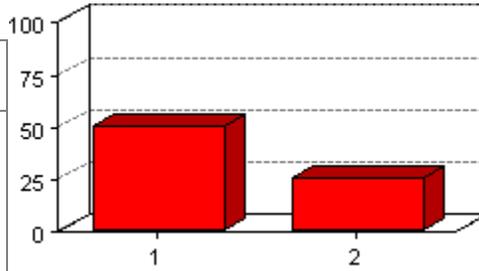
Single vehicle incident

Collision with railing - going to fast

High speed on down grade bridge approach

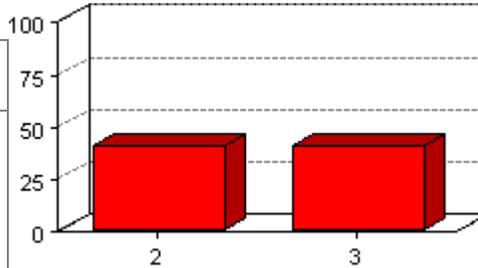
2-3. Did the bicyclist fall over the top of the railing?

		Count	%
1	Yes	2	50%
2	No	1	25%



2-4. What was the height of the railing?

		Count	%
2	54"	2	40%
3	Other	2	40%

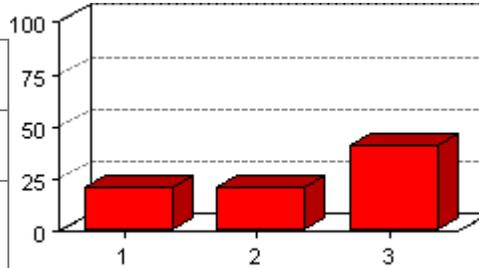


OTHER RESPONSES:

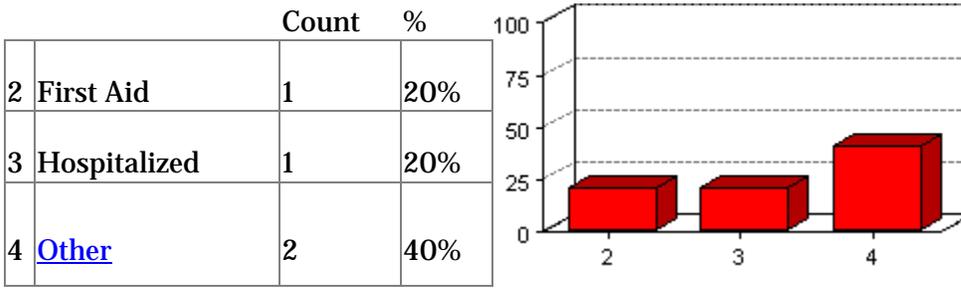
Approx 1.1m

2-5. At what angle did the bicyclist approach the railing?

		Count	%
1	Parallel	1	20%
2	Perpendicular	1	20%
3	Oblique	2	40%



2-6. What was the servery of the bicyclist's injuries?

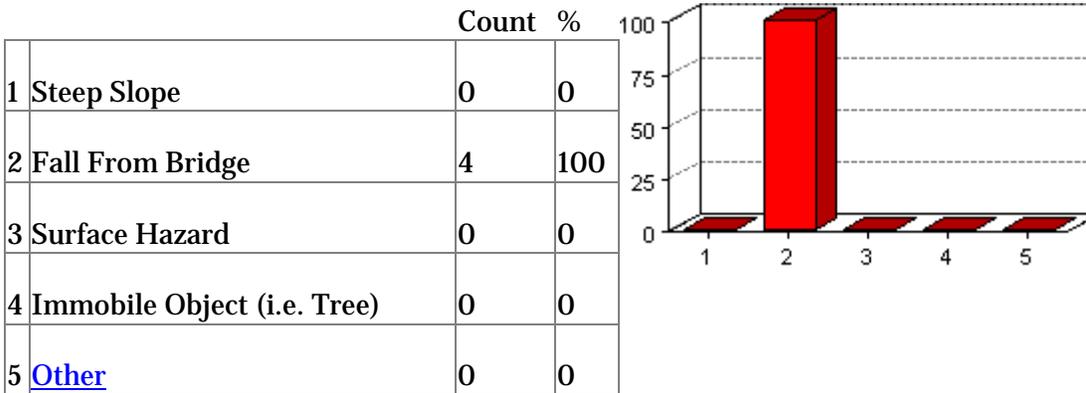


OTHER RESPONSES:

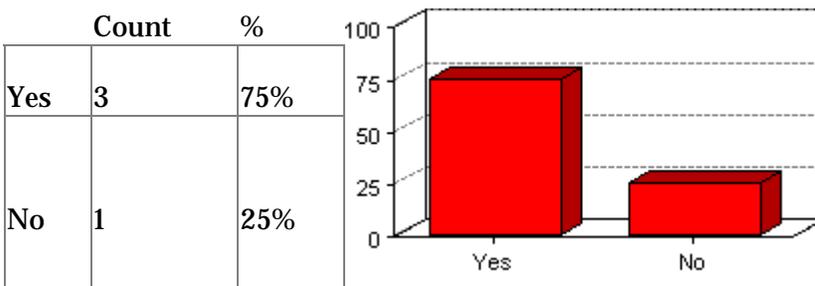
Paraplegic

Dead

2-7. What type of hazard was the railing protecting the bicyclist from? (Choose all that apply)

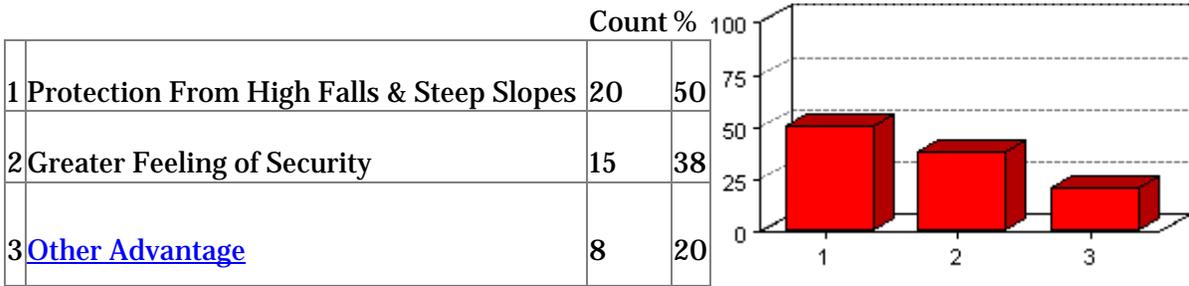


2-8. Would you be available for further discussion of this bicycle crash information?



*BICYCLE RAILING HEIGHT SURVEY
ADVOCACY GROUP RESPONSES*

3a. What are the advantages of a 54" railing height? (Check all that apply)



OTHER ADVANTAGES RESPONSES:

Reduce climbability by children, harder to throw items off bridge onto lower level.

Mitigating insubstantial risks is good, from a liability point of view.

Benefits equestrians

needed only in steep, narrow, and windy areas

If solid, can provide better cross-wind protection

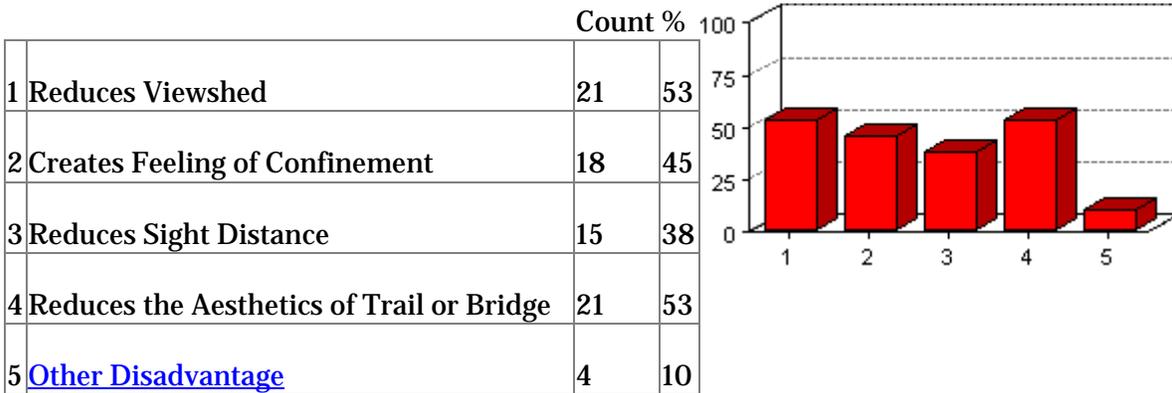
If suitably constructed, protects cyclist from vehicles running off adjacent highway. Also, if opaque in forward direction, shields riders and drivers from being dazzled by opposing headlights. Important when a two-way bikepath is adjacent to a road.

Confinement can encourage slower travel speed

none

*BICYCLE RAILING HEIGHT SURVEY
ADVOCACY GROUP RESPONSES*

3b. What are the disadvantages of a 54" railing height? (Check all that apply)



OTHER DISADVANTAGES RESPONSES:

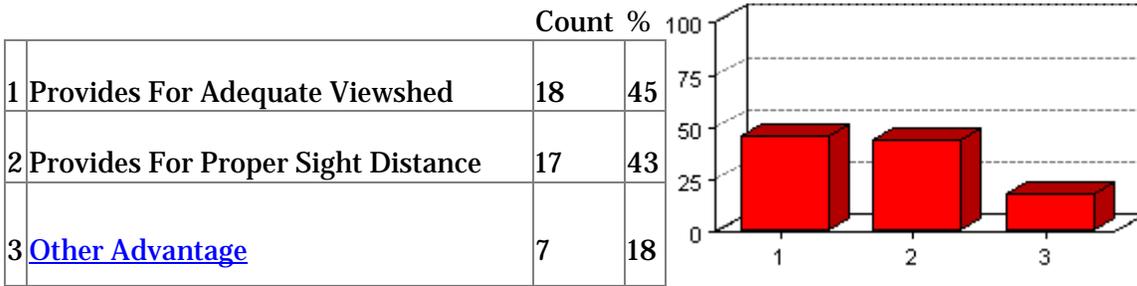
Installation and maintenance cost

Bad for pedestrians, who have a low eye level.

Woman's safety issue and reduces manoeverability

expense of retro-fitting

4a. What are the advantages of a 42" railing height? (Check all that apply)



OTHER ADVANTAGES RESPONSES:

Greater sense of personal security.

May be less impact to a historic structure

sufficient protection from falls, and providing sufficient feeling of security

viewshed/sight distance depends on circumstances

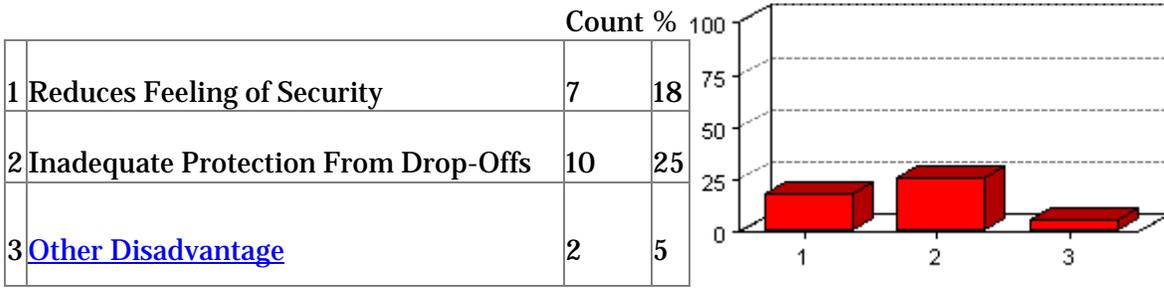
If suitably constructed can also provide protection from errant vehicles.

Less likely to bang head in fall by striking top rail, also closer to height which will form natural rest for cyclist

Better suited for viewpoints/rest areas

*BICYCLE RAILING HEIGHT SURVEY
ADVOCACY GROUP RESPONSES*

4b. What are the disadvantages of a 42" railing height? (Check all that apply)

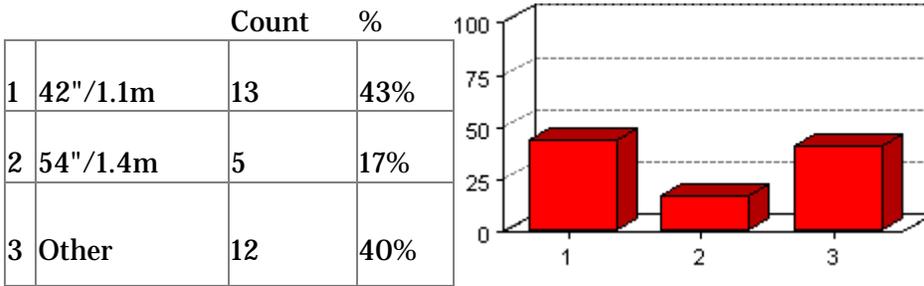


OTHER DISADVANTAGES RESPONSES:

should not be used for higher bridge crossings (i.e. fear of height)

same disadvantages as above.

