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16. Abstract

Motorcycles are among the most vulnerable vehicles on the road. Although a combination of different factors may contribute to motorcycle crashes, roadside safety systems design can play an important role in limiting the severity of motorcycle crashes. Roadside safety systems are not typically designed with the special needs of motorcyclists in mind. The *Roadside Design Guide* provides guidelines for proper concrete barrier placement on roadways but does not address motorcycle barriers. The *Manual for Assessing Safety Hardware* includes testing guidelines and evaluation criteria for roadside safety barriers impacted by errant vehicles but does not specifically address impacts by motorcycles.

There is a need to contribute to motorcyclist safety by designing and evaluating a containment system for upright errant motorcycle riders impacting a concrete barrier. This system would aid in preventing riders from ejecting over the barrier and reduce injury severity to the rider during the impact event. In the study described herein, finite element computer simulations were used to assist with the design and evaluation of proposed containment options to be mounted on a concrete barrier. An upright motorcycle full-scale crash test with a Hybrid III 50th percentile male dummy was conducted to evaluate the crashworthiness of a chain link fence containment system supported by Modified U-shaped posts and attached to a curved concrete barrier section. The test was conducted at a nominal impact speed of 35 mi/h and impact angle of 18° to the barrier. During the impact event, the system successfully prevented the rider/dummy from ejecting over the barrier and the dummy did not interact with the system's support posts.

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

This report is not intended for construction, bidding, or permit purposes. The engineer (researcher) in charge of the project was Roger P. Bligh, P.E. #78550 Texas.

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CHAPTER 1:
INTRODUCTION

Motorcyclists are among the most vulnerable users of the road system. Multiple factors contribute to this vulnerability, including the fact that motorcycles do not provide the same protection as passenger cars or other vehicle types. Although one or a combination of different factors may cause motorcycle crashes, (including motorcyclist behavior, experience, weather, road condition and other hazards), the design of roadside safety systems can play an important role in reducing the severity of motorcycle crashes.

The Texas Department of Transportation (TxDOT) requested the exploration of potential remedies to address motorcycle riders' safety issue. Texas A&M Transportation Institute (TTI) researchers developed a feasibility project to explore design options for a concrete barrier system to be deployed at appropriate bridge locations to improve errant motorcycle riders' safety. The objective of this project was to design, develop, and evaluate, through computer simulations and crash testing, an improved barrier system that is capable of safely containing errant motorcycle riders during an impact event.

1.1 BACKGROUND

Motorcycle collisions with roadside systems are frequently much more severe for their riders than for users of other vehicles because these roadside safety systems are not typically designed with the special needs of motorcyclists in mind. Unfortunately, some design factors that might provide higher levels of safety to users of other types of vehicles may result in more hazardous conditions to motorcyclists.

In addition, there are no guidelines addressing proper design and use of motorcycle barriers. For example, the *Roadside Design Guide* provides guidelines for proper guard fence placement on roadways but does not address motorcycles (*1*). The *Manual for Assessing Safety Hardware* (*MASH*) includes testing guidelines and evaluation criteria for roadside safety barriers impacted by errant vehicles, but similarly does not address impacts by motorcycles (*2*). There is a need to improve motorcyclist safety by designing and evaluating a containment system for errant motorcycle riders who impact a curved roadside safety concrete barrier to prevent the rider from ejecting over the barrier, which will reduce the rider injury severity during impact.

Standards do not exist in the United State for motorcycle crash testing against roadside safety barriers. Europe and Australia are more advanced on this front, having developed a testing protocol for sliding motorcycle riders against barriers, and they are investigating methods to complement the protocol with a testing standard for upright motorcycle impacts (*3*–*6*). Nieboer et al. performed several motorcycle-into-barrier crash tests at the laboratories of the TNO Crash-Safety Research Center (*7*). A special trolley was designed to guide the motorcycle and the dummy prior to impact. Three different test conditions were considered: 20 mi/h at 90°, 30 mi/h at 90°, and 37 mi/h at approximately 67°. DEKRA Automobil GmbH (Germany) and Monash University (Australia) conducted a joint study on motorcycle impacts into roadside barriers (*8*). Findings from real-world crash investigations suggested conducting full-scale crash tests with two different impact scenarios: motorcycle impacting the barrier while driven in an upright position and motorcycle striking the barrier while skidding on its side. Peldschus et al. performed two different motorcycle-into-barrier crash tests by order of the German Federal Highway Research Institute (*9*). The tests were performed with two different configurations for motorcycle and rider: (a) sliding, 37.3 mi/h at 25°; and (b) upright, 37.3 mi/h at 12°.

1.2 RESEARCH OBJECTIVE AND METHODOLOGY

This study sought to explore design options for containment systems on concrete barriers, to be deployed at appropriate locations to improve errant motorcycle riders' safety. The objective of this project was to design and evaluate a containment barrier system with the capability of:

- Containing and redirecting errant upright motorcycle riders during the impact event.
- Avoiding impacted system debris that could potentially result in hazardous conditions to other road vehicles on lower roadways.
- Reducing injury risk for the errant rider by controlling the interaction with the impacted system.

The objective of this project was addressed through engineering analysis, finite element (FE) computer simulations, component pendulum testing, and full-scale crash testing.

A permanent 32-inch high New Jersey concrete barrier was constructed with a radius of curvature of 500 ft. Full-scale impact tests were performed with a motorcycle rider. The nominal impact speed of the motorcycle rider for the full-scale crash test was requested by sponsor to be 35 mi/h. Through engineering analysis, the nominal impact angle was determined to be approximately 18° with respect to the barrier tangent at the location of impact. This project was divided into three phases. The detailed descriptions are reported below.

1.2.1 Concept Development and Design Selection

TTI researchers defined basic requirements for the railing system, including accommodation of service loads, and developed design alternatives with the potential of meeting impact performance requirements, and providing other desirable functional characteristics. TTI researchers worked closely with TxDOT engineers to apply design constraints to the improved railing system. The design concepts were not fully engineered and detailed at this stage, but were sufficient for an initial feasibility assessment of rail behavior and capability.

TTI researchers presented, and discussed with TxDOT engineers, the improved railing system concepts. To the extent practical, TTI researchers documented advantages and disadvantages for each design alternative, including any perceived performance benefits and application limitations.

1.2.2 Engineering Analysis and Component Testing

TTI researchers developed design details of the design options that were selected by TxDOT as candidates for further development. Engineering analyses were performed to determine the appropriate size, spacing, and connection of the rail components for the design concepts, and to verify that each design could accommodate service load requirements.

TTI researchers proposed conducting component testing to validate the developed computer model of the chain link fence, and to allow verification of the final system details prior to full-scale testing.

Researchers developed a plan to conduct specific component testing, which would provide needed information to complete or confirm current model details. The component testing was mainly needed to verify the proposed system's behavior under impact, and to utilize collected system behavior information to validate the final computer models analyzed through computer simulations.

Researchers proposed conducting dynamic component testing through use of the existing TTI Proving Ground Outdoor Pendulum Facility. Researchers suggested impacting a system prototype with an existing pendulum, with the objective of obtaining post and fence force-deflection data that would be used to calibrate the FE simulations.

Once the models were validated using information obtained from the pendulum tests, the details of the retrofit system were verified and finalized through FE impact simulations. Researchers suggested verifying the system behavior through full-scale testing after details of the recommended design were finalized.

1.2.3 Finite Element Analysis

TTI researchers evaluated the ability of the most promising design option to provide desirable functional characteristics. The evaluation involved the use of FE model development and impact simulations.

TTI researchers developed a detailed FE model for each of the selected design concepts. The explicit FE code LS-DYNA was used to perform impact simulations using the developed barrier model, the TTI motorcycle model, and the available Hybrid III 50 percent anthropomorphic test device (ATD) model.

Europe has developed a motorcycle impact protocol that involves a rider sliding against roadside safety devices. However, motorcycle impact standards for the evaluation of roadside safety devices when impacted by motorcycle riders in an upright position have not been developed (*5*). TTI researchers worked closely with TxDOT engineers to develop computer simulation plans that included proposed nominal impact conditions (speed and angle), critical impact points, and ATD containment and redirection.

The results from the computer simulations were used to assess the probability of each design concept meeting impact performance requirements and providing other desirable functional characteristics. Simulation outcomes were also used to evaluate whether design modifications to the proposed railing systems might be needed to improve the probability of meeting the project objectives before proceeding with full-scale testing.

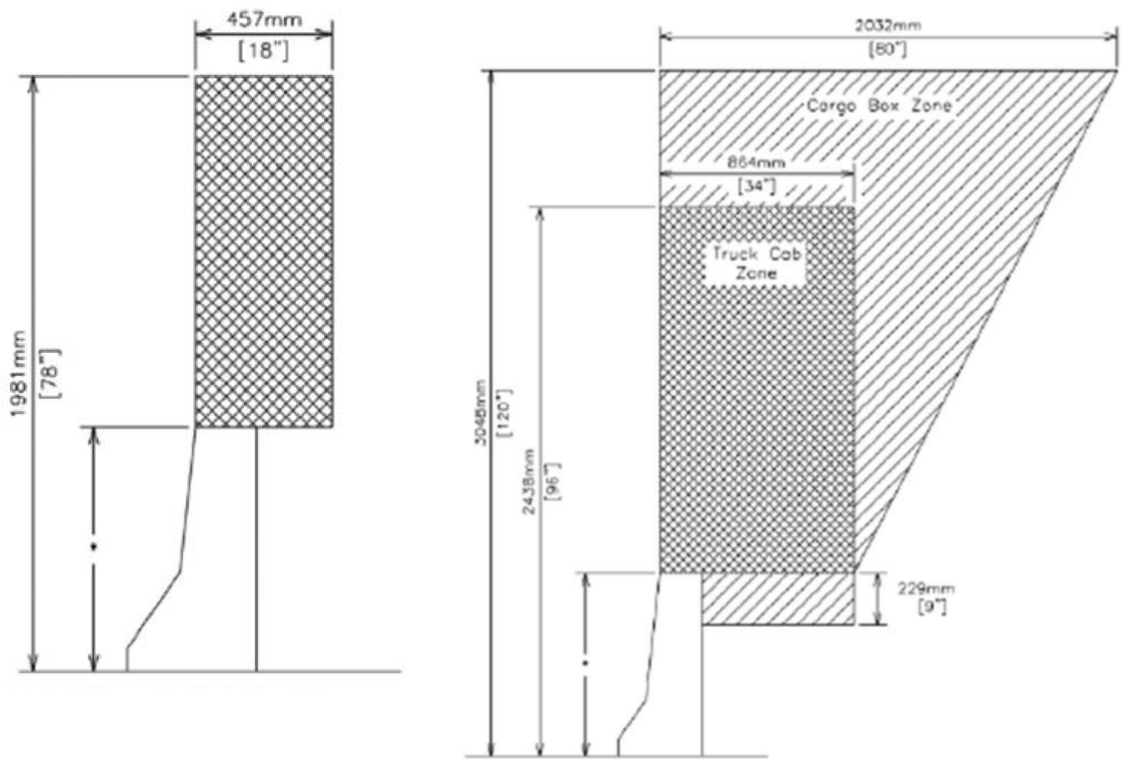
1.2.4 Full-Scale Crash Testing and Analysis

The containment and redirection capability of the final containment system design was evaluated through an upright motorcycle full-scale crash test, with nominal impact conditions of 35 mi/h speed and 18° tangential orientation angle. A Hybrid (H)3 50th percentile male dummy was positioned on the motorcycle, fully equipped with motorcycle gear (leather pants, leather jacket, gloves, boots, and helmet). Researchers instrumented the dummy's head with an accelerometer to capture any potential interaction with posts, and to capture the intensity of head accelerations resulting from interaction with the chain link fence.

CHAPTER 2: DESIGN DEVELOPMENT*

2.1 *NCHRP REPORT 350* ZONE OF INTRUSION

The concept of Zone of Intrusions (ZOIs) for National Cooperative Highway Research Program (*NCHRP) Report 350* Test Level 3 (TL-3) and TL-4 has been previously investigated as a guideline for placement of attachments on top of or behind concrete barriers (*10*). Figure 2.1 shows the ZOIs for a sloped-faced concrete barrier.



(a) TL-3 (b) TL-4

Figure 2.1. Zone of Intrusion for *NCHRP Report 350* TL-3 (a) and TL-4 (b).

At this moment, there are no specific guidelines for evaluation of ZOIs for *MASH* TL-3 and TL-4. However, they are anticipated to be comparable to the ZOIs evaluated for *NCHRP Report 350* tests. From the reported ZOIs, it appears clear that any proposed design containment option discussed for this project would be included in the ZOI for both *MASH* TL-3 and TL-4.

* The opinions/interpretations identified/expressed in this section of the report are outside the scope of TTI Proving Ground's A2LA accreditation.

2.2 PROPOSED DESIGN OPTIONS

To address the containment and safety problem for upright errant motorcycle riders, researchers considered a chain link fence system supported by posts and rails. The chain link fence system was preferred over other options (such as an acrylic [plexiglass] wall) for a variety of reasons, including relatively low cost, availability, ease of installation, and ease of maintenance.

Various design alternative options were developed for initial feasibility. Although all options included employment of posts and rails supporting the chain link fence, they differed by typology of post design (Table 2.1). The first post design used readily available vertical steel posts (Option A), with the chain link fence directly connected to the vertical posts. The second post design included post types protruding toward the back of the system, with the chain link fence directly connected to the horizontal railings, but not to the posts (Option B and C).

2.2.1 Option A: Chain Link Fence Supported by Weak Post

In this design, the chain link fence was directly supported by vertical steel posts, located in the same plane as the chain link fence. In fact, the chain link fence was directly secured to the posts. Since strong steel posts represent discrete systems that can cause severe injury when directly impacted by a motorcycle rider (or, in general, by a human body), the use of weak posts was considered for this concept. In other words, the design of the post was developed to address the minimum post strength required to sustain the weight of the system and applicable wind loading requirements. The weak post system was developed with the objective of having the post deform, yield, or break away upon impact with the errant rider, reducing any consequent body injury severity.

2.2.2 Option B: Chain Link Fence Supported by 7-Shaped Post

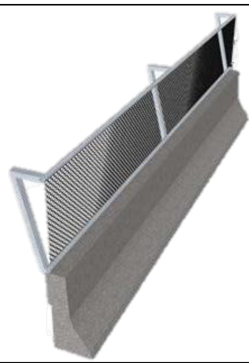
In order to minimize the likelihood of an errant upright motorcycle rider directly impacting the discrete posts, researchers used 7-shaped posts in this option. The objective was to move the post as far as possible from the plane of the chain link fence. In fact, though posts were still needed to support the entire chain link fence system with horizontal rails, the proposed shape was conceived with the objective of minimizing any potential interaction between the impacting rider and the posts, at maximum deformation of the chain link fence during impact.

2.2.3 Option C: Chain Link Fence Supported by U-Shaped Post

Similarly to the 7-shaped posts, an option with U-shaped posts was developed. The concept behind the U-shaped posts was to further minimize the interaction between the impacting rider and the posts. The U-shaped posts were designed with a symmetry that minimizes interaction with the rider even at the bottom of the post.

After a preliminary design of the suggested post options, researchers decided to use FE computer modeling and simulations to better investigate the potential performance of the proposed options under direct impact with an errant rider. Having very little to no information available regarding FE computer material modeling and properties for chain link fence, researchers decided to conduct component pendulum testing to serve as available physical tests for computer modeling calibration. Furthermore, this component testing allowed researchers to identify system components deemed critical to minimize the maximum dynamic deflection.

Table 2.1. Summary of Containment Options.

Name	Configuration	Comments
Post Design Typology: Vertical Posts (chain link fence directly connected to posts)		
Option A—Weak Post		• Components readily available. • Easy construction. • Higher likelihood for upright motorcycle riders to directly impact the posts. • Post concept is intended to function as a type of energy absorbing system.
Post Design Typology: Protruding Posts to the back of the system (chain link fence not directly connected to posts, instead to horizontal railings)		
Option B—7-Shaped Post		• Reduces likelihood for upright motorcycle riders to directly impact the posts. • Post offset may be limited. • Welding needed for post components.
Option C—U-Shaped Post		• Reduces likelihood for upright motorcycle riders to directly impact the posts. • Symmetry minimizes interaction with the rider even at the bottom of the post. • Welding needed for post components.

CHAPTER 3: DYNAMIC COMPONENT TESTING

3.1 PENDULUM FACILITY

The TxDOT Fence Barrier for Motorcycles was tested at the TTI outdoor pendulum testing facility. The pendulum impacted the TxDOT Fence Barrier for motorcycles at a target speed of 12 mi/h and at a height of 27 inches above the ground, which represents the bumper height of a small passenger car. The honeycomb material is replaced after each test, and the bogie is reused.

3.2 TEST ARTICLE DESIGN AND CONSTRUCTION

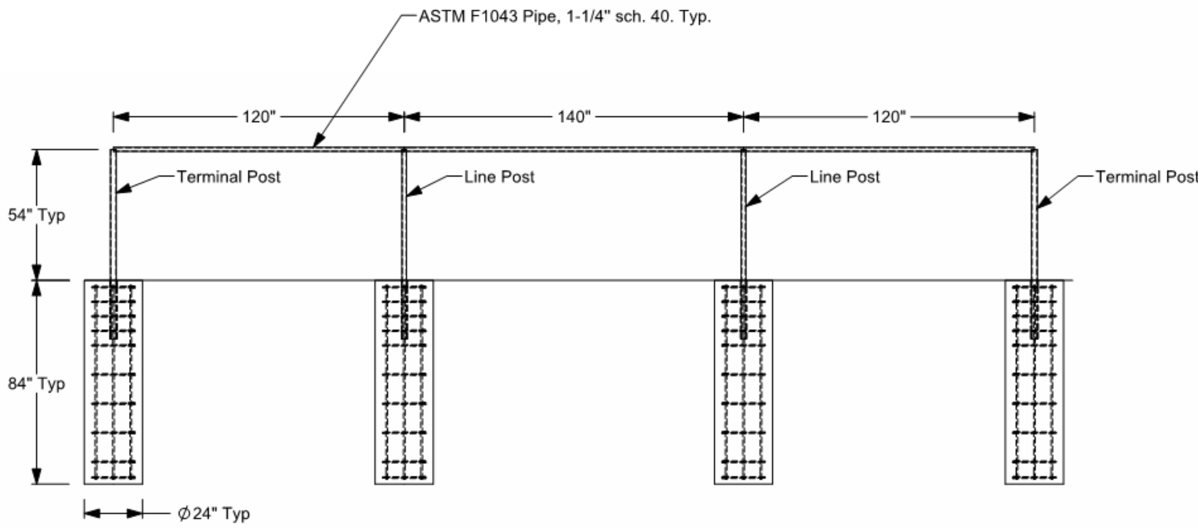
Each test article was comprised of a single panel of chain link fence mesh installed across three spans (four posts) at TTI's Proving Ground Pendulum Facility to dynamically determine performance of the fence when impacted by a 517 lb pendulum bogie at targeted speeds of 7 or 12 mi/h. The target impact point of the bogie on the fence was mid-span between the two center posts at a height of 27 inches above the ground line (grade).

Two types of 48-inch tall galvanized after weaving (GAW), knuckle selvage, chain link fence mesh were used, depending upon the test: either a 1½-inch nominal mesh of AWG 9-gauge (0.1483 inch diameter) wire, or a 2-inch nominal mesh of 9-gauge wire.

Four 78-inch long steel posts supported the mesh: two outboard terminal posts and two inboard line posts. The line posts were spaced on 140-inch centers and straddled the centerline of the pendulum bogie's path. The centerline of each terminal post was located 120-inches from the nearest line post. The line posts were 1½-inch nominal schedule 40 (1.900 inches outside diameter (O.D.) by 0.145-inch wall thickness) galvanized steel pipe, and the terminal posts were 2-inch nominal schedule 40 (2.375 inches O.D. by 0.154-inch wall thickness) galvanized steel pipe. Top railing, when used, was 1¼-inch nominal schedule 40 (1.660 inches O.D. by 0.140-inch wall thickness) galvanized steel pipe. All pipes met ASTM F1043 specifications. Standard post fittings and tension wire were used in the installation on certain tests.

The posts were each inserted into 24-inch long Schedule 40 PVC pipe sleeves (2-inch for line posts, 2½-inch for terminal posts), which were embedded in 24 inches in diameter by 7 ft deep steel reinforced concrete pier foundations. The holes for the foundations were drilled into in-situ soil.

See Figure 2.2 for pendulum test article details.



Test Number	Target Speed (mph)	Mesh Size (inches)	Line Posts	Top Rail	Partial Bottom Rail	Tension Wire
PT1	7	2	Y	N	N	N
PT2	7	2	N	N	N	N
PT3	7	1 1/2	Y	N	N	N
PT4	7	2	Y	Y	N	Y
PT5	7	2	Y	Y	Y, ALUM TIES	N
PT6	12	2	N	N	N	N
PT7	7	2	Y	N	Y, STEEL TIES	N

Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Project #469688-2-P Motorcycle Pendulum Test | 2018-08-27
Drawn by JCK | Scale 1:50 | Sheet 1 of 3 Test Installation

Figure 2.2. Motorcycle Pendulum Test Article.

3.3 TEST NO. 469688-2 P1

For Test P1, the target bogie speed was 7 mi/h into a 2×2-inch mesh supported by four posts, but without the top and bottom rails and tension wire. The mesh was attached to each terminal post with three chainlink fence clamps and was wire-tied with aluminum ties to each line post in three places.

The pendulum bogie impacted the fence mesh at a height of 27 inches above ground level while traveling at an impact speed of 7.0 mi/h. At 0.017 s, the top edge of the fence mesh began to deflect upstream, and at 0.072 s, the top of the right center post began to deflect downstream. By 0.158 s, the leading cables suspending the bogie contacted the top of the fence mesh, and by 0.333 s, the fence mesh reached maximum deflection of 28.7 inches. Maximum permanent deformation of the mesh after the test was 4.5 inches. Photographs of the support before and after the test, and a summary of the test, is provided in Table 3.1.

Longitudinal occupant impact velocity was 13.8 ft/s at 0.392 s, maximum longitudinal occupant ridedown acceleration was 1.6 g between 0.392 and 0.402 s, and the maximum 50-ms average acceleration was −1.8 g between 0.295 and 0.345 s.

3.4 TEST NO. 469688-2 P2

For Test P2, the target bogie speed was 7 mi/h into a 2×2-inch mesh supported by only the two terminal posts and without the line posts, top and bottom rails, and tension wire. The mesh was attached to each terminal post with three chainlink fence clamps.

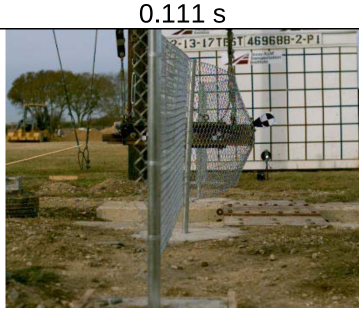
The pendulum bogie impacted the fence mesh at a height of 27 inches above ground level while traveling at an impact speed of 7.0 mi/h. At 0.031 s, the leading cables suspending the bogie contacted the top of the fence mesh, and at 0.102 s, the bottom of the fence mesh released from the 2×8-inch support board. The impact wave of the fence mesh reached the right post at 0.187 s, and the top of the right post began to deflect downstream at 0.208 s. The fence mesh reached maximum deflection of 47.8 inches at 0.570 s. Maximum permanent deformation of the mesh after the test was 4.25 inches. Photographs of the support before and after the test and a summary of the test is provided in Table 3.2.

Longitudinal occupant impact velocity was 10.5 ft/s at 0.516 s, maximum longitudinal occupant ridedown acceleration was 1.3 g between 0.660 and 0.670 s, and the maximum 50-ms average acceleration was −1.3 g between 0.642 and 0.692 s.

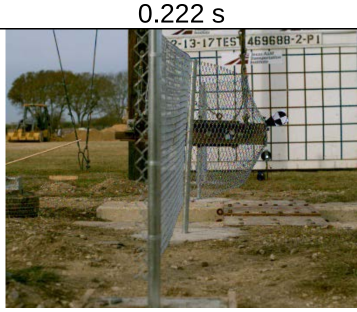
Table 3.1. Summary of Results for Pendulum Test No. 469688-2 P1.