5. As an expert bicyclist, what is your preference for bicycle railing height? [Why?](#)



PREFERRED BICYCLE RAILING EXPLANATION:

At least elbow height when sitting upright on bicycle.

At least elbow height when sitting upright on bicycle.

I prefer 48 inches. I am a tall cyclist at 6'-2" and I ride a road bike so my center of gravity is high. I want a railing that does not obstruct views. I want a railing that will rub my hip if I get too close but not my shoulder or elbow. The railing should be low enough to allow me to comfortably place the palm of my hand on top of it for stability when I am stopped next to it so that I needn't take my feet off of the pedals. A 48" high railing is ideal.

as a tall (6'5") cyclist, i can see how the 42" height could in some cases bother someone who was sensitive to heights. However, I've never heard a cyclist complain about a low (42") railing feeling unsafe, but the rail on Portland's main bike bridge (4,000 bike trips a day) is 45"...

I am 6'5" tall, 38" pants inseam - so most of my height is in my legs. The top of my seat is at 42" so my whole trunk is above the 42" mark. I have to reach down to push off a 42" rail. I think that 48" is a reasonable minimum height but I encourage keeping the 54" height as desirable.

Since I am 6' tall, I need to be convinced that adequate data has been gathered to analyze and define a standard railing height. AASHTO has contradictory standard heights in their publications

One of the reasons we walk or cycle is to be closer to our environment. Build high fences, and you reduce the joy of non-motorized travel.

One of the reasons we walk or cycle is to be closer to our environment. Build high fences, and you reduce the joy of non-motorized travel.

I've been on over 250 rail trails and written 3 books on the subject. I am alarmed at the overkill engineering being brought to these projects.

We specify 54". The bottom 42" is designed to meet BOCA code. The top 12" is designed solely to catch an adult body; this minimized the visibility issues with the high railings. The top 12" are often cantilevered away from the bridge to reduce the conflict with handlebars and reduce the feeling of confinement. You can download a The Clinton River Trail Master Plan from our website at <http://www.greenwaycollab.com/CRTMP.htm> in Section 5; Page 3 there is an elevation and section view of such a railing. I first saw this on a bridge in St. Paul. I can forward a picture of the bridge if you are interested.

This 1.1 m height matches bicycle handlebar height and helps to reduce railing cost for projects with limited budgets.

Aesthetics of views outweighs odds of a fall over the 42" railing vrs a 54" railing.

No preference

except as noted above

This height is providing sufficient protection, so why accepting the disadvantages of higher railings? Falling over would require a deliberate attempt to do so and can hardly happen by accident.

As an experience rider, I feel secure enough with 42". As a professional in bicycle facilities, I find it more cheaper for a DOT to built it the same height as for pedestrians. But I also have to go with Canadian standards for bridges that are consistant with the fact that cyclist's center of gravity is higher than for pedestrian.

Height depends on the circumstances: material used, likelihood of high winds (e.g. near ocean), distance from traffic, width of trail, and surface (metal bridge, etc.).

Better safety. Potential disadvantages (visibility and sight distances) depend upon other criteria such as straightness and gradient of path and should be tackled within these considerations.

It's high enough to protect from falls without spoiling the view for shorter riders.

Two of the principal benefits of cycling are the sense of freedom and enjoyment of views. In an area where a wall / railing might be necessary to protect from a high fall it's primary function will be to arrest a slide (due to a blow-out, mechanical failure or loss of adhesion) rather than a full-on impact. Cyclists do have a responsibility to ride sensibly, even in races.

If the bridge surface is in very bad condition or very narrow, such that the likelihood of a fall is greatly increased, then this should certainly be factored into the railing design (height and other attributes). Similarly, in urban areas where objects being thrown from the bridge is a serious concern, that must be accounted for. Otherwise, I think a 42" railing height provides an appropriate mix of safety, visibility, and aesthetics.

As long as the railing is not higher than 54" than height is of no concern. Railings and fences higher than 54" obscure sight lines and make path users feel like prisoners, demoralizing them and discouraging use, thus making the path less safe and further discouraging use.

1.0m - we're metric.

48" for steep drop offs should be the standard. Because: it should be higher than the standard 42" since bicyclists center of gravity is slightly higher. However, the 42" height should be used for railings that are not adjacent to a steep drop off. 54" is excessive, expensive and unnecessary.

Many cycling routes in U.K. are designated as "Bridle paths" which are used other types of activities including horse riding, as most horses are higher than bicycles this activity may take priority when assessing railing height.

Safety is most important issue although there are issues about vertical members of railings potentially causing conflict with handlebars

Greater protection

The number of railway /canal bridges which now are required to have 'Cyclists and Equestrians dismount' signs because of inadequate railings are confusing and generally ignored. The owners are not going to install 54" railings, and the notices will proliferate.

My preference is typically for the higher railing, however dependent on the type of bridge. A high level crossing warrants 54

There are several bike paths that use railings. However, pedestrians often walk on the bikepaths and then cannot re-enter the pedestrian path due to the railing. Fences and railings are great impediments to enjoying your ride

6. If you are familiar with any references of studies that are relevant to bicycle railing heights, please describe, provide a source, or forward a copy.

no

no

1999 AASHTO Bicycle Facilities Design Guide 2001 Part 2 of 2, Designing Sidewalks and Trails for Access (FHWA)

Comprehensive Cycling Plan (Ottawa, Nov. 1994) indicates railing height of 1.2 m. (47") Same dimension is provided for Waterfront Trail Design and Signage Guidelines, Water Regeneration Trust (Ontario Provincial govt/Victor Ford Associates, Sept. 1993)

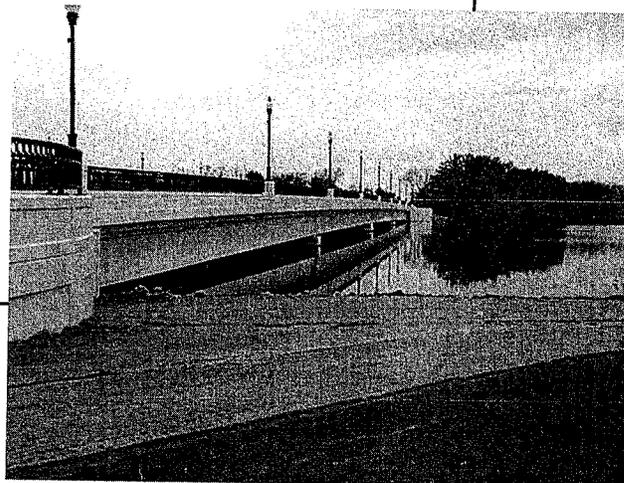
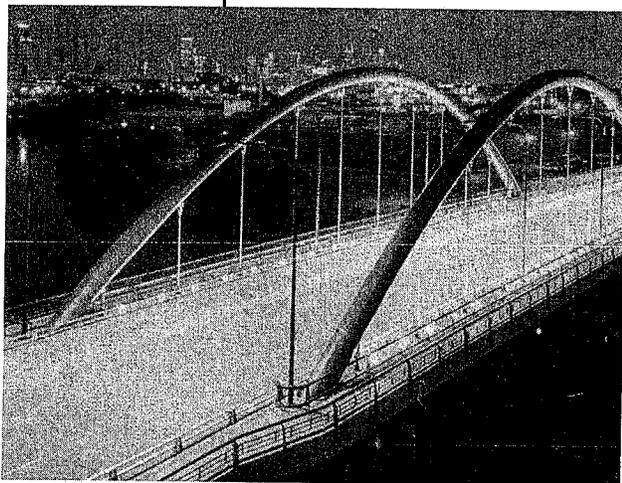
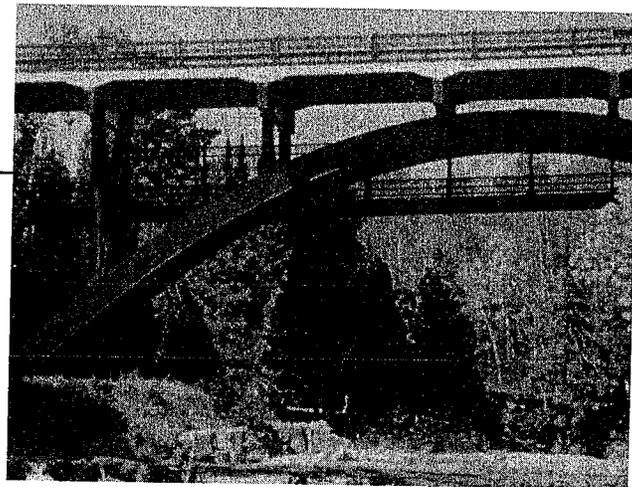
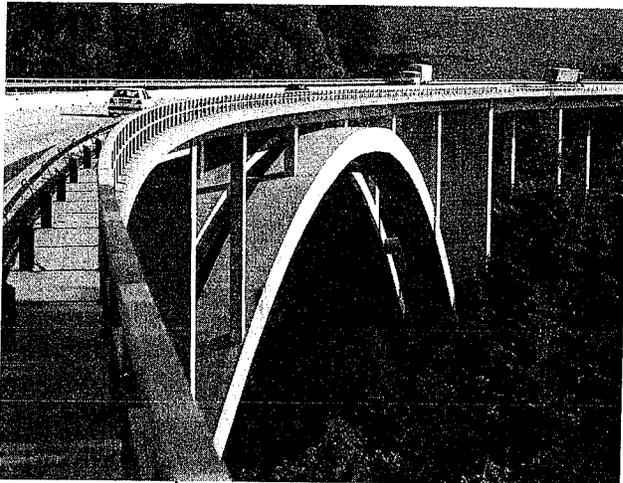
Note re. dazzle on two-way paths: 2002.02.02, group of cyclists on roadside path near Wigton UK, riding opp direction to adjacent traffic, 10W halogen headlamp, one driver confused by bright headlamp on his wrong side, veered to pass it on correct side, realised mistake too late, spun car into group, killing two, maiming one. Hence: two-way roadside paths MUST be protected.

A possible source may be The Highways Agency of U.K.

APPENDIX B

Standard Specifications for Highway Bridges

17th Edition – 2002



*Upper right-hand and lower left-hand pictures courtesy of the National Steel Bridge Alliance.
Lower right-hand picture courtesy of William Oliva and Scott Becker.*

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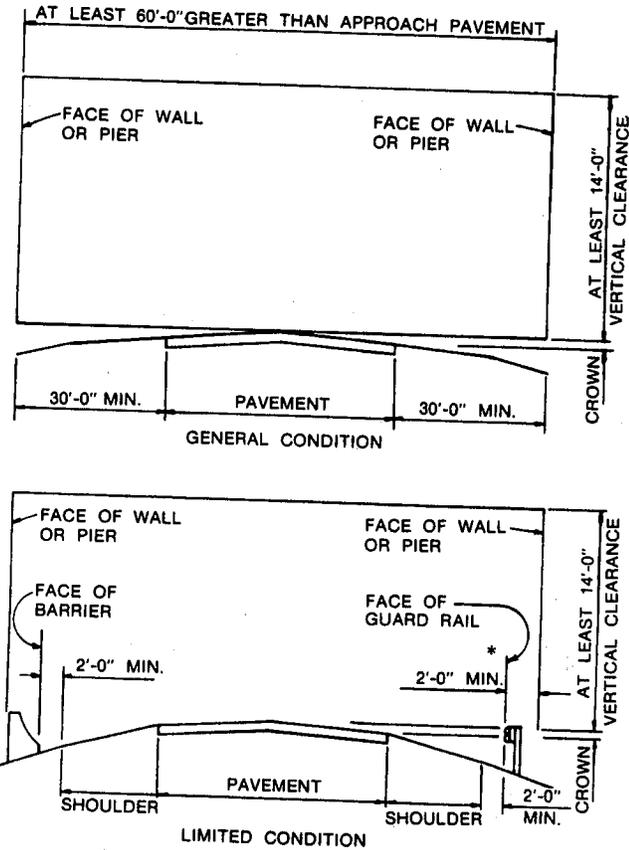
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*The barrier to face of wall or pier distance should not be less than the dynamic deflection of the barrier for impact by a full-sized automobile at impact conditions of approximately 25 degrees and 60 miles per hour. For information on dynamic deflection of various barriers, see AASHTO *Roadside Design Guide*.

FIGURE 2.4A Clearance Diagrams for Underpasses (See Article 2.4 for General Requirements.)

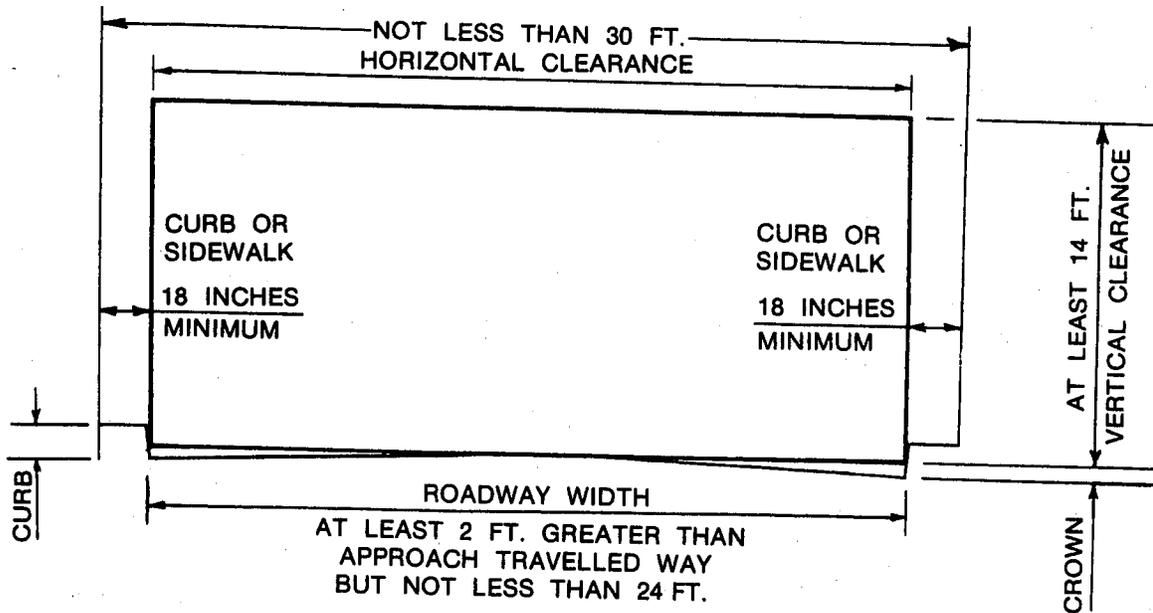


FIGURE 2.5 Clearance Diagram for Tunnels—Two-Lane Highway Traffic

The clearances and width of roadway for two-lane traffic shall be not less than those shown in Figure 2.5. The roadway width shall be increased at least 10 feet and preferably 12 feet for each additional traffic lane.

2.5.2 Clearance between Walls

The minimum width between walls of two-lane tunnels shall be 30 feet.

2.5.3 Vertical Clearance

The vertical clearance between curbs shall be not less than 14 feet.

2.5.4 Curbs

The width of curbs shall be not less than 18 inches. The height of curbs shall be as specified for bridges.

For heavy traffic roads, roadway widths greater than the above minima are recommended.

If traffic lane widths exceed 12 feet the roadway width may be reduced 2 feet 0 inches from that calculated from Figure 2.5.

2.6 HIGHWAY CLEARANCES FOR DEPRESSED ROADWAYS

2.6.1 Roadway Width

The clear width between curbs shall be not less than that specified for tunnels.

2.6.2 Clearance between Walls

The minimum width between walls for depressed roadways carrying two lanes of traffic shall be 30 feet.

2.6.3 Curbs

The width of curbs shall be not less than 18 inches. The height of curbs shall be as specified for bridges.

2.7 RAILINGS

Railings shall be provided along the edges of structures for protection of traffic and pedestrians. Other suitable applications may be warranted on bridge-length culverts as addressed in the AASHTO *Roadside Design Guide*.

Except on urban expressways, a pedestrian walkway may be separated from an adjacent roadway by a traffic

railing or barrier with a pedestrian railing along the edge of the structure. On urban expressways, the separation shall be made by a combination railing.

2.7.1 Vehicular Railing

2.7.1.1 General

2.7.1.1.1 Although the primary purpose of traffic railing is to contain the average vehicle using the structure, consideration should also be given to (a) protection of the occupants of a vehicle in collision with the railing, (b) protection of other vehicles near the collision, (c) protection of vehicles or pedestrians on roadways underneath the structure, and (d) appearance and freedom of view from passing vehicles.

2.7.1.1.2 Materials for traffic railings shall be concrete, metal, timber, or a combination thereof. Metal materials with less than 10-percent tested elongation shall not be used.

2.7.1.1.3 Traffic railings should provide a smooth, continuous face of rail on the traffic side with the posts set back from the face of rail. Structural continuity in the rail members, including anchorage of ends, is essential. The railing system shall be able to resist the applied loads at all locations.

2.7.1.1.4 Protrusions or depressions at rail joints shall be acceptable provided their thickness or depth is no greater than the wall thickness of the rail member or $\frac{3}{8}$ inch, whichever is less.

2.7.1.1.5 Careful attention shall be given to the treatment of railings at the bridge ends. Exposed rail ends, posts, and sharp changes in the geometry of the railing shall be avoided. A smooth transition by means of a continuation of the bridge barrier, guardrail anchored to the bridge end, or other effective means shall be provided to protect the traffic from direct collision with the bridge rail ends.

2.7.1.2 Geometry

2.7.1.2.1 The heights of rails shall be measured relative to the reference surface which shall be the top of the roadway, the top of the future overlay if resurfacing is anticipated, or the top of curb when the curb projection is greater than 9 inches from the traffic face of the railing.

2.7.1.2.2 Traffic railings and traffic portions of combination railings shall not be less than 2 feet 3 inches

from the top of the reference surface. Parapets designed with sloping traffic faces intended to allow vehicles to ride up them under low angle contacts shall be at least 2 feet 8 inches in height.

2.7.1.2.3 The lower element of a traffic or combination railing should consist of either a parapet projecting at least 18 inches above the reference surface or a rail centered between 15 and 20 inches above the reference surface.

2.7.1.2.4 For traffic railings, the maximum clear opening below the bottom rail shall not exceed 17 inches and the maximum opening between succeeding rails shall not exceed 15 inches. For combination railings, accommodating pedestrian or bicycle traffic, the maximum opening between railing members shall be governed by Articles 2.7.2.2.2 and 2.7.3.2.1, respectively.

2.7.1.2.5 The traffic faces of all traffic rails must be within 1 inch of a vertical plane through the traffic face of the rail closest to traffic.

2.7.1.3 Loads

2.7.1.3.1 When the height of the top of the top traffic rail exceeds 2 feet 9 inches, the total transverse load distributed to the traffic rails and posts shall be increased by the factor C. However, the maximum load applied to any one element need not exceed P, the transverse design load.

2.7.1.3.2 Rails whose traffic face is more than 1 inch behind a vertical plane through the face of the traffic rail closest to traffic or centered less than 15 inches above the reference surface shall not be considered to be traffic rails for the purpose of distributing P or CP, but may be considered in determining the maximum clear vertical opening, provided they are designed for a transverse loading equal to that applied to an adjacent traffic rail or P/2, whichever is less.

2.7.1.3.3 Transverse loads on posts, equal to P, or CP, shall be distributed as shown in Figure 2.7.4B. A load equal to one-half the transverse load on a post shall simultaneously be applied longitudinally, divided among not more than four posts in a continuous rail length. Each traffic post shall also be designed to resist an independently applied inward load equal to one-fourth the outward transverse load.

2.7.1.3.4 The attachment of each rail required in a traffic or combination railing shall be designed to resist a vertical load equal to one-fourth of the transverse design

load of the rail. The vertical load shall be applied alternately upward or downward. The attachment shall also be designed to resist an inward transverse load equal to one-fourth the transverse rail design load.

2.7.1.3.5 Rail members shall be designed for a moment, due to concentrated loads, at the center of the panel and at the posts of $P'L/6$ where L is the post spacing and P' is equal to P, P/2, or P/3, as modified by the factor C where required. The handrail members of combination railings shall be designed for a moment at the center of the panel and at the posts of $0.1wL^2$.

2.7.1.3.6 The transverse force on concrete parapet and barrier walls shall be spread over a longitudinal length of 5 feet.

2.7.1.3.7 Railings other than those shown in Figure 2.7.4B are permissible provided they meet the requirements of this Article. Railing configurations that have been successfully tested by full-scale impact tests are exempt from the provisions of this Article.

2.7.2 Bicycle Railing

2.7.2.1 General

2.7.2.1.1 Bicycle railing shall be used on bridges specifically designed to carry bicycle traffic, and on bridges where specific protection of bicyclists is deemed necessary.

2.7.2.1.2 Railing components shall be designed with consideration to safety, appearance, and when the bridge carries mixed traffic freedom of view from passing vehicles.

2.7.2.2 Geometry and Loads

2.7.2.2.1 The minimum height of a railing used to protect a bicyclist shall be 54 inches, measured from the top of the surface on which the bicycle rides to the top of the top rail.

2.7.2.2.2 Within a band bordered by the bikeway surface and a line 27 inches above it, all elements of the railing assembly shall be spaced such that a 6-inch sphere will not pass through any opening. Within a band bordered by lines 27 and 54 inches, elements shall be spaced such that an 8-inch sphere will not pass through any opening. If a railing assembly employs both horizontal and vertical elements, the spacing requirements shall apply to one or the other, but not to both. Chain link fence

is exempt from the rail spacing requirements listed above. In general, rails should project beyond the face of posts and/or pickets.

2.7.2.2.3 The minimum design loadings for bicycle railing shall be $w = 50$ pounds per linear foot transversely and vertically, acting simultaneously on each rail.

2.7.2.2.4 Design loads for rails located more than 54 inches above the riding surface shall be determined by the designer.

2.7.2.2.5 Posts shall be designed for a transverse load of wL (where L is the post spacing) acting at the cen-

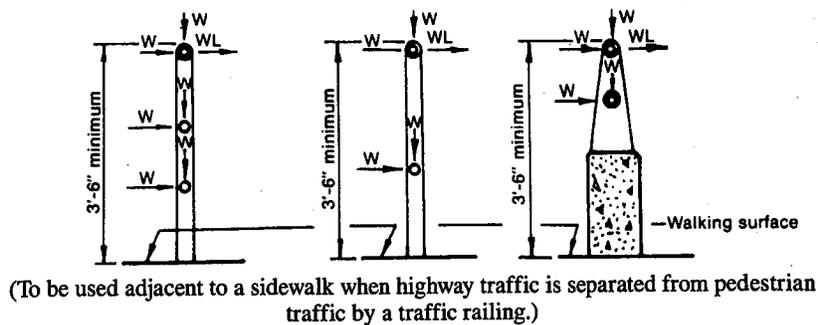
ter of gravity of the upper rail, but at a height not greater than 54 inches.

2.7.2.2.6 Refer to Figures 2.7.4A and 2.7.4B for more information concerning the application of loads.

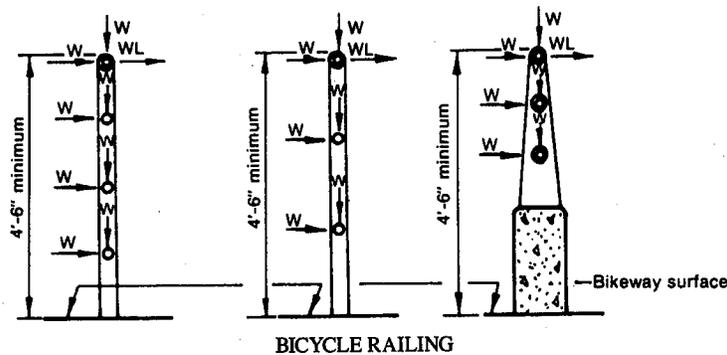
2.7.3 Pedestrian Railing

2.7.3.1 General

2.7.3.1.1 Railing components shall be proportioned commensurate with the type and volume of anticipated



PEDESTRIAN RAILING



NOTE:

If screening or solid face is presented, number of rails may be reduced; wind loads must be added if solid face is utilized.

NOTES:

1. Loadings on left are applied to rails.
2. Loads on right are applied to posts.
3. The shapes of rail members are illustrative only. Any material or combination of materials listed in Article 2.7 may be used in any configuration.
4. The spacing illustrated are maximum values. Rail elements spacings shall conform to Articles 2.7.2.2.2 and 2.7.3.2.1.

NOMENCLATURE:

- w = Pedestrian or bicycle loading per unit length of rail
- L = Post spacing

FIGURE 2.7.4A Pedestrian Railing, Bicycle Railing

pedestrian traffic. Consideration should be given to appearance, safety and freedom of view from passing vehicles.