0.000 s

0.111 s



0.222 s



0.333 s

General Information
- Test Agency....................Texas A&M Transportation Institute
- Test No. 469688-2 P1
- Date...2017-12-13

Test Article
- Type .... Fence Barrier
- Name.......................... TxDOT Fence Barrier for Motorcycles
- Installation Height ....54 inches
- Material of Key Element............Four 78-inch long steel posts supporting 48-inch tall GAW, knuckle selvage, 2-inch chain link fence mesh

Foundation Type............................. Concrete Footing in Soil

Test Vehicle
- Type ....Bogie
- Designation...Pendulum
- Test Inertia Mass ....517 lb

Impact Conditions
- Speed .... 7.0 mi/h
- Angle ....90 deg

Maximum Deflection..28.7 inches

Maximum Permanent Deformation.......................4.5 inches

Occupant Risk Values
- Longitudinal Occupant Impact Velocity .... 13.8 ft/s
- Max Longitudinal 10-ms Ridedown Acceleration............1.6 g
- Max Longitudinal 50-ms Average.................................−1.8 g

Before Test

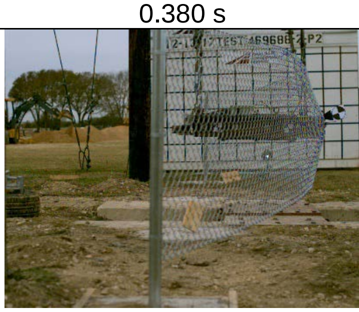
After Test

Table 3.2. Summary of Results for Pendulum Test No. 469688-2 P2.

0.000 s

0.190 s

0.380 s



0.570 s

General Information
- Test Agency: Texas A&M Transportation Institute
- Test No.: 469688-2 P2
- Date: 2017-12-13

Test Article
- Type: Fence Barrier
- Name: TxDOT Fence Barrier for Motorcycles
- Installation Height: 54 inches
- Material of Key Element: Two 78-inch long steel posts supporting 48-inch tall GAW, knuckle selvage, 2-inch chain link fence mesh

Foundation Type: Concrete Footing in Soil

Test Vehicle
- Type: Bogie
- Designation: Pendulum
- Test Inertia Mass: 517 lb

Impact Conditions
- Speed: 7.0 mi/h
- Angle: 90 deg

Maximum Deflection: 47.8 inches

Maximum Permanent Deformation: 4.25 inches

Occupant Risk Values
- Longitudinal Occupant Impact Velocity: 10.5 ft/s
- Max Longitudinal 10-ms Ridedown Acceleration: 1.3 g
- Max Longitudinal 50-ms Average: −1.3 g

Before Test

After Test

3.5 TEST NO. 469688-2 P3

For Test P3, the target bogie speed was 7 mi/h into a 1½×1½-inch mesh supported by four posts, but without the top and bottom rails and tension wire. The mesh was attached to each terminal post with three chainlink fence clamps and was wire-tied with aluminum ties to each line post in three places.

The pendulum bogie impacted the fence mesh at a height of 27 inches above ground level while traveling at an impact speed of 7.2 mi/h. At 0.103 s, the top of the right post began to deflect downstream, and at 0.203 s, the leading cables suspending the bogie contacted the top of the fence mesh. The near end post began to deflect downstream at 0.226 s, and the fence mesh reached maximum deflection of 29.25 inches at 0.309 s. Maximum permanent deformation of the mesh after the test was 2.75 inches. Photographs of the support before and after the test, and a summary of the test, are provided in Table 3.3.

Longitudinal occupant impact velocity was 14.8 ft/s at 0.379 s, maximum longitudinal occupant ridedown acceleration was 1.8 g between 0.379 and 0.389 s, and the maximum 50-ms average acceleration was −2.1 g between 0.269 and 0.319 s.

3.6 TEST NO. 469688-2 P4

For Test P4, the target bogie speed was 7 mi/h into a 2×2-inch mesh supported by four posts, the top rail, and tension wire in lieu of a bottom rail. The top rail was secured to each post with a loop cap. The mesh was wire-tied with aluminum ties to the top rail approximately every 25 inches. The mesh was attached to each terminal post with three chainlink fence clamps and was wire-tied with aluminum ties to the line posts only at the bottom of the fence material. The mesh was attached to the tension wire with hog rings approximately every 25 inches.

The pendulum bogie impacted the fence mesh at a height of 27 inches above ground level while traveling at an impact speed of 7.1 mi/h. At 0.064 s, the leading cables suspending the bogie contacted the top of the fence mesh, and at 0.068 s, the top rail began to deflect. The top of the right center post began to deflect downstream at 0.076 s, and the near outer post began to undulate at 0.115 s. The fence mesh reached maximum deflection of 26.4 inches at 0.282 s. Maximum permanent deformation of the mesh after the test was 3.0 inches. Photographs of the support before and after the test, and a summary of the test, are provided in Table 3.4.

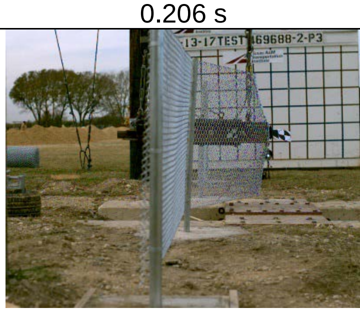
Longitudinal occupant impact velocity was 14.8 ft/s at 0.357 s, maximum longitudinal occupant ridedown acceleration was 1.4 g between 0.357 and 0.367 s, and the maximum 50-ms average acceleration was −2.0 g between 0.213 and 0.263 s.

Table 3.3. Summary of Results for Pendulum Test No. 469688-2 P3.


0.000 s


0.103 s


0.206 s


0.309 s

General Information
Test Agency.....................Texas A&M Transportation Institute
Test No. 469688-2 P3
Date...2017-12-13

Test Article
Type .... Fence Barrier
Name.......................... TxDOT Fence Barrier for Motorcycles
Installation Height ....54 inches
Material of Key Element.............Four 78-inch long steel posts supported 48-inch tall GAW, knuckle selvage, 1½-inch chain link fence mesh

Foundation Type............................. Concrete Footing in Soil

Test Vehicle
Type ....Bogie
Designation..Pendulum
Test Inertia Mass .... 517 lb

Impact Conditions
Speed .... 7.2 mi/h
Angle ....90 deg

Maximum Deflection...29.25 inches

Maximum Permanent Deformation.....................2.75 inches

Occupant Risk Values
Longitudinal Occupant Impact Velocity .... 14.8 ft/s
Max Longitudinal 10-ms Ridedown Acceleration.............1.8 g
Max Longitudinal 50-ms Average.................................−2.1 g

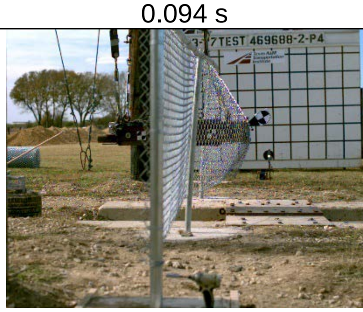

Before Test


After Test

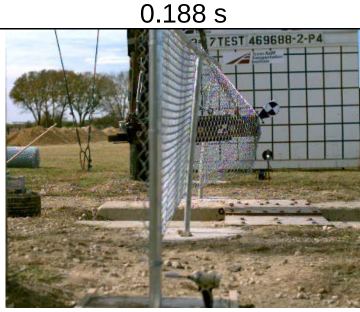
Table 3.4. Summary of Results for Pendulum Test No. 469688-2 P4.

0.000 s

0.094 s



0.188 s



0.282 s

General Information	
Test Agency	Texas A&M Transportation Institute
Test No.	469688-2 P4
Date	2017-12-13
Test Article	
Type	Fence Barrier
Name	TxDOT Fence Barrier for Motorcycles
Installation Height	54 inches
Material of Key Element	Four 78-inch long steel posts supported 48-inch tall GAW, knuckle selvage, 2-inch chain link fence mesh
Foundation Type	Concrete Footing in Soil
Test Vehicle	
Type	Bogie
Designation	Pendulum
Test Inertia Mass	517 lb
Impact Conditions	
Speed	7.1 mi/h
Angle	90 deg
Maximum Deflection	26.4 inches
Maximum Permanent Deformation	3.0 inches
Occupant Risk Values	
Longitudinal Occupant Impact Velocity	14.8 ft/s
Max Longitudinal 10-ms Ridedown Acceleration	1.4 g
Max Longitudinal 50-ms Average	−2.0 g

Before Test

After Test

3.7 TEST NO. 469688-2 P5

For Test P5, the target bogie speed was 7 mi/h. The 2×2-inch mesh was supported by four posts and by a top rail. The mesh was also connected to the bottom rail. The bottom rail, however, did not extend to the terminal posts. Additionally, the bottom rail was not secured to the line posts. The top rail was secured to each post with a loop cap. The mesh was wire-tied with aluminum ties to the top and bottom rails approximately every 25 inches. The mesh was attached to each terminal post with three chainlink fence clamps but was not secured to the line posts. A tension wire was not used in this installation.

The pendulum bogie impacted the fence mesh at a height of 27 inches above ground level while traveling at an impact speed of 7.3 mi/h. At 0.053 s, the near end of the bottom rail began to deflect upstream, and at 0.076 s, the leading cables suspending the bogie contacted the top rail. The top rail began to deflect at 0.077 s, and the top of the right center post began to deflect downward at 0.081 s. At 0.140 s, the near end post began to undulate, and the fence mesh began to separate from the center of the bottom rail at 0.165 s. The fence mesh reached maximum deflection of 23.4 inches at 0.300 s. Maximum permanent deformation of the mesh after the test was 5.25 inches. Photographs of the support, before and after the test, and a summary of the test are provided in Table 3.5.

Longitudinal occupant impact velocity was 14.1 ft/s at 0.332 s, maximum longitudinal occupant ridedown acceleration was 1.2 g between 0.332 and 0.342 s, and the maximum 50-ms average acceleration was −2.1 g between 0.159 and 0.209 s.

3.8 TEST NO. 469688-2 P6

For Test P6, the target bogie speed was 12 mi/h into a 2-inch × 2-inch mesh supported by only the two terminal posts, and without the top and bottom rails. The mesh was attached to each terminal post with three chainlink fence clamps. Tension wire was not used in this installation.

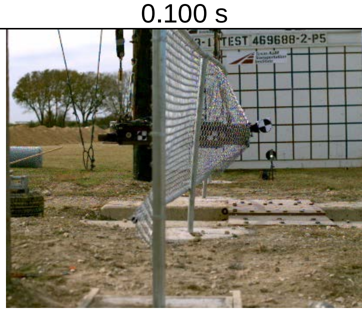
The pendulum bogie impacted the fence mesh at a height of 27 inches above ground level while traveling at an impact speed of 12.2 mi/h. At 0.030 s, the leading cables suspending the bogie contacted the top of the fence mesh, and at 0.164 s, the impact wave in the fence mesh reached the right post. The top of the right post began to deflect downstream at 0.177 s, and fence mesh reached maximum deflection of 71.7 inches at 0.540 s. Maximum permanent deformation of the mesh after the test was 26.5 inches. Photographs of the support before and after the test and a summary of the test is provided in Table 3.6.

Longitudinal occupant impact velocity was 13.1 ft/s at 0.401 s, maximum longitudinal occupant ridedown acceleration was 2.2 g between 0.588 and 0.598 s, and the maximum 50-ms average acceleration was −2.2 g between 0.335 and 0.385 s.

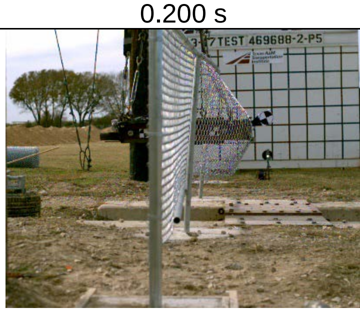
Table 3.5. Summary of Results for Pendulum Test No. 469688-2 P5.

0.000 s

0.100 s



0.200 s



0.300 s

General Information

Test Agency.....................Texas A&M Transportation Institute
Test No. 469688-2 P5
Date..2017-12-13

Test Article

Type .... Fence Barrier
Name.......................... TxDOT Fence Barrier for Motorcycles
Installation Height ....54 inches
Material of Key Element.............Four 78-inch long steel posts supported 48-inch tall GAW, knuckle selvage, 2-inch chain link fence mesh

Foundation Type............................. Concrete Footing in Soil

Test Vehicle

Type ....Bogie
Designation...Pendulum
Test Inertia Mass ....517 lb

Impact Conditions

Speed .... 7.3 mi/h
Angle ....90 deg

Maximum Deflection..23.4 inches

Maximum Permanent Deformation.....................5.25 inches

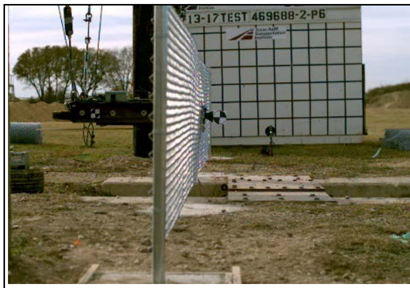
Occupant Risk Values

Longitudinal Occupant Impact Velocity .... 14.1 ft/s
Max Longitudinal 10-ms Ridedown Acceleration.............1.2 g
Max Longitudinal 50-ms Average.................................−2.1 g

Before Test

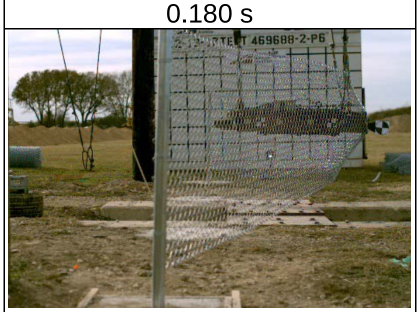

After Test

Table 3.6. Summary of Results for Pendulum Test No. 469688-2 P6.

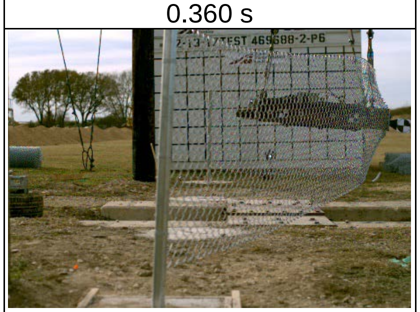


0.000 s

0.180 s



0.360 s



0.540 s

General Information

Test Agency.....................Texas A&M Transportation Institute
Test No. 469688-2 P6
Date..2017-12-13

Test Article

Type .... Fence Barrier
Name.......................... TxDOT Fence Barrier for Motorcycles
Installation Height ....54 inches
Material of Key Element.............Four 78-inch long steel posts supported 48-inch tall GAW, knuckle selvage, 2-inch chain link fence mesh

Foundation Type............................. Concrete Footing in Soil

Test Vehicle

Type ....Bogie
Designation..Pendulum
Test Inertia Mass ....517 lb

Impact Conditions

Speed .... 12.2 mi/h
Angle ....90 deg

Maximum Deflection..71.7 inches
Maximum Permanent Deformation.....................26.5 inches

Occupant Risk Values

Longitudinal Occupant Impact Velocity .... 13.1 ft/s
Max 10-ms Longitudinal Ridedown Acceleration.............2.2 g
Max Longitudinal 50-ms Average.................................−2.2 g

Before Test

After Test

3.9 TEST NO. 469688-2 P7

For Test P7, the target bogie speed was 7 mi/h into a 2×2-inch mesh supported by four posts and the top rail, but only a partial bottom rail that was not connected to the terminal posts. The top rail was secured to each post with a loop cap. The mesh was attached to each terminal post with three chainlink fence clamps. The mesh was also wire-tied with steel ties along with the bottom rail to the line posts only at the bottom of the mesh. The mesh was wire-tied with steel ties to the top and bottom rails approximately every 12 inches. Tension wire was not used in this installation.

The pendulum bogie impacted the fence mesh at a height of 27 inches above ground level while traveling at an impact speed of 7.3 mi/h. At 0.048 s, the top rail began to deflect, and at 0.056 s, the near end of the bottom rail began to deflect upstream. By 0.067 s, the top of the right center post began to deflect downstream, and by 0.080 s, the leading cables suspending the bogie contacted the top rail. The fence mesh reached maximum deflection of 21.2 inches at 0.250 s. Maximum residual deformation of the mesh after the test was 8.0 inches. Photographs of the support, before and after the test, and a summary of the test are provided in Table 3.7.

Longitudinal occupant impact velocity was 16.1 ft/s at 0.314 s, maximum longitudinal occupant ridedown acceleration was 1.4 g between 0.315 and 0.325 s, and the maximum 50-ms average acceleration was −2.5 g between 0.198 and 0.248 s.

3.10 CONCLUSIONS AND RECOMMENDATIONS

Seven pendulum tests were conducted on different chain link fence design alternatives. The basic installation consisted of a chain link fence supported by a combination of end (or terminal) posts, intermediate (or line) posts, and top and/or bottom steel horizontal rails spanning between posts. Table 3.8 summarizes the description and maximum dynamic deflection of all the tests.

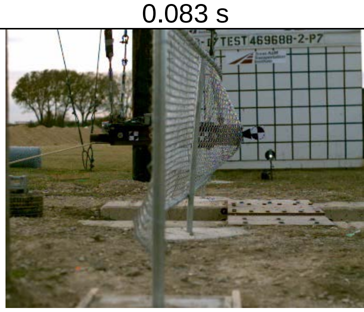
In all seven pendulum tests, the chain link fence successfully contained the pendulum bogie. System modifications were applied to the fence design, including adding interconnecting rails, removing line posts, and a few other minor changes. The P7 alternative design resulted in the least dynamic deflection. Test P7 served as the most rigid scenario, with the most restraints on the chain link mesh. This system contained the pendulum bogie with a maximum dynamic deflection of approximately 21.2 inches. Tests P1 and P7 were selected for reproduction with computer simulations, with the intent of calibrating the chain link fence computer model. Calibration of the model was completed mostly based upon dynamic deflection.

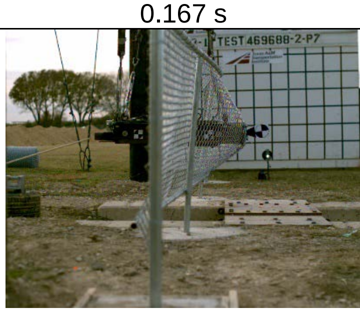
Comparing Test P1 with Test P3, the only relevant difference between the two test installations was the chain link mesh size (2×2 inches for P1; 1½×1½ inches for P3). The mesh size, however, did not seem to have appreciably affected the maximum dynamic deflection of the chain link fence (P1 was 28.7 inches; P3 was 29.25 inches). From an installation perspective, a chain link fence with 2×2 inches mesh size is more desirable because the 2-inch mesh is more common and readily available than the 1½×1½ inches size, which is an important consideration, especially for maintenance purposes after a crash.

Table 3.7. Summary of Results for Pendulum Test No. 469688-2 P7.


0.000 s


0.083 s


0.167 s


0.250 s

General Information
Test Agency.....................Texas A&M Transportation Institute
Test No. 469688-2 P7
Date...2017-12-13

Test Article
Type .... Fence Barrier
Name.......................... TxDOT Fence Barrier for Motorcycles
Installation Height ....54 inches
Material of Key Element.............Four 78-inch long steel posts supported 48-inch tall GAW, knuckle selvage, 2-inch chain link fence mesh

Foundation Type.............................. Concrete Footing in Soil

Test Vehicle
Type ....Bogie
Designation...Pendulum
Test Inertia Mass ....517 lb

Impact Conditions
Speed .... 7.3 mi/h
Angle ....90 deg

Maximum Deflection...21.2 inches

Maximum Permanent Deformation.......................8.0 inches

Occupant Risk Values
Longitudinal Occupant Impact Velocity .... 16.1 ft/s
Max 10-ms Longitudinal Ridedown Acceleration.............1.4 g
Max Longitudinal 50-ms Average.................................−2.5 g


Before Test


After Test

Table 3.8. Pendulum Test Results.

Test No.	Speed (mi/h)	Mesh Size (in×in)	Line Posts	Top Rail	Bottom Rail/Wire	Maximum Dynamic Deflection (ft)
P1	7.0	2×2	Yes	No	No	2.39
P2	7.0	2×2	No	No	No	3.98
P3	7.2	1½×1½	Yes	No	No	2.44
P4	7.1	2×2	Yes	Yes	Wire	2.20
P5	7.3	2×2	Yes	Yes	Partial Rail with aluminum wire-ties	1.95
P6	12.2	2×2	No	No	No	5.97
P7	7.3	2×2	Yes	Yes	Partial Rail with steel wire-ties	1.76

The main difference between tests P4, P5, and P7 was the connection type used to secure the chain link fence to the bottom horizontal rail or tension wire. In Test P4, a tension wire was attached to the bottom of the chain link fence, while for both tests P5 and P7, the central portion of the bottom of the fence was wire-tied to a steel horizontal partial rail. In Test P5, aluminum wire-ties were used, while in test P7 steel wire-ties were installed with 12-inch spacing. The maximum dynamic deflections of these three tests were still comparable. Only for P7, however, the chain link fence remained attached to the bottom rail, while in the other two cases (P4 and P5), the tension wire and the aluminum ties failed and allowed for a large opening at the bottom of the chain link fence installation.

Based on all the above observations, and the results of the pendulum tests performed, researchers suggested developing a chain link fence containment system with a 2×2 chain link mesh size, and top and bottom steel horizontal rails with discrete steel connections spaced at approximately 1 ft. Test P1 and Test P7 were selected for chain link fence computer simulation calibration (Table 3.8).

CHAPTER 4: CHAIN LINK FENCE FE MODEL DEVELOPMENT AND CALIBRATION[†]

4.1 CHAIN LINK FENCE FE MODEL DEVELOPMENT

The modeled chain link fence is a manufactured 2×2-inch mesh of 0.1483-inch O.D. (9 gauge) wire. The chain link net is developed diagonally with elements connected together as a knuckle, which allows some local rotation between the elements. However, considering the complexity in modeling contact interactions between weaved strands of the chain links, and the computer resources needed to simulate these interactions, researchers simplified the representation of the chain link fence by modeling a mesh of beams and null-shell elements that were connected at the beam intersections.

Null-shell elements are shell elements using MAT_NULL in LS-DYNA (*11*). They are low-density shell elements to help establish contact and avoid numerical issues between the beam and other elements. As Figures 4.1 and 4.2 show, the chain link fence beam elements were connected with each other and the null-shell elements by constrained nodal rigid bodies (CNRB), which made the chain link fence FE model stiffer than the actual knuckle connections in chainlink fencing.

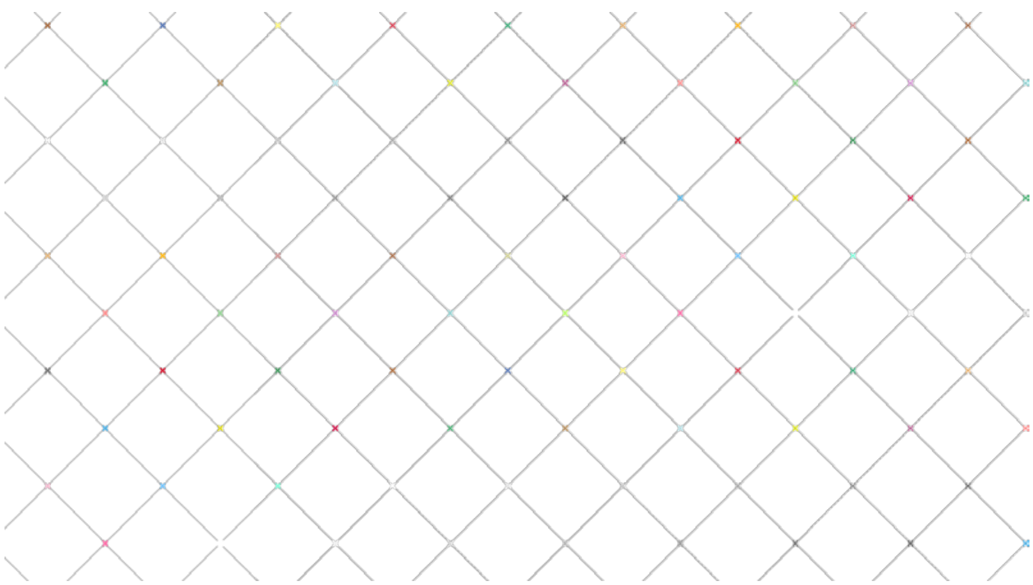


Figure 4.1. Beam Elements of the Chain Link Fence FE Model.