2.7.3.1.2 Materials for pedestrian railing may be concrete, metal, timber, or a combination thereof.

2.7.3.2 Geometry and Loads

2.7.3.2.1 The minimum height of a pedestrian railing shall be 42 inches measured from the top of the walkway to the top of the upper rail member. Within a band bordered by the walkway surface and a line 27 inches above it, all elements of the railing assembly shall be spaced such that a 6-inch sphere will not pass through any opening. For elements between 27 and 42 inches above the walking surface, elements shall be spaced such that an eight-inch sphere will not pass through any opening.

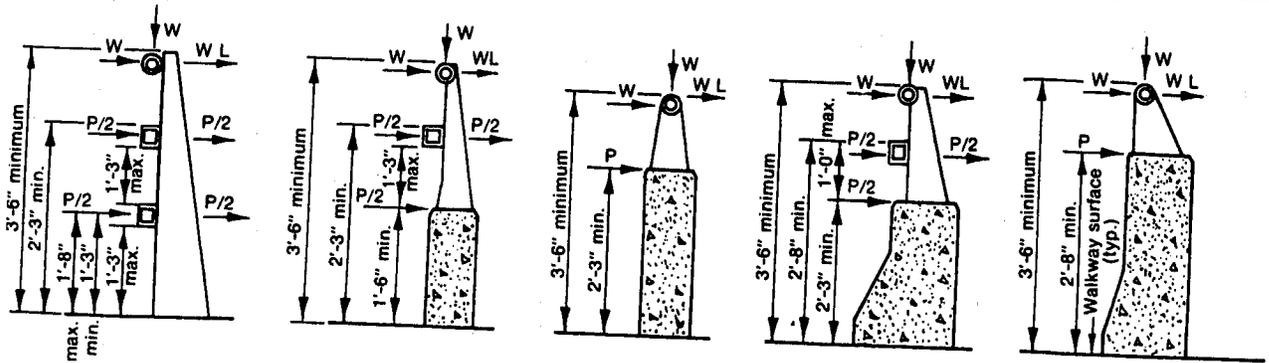
2.7.3.2.2 The minimum design loading for pedestrian railing shall be $w = 50$ pounds per linear foot, transversely and vertically, acting simultaneously on each longitudinal member. Rail members located more than 5 feet 0 inches above the walkway are excluded from these requirements.

2.7.3.2.3 Posts shall be designed for a transverse load of wL (where L is the post spacing) acting at the center of gravity of the upper rail or, for high rails, at 5 feet 0 inches maximum above the walkway.

2.7.3.2.4 Refer to Figures 2.7.4A and 2.7.4B for more information concerning the application of loads.

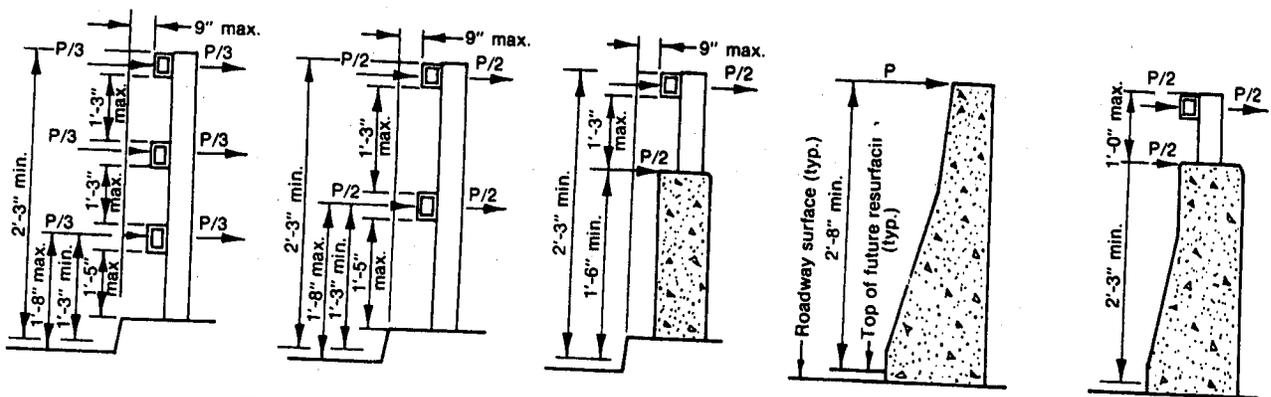
2.7.4 Structural Specifications and Guidelines

2.7.4.1 Railings shall be designed by the elastic method to the allowable stresses for the appropriate material.



(To be used when curb projects more than 9" from the traffic face of railing.)

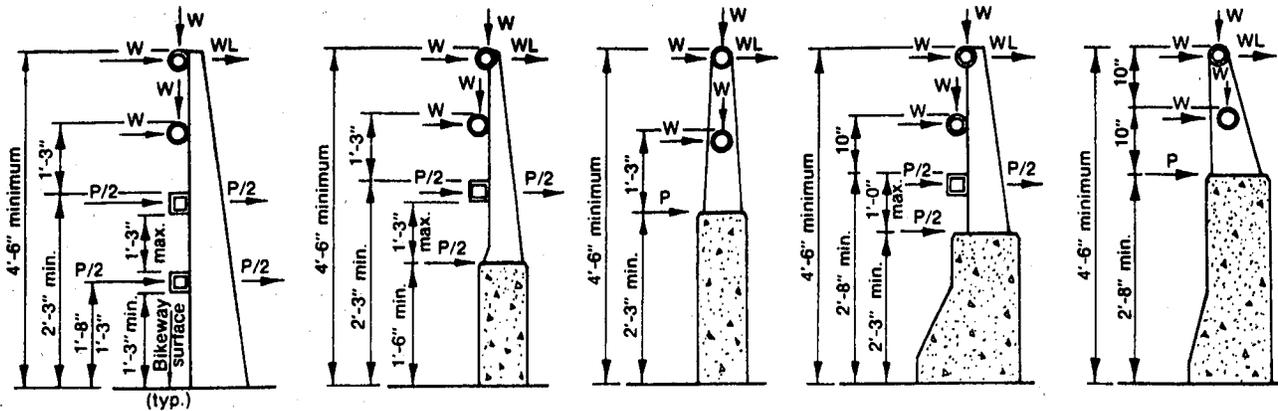
COMBINATION TRAFFIC AND PEDESTRIAN RAILING



(To be used where there is no curb or curb projects 9" or less from traffic face of railing.)

TRAFFIC RAILING

FIGURE 2.7.4B Traffic Railing



COMBINATION TRAFFIC AND BICYCLE RAILING

NOTES:

1. Loadings on left are applied to rails.
2. Loadings on right are applied to posts.
3. The shapes of rail members are illustrative only. Any material or combination of materials listed in Article 2.7 may be used in any configuration.
4. The spacings illustrated are maximum values. Rail element spacings shall conform to Article 2.7.1.2.4.

NOMENCLATURE:

- P = Highway design loading = 10 kips.
- h = Height of top of top rail above reference surface (in.).
- L = Post spacing (ft).
- w = Pedestrian loading per unit length of rail.

$$C = 1 + \frac{h - 33}{18} \geq 1$$

FIGURE 2.7.4B (Continued)

For aluminum alloys the design stresses given in the *Specifications for Aluminum Structures* Fifth Edition, December 1986, for *Bridge and Similar Type Structures* published by the Aluminum Association, Inc. for alloys 6061-T6 (Table A.6), 6351-T5 (Table A.6) and 6063-T6 (Table A.6) shall apply, and for cast aluminum alloys the design stresses given for alloys A444.0-T4 (Table A.9), A356.0-T61 (Table A.9) and A356.0-T6 (Table A.9) shall apply.

For fabrication and welding of aluminum railing, see Article 11.5.

2.7.4.2 The allowable unit stresses for steel shall be as given in Article 10.32, except as modified below.

For steels not generally covered by these Specifications, but having a guaranteed yield strength, F_y , the allowable unit stress, shall be derived by applying the general formulas as given in these Specifications under "Unit Stresses" except as indicated below.

The allowable unit stress for shear shall be $F_v = 0.33F_y$.

Round or oval steel tubes may be proportioned using an allowable bending stress, $F_b = 0.66F_y$, provided the R/t ratio (radius/thickness) is less than or equal to 40.

Square and rectangular steel tubes and steel W and I sections in bending with tension and compression on extreme fibers of laterally supported compact sections having an axis of symmetry in the plane of loading may be designed for an allowable stress $F_b = 0.60F_y$.

2.7.4.3 The requirements for a compact section are as follows:

- (a) The width to thickness ratio of projecting elements of the compression flange of W and I sections shall not exceed

$$\frac{b}{t} \leq \frac{1600}{\sqrt{F_y}} \tag{2-1}$$

- (b) The width to thickness ratio of the compression flange of square or rectangular tubes shall not exceed

$$\frac{b}{t} \leq \frac{6000}{\sqrt{F_y}} \tag{2-2}$$

(c) The D/t ratio of webs shall not exceed

$$\frac{D}{t} \leq \frac{13,000}{\sqrt{F_y}} \quad (2-3)$$

(d) If subject to combined axial force and bending, the D/t ratio of webs shall not exceed

$$\frac{D}{t} < \frac{13,300 \left[1 - 1.43 \left(\frac{f_a}{F_a} \right) \right]}{\sqrt{F_y}} \quad (2-4)$$

but need not be less than

$$\frac{D}{t} < \frac{7,000}{\sqrt{F_y}} \quad (2-5)$$

(e) the distance between lateral supports in inches of W or I sections shall not exceed

$$\leq \frac{2,400b}{\sqrt{F_y}} \quad (2-6)$$

or

$$\leq \frac{20,000,000 A_f}{d F_y} \quad (2-7)$$

GUIDE SPECIFICATIONS FOR BRIDGE RAILINGS

1989



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SPECIFICATIONS

G2.1 GENERAL

G2.1.1* Notations

- A = Distance from front of vehicle to its center of gravity, ft. (Table G2.7.1.3A)
- A_f = Area of Flange, in² (Article G3.7.4.3)
- B = Width of vehicle, ft. (Table G2.7.1.3A)
- b = Flange width, in. (Article G2.7.4.3)
- D = clear unsupported distance between flange components, in. (Article G2.7.4.3)
- d = depth of W or I section, in. (Article G2.7.4.3)
- F_a = allowable axial stress, psi (Article G2.7.4.3)
- F_b = allowable bending stress, psi (Article G2.7.4.2)
- F_v = allowable shear stress, psi (Article G2.7.4.2)
- F_y = minimum yield stress, psi (Article G2.7.4.2)
- f_a = axial compression stress, psi (Article G2.7.4.3)
- H_{cg} = Height of vehicle center of gravity, in. (Table G2.7.1.3A)
- K_c = Traffic Adjustment Factor for Curvature (Article G2.7.1.3, Figure G2.7.1.3A, and Table G2.7.1.3B)
- K_g = Traffic Adjustment Factor for Grade, (Article G2.7.1.3, Figure G2.7.1.3A, and Table G2.7.1.3B)
- K_s = Traffic Adjustment Factor for deck height and under-structure conditions (Article G2.7.1.3, Figure G2.7.1.3B, and Table G2.7.1.3B)
- L = post spacing (Figure G2.7.4)
- R = Ratio of weight assumed to be acting on tractor unit to total vehicle weight (Table G2.7.1.3A)
- t = web thickness, in. (Article G2.7.4.3)
- V = Impact speed, mph (Table G2.7.1.3A)
- V_p = Speed of vehicle when it becomes parallel to railing, mph (Table G2.7.1.3A)
- W = Gross weight of vehicle, Kips (Table G2.7.1.3A)
- w = pedestrian or bicycle loading (Articles G2.7.2.2, G2.7.3.2, and Figure G2.7.4)
- θ = Impact angle, deg. (Table G2.7.1.3A)
- μ = Effective coefficient of friction between railing and impacting vehicle (Table G2.7.1.3A)

G2.2.5 Curbs and Sidewalks

The face of the curb is defined as the vertical or sloping surface on the roadway side of the curb. Horizontal measurements of roadway curbs are from

* See preface for explanation of article numbering.

the bottom of the face or, in the case of stepped back curbs, from the bottom of the lower face. A sidewalk or a brush curb located on the highway traffic side of a bridge railing shall be considered an integral part of the railing and shall be subject to the crash test requirements of Article G2.7.1.1.3. The width of a brush curb shall not exceed 9 inches, desirably, should not exceed 6 inches. When curb and gutter sections are used on the roadway approach, at either or both ends of the bridge, the curb height on the bridge shall preferably equal, but may exceed, the curb height on the roadway approach. Changes in curb height shall be uniformly transitioned over a distance equal to or greater than 20 times the change in height. Where no curbs are used on the roadway approaches, the height of the bridge curb above the roadway shall be not less than 6 inches, and preferably not more than 8 inches.