To predict more accurate dynamic deflections of the chain link fence in full-scale crash test simulations, the FE model of the chain link fence needed to be calibrated with the results of the pendulum tests completed in Chapter 3. Test P1 and Test P7 were chosen to calibrate the FE

[†] The opinions/interpretations identified/expressed in this chapter are outside the scope of TTI Proving Ground's A2LA Accreditation.

model of chain link fence, given the differences in construction these two tests presented. For the pendulum tests, the terminal posts were 2-inch schedule 40 pipe ((2.375-inch O.D. and 0.154-inch wall thickness). The line posts were 1½-inch schedule 40 pipe (1.900-inch O.D. and 0.145-inch wall thickness). The rails were 1¼-inch schedule 40 (1.660-inch O.D. and 0.140-inch wall thickness). The post and rail material were steel with 30 ksi yield strength. Figure 4.3 shows the FE models of posts and rails.

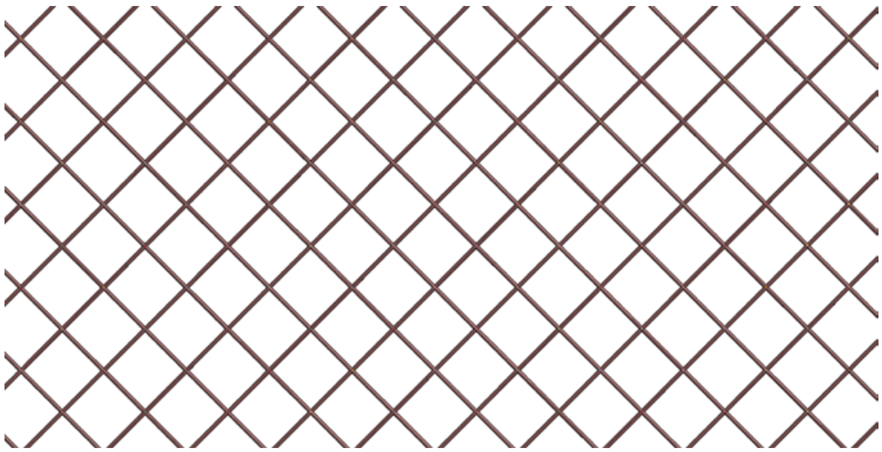


Figure 4.2. Chain Link Fence FE Model.

(a) Rail

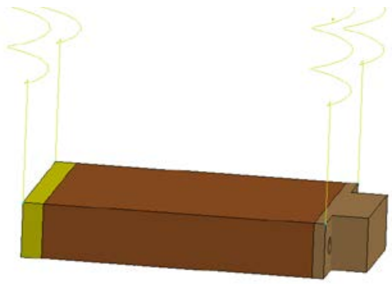
(b) Terminal Post

(c) Line Post

Figure 4.3. FE Model of Posts and Rail.

The chain link fence system used in the pendulum tests had three spans, with spacing of 10 ft, 11.67 ft, and 10 ft. The pendulum bogie was 517 lb and impacted the target at 7 mi/h (approximately replicating the impact severity when a 50th percentage male impacts the system with the designed angle and velocity). Figure 4.4 shows the pendulum FE model and pendulum bogie.

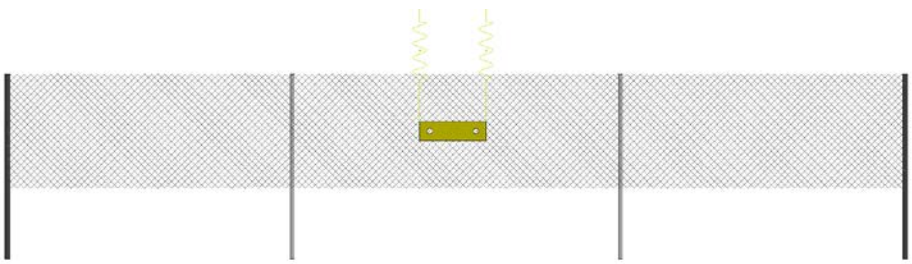
Figures 4.5 and 4.6 demonstrate the FE models of pendulum tests P1 and P7. In Test P1, the chain link fence system had two terminal posts and two line posts, but no top and bottom rails. In test P7, the chain link fence was supported by two terminal posts and two line posts, with top and partial bottom rails.



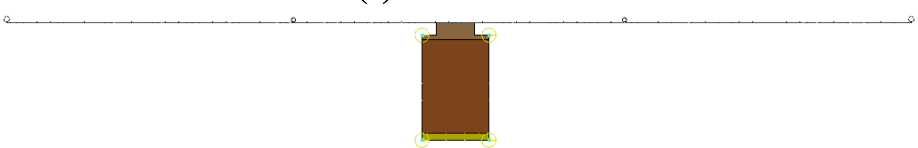
(a) Pendulum Bogie FE Model

(b) 517 lb Pendulum Bogie

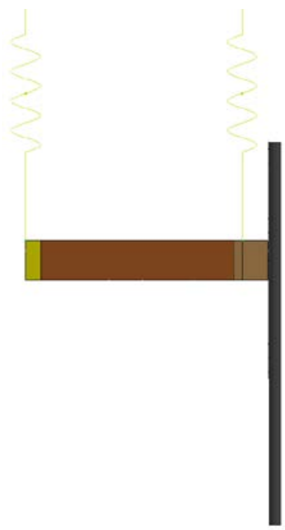
Figure 4.4. FE Model of the 517 lb Pendulum Bogie.



(a) Front View

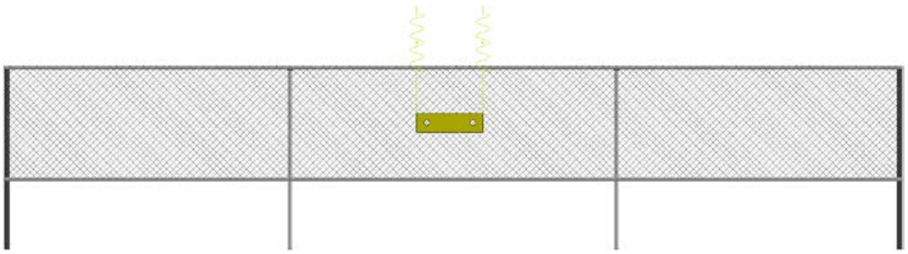


(b) Top View

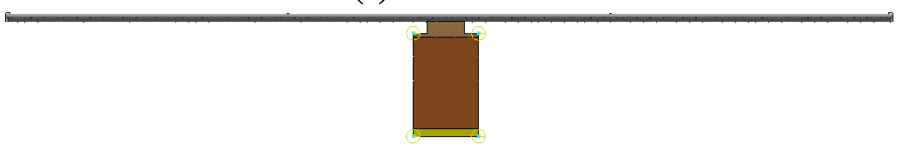


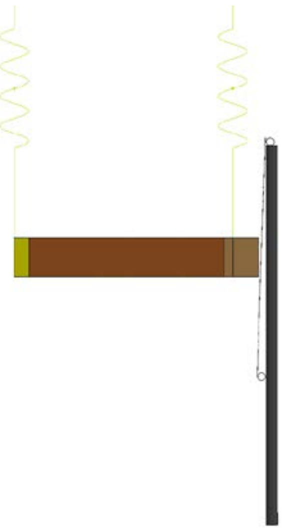
(c) Left View

Figure 4.5. FE Models of Pendulum Test P1.



(a) Front View





(b) Top View (c) Left View

Figure 4.6. FE Models of Pendulum Test P7.

4.2 CHAIN LINK FENCE FE MODEL CALIBRATION

The objective of this project was to develop a containment system, so researchers focused on the calibration of chain link fence's maximum dynamic deflection. After preliminary simulations, researchers found that using the original size of the beam elements resulted in much less maximum dynamic deflections. Therefore, an area reduction factor λ was introduced to calibrate the chain link fence's maximum dynamic deflection. A series of simulations was conducted to determine the best λ value. Figures 4.7 and 4.8 illustrate the maximum dynamic deflections by using different λ values in Test P1 and Test P7, respectively.

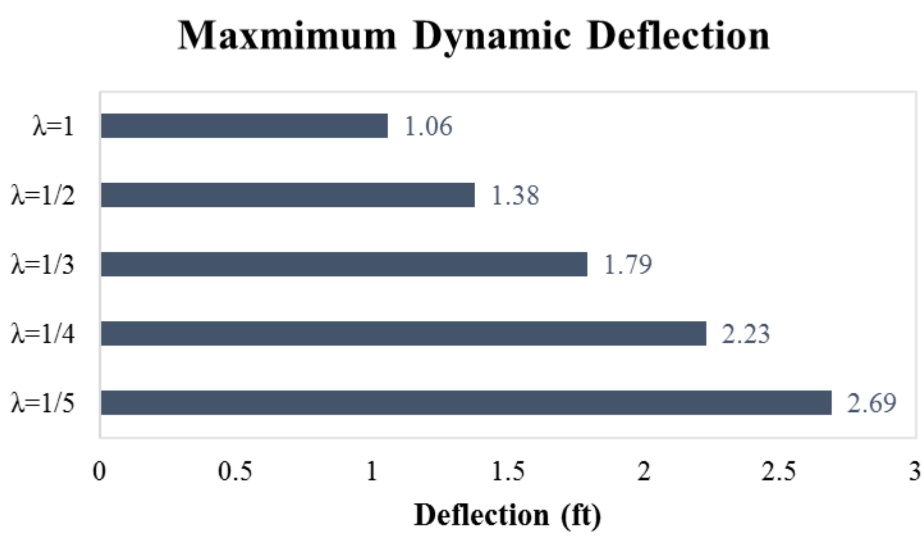


Figure 4.7. Maximum Dynamic Deflection with Different λ Values in Test P1 FE Simulation.

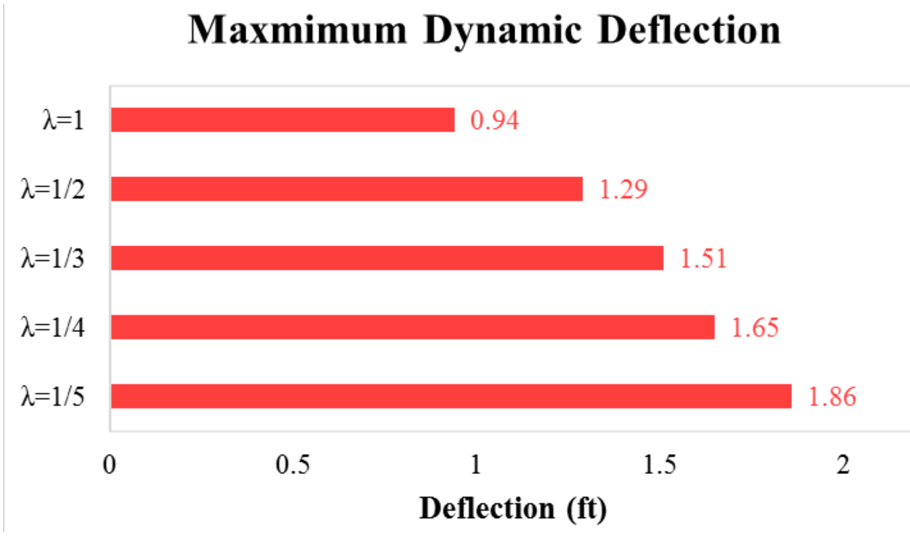
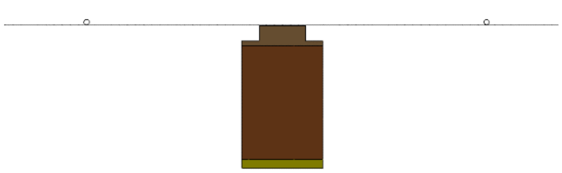
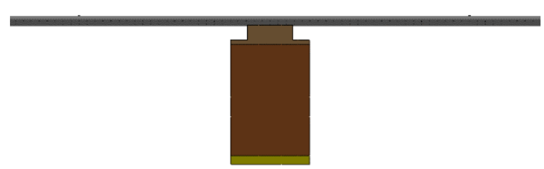
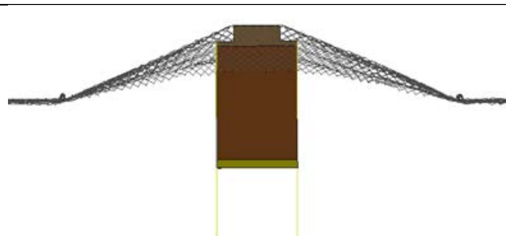
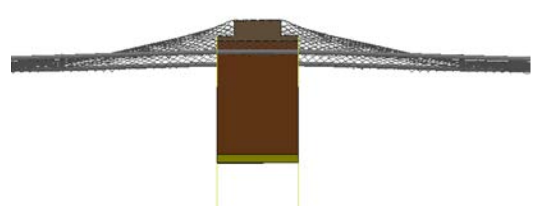


Figure 4.8. Maximum Dynamic Deflection with Different λ Values in Test P7 FE Simulation.

When λ equals to ¼, the chain link fence FE model had similar maximum dynamic deflections to what was exhibited in both Tests P1 and P7. The maximum dynamic deflections were 2.23 ft in Test P1 simulation (6.5 percent difference), and 1.65 ft in Test P7 simulation (6.2 percent difference). Table 4.1 includes the configurations of chain link fence at initial moment and at maximum dynamic deflection for Test P1 and test P7. Table 4.2 compares the frames of Test P1, and Table 4.3 compares the frames of Test P7 with the real pendulum tests.

Table 4.1. Initial and Maximum Dynamic Deflection Configurations in Test P1 and Test P7 Finite Element Simulations (Top Views).

Moment	FE Simulation of Pendulum Test P1	FE Simulation of Pendulum Test P7
Initial		
Maximum Dynamic Deflection		

Once the FE models of the chain link fence and other major components (posts and railings) were acceptably calibrated against the dynamic component testing, FE models of initially proposed system designs were developed for predictive FE impact simulations.

Table 4.2. Comparison between Finite Element Simulation and Pendulum Test P1.

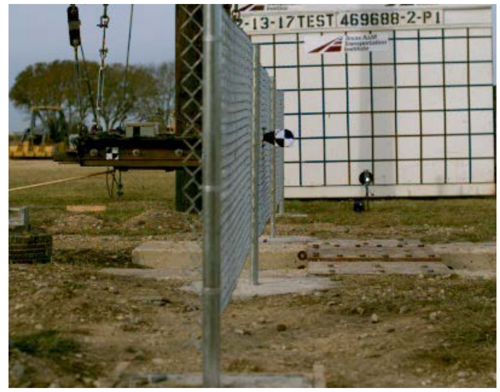
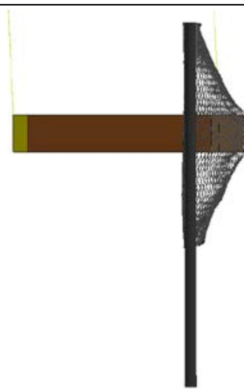
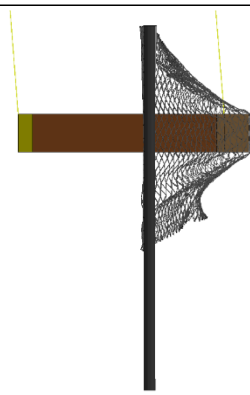
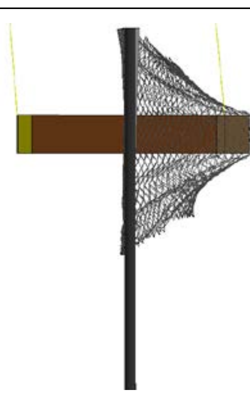
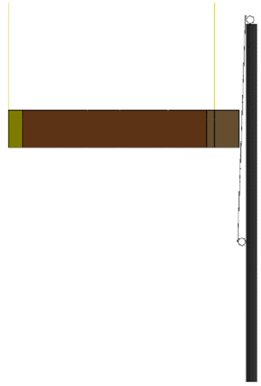
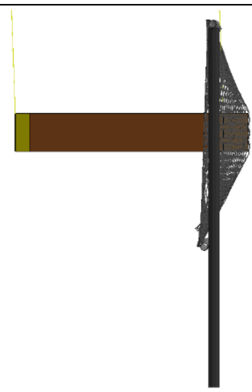
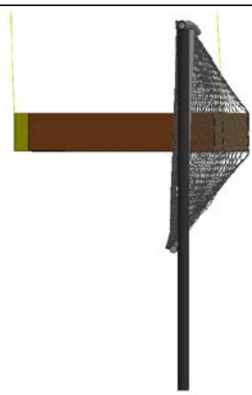
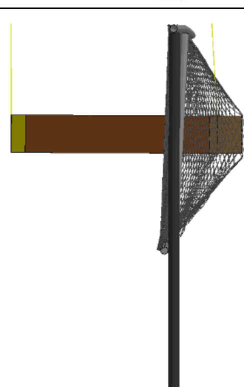
Time (s)	Finite Element Simulation	Pendulum Test
0.00		
0.11		
0.22		
0.33		

Table 4.3. Comparison between Finite Element Simulation and Pendulum Test P7.

Time (s)	Finite Element Simulation	Pendulum Test
0.000		
0.085		
0.165		
0.250		

CHAPTER 5: FE SIMULATIONS OF THE PROPOSED POST OPTIONS‡

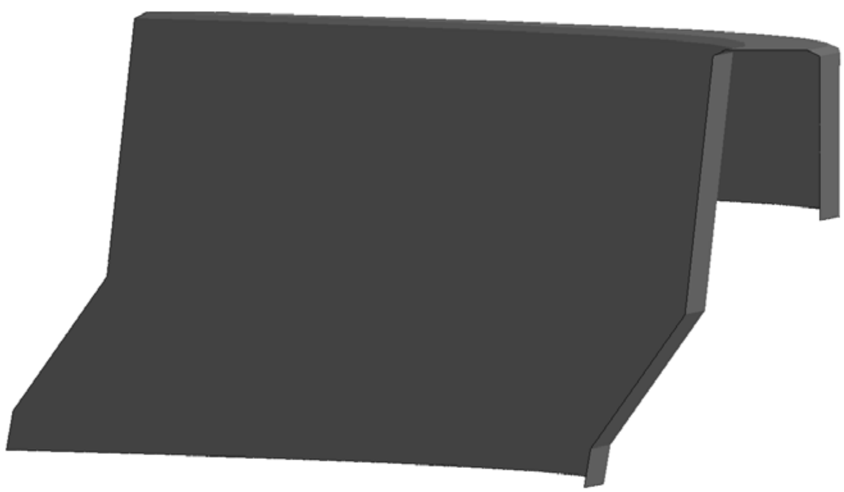
5.1 NEW JERSEY SHAPE BARRIER

An FE model of a 32-inch tall New Jersey profile barrier was developed and computer simulations were conducted with the LS-DYNA solver. Per TxDOT requirements, the barrier system was modeled replicating a radius of 500 ft.

The concrete barrier model was modeled with a total length of 72 ft. The concrete barrier was built using shell elements with rigid material properties. Figure 5.1 shows the 32-inch New Jersey shape concrete barrier model.

(a) Front View

(b) Top View



(c) Side View

Figure 5.1. 32-inch Tall New Jersey Shape Concrete Barrier FE Model.

‡ The opinions/interpretations identified/expressed in this chapter are outside the scope of TTI Proving Ground's A2LA Accreditation.

5.2 FAST HYBRID III 50TH PERCENTILE MALE DUMMY MODEL

TTI researchers included an existing available version of the simplified Hybrid III 50^{th} percentile male dummy model, referred to as the fast model. Although a detailed Hybrid III dummy model is also available, the fast model version was ultimately preferred to limit computational time needed for simulation completion. The detailed dummy requires longer simulation time and has previously encountered numerical instability in preliminary trial simulations. Given the aggressive schedule of this feasibility project, TTI researchers decided to use the fast dummy model in all simulations to limit the computational time without sacrificing dummy behavior and post-impact trajectory accuracy. Figures 5.2 and 5.3 compare the fast model to the detailed model.

Figure 5.2. Comparison of Detailed Dummy Model (Left) and Fast Dummy Model (Right).

Figure 5.3. Comparison of Mesh Size for Detailed Dummy Model (Left) and Fast Dummy Model (Right).

5.3 MOTORCYCLE FE MODEL

An FE computer model of a sport bike, the Kawasaki Ninja 500R, was used in this simulation research effort. The motorcycle model consists of 193,170 nodes and 194,120 elements, as shown in Figure 5.4.

Most of the connections were modeled with CNRBs because the majority of the joints between motorcycle parts are simple bolted connections. Other connections, such as the front and rear axles and the connection between the frame and the fork holders, were modeled as revolute joints. The contact between various parts of the model was defined using the Automatic Single Surface contact in LS-DYNA.

Another key step in the development of a reliable motorcycle FE model is the implementation of tire models. The working principle of a tire is somewhat similar to an airbag. Both use an enclosed volume that contains air at a specific pressure. Therefore the tires were modeled using the Simple Pressure Volume airbag definition in LS-DYNA. A pressure of 0.28 MPa (41 psi) was used to replicate typical motorcycle tire pressure.

In Table 5.1, Kawasaki Ninja 500R specifications were compared to the developed FE model to verify the geometric accuracy of the model. The model's measurements are relatively consistent with those of the physical motorcycle, because in all cases a difference of less than 5 percent was observed. Figure 5.4 compares the FE and the physical motorcycle models.

Table 5.1. Comparison of Geometrical Measurements of Physical and FE Motorcycle (Kawasaki Ninja 500R).

	Physical Motorcycle (mm)	FE Motorcycle (mm)	Percent Difference (*percent*)
Width	701	722.6	3.08
Height	1195	1194	0.08
Length	2096	2094.5	0.07
Wheelbase	1435	1448.5	0.94
Wheel Radius	292.1	289.9	0.75
Seat Height	787.4	786.1	0.17
Ground Clearance	150	155	3.33

Figure 5.4. Comparison of FE Model without Mesh to Physical Motorcycle.

5.4 IMPACT PARAMETERS

As previously mentioned, the 32-inch high New Jersey concrete barrier installation was to be rigidly installed with a radius of curvature of 500 ft. The nominal impact speed of the motorcycle rider for the full-scale crash test was 35 mi/h. The nominal impact angle was determined to be approximately 18°, with respect to the barrier tangent at the location of impact.

5.5 FE MODELS OF PROPOSED POST OPTIONS

5.5.1 Option A – Weak Post

The size of line and terminal posts, as well as horizontal rails, was determined by engineering analysis based on the ASTM Standard Specification for Strength and Protective Coatings on Steel Industrial Fence Framework (*12*) and Chain Link Fence Wind Load Guide for the Selection of Line Post and Line Post Spacing (*13*): a 1.900-inch O.D. and 0.145-inch wall thickness were chosen for line posts; a 2.375-inch O.D. and 0.154-inch wall thickness were used for terminal posts; and a 1.660-inch O.D. and 0.140-inch wall thickness were selected for horizontal rails. The yield strength of steel posts/rails and chain link fence were 30 ksi and 55 ksi, respectively. The chain link fence system was attached to the back of the concrete barrier, resulting in a system height of 4 ft above the top of the New Jersey system. Figure 5.5 shows the model of the chain link fence with a weak post system.

5.5.2 Option B – 7-Shaped Post

A 2½-inch × 2½-inch × $^{3}/_{16}$-inch square section was used for modeling the 7-shaped steel posts. As for the top and bottom horizontal rails, 2½-inch × 2½-inch × ¼-inch square sections were used. The posts are installed behind the chain link fence and are attached to the back side of the existing New Jersey safety shape barrier. The posts extended 1 ft beyond the back face of the concrete barrier. The total height of the retrofit attachment was 4 ft with a post spacing of 8 ft. The yield strength of the steel posts and chain-link fence were 30 ksi and 55 ksi, respectively.

The posts and rails were built using shell elements. One-foot length of the posts, starting from the bottom of the posts, was rigidly connected to the back of the barrier. The bottom rails were connected with line and terminal posts by CNRB. Figure 5.6 shows the FE model of 7-shaped post chain link fence system.

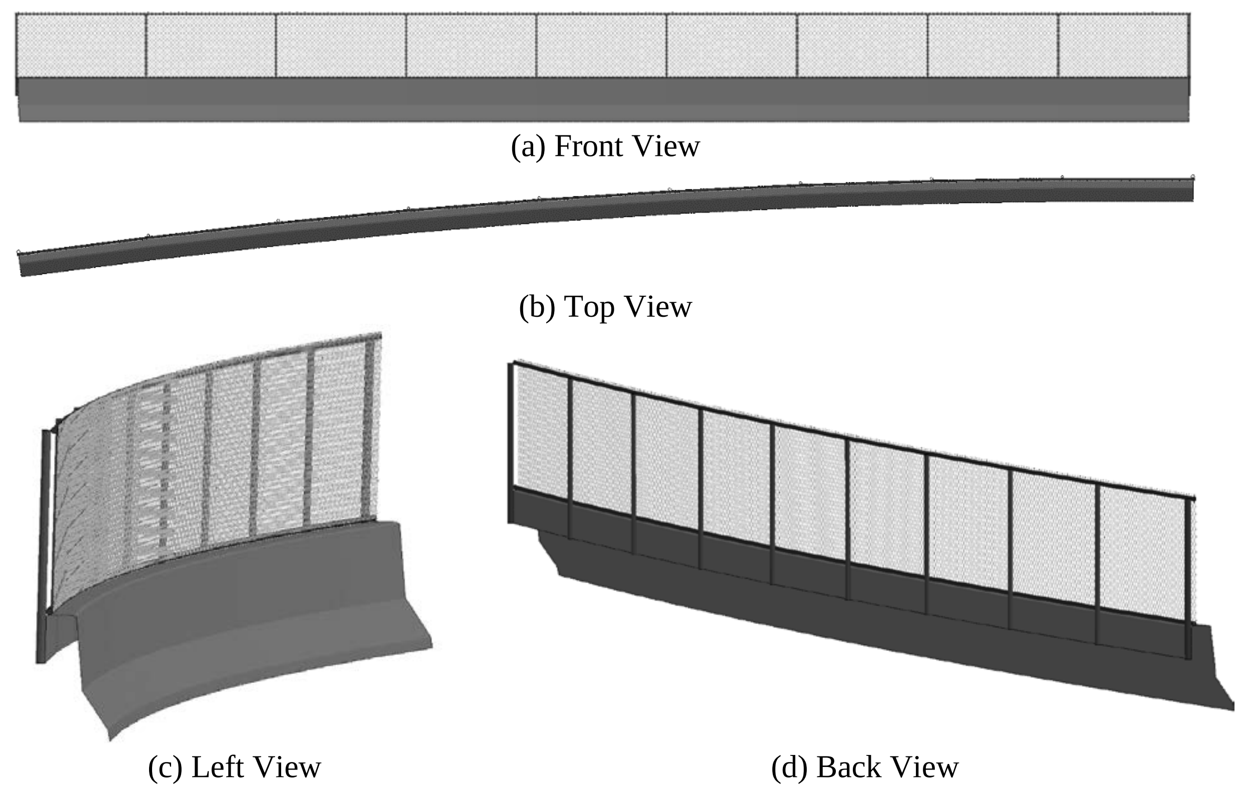


Figure 5.5. Option A – Weak Post FE Model.

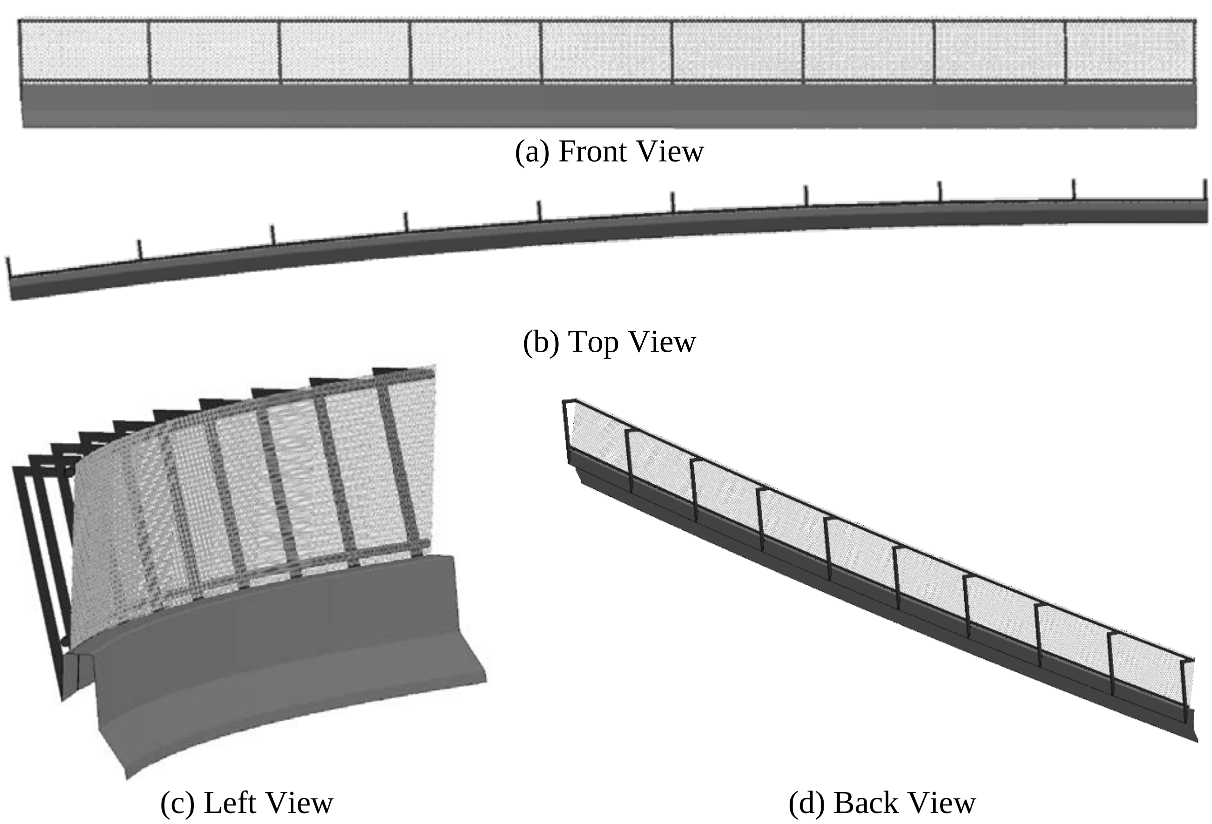


Figure 5.6. Option B – 7-Shaped Post FE Model.

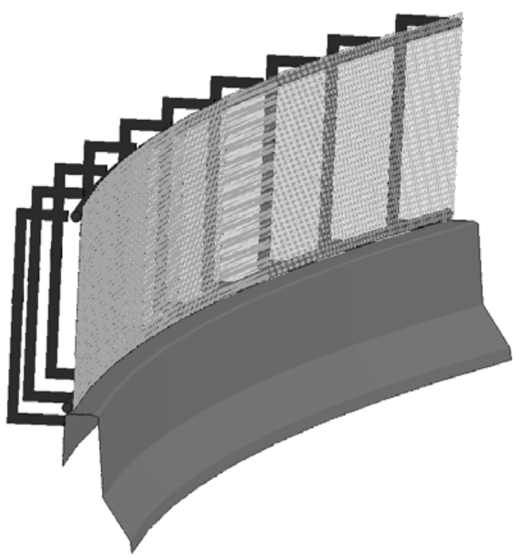
5.5.3 Option C – U-Shaped Post

A 2½-inch × 2½-inch × $^{3}/_{16}$-inch square section was used to model the U-shaped steel posts, and 2½-inch × ¼-inch tubes were used for the top and bottom horizontal rails. The posts were installed behind the chain link fence and attached to the back side of the existing New Jersey safety shape barrier. The posts extended 1 ft beyond the back face of the concrete barrier. The total height of the retrofit attachment was 4 ft, with post spacing of 8 ft. The yield strength of the steel posts and chain-link fence were 30 ksi and 55 ksi, respectively.

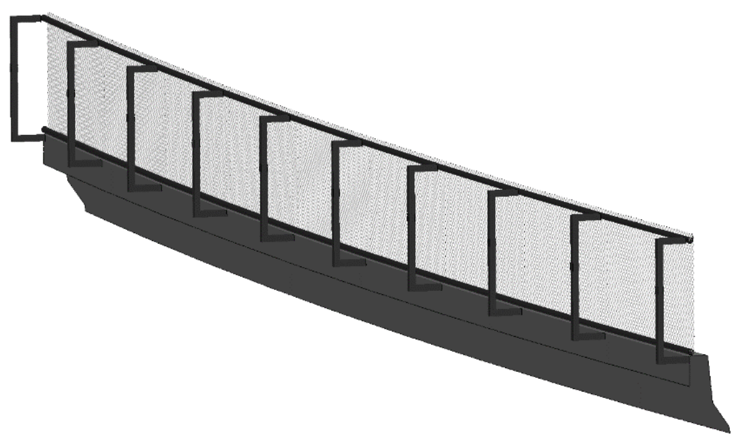
The posts and rails were built using shell elements. The bottom of the post was rigidly connected to the back of the barrier. The bottom rails were connected with line and terminal posts by CNRB. Figure 5.7 shows the FE model of the U-shaped post system.

(a) Front View

(b) Top View



(c) Left View



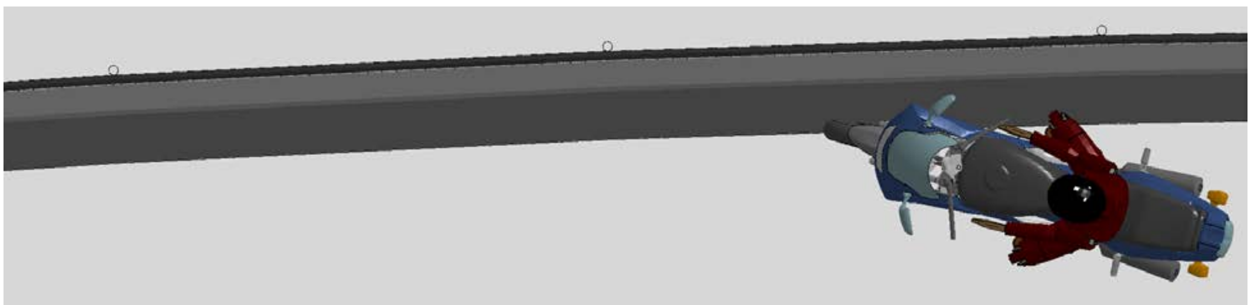
(d) Back View

Figure 5.7. Option C – U-Shaped Post FE Model.

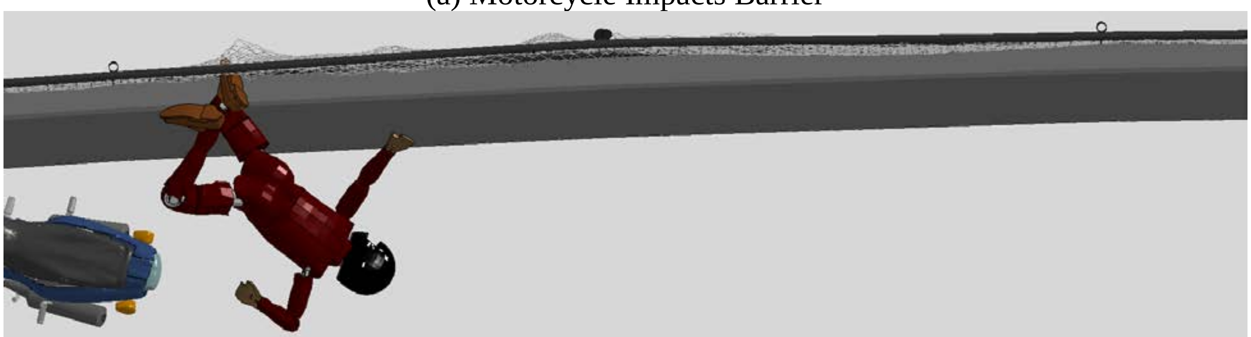
5.6 FE ANALYSIS RESULTS OF PROPOSED POST OPTIONS

5.6.1 Option A – Weak Post

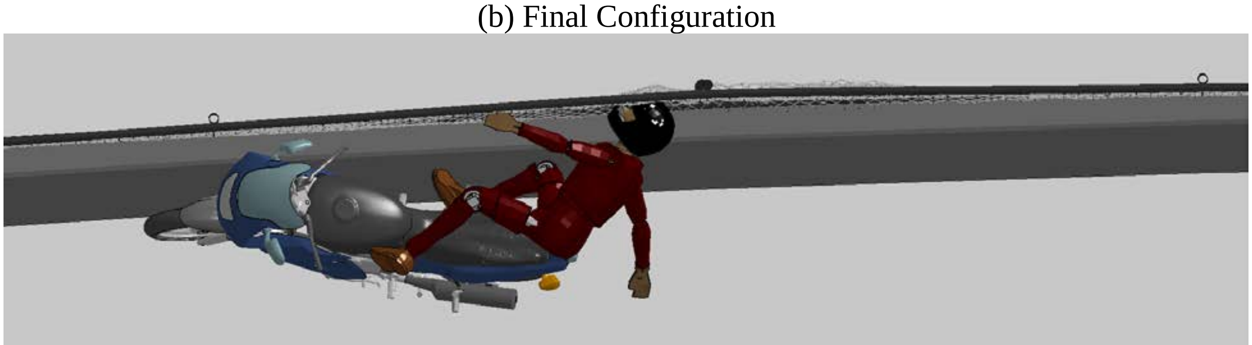
The dummy was positioned on the motorcycle in an upright position, and an initial 35 mi/h velocity was applied to them. The dummy impacted just before the post at an 18° impact angle with the chain link fence weak post system. The maximum deflection of the impacted line post was approximately 2.5 inches. Figure 5.8 shows the configuration at post's maximum displacement. The dummy was contained and redirected during the impact event, as shown in Figures 5.9 and 5.10.



(a) Motorcycle Impacts Barrier

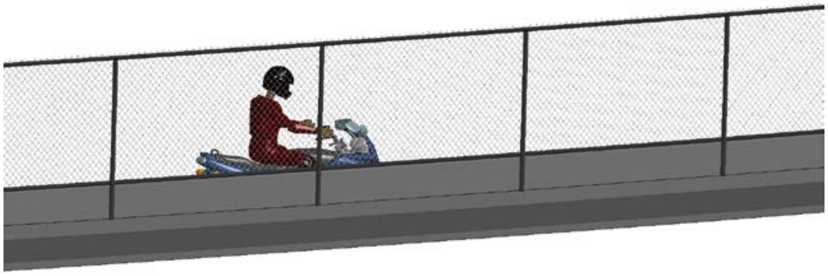


(b) Final Configuration



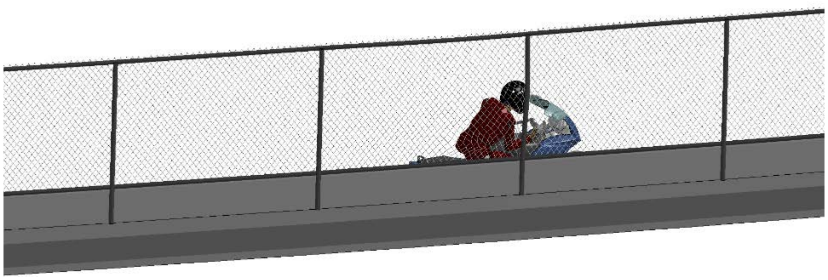
(c) Post Maximum Deflection

Figure 5.8. Impact Configuration – Weak Post Option.

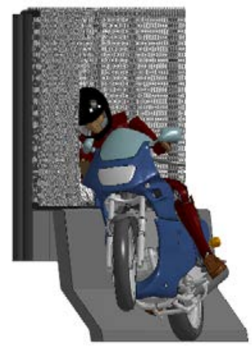


(a) Motorcycle Impacts Barrier

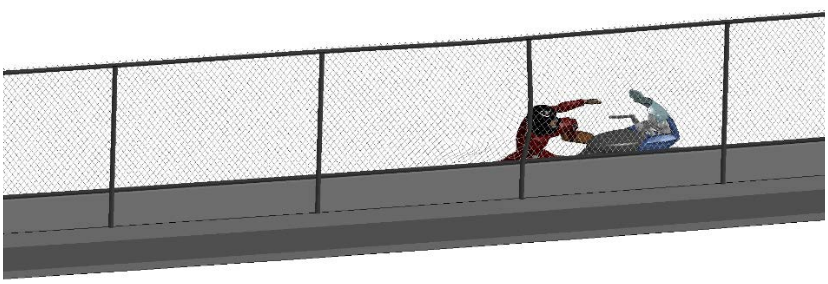
(a) Motorcycle Impacts Barrier



(b) Head and Shoulder Impact Fence

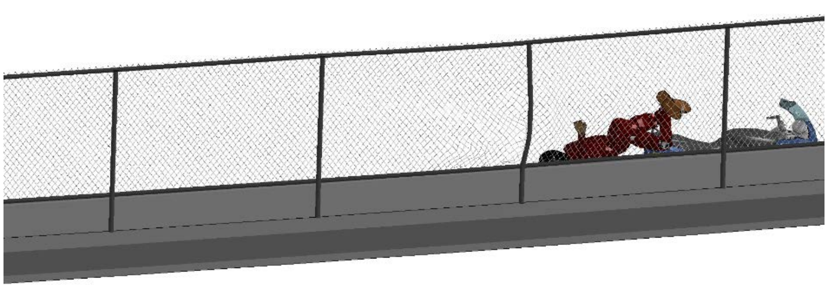


(b) Head and Shoulder Impact Fence



(c) Maximum Deflection of Impact Post

(c) Maximum Deflection of Impact Post



(d) Final Configuration

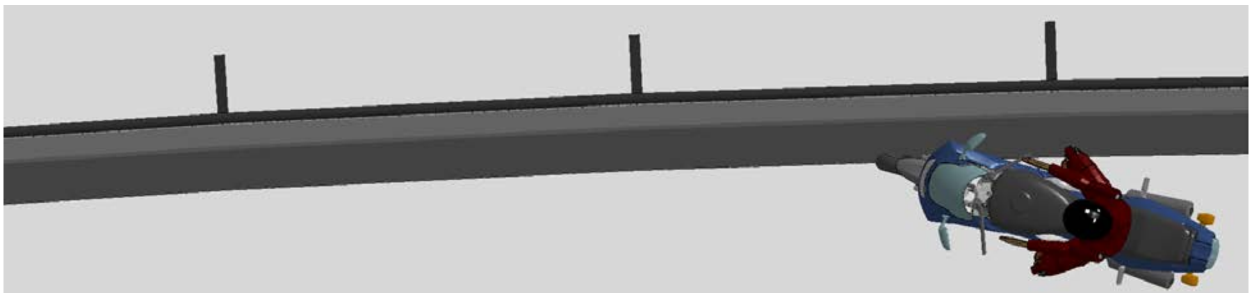
(d) Final Configuration

Figure 5.9. Motorcyclist's Interaction for Weak Post Option – Isometric View.

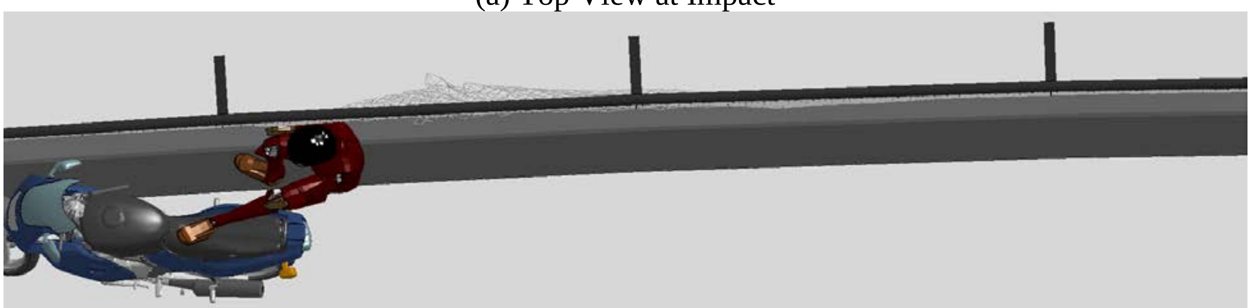
Figure 5.10. Motorcyclist's Interaction for Weak Post Option – Front View.

5.6.2 Option B – 7-Shaped Post

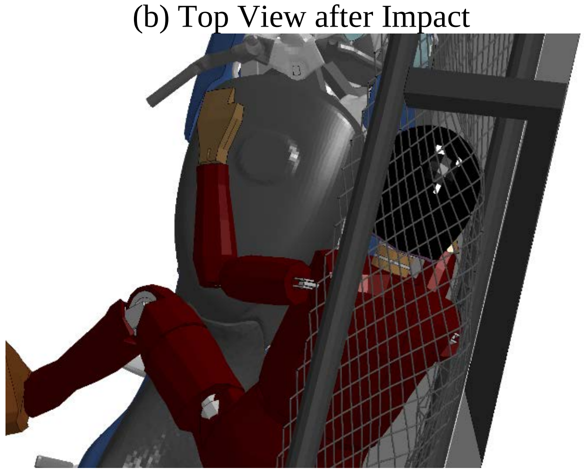
The dummy was positioned on the motorcycle in an upright position, and an initial 35 mi/h velocity was applied to them. The dummy impacted just before the post at an 18° impact angle with the chain link fence 7-shaped post system. Figure 5.11 shows images from the impact simulation. The maximum deflection of the chain link fence was approximately 6.25 inches. Figure 5.11c shows the configuration at the chain link fence's maximum displacement. The dummy was contained and redirected during the impact event, as shown in Figure 5.12 and 5.13.



(a) Top View at Impact

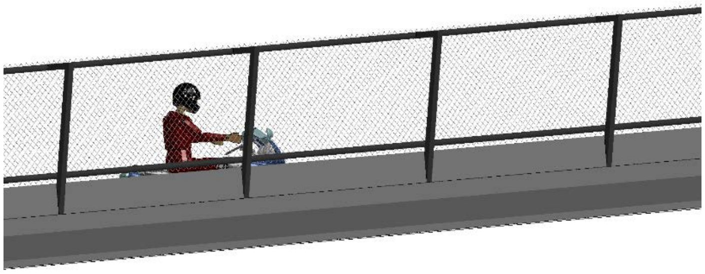


(b) Top View after Impact

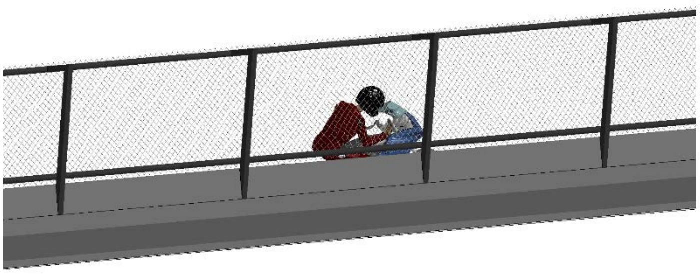


(c) Chain Link Fence Maximum Deflection

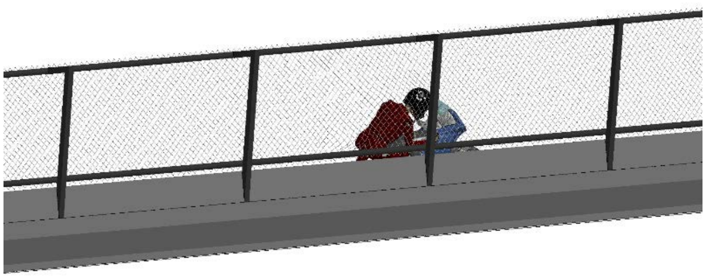
Figure 5.11. Impact Configuration – 7-Shaped Post Option.



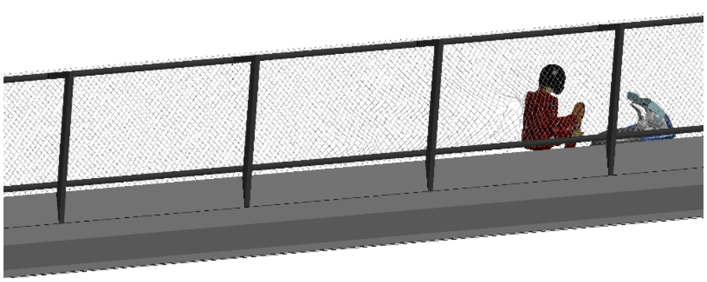
(a) Motorcycle Impacts Barrier



(b) Head and Shoulder Impact Fence

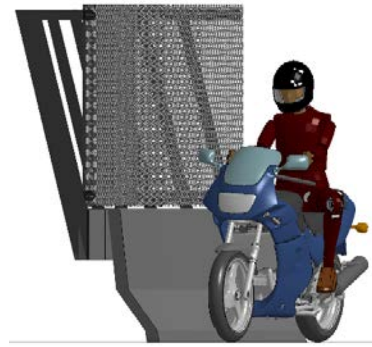


(c) Chain Link Fence Maximum Deflection at Post Location

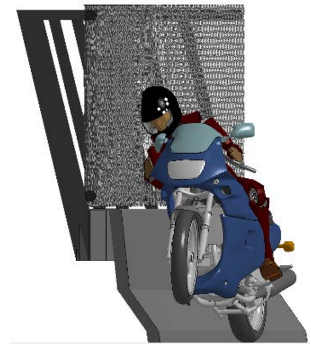


(d) Final Configuration

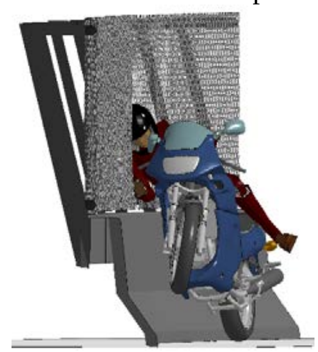
Figure 5.12. Motorcyclist's Interaction for 7-Shaped Post Option – Isometric View.