Raised sidewalks on bridges usually should not be used where the approach roadway is not curbed. However, when staged construction, a change in roadway cross section from one end of the bridge to the other, or some other condition requires a raised sidewalk on a bridge with no connecting approach curb, a transition section of sidewalk with a length at least 20 times the height of the sidewalk curb on the bridge shall be provided to ramp the bridge sidewalk to the level of the approach surface.

For recommendations on sidewalk widths see *AASHTO A Policy on Geometric Design of Highways and Streets*.

Where sidewalks are used for pedestrian traffic on urban expressways they shall be separated from the bridge roadway by the use of a traffic railing or combination railing as discussed in Article G2.7.

In those cases where a New Jersey type parapet or other railing or a curb is constructed on a bridge, particularly in urban areas that have curbs and gutters leading to a bridge, the same width between curbs on the approach roadway will be maintained across the bridge structure. A parapet or other railing installed at or near the curb line shall have its ends properly flared, sloped, or shielded.

G2.7 RAILINGS

Railings shall be provided along the edges of structures for protection of traffic and pedestrians. A pedestrian walkway *may* be separated from an adjacent roadway by a traffic railing or combination railing, with a pedestrian railing along the edge of the

structure, except on urban expressways where a pedestrian walkway, if provided, *shall* be separated from the adjacent roadway by a traffic railing or combination railing.

G2.7.1 Traffic Railings and Combination Railings

G2.7.1.1 General

G2.7.1.1.1 Although the primary purpose of traffic railings is to contain vehicles using the structure, consideration should also be given to (a) protection of the occupants of a vehicle in collision with the railing, (b) protection of other vehicles near the collision, (c) protection of persons and property on roadways or other areas underneath the structure, (d) railing cost-effectiveness, and (e) appearance and freedom of view from passing vehicles.

G2.7.1.1.2 The approach end of a parapet or railing shall have an appropriate crashworthy configuration or be shielded by a crashworthy traffic barrier. Traffic barriers on bridge approaches must be properly transitioned to traffic railings on bridges. Bridge-end drainage control should be an integral part of the barrier transition design.

G2.7.1.1.3 To ensure safe performance, traffic railings, combination railings (traffic railings combined with pedestrian railings or bicycle railings), and barrier transitions shall be crash tested and evaluated in accordance with the crash test procedures given in the National Cooperative Highway Research Program Report 230, *Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances*, except as otherwise directed in Article G2.7.1.3 of these specifications. In addition, combination railings are to meet the loading requirements for bicycle railings given in Article G2.7.2.2 or for pedestrian railings given in Article G2.7.3.2, as appropriate.

A combination railing may be crash tested and certified for use with a raised sidewalk having unique dimensions. However, a combination railing crash tested with a flush roadway approach surface and with a sidewalk conforming to the dimensions given in Figure G2.7.1.1.3 may be considered as acceptable for use with sidewalks having widths 3.5 feet or greater and heights up to 8 inches, provided the crash test results meet the requirements given in Table G2.7.1.3A under "Crash Test Evaluation Criteria."

G2.7.1.1.4 Variations in traffic volume, speed, vehicle mix, roadway alignment, under-structure activities and conditions, and other factors combine to produce a vast variation in traffic railing perform-

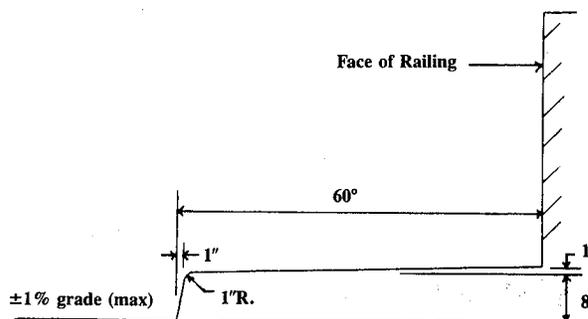


FIGURE G2.7.1.1.3 Standard Raised Sidewalk for Use in Combination Railing Testing.

ance needs from one site to another. The performance requirements for traffic railings and the criteria for their selection are given in Article G2.7.1.3.

G2.7.1.2 Geometry

G2.7.1.2.1 Acceptability of traffic railing and combination railing geometry shall be verified through crash testing. However, the minimum height of a traffic railing, measured at its roadway face, from the top of the roadway or from the top of an anticipated future overlay shall not be less than 27 inches.

G2.7.1.2.2 When a traffic railing is located between the roadway and a sidewalk or bikeway, the minimum height of the railing above the surface of the sidewalk or bikeway shall be 24 inches and the railing should have a smooth surface to avoid snag points for pedestrians or cyclists. When a greater height of railing above a sidewalk or bikeway surface is desired to improve comfort or safety of pedestrians or cyclists with a potential of falling over the railings and onto the roadway, the railing may be a traffic railing or a modified combination railing giving a selected height other than required by Article G2.7.1.2.3.

G2.7.1.2.3 The minimum geometric requirements for combination railings, beyond those required to meet crash test requirements and the requirements of Article G2.7.1.2.1, shall be those required for bicycle railings or pedestrian railings, as appropriate. (See Articles G2.7.2 and G2.7.3.)

G2.7.1.3 Performance Levels and Selection Procedures

G2.7.1.3.1 Railing performance levels are described by crash test requirements. Table G2.7.1.3A

greater than 10,000 vehicles per day per lane (vpdpl), the construction-year ADT value used in selecting a bridge railing performance level may be limited to 10,000 vpdpl.

G2.7.2 Bicycle Railing

G2.7.2.1 General

G2.7.2.1.1 Bicycle railings shall be used on bridges specifically designed to carry bicycle traffic, and on bridges where specific protection of bicyclists is deemed necessary.

G2.7.2.1.2 Railing components shall be designed with consideration to safety, appearance, and freedom of view.

G2.7.2.1.3 Materials for bicycle railing may be concrete, metal, timber, plastic, fiber reinforced plastic, or a combination thereof.

G2.7.2.2 Geometry and Loads

G2.7.2.2.1 The minimum height of a railing used to protect a bicyclist shall be 54 inches, measured from the top of the surface on which the bicycle rides to the top of the top rail.

G2.7.2.2.2 Within a band bordered by the riding surface and a line 54 inches above it, horizontal elements of the railing assembly shall have a maximum clear spacing of 15 inches. Vertical elements of the railing assembly shall have a maximum clear spacing of 8 inches. If a railing assembly employs both horizontal and vertical elements, the spacing requirements shall apply to one or the other, but not to both. Chain link fence is exempt from the rail spacing requirements listed above. In general, rails should project beyond the face of posts and/or pickets. Smooth rubrails should be attached to the railings at a height of 42 inches.

G2.7.2.2.3 The minimum design loadings for bicycle railing shall be $w = 50$ pounds per linear foot transversely and vertically, acting simultaneously on each rail.

G2.7.2.2.4 Design loads for rails located more than 54 inches above the riding surface shall be determined by the designer.

G2.7.2.2.5 Posts shall be designed for a transverse load of wL (where L is the post spacing) acting at the center of gravity of the upper rail, but at a height not greater than 54 inches.

G2.7.2.2.6 Refer to Figure G2.7.4 for more information concerning the application of loads.

G2.7.3 Pedestrian Railing

G2.7.3.1 General

G2.7.3.1.1 Railing components shall be designed with consideration to safety, appearance, and freedom of view.

G2.7.3.1.2 Materials for pedestrian railings may be concrete, metal, timber, plastic, fiber reinforced plastic, or a combination thereof.

G2.7.3.2 Geometry and Loads

G2.7.3.2.1 The minimum height of a pedestrian railing shall be 3 feet 6 inches measured from the top of the walkway to the top of the upper rail member.

G2.7.3.2.2 Within a band bordered by the walkway surface and a line 42 inches above it, horizontal elements of the railing assembly shall have a maximum clear spacing of 15 inches. Vertical elements of the railing assembly shall have a maximum clear spacing of 8 inches. If a railing assembly employs both horizontal and vertical elements, the spacing requirements shall apply to one or the other, but not to both. Chain link fence is exempt from the rail spacing requirements listed above. In general, rails should project beyond the face of posts and/or pickets.

G2.7.3.2.3 The minimum design loading for pedestrian railing shall be $w = 50$ pounds per linear foot, transversely and vertically, acting simultaneously on each longitudinal member. Rail members located more than 5 feet 0 inches above the walkway are excluded from these requirements.

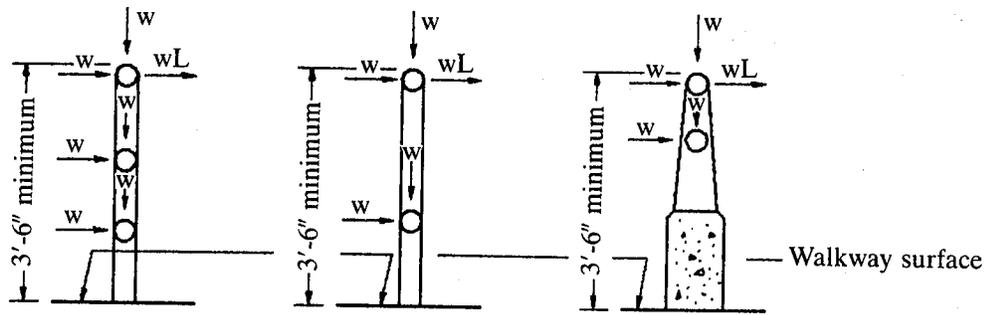
G2.7.3.2.4 Posts shall be designed for a transverse load of wL (where L is the post spacing) acting at the center of gravity of the upper rail or, for high rails, at 5 feet 0 inches maximum above the walkway.

G2.7.3.2.5 Refer to Figure G2.7.4 for more information concerning the application of loads.

G2.7.4 Structural Specifications and Guidelines for Bicycle and Pedestrian Railings

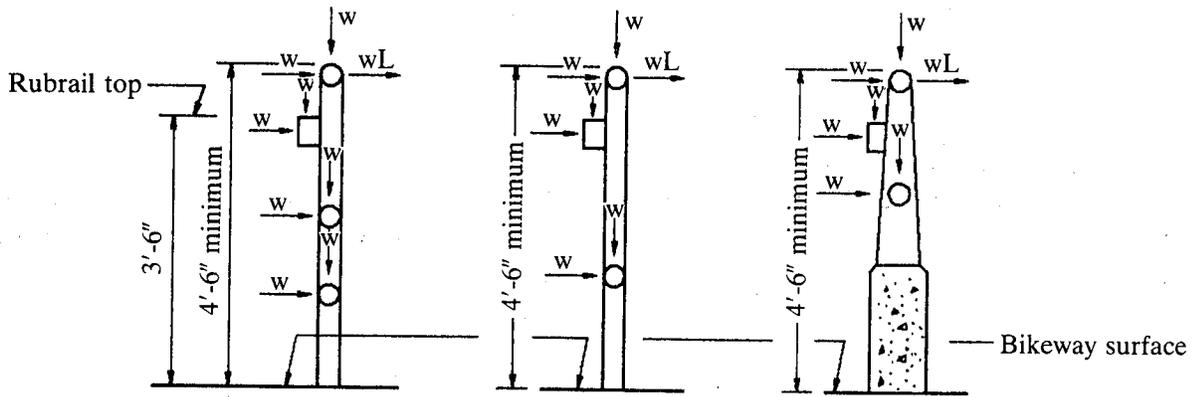
G2.7.4.1 Bicycle and Pedestrian Railings shall be designed by the elastic method to the allowable stresses for the appropriate material.

For aluminum alloys the design stresses given in the *Specifications for Aluminum Structures* Fifth Edition, December 1986, published by the Aluminum Association, Inc., for "Bridge and Similar Type Structures" for alloys 6061-T6 (Table A.6), 6351-T5 (Table A.6), and 6063-T6 (Table A.8) shall apply,



(To be used on the outer edge of a sidewalk when highway traffic is separated from pedestrian traffic by a traffic railing.)

PEDESTRIAN RAILING



(To be used on the outer edge of a bikeway when highway traffic is separated from bicycle traffic by a traffic railing.)

BICYCLE RAILING

NOTE:

If screening or solid face is presented, number of rails may be reduced; wind loads must be added if solid face is utilized.

NOTES:

1. Loadings on left are applied to rails.
2. Loads on right are applied to posts.
3. The shapes of rail members are illustrative only. Any material or combination of materials listed in Article G2.7 may be used in any configuration.

NOMENCLATURE:

w = Pedestrian or bicycle loading per unit length of rail
 L = Post spacing

FIGURE G2.7.4 Pedestrian Railing, Bicycle Railing

and for cast aluminum alloys the design stresses given for alloys A444.0-T4 (Table A.9), A356.0-T61 (Table A.9) and A356.0-T6 (Table A.9) shall apply.

For fabrication and welding of aluminum railing see Article 11.5 of the AASHTO *Standard Specifications for Highway Bridges*.

G2.7.4.2 The allowable unit stresses for steel shall be as given in Article 10.32 of the AASHTO *Standard Specifications for Highway Bridges*, except as modified below.

For steels not generally covered by the "Standard Specifications," but having a guaranteed yield strength, F_y , the allowable unit stress, shall be derived by applying the general formulas as given in the "Standard Specifications" under "Unit Stresses" except as indicated below.

The allowable unit stress for shear shall be $F_v = 0.33F_y$.

Round or oval steel tubes may be proportioned using an allowable bending stress, $F_b = 0.66F_y$, provided the R/t ratio (radius/thickness) is less than or equal to 40.

Square and rectangular steel tubes and steel W and I sections in bending with tension and compression on extreme fibers of laterally supported compact sections having an axis of symmetry in the plane of loading may be designed for an allowable stress $F_b = 0.60F_y$.

G2.7.4.3 The requirements for a compact section are as follows:

(a) The width to thickness ratio of projecting elements of the compression flange of W and I sections shall not exceed

$$\frac{b}{t} \leq \frac{1600}{\sqrt{F_y}} \quad (2-1)$$

(b) The width to thickness ratio of the compression flange of square or rectangular tubes shall not exceed

$$\frac{b}{t} \leq \frac{6000}{\sqrt{F_y}} \quad (2-2)$$

(c) The D/t ratio of webs shall not exceed

$$\frac{D}{t} \leq \frac{13000}{\sqrt{F_y}} \quad (2-3)$$

(d) If subject to combined axial force and bending, the D/t ratio of webs shall not exceed

$$\frac{D}{t} < \frac{13,300 \left[1 - 1.43 \left(\frac{f_a}{F_a} \right) \right]}{\sqrt{F_y}} \quad (2-4)$$

but need not be less than

$$\frac{D}{t} < \frac{7000}{\sqrt{F_y}} \quad (2-5)$$

(e) The distance between lateral supports in inches of W or I sections shall not exceed

$$\leq \frac{2400b}{\sqrt{F_y}} \quad (2-6)$$

or

$$\leq \frac{20,000,000 A_f}{dF_y} \quad (2-7)$$

G3.24 DISTRIBUTION OF LOADS AND DESIGN OF CONCRETE SLABS

G3.24.5 Cantilever Slabs

G3.24.5.2 Railing Loads on Bridge Decks

Railing loads applied to the bridge deck slab shall be based on the ultimate strength of the railing used (See Note 1 in Table G2.7.1.3A). Loads shall be applied and the deck designed in a manner to assure the ultimate strength of the slab will exceed that required to resist the maximum bending, shear, and punching loads that can be transmitted through the bridge railing, along with simultaneously applied wheel loads.

APPENDIX C

**A STUDY ON THE REQUIRED HEIGHT
OF A BRIDGE RAILING TO
ACCOMMODATE BICYCLE IMPACTS**

An Engineering Paper by

DAVID W. ORR

452-35-4093

To fulfill the requirements for

Master of Engineering degree

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INTRODUCTION

Guardrail research of today is primarily concerned with the refining of design such that severity of single vehicle impacts is reduced. With the growing number of bicyclists on the road today, this research should be expanded to include bicycles as well as automobiles or trucks. The research should also be augmented to include not only strength determinations, but also geometric design. Geometric design is a key factor in guardrail research. The determination of the required height for a bridge railing such that it accommodates bicyclists is a complex problem of a geometric nature. In the spring of 1993, a conference of state transportation officials was held at Texas A&M University. At this conference, many different aspects of bridge rail design were discussed. Among the questions raised was the height requirement for bicycle railings. In the bridge design manual by The American Association of State Highway Transportation Officials (AASHTO, 1992), the height requirement for railings where bicycle traffic is common is 54 inches. No one at the conference was able to determine the origin of the 54 inch height requirement. The AASHTO bridge design manual also states that a pedestrian railing must be at least 42 inches high. Within the AASHTO bridge manual, however, no sources are referenced as to the origin of this 54 inch height value, suggesting that this value might be somewhat arbitrary. Therefore, this important issue of height requirement should be addressed. (AASHTO, 1992)

The determination of height of a bridge railing is a problem that concerns the field of dynamics. The scope of this paper includes the determination of key variables

that will aid in this dynamic analysis. The dynamics of the situation, including the variations of wheel stiffness, force locations, accelerations, velocities, and force magnitudes will be left to future research. This paper will determine various properties of a bicyclist, including mass, geometry, and center of gravity that can be used for dynamic analysis. Using these values and a few assumptions concerning the dynamics of the situation, a range of required bridge railing heights will be determined. The scope of this paper will also deal with the determination of railing height without regard to railing configuration, or type.

The primary function of a bridge railing, as far as cyclists are concerned, is that the railing keeps the cyclist from going over the edge of a rail. Generally, when a bridge railing exists, it is protecting motor vehicles from hazards. The railing also should protect the bicyclist from these off-road hazards. The height requirement will be determined in two ways. The first determination of height is obtained by requiring that the guardrail be at least as high as the center of gravity of the person on a bicycle. This scenario assumes that if a perpendicular force were applied to the rider such that they become detached from the bicycle and impact the railing, half the rider's mass would attempt to go over the rail, while half their mass would attempt to keep them from going over the railing. Since this loading scenario is idealized, the resulting value of height will be the minimum required value for such a railing system. The second method of determining the height requirement of a railing is to rotate the bicycle and its passenger about the center of the front wheel such that the center of gravity of the rider in that position will be a maximum height above the ground. This

maximum height occurs when the cyclist's center of gravity is directly over the front wheel's ground contact point. This idealized situation will be used to simulate the case of a cyclist impacting a railing and staying on the bicycle as inertia causes them to rotate about the bicycle's front axle. In cyclists' terms this is an "endo," short for end-over.

DEFINITIONS

The center of gravity of an object is defined as the center of the gravitational attraction experienced by the body. (Long, 1991) It is also defined by the point having coordinates X_1 , Y_1 , and Z_1 in the equations (Beer, 1987)

$$(\Sigma m) X_1 = \Sigma mX \quad (\Sigma m) Y_1 = \Sigma mY \quad (\Sigma m) Z_1 = \Sigma mZ$$

Anthropometrics, from Greek *anthropos* man, and *metrein* to measure, is the description of the dimensions of the human body. These dimensions are measured using landmarks on the human body. Heights, breadths, depths, distances, circumferences, and curvatures are all described with references to these landmarks. Most of these data are retrieved from military personnel, but various professions, such as truck drivers and pilots, provide data as well. (Kroemer, 1992) Additionally, measurements on cadavers have been performed. For the data used in this report, the centers of gravity of a member defined in relationship to the proximal end of the member. The proximal end is the end that is nearest the spinal chord. However, when looking at the thorax, there is some confusion about which end is closer to the

spinal chord. For the thorax, the end nearest the buttocks is considered the proximal end.

Bicycle definitions necessary to this report can be found in figures 1 and 2. The bicycle geometry dimensions are found in table 1. The crank center is the point where each crank originates. It is also the intersection of the down tube and the chain stay. The down tube is the main lower tube on a bicycle and connects at the crank center and the head set. The head set is the mostly vertical member that connects the down tube and the top tube. It is also the support for both the front fork and the stem. The fork connects the front wheel to the bicycle and runs from the head set to the center of the front tire. The stem is the member that connects the handlebars to the rest of the frame and enters the bicycle at the head set. The stem includes both the vertical and horizontal members that perform this function. However, the stem length refers to the horizontal portion of this member. The seat tube rises from the crank center to the top tube, and the saddle, commonly known as the seat, fits into it. The top tube connects between the seat tube and the head set. The chain stay includes the mostly horizontal member that connects the crank center and the rear wheel center, as well as the tube that connects the rear wheel and the seat tube. The saddle point is the point that represents the top, center point of the saddle. The saddle-pedal start distance is the distance from the saddle point to the end of the lower crank along the line of the seat tube. The straddle height is the height above the ground of the topmost point of the top tube, aligned over the crank center. In defining the frame geometry, as in figure 2, the angles are measured counterclockwise

as shown. The "b.b." in the term "b.b. drop" stands for bottom bracket. The distance between wheel centers is known as the wheel base. The offset is the perpendicular distance between an extension of the head set line and the front wheel center.

Frame Size	16"	18"	20"	22"
Top Tube	21.3"	22.0"	23.0"	23.5"
Seat Tube	16"	18"	20"	22"
Seat Angle	73.0°	73.0°	73.0°	73.0°
Head Angle	71.0°	71.0°	71.0°	71.0°
B.B. Drop	1.4"	1.4"	1.4"	1.4"
Rear Center	16.7"	16.7"	16.7"	16.7"
Off-Set	1.5"	1.5"	1.5"	1.5"
Wheel Base	39.9"	40.7"	41.8"	42.3"
Stand-Over Ht.	29.3"	30.1"	31.3"	33.2"

Table 1. Giant ATX 760 Frame Dimensions (Giant, 1993)

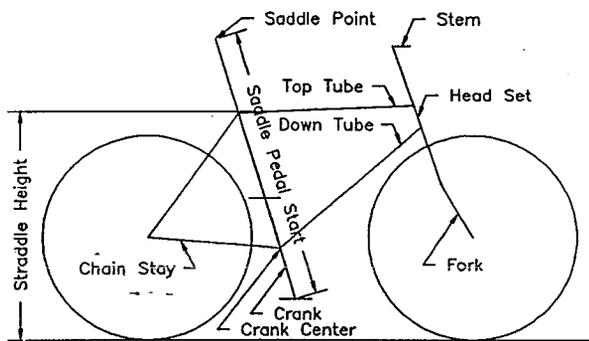


Figure 1 Bicycle Geometry Definitions

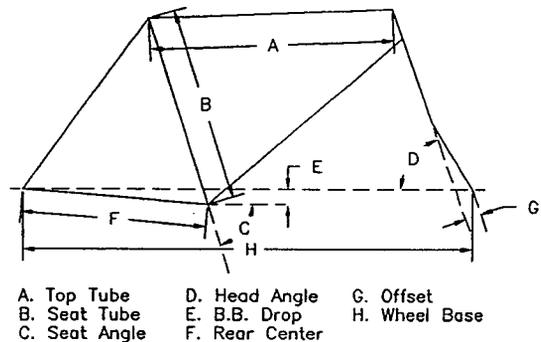


Figure 2 Frame Geometry

SELECTION OF HUMAN MODELS

The first variable in dealing with this height determination problem is the selection of a standard human being. Two different sizes of human beings have been selected. A 50th percentile male and a 95th percentile male have been chosen. Since females are smaller than males, a railing that will accommodate males will also accommodate females. To clarify what is meant by a "percentile" when referring to a person, dummy, body part, or other measurement, a definition is required. A "percentile" is the point on a distribution curve for a specified variable where that percent of the measured (or calculated) values would be less, and hence 100 minus that percent would be greater than that particular value. (NTIS, 1976) For example, the term "95th percentile weight", which is equivalent to 217 pounds, would be larger than 95 percent of weights in the population, and smaller than 5 percent of weights. The determination of the dimensions of a 95th percentile male is quite difficult since a wide variety of body shapes and distributions exist. For example, the 95th percentile height of a human male is 72.8 inches. The 95th percentile weight of a

human male is 217 pounds. However, a person who weighs 217 pounds is generally not 72.8 inches tall and a 72.8 inch person is usually not 217 pounds. (Young, 1970)

The 95th percentile dummy, as manufactured by Calspan Corporation and used by the Texas Transportation Institute, has been selected to simulate a 95th percentile person in order to be a little more conservative, since data from a 50th percentile dummy does not accommodate approximately half the adult male cyclists. Because mostly children ride bicycles, the 95th percentile male is much larger than the 95th percentile cyclist. The decision to use a 95th percentile male is therefore extremely conservative, yet reasonable.

For the 95th percentile dummy, both the 95th percentile weight and 95th percentile height will be used. In proportioning the rest of the body, 95th percentile values are not used since this would lead to a disproportionate looking dummy. Body shapes vary greatly and are generally proportioned such that not all body parts are 95th percentile. For example, many people who have long legs have short midsections, and vice-versa. The same is true of weight distribution: people whose weight is 95th percentile, generally do not have legs, arms, and midsections whose lengths are all 95th percentile. It would be possible to scale up the segment values from a 50th percentile dummy, but these figures prove to be disproportionate. Calspan has developed a computer program that uses actual human dimensions as an anthropometric data base for proportioning segment sizes as a function of given input values. These computed values have been used as a basis for the proportioning of the dummy's segments. (Walunas, 1973)

To simulate a 50th percentile male, the measurements of the NHTSA Advanced "S" Series 50th percentile dummy, as used by the Texas Transportation Institute, are utilized. The 50th percentile dummy has also been chosen because the Society of Automotive Engineers, SAE, has chosen this dummy for many simulations.