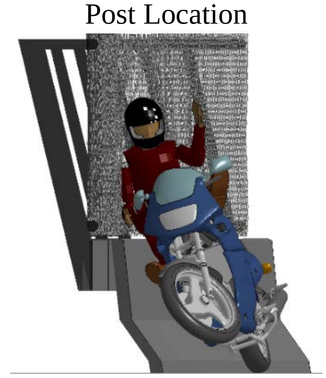
(a) Motorcycle Impacts Barrier



(b) Head and Shoulder Impact Fence



(c) Chain Link Fence Maximum Deflection at Post Location

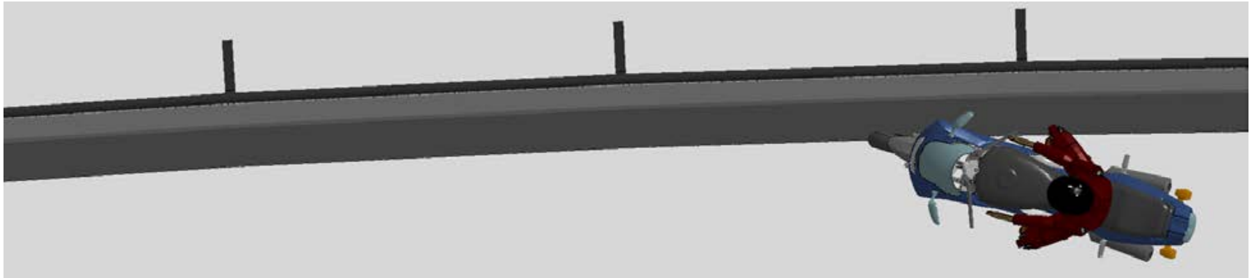


(d) Final Configuration

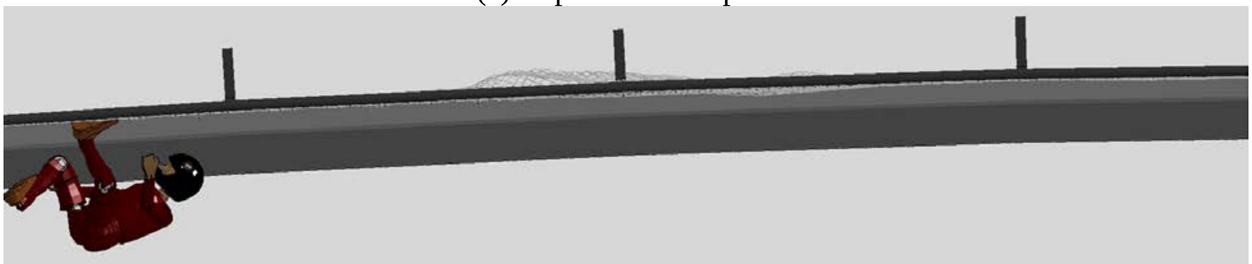
Figure 5.13. Motorcyclist's Interaction for 7-Shaped Post Option – Front View.

5.6.3 Option C – U-Shaped Post

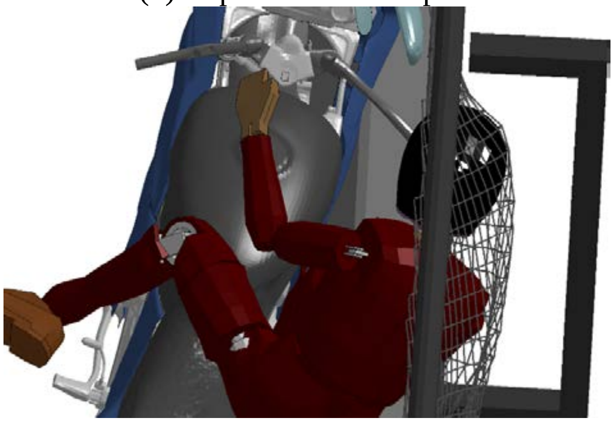
The dummy was positioned on the motorcycle in an upright position, and an initial 35 mi/h velocity was applied to them. The dummy impacted just before the post at an 18° impact angle with the chain link fence U-shaped post system. Figure 5.14 shows images from the impact simulation. The maximum dynamic deflection of the chain link fence was approximately 6.30 inches. Figure 5.14c shows the configuration at the chain link fence's maximum displacement. The dummy was contained and redirected during the impact event, as shown in Figures 5.15 and 5.16.



(a) Top View at Impact

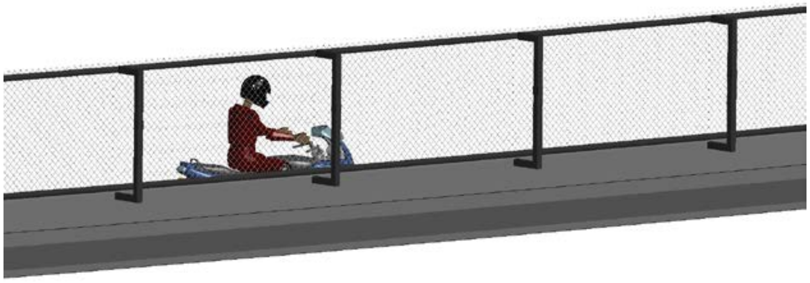


(b) Top View after Impact

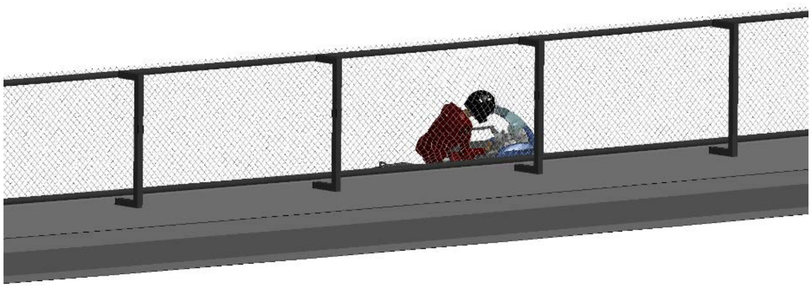


(c) Chain Link Fence Maximum Deflection

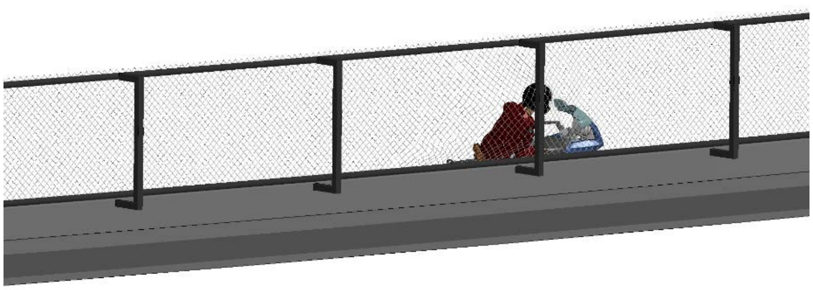
Figure 5.14. Impact Configuration – U-Shaped Post Option.



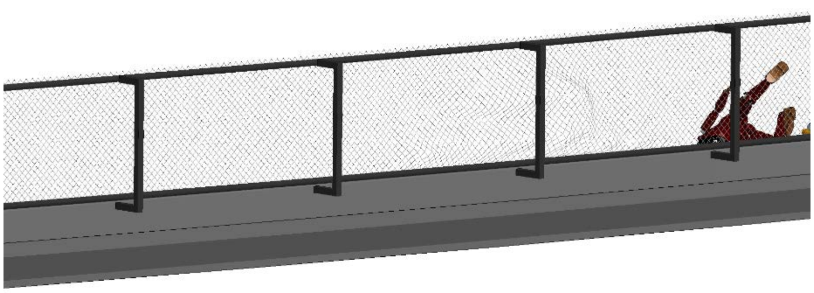
(a) Motorcycle Impacts Barrier



(b) Head and Shoulder Impact Fence

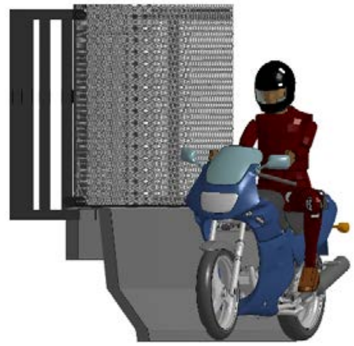


(c) Chain Link Fence Maximum Deflection at Post Location

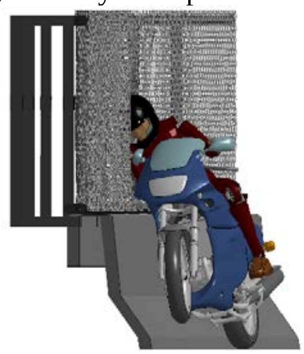


(d) Final Configuration

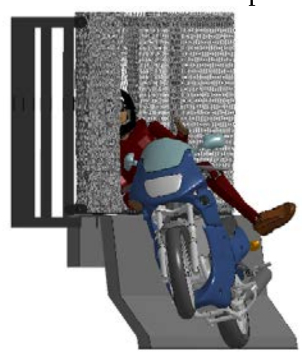
Figure 5.15. Motorcyclist's Interaction for U-Shaped Post Option – Isometric View.



(a) Motorcycle Impacts Barrier



(b) Head and Shoulder Impact Fence



(c) Chain Link Fence Maximum Deflection at Post Location

(d) Final Configuration

Figure 5.16. Motorcyclist's Interaction for U-Shaped Post Option – Front View.

5.7 INJURY EVALUATION

Head injury and chest accelerations obtained from the FE simulations of the Hybrid III dummy were used to determine the likelihood that an occupant would have sustained significant injury. The head injury criterion (HIC) is determined on the basis of the head acceleration. In the Hybrid-III and the THOR dummy FE model, the HIC is achieved by nodal output of acceleration from the center of gravity of the head. Head acceleration recorded during impact event is employed to calculate HIC_{15} value as follows (*14*):

$$HIC = \max\left[\left[\frac{\int_{t_1}^{t_1} a(t)dt}{t_2 - t_1}\right]^{2.5} (t_2 - t_1)\right]$$

The Hybrid III dummy is calibrated for frontal impacts only. Oblique impacts are not calibrated. Since the dummy FE model was not validated, the values obtained from the accelerometer could be unrealistic. However, relative differences in HIC values can be used to assess the performance of one design concept over the other. Researchers decided to use percentage ratios to compare the injury severity from different retrofit systems. The weak post revealed the worst injury to the impacted dummy. Compared with the weak post option, the 7-shaped post and U-shaped post options had approximately 13 percent HIC_{15} values and 9 percent chest acceleration values.

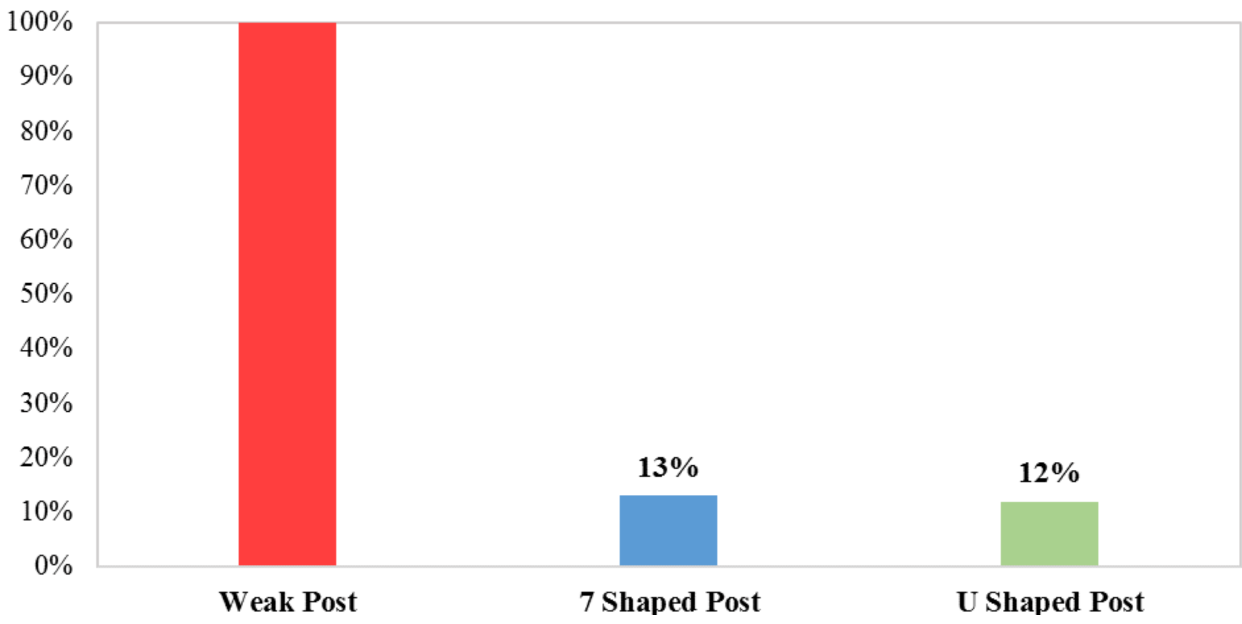


Figure 5.17. HIC15 Values Comparison.

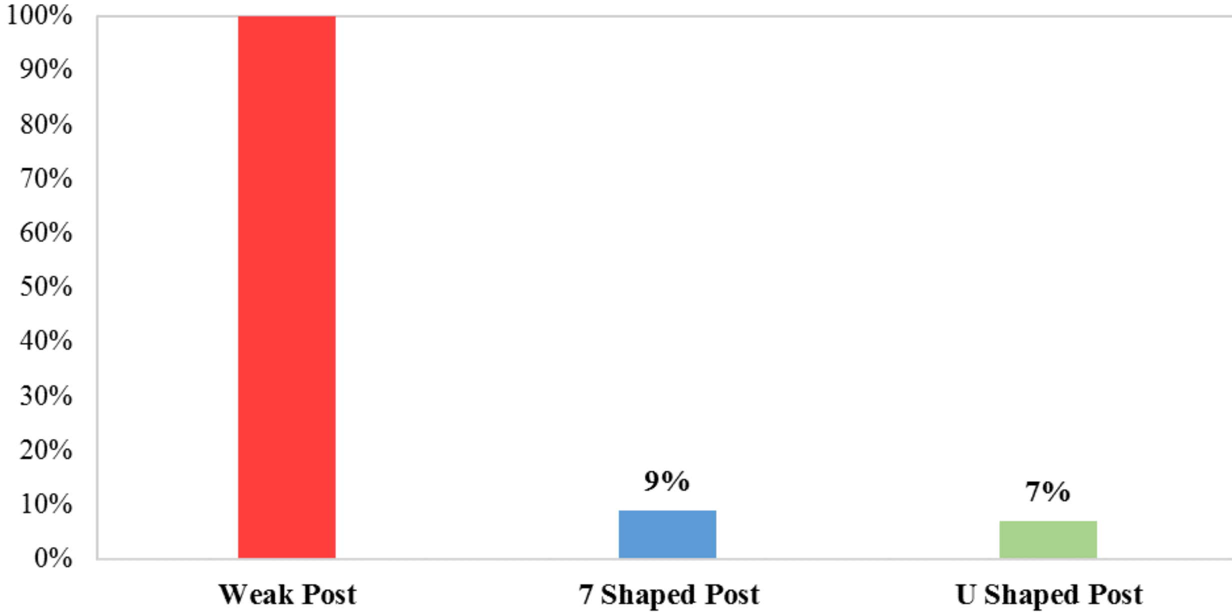


Figure 5.18. Chest Acceleration Values Comparison.

5.8 Conclusion of the Proposed Containment Options

The motorcycle rider was contained and redirected by all the simulated containment barrier designs. Maximum chain link fence deflection and post deflection were evaluated. In all cases, there was no indication of possible failure of the system components as a result of the impact event.

Rider-system interaction shows significant difference between the weak post option and the 7- and U-shaped post options. TxDOT specified the protrusion shall not be larger than 11 inches from the back face of the barrier to accommodate other attachments, such as signs, on the back of the concrete parapet. Impact computer simulations of the proposed 7-shaped post indicated that, because of the oblique nature of the post design, protrusion much larger than 11 inches should be considered to avoid interaction between the errant rider and the post during an anticipated impact event.

Therefore, the 7-shaped post option was eliminated in favor of a more symmetric post shape, such as the U-shaped posts. The U-shaped post option design was subsequently refined to consider the added 11-inch lateral protrusion constraint. Consideration was also given to ease of constructability for this post design. Therefore, it was decided to modify the original U-shaped post to a similar symmetric shape post pipe, which would limit its protrusion to a value not larger than 11 inches. The newly symmetrical U-shaped pipe design was named Modified U-shaped post.

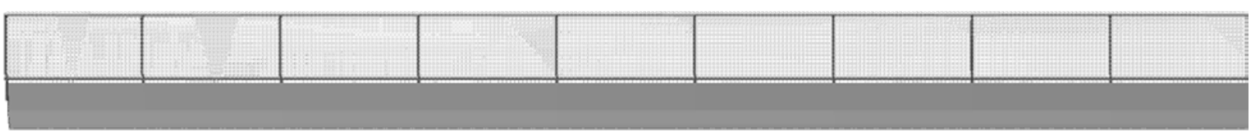
5.9 FE ANALYSIS OF MODIFIED U-SHAPED POST OPTION

5.9.1 Model Description

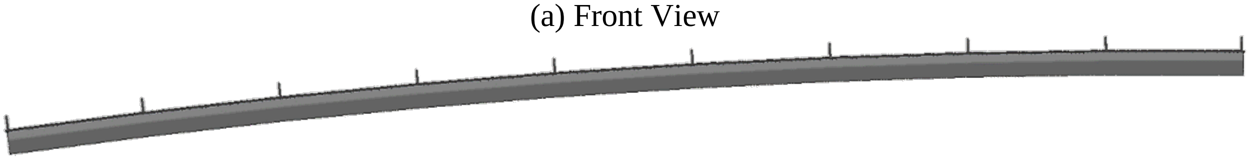
The Modified U-shaped option was designed to minimize the likelihood of an errant upright motorcycle rider directly impacting the discrete posts of the proposed chain link fence system.

A 1¼-inch schedule 40 pipe (1.660-inch O.D. and 0.140-inch wall thickness) was chosen for line post and rail modeling. The posts were attached to the back side of the existing New Jersey safety barrier. The total height of the chain link fence system attachment was 4 ft from the New Jersey top surface, and post spacing was 8 ft. The material yield strength properties of the modeled steel posts and the chain link fence were 30 ksi and 55 ksi, respectively.

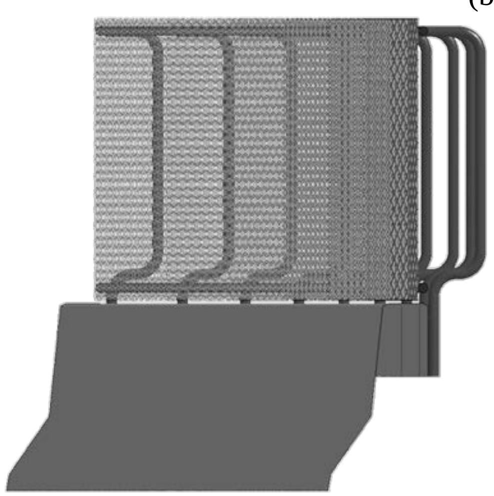
The posts and horizontal rails were modeled using shell elements. The bottom of the post was rigidly connected to the back of the barrier. The bottom horizontal rails were rigidly connected to the posts through a constrained nodal rigid body connection type. Figure 5.19 shows the Modified U-shaped post system FE model.

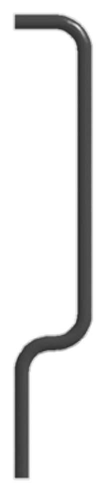


(a) Front View



(b) Top View



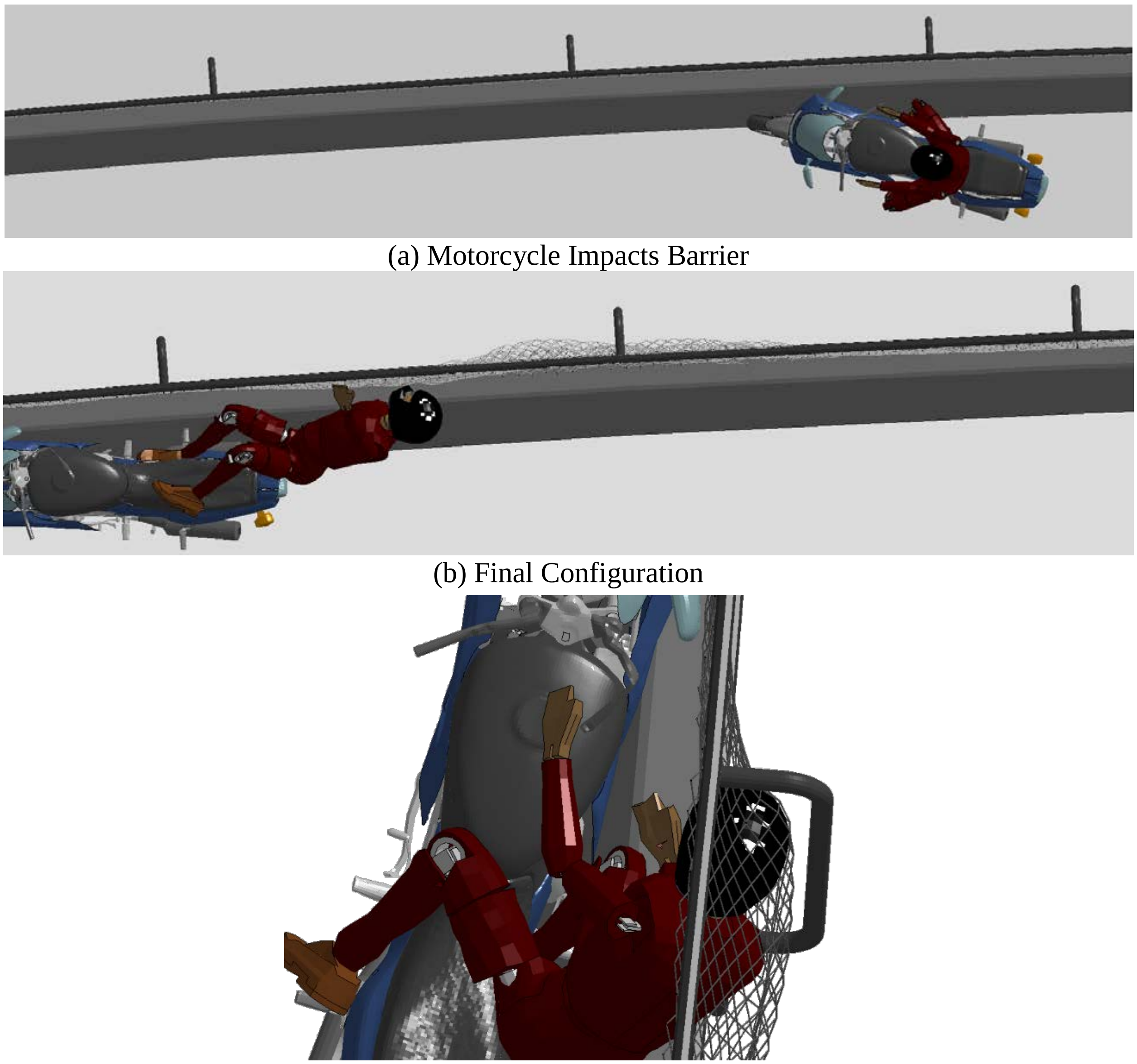


(c) Left View (d) The Modified U-Shaped Post

Figure 5.19. Modified U-Shaped Post FE Model.

5.9.2 Modified U-Shaped Post Option

The dummy was positioned on the motorcycle in an upright position, and an initial 35 mi/h velocity was applied to them. The dummy impacted just before the post at an 18° impact angle with the retrofit system. Figure 5.20 shows images from the impact simulation. The maximum deflection of the chain link fence resulted in approximately 6.8 inches. Figure 5.20c shows the configuration at chain link fence's maximum displacement. The dummy was contained and redirected during the impact event, as shown in Figures 5.21 and 5.22.