The length dimensions of the individual members of the 50th and 95th percentile dummies are given in table 2. The weights of each of the individual members of the 50th and 95th percentile dummies are given in table 3. (NTIS, 1976) (Walunas, 1973)

	50th Dummy	95th Dummy
Head	12.1"	12.3"
Hip-neck	20.1"	21.8"
Hip-shoulder	18.1"	19"
Upper Arms	10.7"	11.6"
Lower Arms	10.3"	10.2"
Upper Leg	15.4"	15.1"
Lower Leg	16.2"	17.9"
Ankle-Foot	3.1"	3.1"
Seat-Hip	2.0"	3.0"
Hand	7.6"	n/a
Foot	10.5"	12.0"

Table 2. Dummy Member Lengths

	50th Dummy	95th Dummy
Head	11.2 lb	17.5 lb
Torso	79 lb	112 lb
Upper Arm	4.8 lb	6.8 lb
Lower Arm	3.4 lb	3.9 lb
Upper Leg	17.6 lb	17.6 lb
Lower Leg	6.9 lb	9.1 lb
Hand	1.4 lb	1.4 lb
Foot	2.8 lb	3.6 lb

Table 3. Dummy Member Weights

SELECTION OF BICYCLE

The second variable to be chosen is a bicycle. Several kinds of bicycles are popular today: mountain bicycles are used primarily for riding rough trails, road bicycles are used primarily for racing and riding on roads, cross terrain bicycles can be used for the same purposes as road or mountain bikes with some sacrifices of performance, and BMX bicycles are used for dirt race tracks and for performing tricks. A mountain bike has been chosen as the model bicycle since mountain bikes put the rider higher above the ground than any other kind of bicycle. Additionally, the proper posture of a mountain bike rider puts their center of gravity higher, regardless of saddle height. Mountain bicycles, though designed for off road riding, are often chosen for road use due to their ruggedness. Although bicycle components are adjusted to the comfort and individual taste of a rider, standard procedures exist to fit a bicycle to a person. The New England Cycling Academy has put together a system, called "The Fit Kit," for fitting a bicycle to a person. Tabular values for bicycle component sizes are read using known body dimensions. For instance, the tables for straddle height and crank length are based on the inseam measurement. The saddle-pedal starting distance is based on inseam measurement and foot length. A full discussion of the fit kit's procedure will occur later in this report. From these straddle height values, a frame size is chosen based on the 1994 Giant ATX 760 bicycle frame dimensions. The ATX 760, made by Giant, is a mountain bike. Giant has several mountain bikes, each of which has the same basic frame geometry. Both Giant and their ATX 760 were chosen for this study based on the availability of

essential information. It is important to note that changes in bicycle frame size do not change the location of the crank center, and therefore seat height is only a function of saddle-pedal start distance. However, posture will change due to a longer top tube on larger framed bicycles. (Giant, 1993)

FITTING PERSON ON BICYCLE

For determination of the postures for the 50th percentile and 95th percentile dummies, the dimensions of the individual body parts are required. The lengths of these body parts are based on the hinge points of the dummies. Fourteen hinge points exist in the dummies and are located at the ankles, the knees, the hips, the small of the back, the shoulders, the elbows, the wrists, and the neck. The posture in this study is shown in figure 3. To simulate the position of the rider on a bicycle, a stick figure is drawn by properly connecting these hinge, or pivot, points. This stick figure is then placed on a stick bicycle. For the posture in this study, the hip joint is assumed to be directly above the saddle point. The back is assumed to be straight from the hip joint through the neck joint. The head is assumed to be perpendicular to the ground. Although not proper riding posture, arms are considered to be straight from the shoulders to the wrist. The wrist is assumed to be on the handle bars, and the hand is assumed to be a point mass at the wrist pivot location. One leg (referred to as the straight leg) is assumed to be straight from the hip to the ankle and at an angle such that if the leg were extended, it would touch the middle of the lower pedal. Although the straight leg assumption does not simulate proper riding posture,

it allows calculations to be performed more easily. Additionally, the proper bend in the leg would not affect the center of gravity location significantly, since the leg is to be mostly straight on the downstroke. The cranks are to be rotated such that they are aligned with the seat tube. The second leg (referred to as the bent leg) is bent such that the ankle pivot point is above the middle of the pedal. The placement of the body on the bicycle is based on the hip pivot point. Although dimensions are given for seat to hip pivot distances, a one and a half inch correction factor was subtracted from this value. In anthropometrics, when the seat to hip pivot distances are measured, the subject or dummy is placed on a flat surface and the buttocks rest flatly on this surface. However, when a person is sitting on a bicycle saddle, the buttocks hang over the saddle and the saddle is higher than the lowest point of the buttocks. From personal measurements, a one and a half inch correction factor is determined. This one and a half inch factor is also affirmed when the model person is placed on the model of the bicycle. Without the correction factor, the model person's leg did not come sufficiently close to the pedal for proper fit.

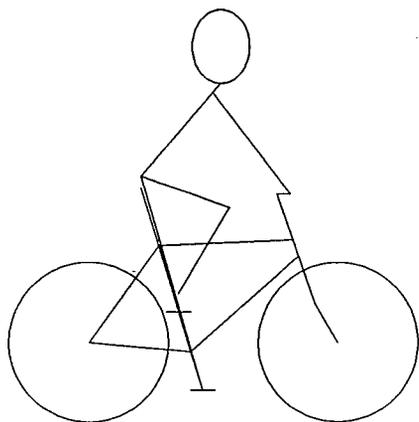


Figure 3 Proper Bicycling Posture

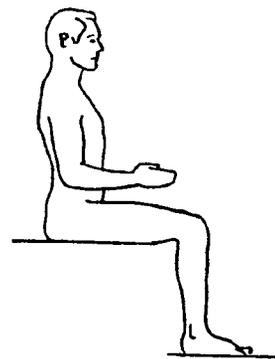


Figure 4 Standard Anthropometric Posture

Difficulties exist in attempting to determine the proper posture on a bicycle when given anthropometric data, whether this data is from human or dummy measurements. The primary difficulty, as discussed previously, is that anthropometric measurements are generally performed with the human or dummy sitting squarely as shown in figure 4. (NASA, 1978) Additionally, many lengths that are reported are not measured in the same manner, and assumptions must be made to convert from and compare one to the other. For example, the torso weight measurement for the 50th and 95th percentile dummies includes some of the thigh, due to the nature of the construction of the dummy, and thus the thigh weight misrepresents the actual weight of a thigh. When attempting to apply percentile center of gravity data to the thigh, discrepancies will exist.

Most of the inconsistencies occur when attempting to apply the percentile center of gravity data to a dummy. The torso and thigh weight measurements differ significantly between dummy data and center of gravity data. The torso weight measurement for the dummies, as discussed previously, includes the section from the neck pivot to the thigh connection. The thigh connection is actually 4 inches away from the hip pivot. The torso weight measurement for center of gravity data is made by weighing the section from the neck pivot to the hip pivot. This discrepancy in torso measurement leads to a discrepancy in thigh measurement.

One critical measurement that is not directly available from anthropometric dummy measurements is the crotch height. To alleviate this problem, an actual measurement has been made on a 50th percentile dummy and assumptions were

made from this measurement and applied to the 95th percentile dummy. When the crotch height is compared to the distance from the hip pivot to the ankle pivot, the crotch height is 0.5 inches greater than the sum of the distances from the hip pivot to knee pivot and the knee pivot to the ankle pivot. This 0.5 inch correction factor is then applied to the 95th percentile dummy without any scaling up.

A spreadsheet is used to calculate the center of gravity. Since the center of gravity locations are given as a function of distance from their proximal ends as recorded in table 5, of primary concern are the coordinates of the end points of the body's individual members. These coordinates are determined by utilizing the bicycle's geometry. The origin of the coordinate system utilized is the crank center. (Kroemer, 1990)

The fit kit is utilized to determine the frame size. The input data, as well as the fit kit results, are given in table 4. The first variable required by the fit kit is the crotch height, which is defined as the distance from the floor to the crotch. The subject is assumed to be barefoot. As previously discussed, this distance is estimated from the dummies by adding 0.5 inches to the sum of the upper leg and lower leg. By reading the fit kit tables, the crotch height determines the standover height of the bicycle. By looking at the standover heights of the various frame sizes of the Giant ATX 760, the frame size can be determined. The fit kit gives a range of saddle-pedal starting distances as a function of both inseam and foot size. The maximum value of the range is used, since this value will give the maximum saddle height and center of gravity. The fit kit tables also specify a range of crank length as a function of crotch

height. The minimum value of this range was chosen since the minimum value, combined with the given saddle-pedal distance, would give the maximum saddle height, and thus, the maximum center of gravity height. The next step in the fit kit

	50th Percentile Dummy	95th Percentile Dummy
Inseam	29.6"	31.5"
Foot	10.5"	12.0"
Standover	28.2"	29.8"
Frame	18"	20"
Saddle-Pedal	31.8"	34.4"
Crank	6.6"	6.9"
Upper Body	46.4"	47.7"
Stem	2.17"	2.56"

Table 4. Fit Kit Data and Results

is to determine the upper body measurement. The upper body measurement is the sum of the torso length and the shoulder width. From this measurement, a combination of top tube and stem lengths can be obtained from additional tables. (NECA, 1988) However, the shortest possible specified stem length is used, since

bicycle frame size, and thus top tube size, is selected based on standover height. Also, a smaller value of stem length will require the cyclist to sit higher, thus increasing the center of gravity height. From discussions with cyclists, bicycle salespeople, and bicycle store owners, it is determined that the vertical distance from the saddle to the handle bars should be 1.0 inches. Normal distances range from 1 inch to 3 inches, but a 1 inch difference would require the most upright posture, again increasing the center of gravity height. All other distances are due to bicycle geometry.

When using the spreadsheet to calculate the center of gravity, the crank center is assumed to be the origin, or where the X and Y coordinates are both assumed to be zero. Knowing the seat tube angle and the saddle-pedal starting distance, the coordinates for the saddle can be determined.

$$X_{\text{saddle}} = - (\text{Dist}_{\text{saddle-pedal}} - \text{Length}_{\text{crank}}) \times \text{Cos} (\text{SeatAngle})$$

$$Y_{\text{saddle}} = (\text{Dist}_{\text{saddle-pedal}} - \text{Length}_{\text{crank}}) \times \text{Sin} (\text{Seat Angle})$$

From this point, the hip joint is located by fixing the X coordinate and adding the seat-hip distance and appropriate correction factor to the Y coordinate of the saddle point.

$$X_{\text{Hip}} = X_{\text{saddle}}$$

$$Y_{\text{Hip}} = Y_{\text{saddle}} + \text{Dist}_{\text{saddle Hip}} - \text{CorrectionFactor}$$

Next, a triangle is formed with the torso, the arms, and an imaginary line from the handle bars to the hip pivot. The distances of the torso and arms are known from the

anthropometric data. The length of the imaginary line can be calculated by knowing the bicycle geometry and finding the distance by taking the square root of the sum of the differences in the X and Y coordinates of the known points.

$$\text{Dist}_{\text{Hip-Hand}} = \sqrt{(X_{\text{Hip}} - X_{\text{Hand}})^2 + (Y_{\text{Hip}} - Y_{\text{Hand}})^2}$$

Additionally, the angle that the imaginary line forms with the horizontal is known from the bicycle geometry data. From the law of cosines, the angle, θ , that the torso makes with the imaginary hip-hand line can now be determined.

$$\theta = \cos^{-1} \frac{\text{Dist}_{\text{Hip-Hand}}^2 + \text{Dist}_{\text{Hip-Shoulder}}^2 - \text{Dist}_{\text{Shoulder-Hand}}^2}{2 \times \text{Dist}_{\text{Hip-Hand}} \times \text{Dist}_{\text{Hip-Shoulder}}}$$

The angle, γ , that the imaginary line makes with the horizontal is found by the inverse tangent relationship.

$$\gamma = \tan^{-1} \frac{X_{\text{Hands}} - X_{\text{Hip}}}{Y_{\text{Hands}} - Y_{\text{Hip}}}$$

The angle, α , that the torso makes with the vertical plane is found by the relationship

$$\alpha = 90^\circ - \theta + \gamma$$

The neck pivot coordinates are located by extending the torso line along the known angle, α , by the proper distance.