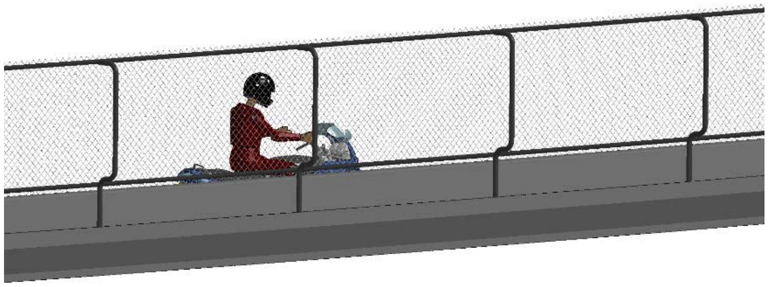


(a) Motorcycle Impacts Barrier

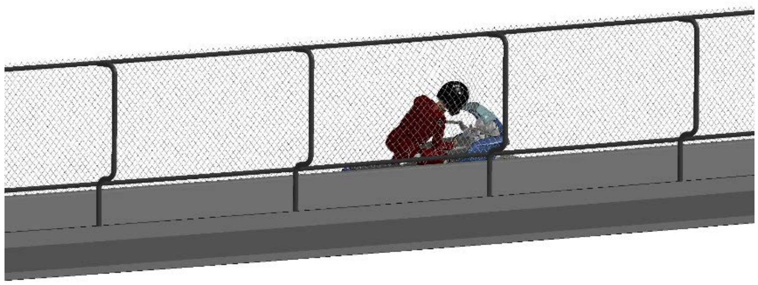
(b) Final Configuration

(c) Chain Link Fence Maximum Deflection

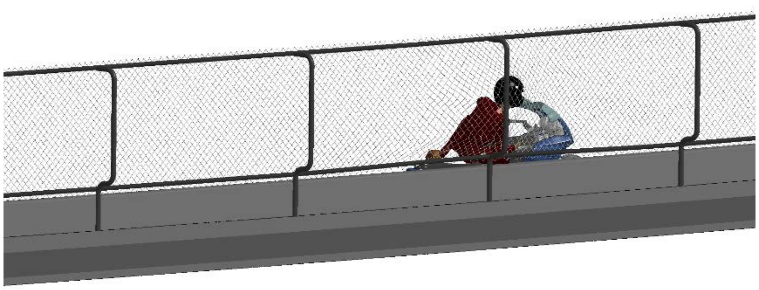
Figure 5.20. Impact Configuration – Modified U-Shaped Post Option.



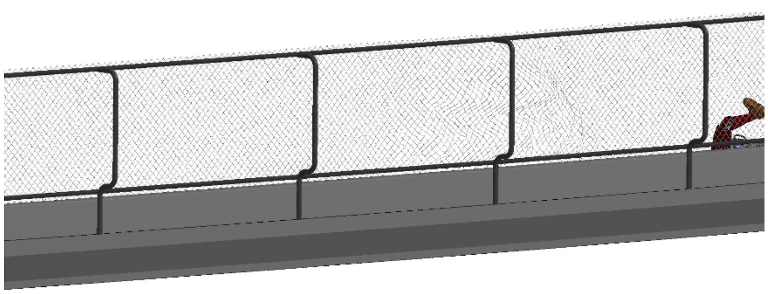
(a) Motorcycle Impacts Barrier



(b) Head and Shoulder Impact Fence



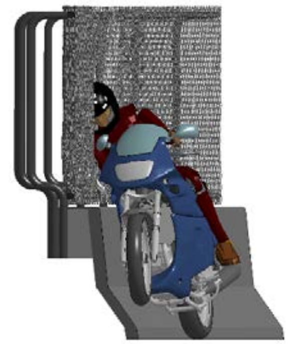
(c) Chain Link Fence Maximum Deflection at Post Location



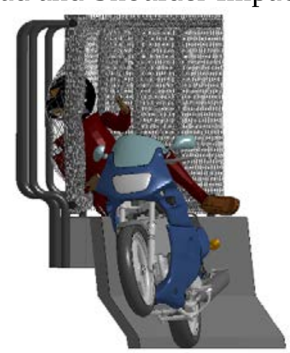
(d) Final Configuration

Figure 5.21. Motorcyclist's Interaction for Modified U-Shaped Post Option – Isometric View.

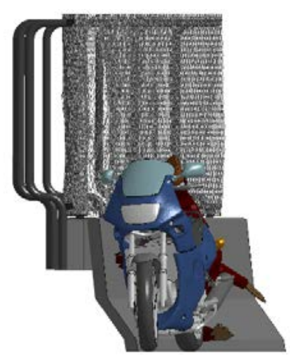
(a) Motorcycle Impacts Barrier



(b) Head and Shoulder Impact Fence



(c) Chain Link Fence Maximum Deflection at Post Location



(d) Final Configuration

Figure 5.22. Motorcyclist's Interaction for Modified U-Shaped Post Option – Front View.

There was no interaction between the dummy and the Modified U-shaped post. The dummy was contained and redirected by the chain link fence system during the impact event.

The HIC was calculated and compared for both design options (weak and Modified U-shaped post systems). With no direct interaction between the dummy and the post, the HIC_{15} value recorded during the impact with the chain link fence with Modified U-shaped posts resulted in a reduction of 88 percent, compared to the value documented during the impact against the system with weak posts option.

5.9.3 Conclusions

Based on the results obtained from the detailed predictive FE computer simulations, researchers suggested the Modified U-shaped posts as part of the final chain link fence containment system design. Thus, the containment and redirection capabilities of the final containment system design were evaluated through an upright motorcycle full-scale crash test, with nominal impact conditions of 35 mi/h speed and 18° tangential orientation angle, as described next.

CHAPTER 6: TXDOT FENCE BARRIER FOR MOTORCYCLES (CRASH TEST NO. 469688-2-1)

6.1 TEST ARTICLE AND INSTALLATION DETAILS

The test installation was a 75 ft long arc on a 500-ft radius and consisted of a reinforced concrete New Jersey style profile barrier, 32 inches tall, with chain link mesh attached above the top of the barrier.

The chain link was 9-gauge 2×2-inch mesh, 48 inches tall, and secured to horizontal rails near its top and bottom. The rails were supported by vertical posts, which were spaced at 96 inches and anchored to the field side of the barrier. The posts were fabricated from bent pipe supplemented with steel plates.

Figure 6.1 presents overall information on the TxDOT Fence Barrier for Motorcycles, and Figure 6.2 provides photographs of the installation. Appendix A provides further details of the TxDOT Fence Barrier for Motorcycles.

6.2 MATERIAL SPECIFICATIONS

Appendix B provides material certification documents for the materials used to install/construct the TxDOT Fence Barrier for Motorcycles.

6.3 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

The crash test involved a motorcycle weighing 410 lb impacting the critical impact point (CIP) of the TxDOT Fence Barrier for Motorcycles at a target impact speed of 35 mi/h ±2.5 mi/h, and a target angle of 15.5° ±1.5° at the point of impact (18° ±1.5° tangential angle to the barrier). The target CIP on the TxDOT Fence Barrier for Motorcycles was 4.7 ft ±1 ft upstream of the center of post 5 (see Figure 6.3).

The motorcycle weighed 410 lb, and the impact speed and angle were 34.6 mi/h and 15.2°, respectively. The impact point was 4.8 ft upstream of the center of post 5.

6.4 WEATHER CONDITIONS

The test was performed on the morning of July 5, 2018. Weather conditions at the time of testing were as follows: wind speed: 4 mi/h; wind direction: Northerly (360°), (vehicle was traveling in a northwesterly direction); temperature: 87°F; humidity: 58 percent.

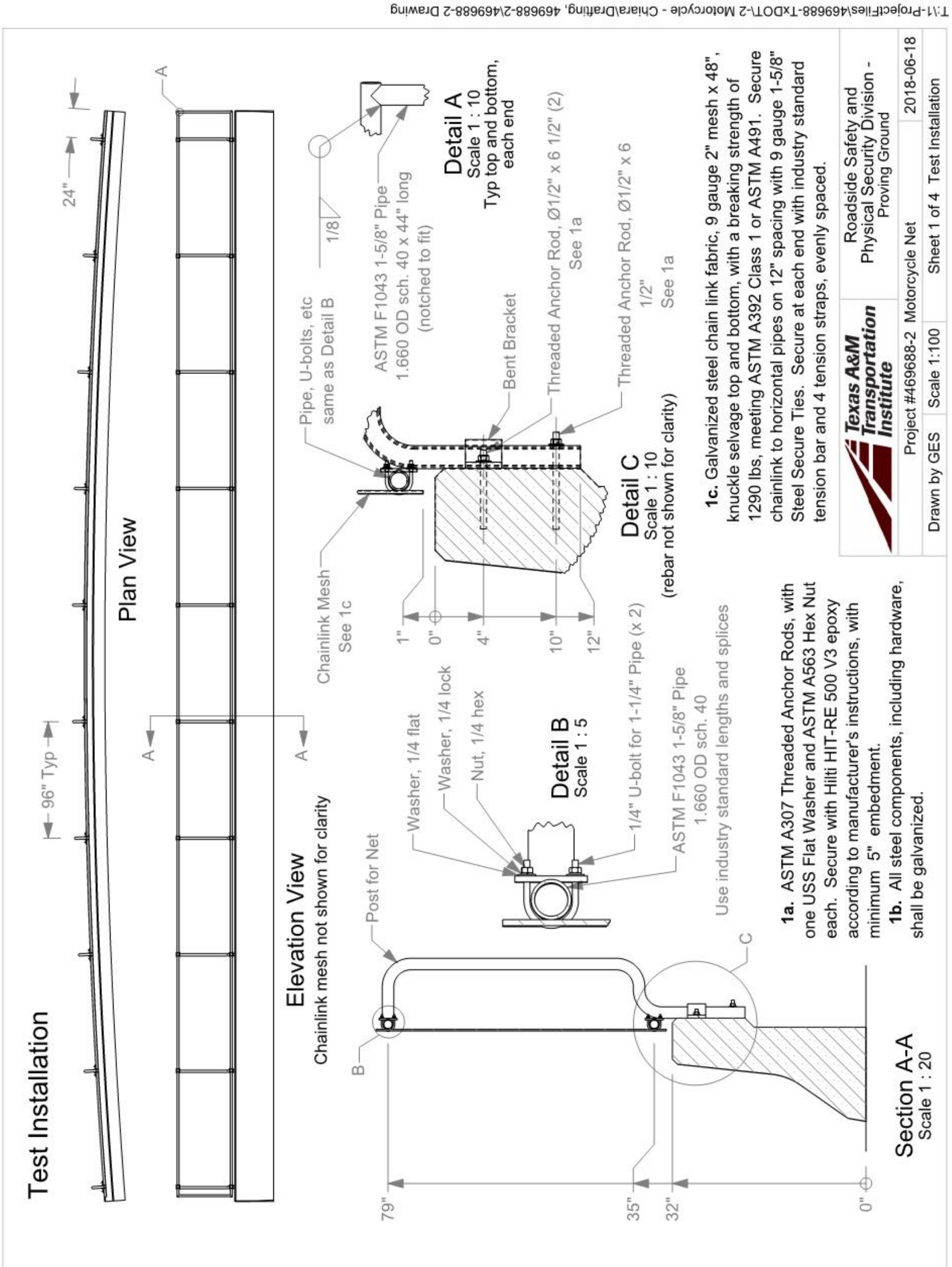


Figure 6.1. Overall Details of the TxDOT Fence Barrier for Motorcycles.

Figure 6.2. TxDOT Fence Barrier for Motorcycles prior to Testing.

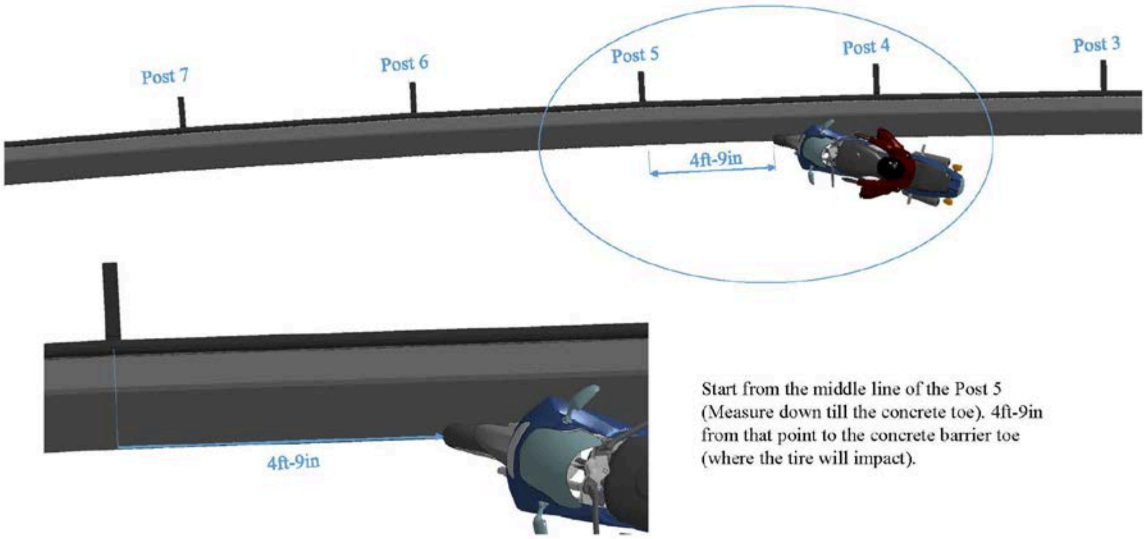


Figure 6.3. Target CIP for Test No. 469688-2-1.

6.5 TEST VEHICLE

Figures 6.4 and 6.5 show the 2012 Kawasaki 250 Ninja motorcycle used for the crash test. The vehicle’s test inertia weight was 410 lb, and its gross static weight was 600 lb. Table C.1 in Appendix C1 gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using the reverse cable tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 6.4. TxDOT Fence Barrier for Motorcycles/Test Vehicle Geometrics for Test No. 469688-2-1.

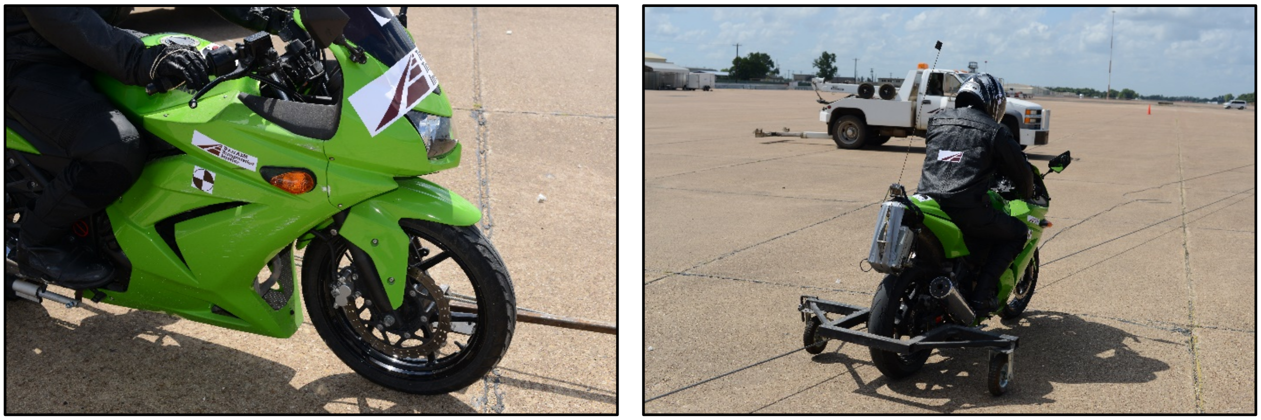


Figure 6.5. Test Vehicle before Test No. 469688-2-1.

6.6 ANTHROPOMORPHIC TEST DUMMY

FE computer simulations showed no interaction between the dummy and the Modified U-shaped post. For the full-scale crash test, the dummy's head was instrumented with an accelerometer to capture any potential interaction with posts. The accelerometer would also capture the intensity of head accelerations resulting from interaction with the chain link fence. The dummy used in this test was an H3 50th percentile male calibrated for frontal impacts. The instrumentation used was a TSR PRO-HB triaxial accelerometer. Researchers recognized that the H3 dummy is calibrated for frontal impacts, while these test impact conditions included an oblique angle. Unfortunately, a calibrated dummy for use in oblique impacts has not been developed. Therefore, researchers decided to equip the dummy's head with the accelerometer to collect data for possible future research studies.

6.7 TEST DESCRIPTION

The test vehicle was traveling at an impact speed of 34.6 mi/h as it contacted the TxDOT Fence Barrier for Motorcycles 4.8 ft upstream of the center of post 5, at an impact angle of 15.24° at the point of contact (17.74° tangential angle). Table 6.1 lists events that occurred during Test No. 469688-2-1. Figures C.1 and C.2 in Appendix C2 present sequential photographs during the test.

After loss of contact with the barrier, the motorcycle laid over on its left side and came to rest 81 ft downstream of the impact point. Figure 6.6 depicts events that occurred during Test No. 469688-2-1. The chain link fence supported by the Modified U-shaped post containment system successfully contained and redirected the errant rider. The dummy did not interact with the posts. The recorded HIC_{15} value was 92 (700 is the maximum HIC value allowed before serious injuries occur).

Table 6.1. Events during Test No. 469688-2-1.

TIME (s)	EVENTS
0.000	Motorcycle front tire makes contact with barrier and motorcycle begins to lean to right
0.019	Front tire begins to ride up barrier
0.024	Front right side of motorcycle makes contact with barrier
0.076	Riders right arm makes contact with mesh
0.076	Riders right shoulder makes contact with mesh
0.092	Rear tire comes off ground (motorcycle is airborne)
0.116	Riders right side of helmet makes contact with mesh
0.172	Helmet passes by post 5 with no contact on post (1 to 1.6 inches away)
0.174	Riders left hand begins to come off handlebar grip
0.404	Rear tire makes contact with pavement
0.447	Rider no longer in mesh and no longer gripping handle bars
0.518	Front tire makes contact with pavement
0.699	Rider recumbent and still on motorcycle but falling off.
0.828	Rider begins to fall off of motorcycle
0.906	Motorcycle makes contact with barrier again
1.844	Motorcycle lays over on side and skids along pavement

Time = 0.0 s	Time = 0.2 s	Time = 0.4 s	Time = 0.6 s

(a) Perpendicular View

(b) Overhead View

(c) Zoomed-in View of the Impact Area

Figure 6.6. Sequential Images for Test 469688-2-1 (Perpendicular, Overhead, and Close Up Views).

6.8 DAMAGE TO TEST INSTALLATION

Figure 6.7 shows the damage to the TxDOT Fence Barrier for Motorcycles. The mesh fence at Post 5 was permanently deformed 7.0 inches toward the field side. Working width was 2.2 ft, and the height of maximum working width was 6.6 ft. Maximum dynamic deflection during the test was 9.4 inches, and maximum permanent deformation of the mesh was 7 inches.

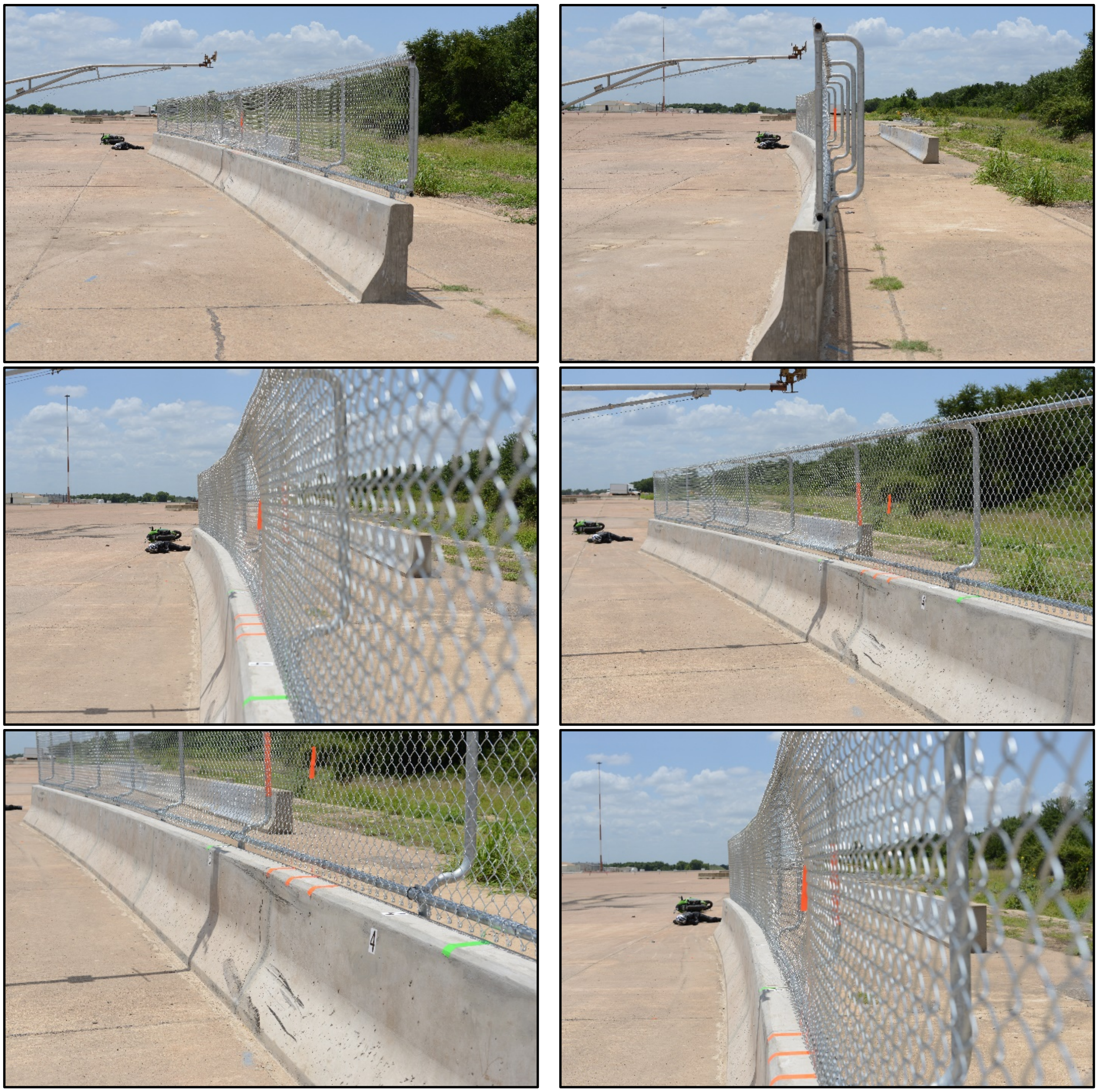


Figure 6.7. TxDOT Fence Barrier for Motorcycles after Test No. 469688-2-1.

6.8 DAMAGE TO DUMMY AND MOTORCYCLE

Figures 6.8 and 6.9 show the damage to the dummy and motorcycle. The dummy came to rest 58 ft downstream of impact and 8 ft toward traffic lanes. The dummy's hip was deformed, but otherwise appeared intact. The motorcycle sustained damage to the right side muffler, right rear brake pedal, and right and left turn signals, and the right and left side fairings sustained scuff marks.

Figure 6.8. Test Dummy after Test No. 469688-2-1.

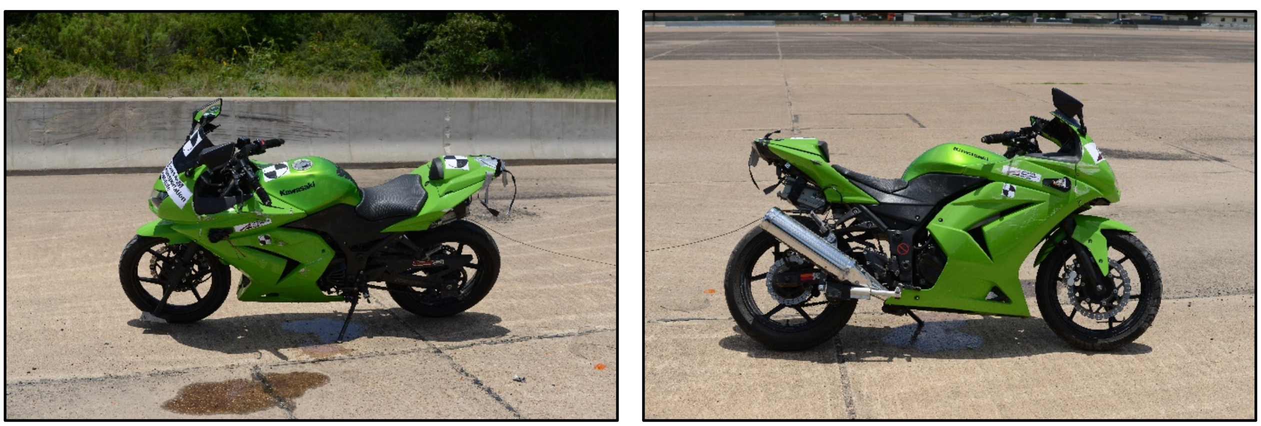
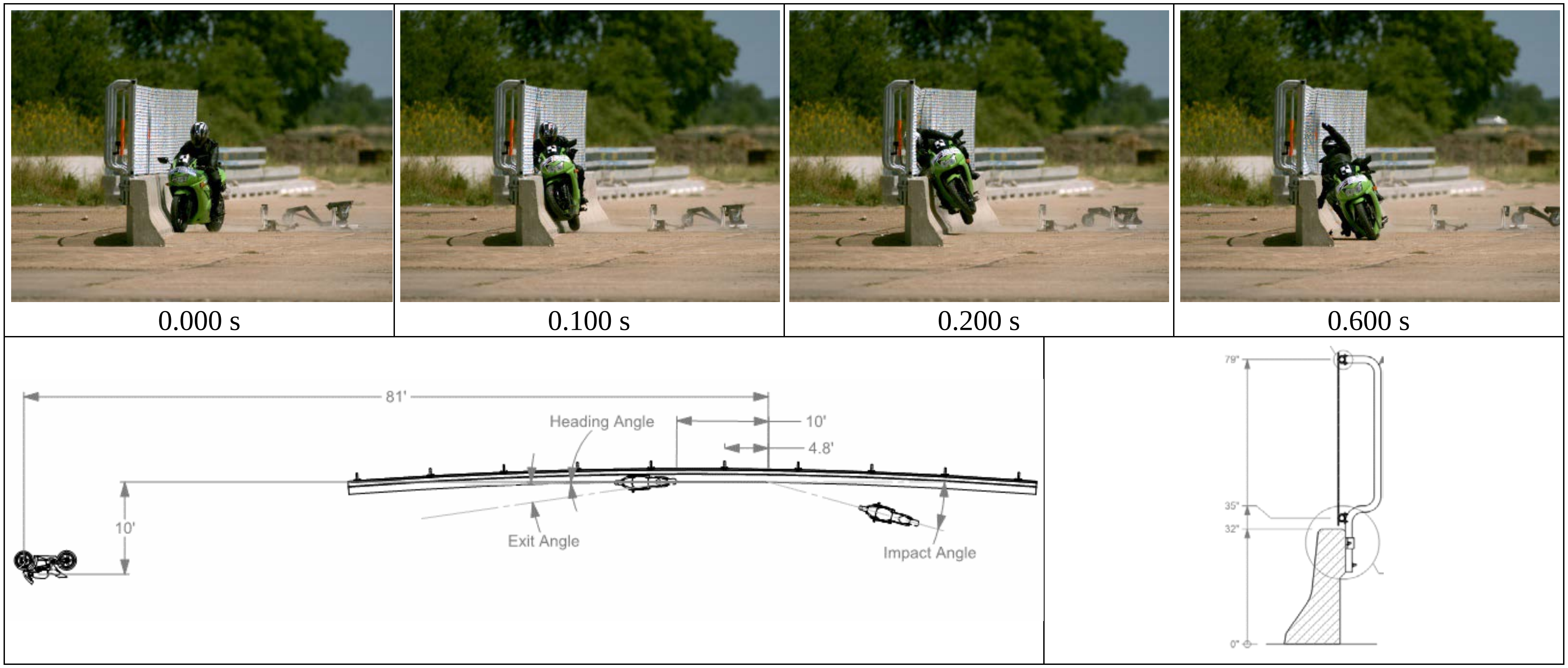


Figure 6.9. Motorcycle Upright on Kickstand after Test No. 469688-2-1.



General Information		**Test Vehicle**		**Post-Impact Trajectory**	
Test Agency	Texas A&M Transportation Institute (TTI)	Type/Designation	Motorcycle	Stopping Distance	81 ft downstream
Test Standard Test No.	Non-Standard Test	Make and Model	2012 Kawasaki 250 Ninja		
TTI Test No.	469688-2-1	Curb	374 lb	**Test Article Deflections (Mesh)**	
Test Date	2018-07-05	Test Inertial	410 lb		
		Dummy	190 lb	Dynamic	9.4 inches
Test Article		Gross Static	600 lb	Permanent	7 inches
Type	Fence Barrier			Working Width	26.6 inches
Name	TXDOT Fence Barrier for Motorcycles	**Impact Conditions**		Working Width Height	79 inches
Installation Length	75 ft	Speed	34.6 mi/h		
Material or Key Elements	Chain Link Fence, Tubular Posts, Concrete barrier	Angle	15.2°	**Injury Criteria**	
		Location/Orientation	57-inches upstream of center of post 5	HIC15 Value	92
Soil Type and Condition	Concrete pavement, damp	**Exit Conditions**			
		Speed of motorcycle	28.1 mi/hr		
		Angle of motorcycle	8.3°		

Figure 6.10. Summary of Results for Test on the TxDOT Fence Barrier for Motorcycles.

CHAPTER 7: SUMMARY AND CONCLUSIONS

FE computer simulations were used to assist with the design and evaluation of proposed containment options to be mounted on a concrete barrier. An upright motorcycle full-scale crash test with a Hybrid III 50th percentile male dummy was conducted to evaluate the crashworthiness of a chain link fence containment system supported by Modified U-shaped posts and attached to a curved concrete barrier section. The test was conducted at nominal impact speed of 35 mi/h and impact angle of 18° to the barrier. During the impact event, the system successfully prevented the rider/dummy from ejecting over the barrier. The dummy did not interact with the system's support posts.

An upright motorcycle test was performed to evaluate a newly developed post-chain link fence system for attachment to a concrete barrier. The tested system demonstrated the ability to contain upright errant motorcycle riders, reducing rider injury risks during the impact event. This system would prevent riders from ejecting over the barrier, thus reducing injury severity to the rider during the impact event.

CHAPTER 8: IMPLEMENTATION§

The developed and crash tested Modified U-Shaped Post and mesh fence containment system is considered suitable for implementation at locations where an upright motorcycle rider containment option is needed and/or desired. The system can be retrofit on existing cast-in-place roadside safety concrete barriers and can be easily adapted for application to concrete profiles differing from the New Jersey shape tested in this research study, such as single slope, vertical, F-shape profiles.

To achieve *MASH* TL-3 compliance for the proposed containment design, researchers suggest system evaluation through full-scale crash test *MASH* Test 3-11. This test involves a pickup truck vehicle impacting the system at 62 mi/h speed and 25° angle. This test would serve to evaluate the structural integrity of the system during impact and to investigate occupant risk and vehicle deformation per *MASH* standard criteria.

§ The opinions/interpretations identified/expressed in this chapter are outside the scope of TTI Proving Ground's A2LA Accreditation.

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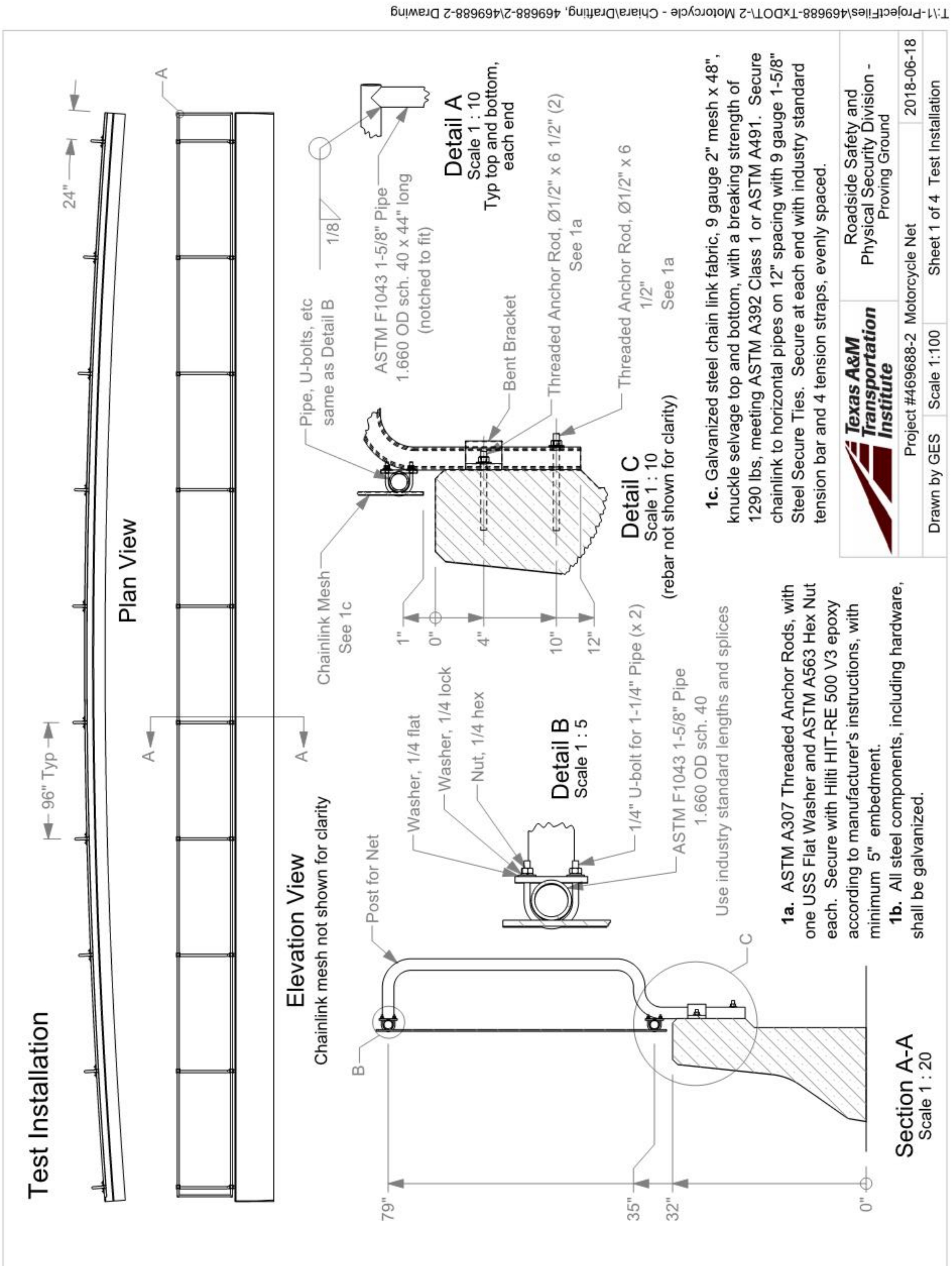
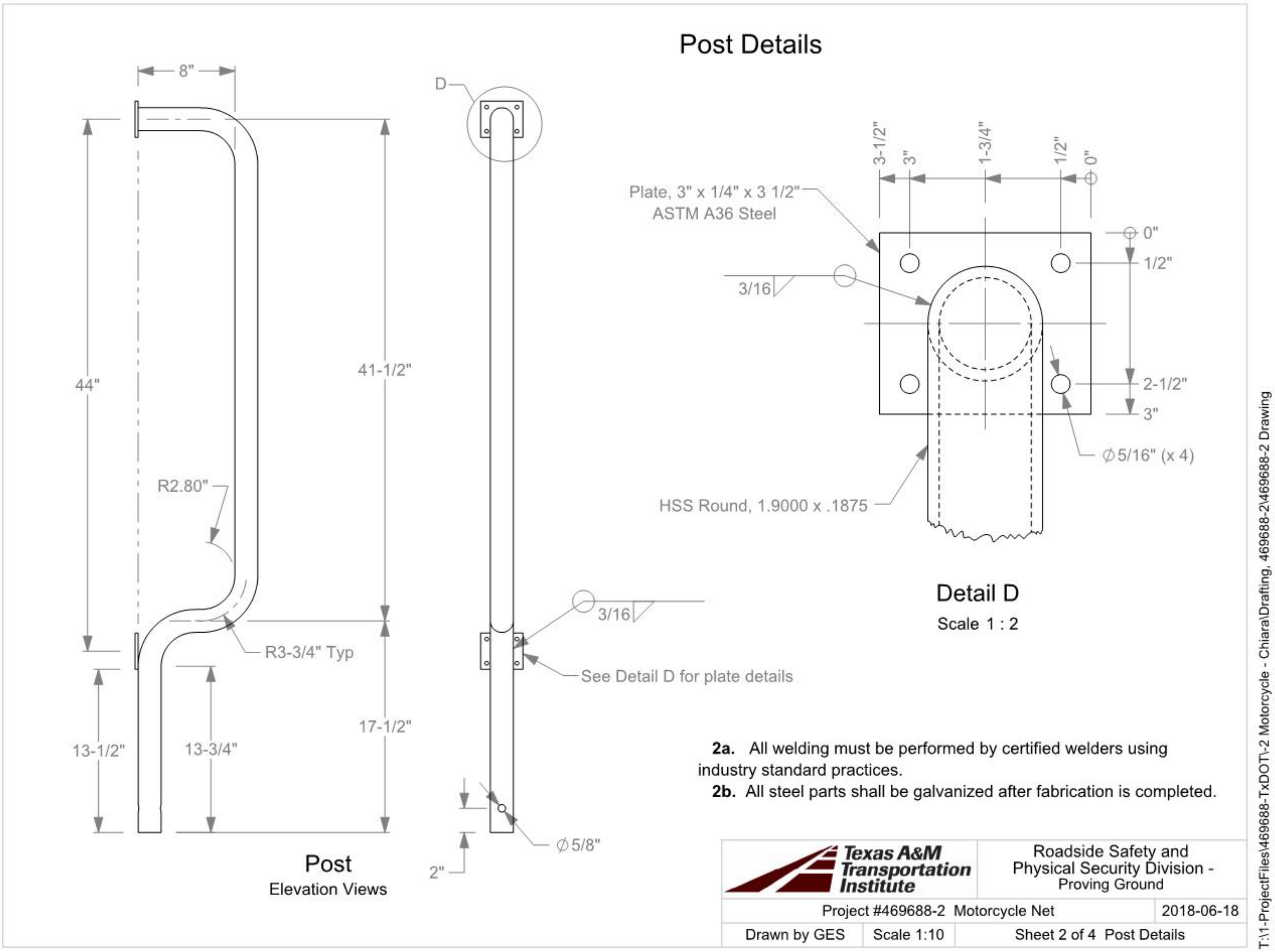
SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSTIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	*ft*	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square *ft*	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic *ft*	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5(F-32)/9 or (F-32)/1.8	Celsius	°C
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSTIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	*ft*	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square *ft*	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	Square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic *ft*	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lb/in^2

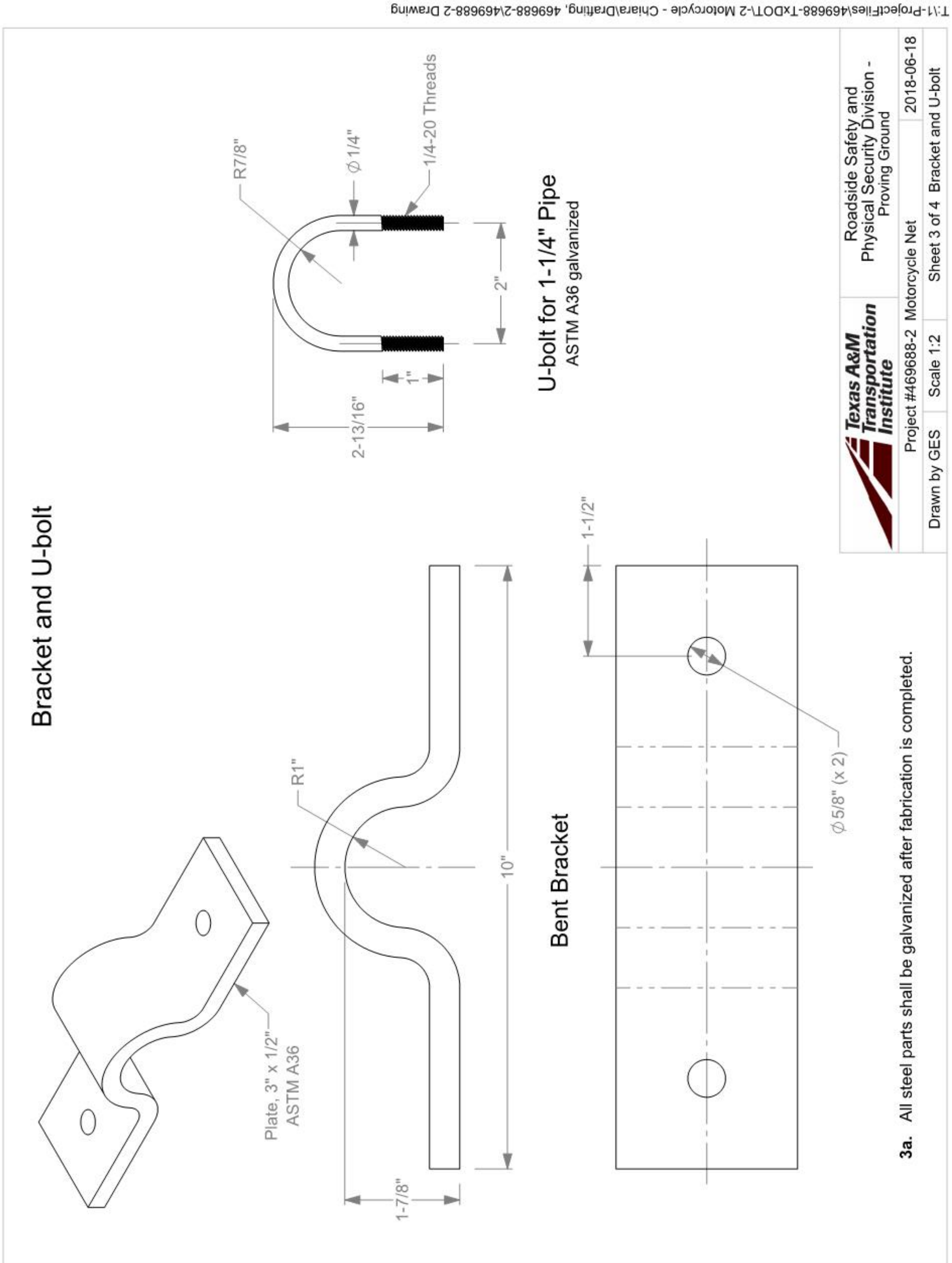
*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

APPENDIX A. DETAILS OF THE MOTORCYCLE NET

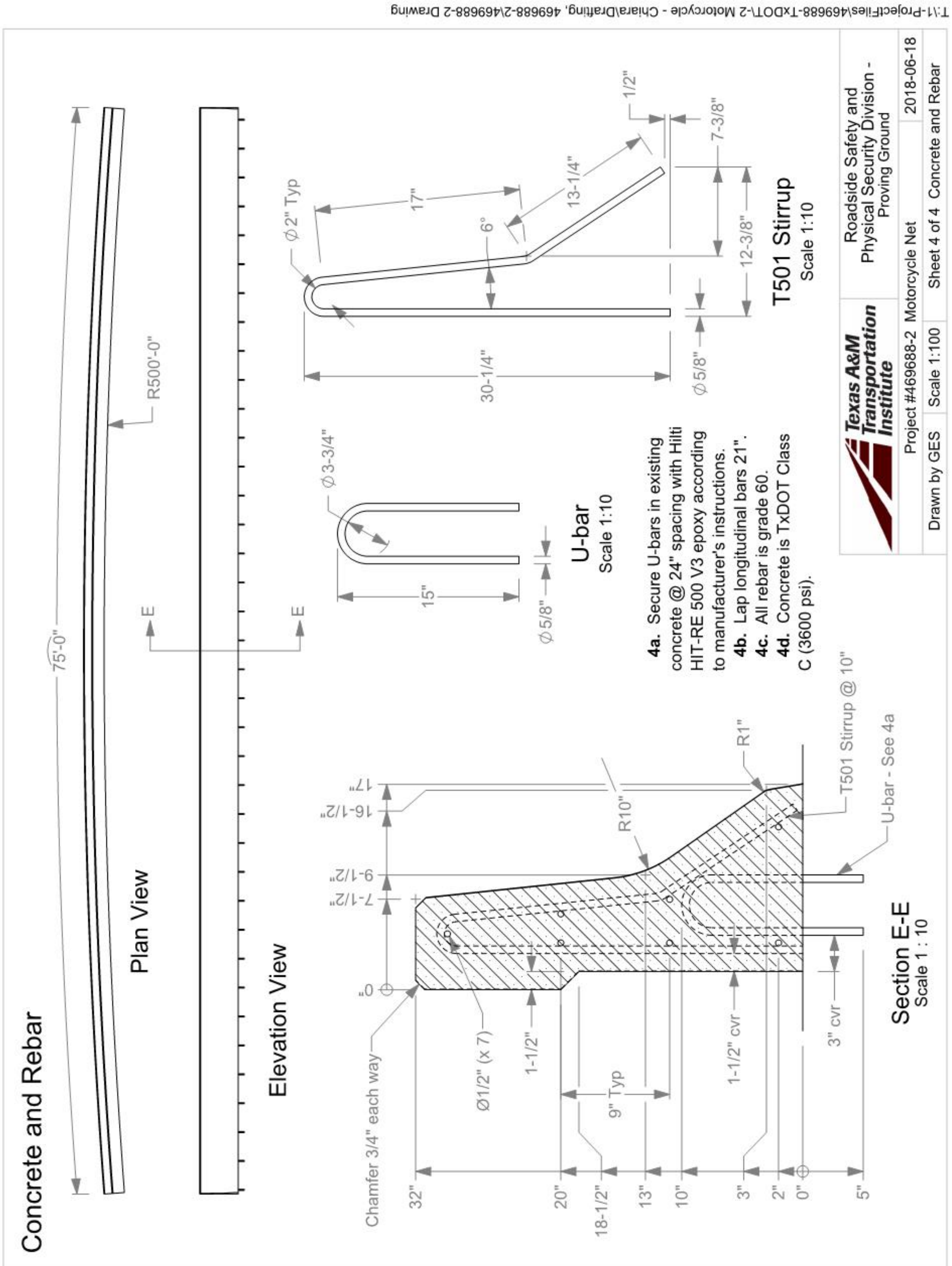




Post Details
8"
D
44"
41-1/2"
R2.80"
R3-3/4" Typ
13-1/2"
13-3/4"
17-1/2"
2"
∅5/8"
Post
Elevation Views
3/16
See Detail D for plate details
Plate, 3" x 1/4" x 3 1/2"
ASTM A36 Steel
3-1/2"
3"
1-3/4"
1/2"
0"
2-1/2"
∅5/16" (x 4)
HSS Round, 1.9000 x .1875
Detail D
Scale 1 : 2
2a. All welding must be performed by certified welders using industry standard practices.
2b. All steel parts shall be galvanized after fabrication is completed.
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Project #469688-2 Motorcycle Net
2018-06-18
Drawn by GES
Scale 1:10
Sheet 2 of 4 Post Details
T:\1-ProjectFiles\469688-TxDOT\-2 Motorcycle - Chiara\Drafting, 469688-2\469688-2 Drawing



T:\1-ProjectFiles\469688-TxDOT\-2 Motorcycle - Chiara\Drafting, 469688-2\469688-2 Drawing
Bracket and U-bolt
R7/8"
Ø1/4"
1/4-20 Threads
2"
1"
2-13/16"
U-bolt for 1-1/4" Pipe
ASTM A36 galvanized
R1"
Plate, 3" x 1/2"
ASTM A36
10"
1-7/8"
Bent Bracket
1-1/2"
Ø5/8" (x2)
3a. All steel parts shall be galvanized after fabrication is completed.
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Project #469688-2 Motorcycle Net
2018-06-18
Drawn by GES
Scale 1:2
Sheet 3 of 4 Bracket and U-bolt



T:\1-ProjectFiles\469688-TxDOT\-2 Motorcycle - Chiara\Drafting, 469688-2\469688-2 Drawing
Concrete and Rebar
Plan View
75'-0"
R500'-0"
Elevation View
E
E
U-bar
Scale 1:10
Ø3-3/4"
15"
Ø5/8"
T501 Stirrup
Scale 1:10
Ø2" Typ
17"
6°
13-1/4"
1/2"
7-3/8"
12-3/8"
30-1/4"
Ø5/8"
4a. Secure U-bars in existing concrete @ 24" spacing with Hilti HIT-RE 500 V3 epoxy according to manufacturer's instructions.
4b. Lap longitudinal bars 21".
4c. All rebar is grade 60.
4d. Concrete is TxDOT Class C (3600 psi).
Section E-E
Scale 1 : 10
Chamfer 3/4" each way
Ø1/2" (x 7)
1-1/2"
9" Typ
1-1/2" cvr
3" cvr
T501 Stirrup @ 10"
U-bar - See 4a
R1"
R10"
0"
7-1/2"
9-1/2"
16-1/2"
17"
32"
20"
18-1/2"
13"
10"
3"
2"
0"
5"
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Project #469688-2 Motorcycle Net
2018-06-18
Drawn by GES
Scale 1:100
Sheet 4 of 4 Concrete and Rebar