$$Y_{\text{Shoulder}} = \text{Dist}_{\text{Shoulder-Hip}} \times \cos \alpha$$

$$X_{\text{Shoulder}} = \text{Dist}_{\text{Shoulder-Hip}} \times \sin \alpha$$

Next a triangle is formed by the pivot points at the hip, the knee of the bent leg, and the ankle of the bent leg. The lengths of the upper leg and lower leg of the bent leg are known. Since the cranks are assumed to be aligned with the seat tube and the crank length is known, the coordinates for the end of the upper crank can be determined.

$$X_{\text{Top Pedal}} = - \text{Length}_{\text{Crank}} \times \cos(\text{Seat Angle})$$

$$Y_{\text{Top Pedal}} = \text{Length}_{\text{Crank}} \times \sin(\text{Seat Angle})$$

Adding the foot-ankle distance to the Y coordinate of the upper crank, the ankle coordinates can be determined.

$$Y_{\text{Bent Ankle}} = Y_{\text{Top Crank}} + \text{Dist}_{\text{Foot-Ankle}}$$

Now that the coordinates of the bent leg's ankle are known, the distance from the ankle to the hip can be calculated.

$$\text{Dist}_{\text{Hip-Ankle}} = \sqrt{(X_{\text{Ankle}} - X_{\text{Hip}})^2 + (Y_{\text{Ankle}} - Y_{\text{Hip}})^2}$$

Knowing the lengths of the three sides of this triangle, the angle, θ_1 , between the imaginary line and the upper leg can be calculated by again employing the law of cosines.

$$\theta_1 = \cos^{-1} \frac{\text{Dist}_{\text{Hip-Ankle}}^2 + \text{Dist}_{\text{Hip-Knee}}^2 - \text{Dist}_{\text{Knee-Ankle}}^2}{2 \times \text{Dist}_{\text{Hip-Ankle}} \times \text{Dist}_{\text{Hip-Knee}}}$$

The angle, γ_1 , that the imaginary line from the bent leg's ankle to the hip forms with the vertical is also required and can be calculated by the inverse tangent function.

$$\gamma_1 = \tan^{-1} \frac{X_{\text{B.Ankle}} - X_{\text{Hip}}}{Y_{\text{B.Ankle}} - Y_{\text{Hip}}}$$

The angle, α_1 , that the upper leg forms with the horizontal can be found by the relationship

$$\alpha_1 = 90^\circ - \theta + \gamma_1$$

Now that the angle α_1 is known, and knowing the length of the upper leg, the coordinates of the bent leg's knee pivot can be calculated.

$$X_{\text{Knee}} = X_{\text{Hip}} + \text{Dist}_{\text{Hip-Knee}} \times \cos \alpha_1$$

$$Y_{\text{Knee}} = Y_{\text{Hip}} + \text{Dist}_{\text{Hip-Knee}} \times \sin \alpha_1$$

The straight leg, as previously mentioned, is assumed to be in a straight line from the hip to the end of the lower crank. Utilizing the inverse tangent function, the angle, γ_2 that the straight leg forms with the horizontal can be determined.

$$\gamma_2 = \tan^{-1} \frac{X_{\text{S.Ankle}} - X_{\text{Hip}}}{Y_{\text{S.Ankle}} - Y_{\text{Hip}}}$$

The straight leg's knee and ankle coordinates are located by going along the known angle the appropriate distances.

$$X_{S.Knee} = X_{Hip} + Dist_{Hip-S.Knee} \times \sin \gamma_2$$

$$Y_{S.Knee} = Y_{Hip} - Dist_{Hip-S.Knee} \times \cos \gamma_2$$

$$X_{S.Ankle} = X_{S.Knee} + Dist_{S.Knee-S.Ankle} \times \sin \gamma_2$$

$$Y_{S.Ankle} = Y_{S.Knee} - Dist_{S.Knee-S.Ankle} \times \cos \gamma_2$$

The hands are considered to be point masses whose coordinates are the same as the wrist. Similarly, the feet are assumed to be point masses. The bent leg's foot is assumed to be located below the ankle by a distance known as the ankle-foot distance.

$$Y_{B.Foot} = Y_{B.Ankle} - Dist_{Foot-Ankle}$$

The X-coordinate of the bent leg's foot is the same as the X-coordinates of the bent leg's ankle. The straight leg's foot is assumed to be located the same ankle-foot distance away, but located along the line from the hip to the lower crank end.

$$X_{S.Foot} = X_{S.Ankle} + Dist_{Foot-Ankle} \times \sin \gamma_2$$

$$Y_{S.Foot} = Y_{S.Ankle} - Dist_{Foot-Ankle} \times \cos \gamma_2$$

Once the coordinates of each pivot point are known, the center of mass of the member(s) connecting them needs to be determined. The center of mass of each member, expressed as a percentage of length from their proximal end, is known. These values are independent of mass or length. They do not need to be changed for each different person. This percentage is multiplied by the change in X coordinates

of the member, then added to the X coordinate of the proximal end of that member. The same is done for the Y coordinate. The location of the center of mass of that member is now known.

The X coordinate of the center of mass of the entire person on the bicycle is now to be determined. First, the X coordinate of each of the members is multiplied by the mass of that member. These values are summed, and the result is divided by the total mass of the body. The Y coordinate of the center of mass is obtained in the same manner, except that the Y coordinate, not the X coordinate, is initially multiplied by the masses.

Once the coordinates for the center of gravity of the person on the bicycle are known, the distance of that point above the ground is of interest. Since the zero point was previously assumed to be the crank center, the Y coordinate obtained for the center of gravity is added to the crank center's distance above the ground. For all Giant ATX bicycles, the crank center is located 11.6 inches above the ground. This height is found by subtracting the B.B. drop distance from the center of the rear wheel, and needs to be added to the Y coordinate of the center of gravity to determine properly the height of the center of gravity with reference to the ground.

RESULTS

The locations the center of gravity are shown in figures 5 and 6. Figure 5 is the 50th percentile person, while figure 6 is the 95th percentile. The center of gravity of each individual member is given by a small center of gravity symbol, while the large

center of gravity represents the center of gravity of the entire person. The center of gravity of a 50th percentile person, as estimated by a 50th percentile anthropometric dummy, is located 41.9 inches above the ground. The height of the center of gravity of the 95th percentile person, as estimated by a dummy, is 45.9 inches. Both of these locations are well below the 54 inches that AASHTO specifies.

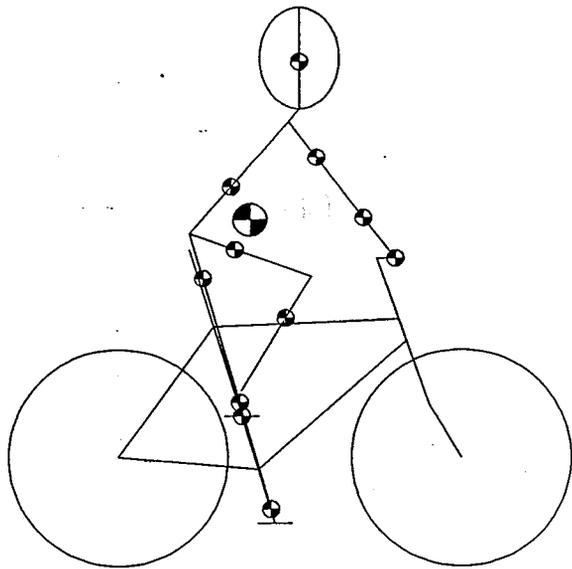


Figure 5 50th Percentile

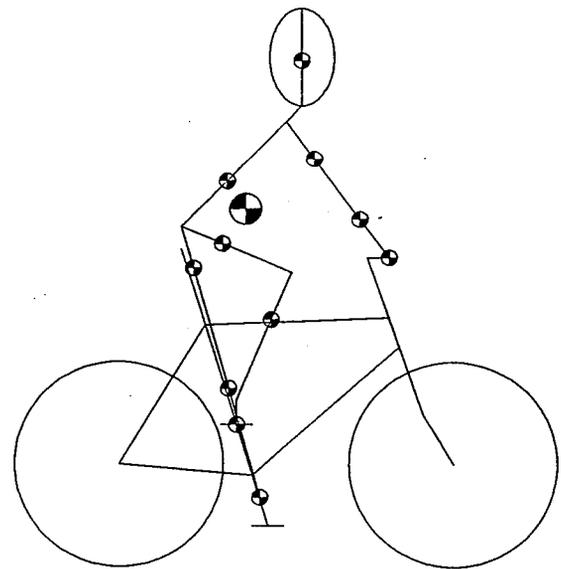


Figure 6 95th Percentile

However, the second simulation has the cyclist's center of gravity rotated such that it is located above the center of the front wheel in order to maximize the center of gravity height. When this simulation is performed, then the 50th percentile dummy's center of gravity is located 51.24 inches above the ground after the dummy has rotated through 40.8 degrees. By the same simulation, the 95th percentile dummy's center of gravity is located 54.89 inches above the ground after rotating through 38.25 degrees. These centers of gravity are shown in figures 7 and 8. If this

simulation is accurate, then AASHTO's 54 inch height limit is a little short, but reasonable.

	General Distance (Percent)	50th dummy C.G. X Location	50th dummy C.G. Y Location	95th dummy C.G. X Location	95th dummy C.G. Y Location
Head	46.6%	4.95"	49.49"	6.33"	53.34"
Torso	38%	-3.16"	34.39"	-3.09"	37.90"
Upper Arm	51.3%	6.96"	37.96"	7.87"	40.78"
Lower Arm	39%	12.52"	30.60"	13.53"	33.00"
Upper Leg 1	37.2%	-2.73"	26.65"	-3.69"	29.74"
Lower Leg 1	37.1%	3.28"	18.24"	2.43"	19.87"
Upper Leg 2	37.2%	-6.54"	23.00"	-7.33"	26.55"
Lower Leg 2	37.1%	-2.20"	8.01"	-2.96"	11.03"
Foot 1	44.9%	-1.96"	6.40"	-1.96"	6.40"
Foot 2	44.9%	1.48"	-4.76"	0.94"	-2.79"
Hand	18%	16.31"	25.59"	17.19"	27.96"

Table 5. Center of Gravity Coordinates

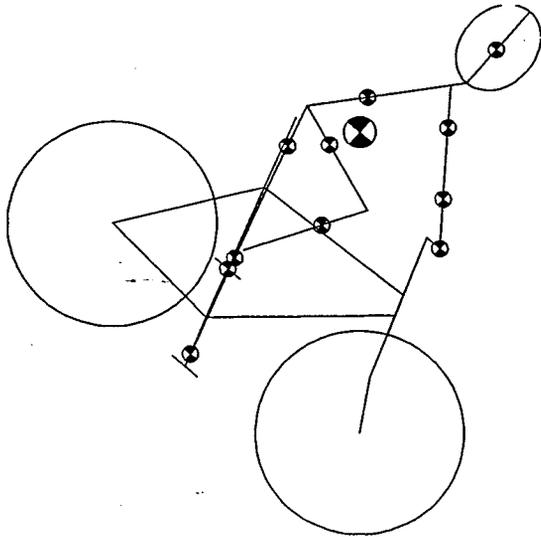


Figure 7 50th Percentile

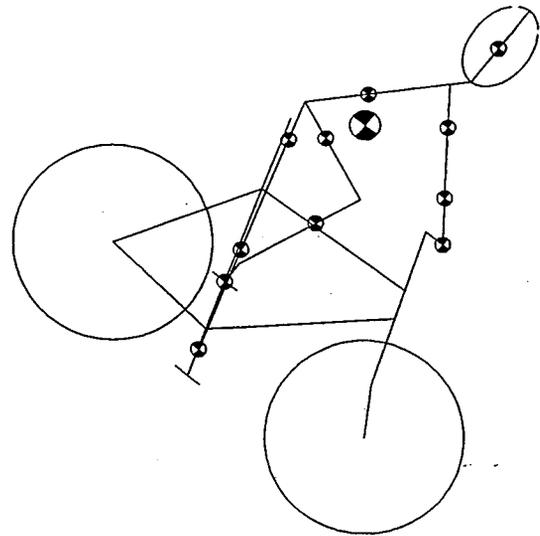


Figure 8 95th Percentile

On the other hand, if a human being on a bicycle impacts a railing, then at some point in their rotation, they will also have some vertical velocity associated with this rotation that will cause them to leave the bicycle. If this person with vertical velocity is treated as a free projectile in space, then the cyclist might reach a higher point as a free projectile than if they were still on the bicycle. If this is the case, then AASHTO's 54 inch height requirement needs to be raised to accommodate this situation.

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