APPENDIX B. SUPPORTING CERTIFICATION DOCUMENTS

Texas A&M Transportation Institute Proving Ground 3100 SH 47, Bldg 7091 Bryan, TX 77807 Texas A&M University College Station, TX 77843 Phone 979-845-6375	5.7.2 Concrete Sampling	Doc. No. QPF 5.7.2	Revision Date: 2018-04-17
Quality Policy Form	Revised by: B. L. Griffith Approved by: D. Kuhn	Revision: 6	Page: 1 of 1

MOTORCYCLE **Project No:** 469688-2-1 **Casting Date:** 2018-04-26 **Mix Design (psi):** 3600psi CLASSC

Printed Name of Technician taking Sample: GREG FRITZ

Printed Name of Technician breaking Sample: GREG FRITZ

Signed Name of Technician taking Sample: [signature]

Signed Name of Technician breaking Sample: [signature]

Load No.	Truck No.	Ticket No.	Location (from concrete map)
T1	390126	0041633	Filled in ONE LOAD

Load No.	Break Date	Cylinder Age	Total Load (lbs)	Break (psi)	Average
T1	2018-7-5	70 DAYS	215,000	7,605	
↓	↓	↓	211,000	7465	7560
			215,000	7,605	

KNIFE RIVER
AN MDU RESOURCES COMPANY

SOUTH REGION/MAIN OFFICE
6310 State Highway 21 West
Bryan, TX 77807
PH: (979) 361-2900
FAX: (979) 361-2920

BRYAN
6310 Hwy. 21 West
Bryan, TX 77807
DISPATCH: (979) 361-2931
FAX: (979) 361-2920

B 0041633

469688-2

Bryan Plant #6

ELLIS-MCGINNIS CONSTRUC
P.O. BOX 40
EDDY

RELLIS CAMPUS/3100 STATE HWY 47, LF47 LF RELLIS CAMPUS RT AT THE STOP SIGN 2ND STOP TAKE A LF 2ND STOP TAKE A RT GO 2 STOP SIGN DOWN TAKE A LF GO TO MORE STOP SIGN DOWN TAKE RT GO THE NEXT STOP

Disp Order#: 2020

TIME	FORMULA	LOAD SIZE	YARDS ORDERED		DRIVER/TRUCK		PLANT TRANSACTION #
10:22:21	CLCLS	10.00	10.00	8001	FREDDIE 9	390126	
DATE		**LOAD #**	**YARDS DEL.**	**BATCH #**	**WATER TRIM**	**SLUMP**	**TICKET NUMBER**
04/26/18	TAMUTRANS	1	10.00			5.00in	6140984

WARNING
IRRITATING TO THE SKIN AND EYES

Contains Portland Cement. Wear Rubber Boots and Gloves. PROLONGED CONTACT MAY CAUSE BURNS. Avoid Contact With Eyes and Prolonged Contact With Skin. In Case of Contact With Skin or Eyes, Flush Thoroughly With Water. If Irritation Persists, Get Medical Attention. **KEEP CHILDREN AWAY.**

CONCRETE is a PERISHABLE COMMODITY and BECOMES THE PROPERTY of the PURCHASER UPON LEAVING the PLANT. ANY CHANGES or CANCELLATION of ORIGINAL INSTRUCTIONS MUST be TELEPHONED to the OFFICE BEFORE **LOADING** starts.

The undersigned promises to pay all costs, including reasonable attorney's fees, incurred in collecting any sums owed.

All accounts not paid within 30 days of delivery will bear interest at the rate of 18% per annum.

Not Responsible for Reactive Aggregate or Color Quality. No Claim Allowed Unless Made at Time Material is Delivered.

A $15.00 Service Charge and Loss of the Cash Discount will be Collected on all Returned Checks.

Excess Delay Time Charged @ $75.00/hr.

PROPERTY DAMAGE RELEASE
(TO BE SIGNED IF DELIVERY TO BE MADE INSIDE CURB LINE)

Dear Customer - The driver of this truck in presenting this RELEASE to you for your signature is of the opinion that the size and weight of this truck may possibly cause damage to the premises and/or adjacent property if he places the material in this load where you desire it. It is our wish to help you in every way that we can, but in order to do this the driver is requesting that you sign this RELEASE relieving him and this supplier from any responsibility from damage that may occur to the premises and or adjacent property, buildings, sidewalks, drive-ways, curbs, etc., by the delivery of this material, and that you also agree to help him remove mud from the wheels of his vehicle so that he will not litter the public street. Further, as additional consideration, the undersigned agrees to indemnify and hold harmless the driver of this truck and this supplier for any and all damage to the premises and/or adjacent property which may be claimed by anyone to have arisen out of delivery of this order.

SIGNED
X

Excessive Water is Detrimental to Concrete Performance.
H_2O Added by Request / Authorized By:

GAL X

WEIGHMASTER

Thank you for your business

NOTICE: MY SIGNATURE BELOW INDICATES THAT I HAVE READ THE HEALTH WARNING NOTICE AND SUPPLIER WILL NOT BE RESPONSIBLE FOR ANY DAMAGE CAUSED WHEN DELIVERING INSIDE CURB LINE.

LOAD RECEIVED BY
x

QUANTITY	CODE	DESCRIPTION	OUR MIXES ARE DESIGNED TO ACHIEVE SPECIFICATIONS AT A MAX 4" SLUMP	UNIT PRICE	EXTENDED PRICE
10.00CY	CLCLS	CLASS C 3600 PSI			

RETURNED TO PLANT	LEFT JOB	FINISH UNLOADING	ON SITE TESTING		AIR TEMP
			TESTING LAB:		
LEFT PLANT	**ARRIVED JOB**	**START UNLOADING**	**SLUMP**	**CONCRETE TEMP.**	
10:36	10:55				
TOTAL ROUND TRIP	**TOTAL AT JOB**	**UNLOADING TIME**	**AIR**	**CYLINDERS**	

Tax
Prev. AMT
Ticket Tot
Grand Tota

ADDITIONAL CHARGE 1 ____________
ADDITIONAL CHARGE 2 ____________
GRAND TOTAL ▶

Truck	Driver	User	Disp Ticket Num	Ticket ID	Time	Date
390126	559579	user	6140984	49439	10:22	4/26/18

Load Size	Mix Code	Returned	Qty	Mix Age	Seq	Load ID
10.00 CYDS	CLCLS				D	4

B 0041633

Material	Design Qty	Required	Batched	% Var	Moisture	Actual Wat
SAND	1287 lb	13514 lb	13500 lb	-0.10%	5.00% M	77 gl
LMSTN1"	1380 lb	13904 lb	13800 lb	-0.74%	0.75% M	12 gl
GRAVEL3/8"	480 lb	4872 lb	4860 lb *	-0.25%	1.50% M	9 gl
CEMENT	396.0 lb	3960.0 lb	3988.0 lb	0.71%		
FLYASH	154.0 lb	1540.0 lb	1544.0 lb	0.26%		
WATER	29.7 gl	178.9 gl	178.8 gl	-0.04%		178.8 gl
POZZ80	28.00 oz	280.00 oz	280.00 oz	0.00%		

Actual Num Batches: 1 Manual 10:22:21
Load Total: 39202 lb Design W/C: 0.451 Water/Cement: 0.448 T Design Water: 297.0 gl Actual Water: 276.7 gl To Add: 20.3 gl
Slump: 5.00 in Water in Truck: 0.0 gl Adjust Water: 0.0 gl/ Load Trim Water: -2.0 gl/ CYDS

CMC STEEL OKLAHOMA
584 Old Highway 70
Durant OK 74701-0000

CERTIFIED MILL TEST REPORT
For additional copies call

We hereby certify that the test results presented here are accurate and conform to the reported grade specification

Jacob Selzer – CMC Steel
Quality Assurance Manager

HEAT NO.:6000309 SECTION: REBAR 13MM (#4) 20'0" 420/60 GRADE: ASTM A615-16 Gr 420/60 ROLL DATE: 03/20/2018 MELT DATE: Cert. No.: 82344800 / 000309J130	SOLD TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	SHIP TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900

Delivery#: 82344800
BOL#: 72415067
CUST PO#: 777141
CUST P/N:
DLVRY LBS / HEAT: 17528.000 LB
DLVRY PCS / HEAT: 1312 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.29%	Elongation Gage Lgth test 1	8IN		
Mn	0.82%	Bend Test Diameter	1.750IN		
P	0.021%	Bend Test 1	Passed		
S	0.030%	Rebar Deformation Avg. Spaci	0.335IN		
Si	0.15%	Rebar Deformation Avg. Heigh	0.029IN		
Cu	0.22%	Rebar Deformation Max. Gap	0.110IN		
Cr	0.10%	Uniform Elongation	6.5%		
Ni	0.07%				
Mo	0.015%				
V	0.005%				
Sn	0.009%				
Al	0.000%				
N	0.0000%				
Carbon Eq A6	0.47%				
Yield Strength test 1	100.0ksi				
Yield Strength test 1 (metri	690MPa				
Tensile Strength test 1	117.0ksi				
Tensile Strength 1 (metric)	807MPa				
Elongation test 1	12%				

The Following is true of the material represented by this MTR:
- *Material is fully killed
- *100% melted and rolled in the USA
- *EN10204:2004 3.1 compliant
- *Contains no weld repair
- *Contains no Mercury contamination
- *Manufactured in accordance with the latest version of the plant quality manual
- *Meets the "Buy America" requirements of 23 CFR635.410

REMARKS :

For Jobs 465688-2 & 465468-2

03/22/2018 15:09:51
Page 1 OF 1

CMC STEEL TEXAS
1 STEEL MILL DRIVE
SEGUIN TX 78155-7510

CERTIFIED MILL TEST REPORT

For additional copies call
830-372-8771

We hereby certify that the test results presented here are accurate and conform to the reported grade specification

TOMMY HEWITT
Quality Assurance Manager

HEAT NO.:3078309 SECTION: REBAR 16MM (#5) 20'0" 420/60 GRADE: ASTM A615-16 Gr 420/60 ROLL DATE: 03/06/2018 MELT DATE: 03/04/2018 Cert. No.: 82336909 / 078309A371	SOLD TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	SHIP TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	Delivery#: 82336909 BOL#: 72403407 CUST PO#: 776230 CUST P/N: DLVRY LBS / HEAT: 24090.000 LB DLVRY PCS / HEAT: 1155 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.43%				
Mn	0.98%				
P	0.011%				
S	0.045%				
Si	0.20%				
Cu	0.28%				
Cr	0.10%				
Ni	0.13%				
Mo	0.042%				
V	0.000%				
Cb	0.003%				
Sn	0.010%				
Al	0.002%				
Yield Strength test 1	63.9ksi				
Tensile Strength test 1	104.1ksi				
Elongation test 1	13%				
Elongation Gage Lgth test 1	8IN				
Bend Test Diameter	2.188IN				
Bend Test 1	Passed				

The Following is true of the material represented by this MTR:

*Material is fully killed
*100% melted and rolled in the USA
*EN10204:2004 3.1 compliant
*Contains no weld repair
*Contains no Mercury contamination
*Manufactured in accordance with the latest version of the plant quality manual
*Meets the "Buy America" requirements of 23 CFR635.410

REMARKS :

For Job #5-465688-2

03/14/2018 22:19:16
Page 1 OF 1

CMC

STRAIGHT BILL OF LADING-SHORT FORM
ORIGINAL-NON NEGOTIABLE

72421556-01

SHIPMENT NO.(BOL) : 72421556
DATE AND TIME : 04/02/2018 12:53:46
SHIP FROM :
CMC Sterling Steel Truck
2001 Brittmoore Road
Houston, TX 77043-2208
USA
Contact Phone No. :713-690-0347
Fax No. :

CARRIER'S NAME: Imber Ventura
TRUCK/UNIT No:
CMC INCO TERMS: CPT Bryan
SHIP TO: 3101939
Tx A & M University Transporation
3100 State Hwy 47, Bldg. 7091
Bryan, TX 77807-0000 USA
Contact Phone No. :(254)859-5494
Fax No. :(254)859-5497

SEAL NUMBER :
TRAILER/RAILCAR No: f553015
SOLD TO: 3007327
Ellis Mc Ginnis Construction
2895 Eddy Gatesville Pkwy
Eddy, TX 76524-3911
USA
Contact Phone No. :2548595494
Fax No. :2548595497

Subject to Section 7: Subject to Section 7 of Conditions of applicable bill of lading, if this shipment is to be delivered to the consignee without recourse on the consignor, the consignor shall sign the following statement. The carrier shall not make delivery of this shipment without payment of freight and all other lawful charges.

Consignor's Signature : ______________________
BOL INSTRUCTIONS:

NOTES/SPECIAL INSTRUCTIONS:
Additional Instructions :

Jim (254)227-2815 1st Stop

Material Details

Delivery	Cust PO	Ctrl Cd	Rel No.	Release Description	Dwg #	Material Description	PCS	Weight LB
PROJECT: R/1823300796	UP							
3137044	2802	0NKQ	1	C402 BRIDGE RAIL		Rebar Black 60/420		4,230
3137048	2802	0NKR	2	C411 BRIDGE RAIL		Rebar Black 60/420		3,931
3137050	2802	0NKW	3	C412 BRIDGE RAIL		Rebar Black 60/420		8,533
						Total Weight		16,694

MTR'S INCLUDED

95 Miles

RECEIVED, subject to the classifications in effect on the date of the issue of the Bill of Lading, the property described above, in apparent good order, except as noted (contents of packages unknown), marked, consigned, and destined as indicated below, which said carrier (the word carrier being understood throughout this contract as meaning any person or corporation in possession of the property under the contract) agrees to carry to its usual place of delivery at said destination, if on its route, otherwise to deliver to another carrier on the route to said destination. It is mutually agreed, as to each carrier of all or any said property over all or any said property over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service to be performed hereunder shall be subject to all the terms and conditions of the Uniform Domestic Straight Bill of Lading set forth (1) in Official, Southern, Western and Illinois Freight Classifications in effect on the date hereof, if this is a rail or a rail-water shipment, or (2) in the applicable motor carrier classification or tariff if this is a motor carrier shipment. Shipper hereby certifies that he is familiar with all the terms and conditions of the said bill of lading, including those on the back thereof, set forth in the classification or tariff which governs the transportation of this shipment and the said terms and conditions are hereby agreed to by the shipper and accepted for himself and his assigns. This is to certify that the above articles are property describe by name and are packed and marked and are in proper condition for transportation according to regulations by the Interstate Commerce Commission. * If the shipment moves between two ports by a carrier by water, the law requires that the bill of lading shall state whether it is "carrier's or shipper's weight." * Shipper's imprints in lieu of stamp; not a part of Bill of Lading approved by the Interstate Commerce Commission. NOTE: Where the rate is dependent on value, shippers are required to state specifically in writing the agreed or declared value of property. The agreed or declared value of the property is hereby specifically state by the shipper to be not exceeding.

DRIVER'S SIGNATURE/AGENT : Ventura

NOTICE TO RECEIVERS :Please check each item on this shipping bill carefully. CMC will not be responsible for any exceptions to goods unless notified within twenty four hours and noted on this document.

RECEIVED BY : ____________ DATE: ____________ TIME: ____________,
DELIVERED BY: Imber Ventura DATE: 4-3-18 TIME IN: ____________,TIME OUT ____________

Page 1 of 2

469468

CMC

STRAIGHT BILL OF LADING-SHORT FORM
ORIGINAL-NON NEGOTIABLE

72421556-01

SHIPMENT NO.(BOL) : 72421556 DATE AND TIME : 04/02/2018 12:53:46 SHIP FROM : CMC Sterling Steel Truck 2001 Brittmoore Road Houston, TX 77043-2208 USA Contact Phone No. :713-690-0347 Fax No. :	CARRIER'S NAME: Imber Ventura TRUCK/UNIT No: CMC INCO TERMS: CPT Bryan SHIP TO: 3101939 Tx A & M University Transporation 3100 State Hwy 47, Bldg. 7091 Bryan, TX 77807-0000 USA Contact Phone No. :(254)859-5494 Fax No. :(254)859-5497	SEAL NUMBER : TRAILER/RAILCAR No: SOLD TO: 3007327 Ellis Mc Ginnis Construction 2895 Eddy Gatesville Pkwy Eddy, TX 76524-3911 USA Contact Phone No. :2548595494 Fax No. :2548595497

Subject to Section 7: Subject to Section 7 of Conditions of applicable bill of lading, If this shipment is to be delivered to the consignee without recourse on the consignor, the consignor shall sign the following statement. The carrier shall not make delivery of this shipment without payment of freight and all other lawful charges.

Consignor's Signature : ______________________

BOL INSTRUCTIONS:

NOTES/SPECIAL INSTRUCTIONS:
Additional Instructions :

Material Details

Delivery	Cust PO	Ctrl Cd	Rel No.	Release Description	Dwg #	Material Description	PCS	Weight LB
PROJECT: R/1823300796	UP							
3137044	2802	0NKQ	1	C402 BRIDGE RAIL		Rebar Black 60/420		4,230
3137048	2802	0NKR	2	C411 BRIDGE RAIL		Rebar Black 60/420		3,931
3137050	2802	0NKW	3	C412 BRIDGE RAIL		Rebar Black 60/420		8,533
						Total Weight		16,694

MTR'S INCLUDED

RECEIVED, subject to the classifications in effect on the date of the issue of the Bill of Lading, the property described above, in apparent good order, except as noted (contents of packages unknown), marked, consigned, and destined as indicated below, which said carrier (the word carrier being understood throughout this contract as meaning any person or corporation in possession of the property under the contract) agrees to carry to its usual place of delivery at said destination. If on its route, otherwise to deliver to another carrier on the route to said destination. It is mutually agreed, as to each carrier of all or any said property over all or any said property over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service to be performed hereunder shall be subject to all the terms and conditions of the Uniform Domestic Straight Bill of Lading set forth (1) in Official, Southern, Western and Illinois Freight Classifications in effect on the date hereof, if this is a rail or a rail-water shipment, or (2) in the applicable motor carrier classification or tariff if this is a motor carrier shipment. Shipper hereby certifies that he is familiar with all the terms and conditions of the said bill of lading, including those on the back thereof, set forth in the classification or tariff which governs the transportation of this shipment and the said terms and conditions are hereby agreed to by the shipper and accepted for himself and his assigns. This is to certify that the above articles are properly describe by name and are packed and marked and are in proper condition for transportation according to regulations by the Interstate Commerce Commission. * If the shipment moves between two ports by a carrier by water, the law requires that the bill of lading shall state whether it is "carrier's or shipper's weight." * Shipper's imprints in lieu of stamp; not a part of Bill of Lading approved by the Interstate Commerce Commission. NOTE: Where the rate is dependent on value, shippers are required to state specifically in writing the agreed or declared value of property. The agreed or declared value of the property is hereby specifically state by the shipper to be not exceeding.

DRIVER'S SIGNATURE/AGENT : ______________________

NOTICE TO RECEIVERS :Please check each item on this shipping bill carefully. CMC will not be responsible for any exceptions to goods unless notified within twenty four hours and noted on this document.

RECEIVED BY : ____________ DATE: ____________ TIME: ____________,

DELIVERED BY: ____________ DATE: ____________ TIME IN: ____________, TIME OUT ____________

Page 1 of 2

CMC Sterling Steel
2001 Britmoore
Houston, TX 77043-
Phone: (713) 690-0347 FAX: (713) 690-5758

JOB NUMBER	RELEASE NUMBER	REQ. DELIVERY DATE	PAGE
1823300796	1		1 of 1

JOB NAME	CC
TX A&M UNIV TRANSP INSTITUT(DW	0NKQ

CUSTOMER	BY
ELLIS-MCGINNIS CONSTRUCTION CO.	GL

MATERIAL TYPE	REFERENCE	DRAWING ID	DESCRIPTION
Rebar, Grade 60, Black			C402 BRIDGE RAIL

Itm	Qty	Size	Length	Mark	Shape	Lbs	A	B	C	D	E	F/R	G	H	J	K	O	BC
1	310	5	6-02	TL	17	1995		3-01	3-01									AC03
2	120	5	2-07	TB	17	323		0-07	2-00									AC03
	430.					2318.												
3	105	4	5-02	BL	17	363		2-07	2-07									AC02
4	58	4	40-00	R4		1550												ST
	163.					1913.												

Total Weight: 4,231 Lbs

Longest Length: 40-00

WEIGHT SUMMARY

	TOTAL			STRAIGHT			LIGHT BENDING			HEAVY BENDING		
SIZE	ITEMS	PIECES	LBS	ITEMS	PIECES	LBS	ITEMS	PIECES	LBS	ITEMS	PIECES	LBS
Rebar, Grade 60, Black												
4	2	163	1,913	1	58	1,550	0	0	0	1	105	363
5	2	430	2,318	0	0	0	0	0	0	2	430	2,318
	4	593	4,231	1	58	1,550	0	0	0	3	535	2,681

Total Weight: 4,231 Lbs

Longest Length: 40-00

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CMC Sterling Steel
2001 Britmoore
Houston, TX 77043-
Phone: (713) 690-0347 FAX: (713) 690-5758

JOB NUMBER	RELEASE NUMBER	REQ. DELIVERY DATE	PAGE
1823300796	2		1 of 1

JOB NAME: TX A&M UNIV TRANSP INSTITUT(DW — CT: 0NKR

CUSTOMER: ELLIS-MCGINNIS CONSTRUCTION CO. — BY: GL

MATERIAL TYPE: Rebar, Grade 60, Black — REFERENCE: — DRAWING ID: — DESCRIPTION: C411 BRIDGE RAIL

Itm	Qty	Size	Length	Mark	Shape	Lbs	A	B	C	D	E	F/R	G	H	J	K	O	BC
1	4	7	40-00	R7		327												ST
	4.					327.												
2	105	5	8-08	S	T2	949	0-06	0-06	3-04	0-06	3-04		0-06					AC14
3	155	5	6-02	TL	17	997		3-01	3-01									AC03
4	105	5	3-05	U	18	375	1-051	1-021	0-10						0-06			AC03
5	60	5	2-07	TB	17	161		0-07	2-00									AC03
6	4	5	40-00	R5		167												ST
	429.					2649.												
7	60	4	5-02	BL	17	207		2-07	2-07									AC02
8	28	4	40-00	R4		748												ST
	88.					955.												

Total Weight: 3,931 Lbs

Longest Length: 40-00

WEIGHT SUMMARY

Rebar, Grade 60, Black

	TOTAL			STRAIGHT			LIGHT BENDING			HEAVY BENDING		
SIZE	ITEMS	PIECES	LBS	ITEMS	PIECES	LBS	ITEMS	PIECES	LBS	ITEMS	PIECES	LBS
4	2	88	955	1	28	748	0	0	0	1	60	207
5	5	429	2,649	1	4	167	1	105	949	3	320	1,533
7	1	4	327	1	4	327	0	0	0	0	0	0
	8	521	3,931	3	36	1,242	1	105	949	4	380	1,740

Total Weight: 3,931 Lbs

Longest Length: 40-00

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CMC Sterling Steel
2001 Britmoore
Houston, TX 77043-
Phone: (713) 690-0347 FAX: (713) 690-5758

JOB NUMBER: 1823300796 | RELEASE NUMBER: 3 | REQ. DELIVERY DATE: | PAGE: 1 of 1

JOB NAME: TX A&M UNIV TRANSP INSTITUT(DW | CC: 0NKW

CUSTOMER: ELLIS-MCGINNIS CONSTRUCTION CO. | BY: GL

MATERIAL TYPE: Rebar, Grade 60, Black | REFERENCE: | DRAWING ID: | DESCRIPTION: C412 BRIDGE RAIL

Itm	Qty	Size	Length	Mark	Shape	Lbs	A	B	C	D	E	F/R	G	H	J	K	O	BC
1	3	8	5-00	R3		40												0
	3.					40.												
2	170	6	6-11	U	S11	1767		6-112						3-042			0-063	TB
	170.					1767.												
3	340	5	7-01	TL-5	17	2511		4-00	3-012									AC03
4	85	5	6-03	BL	17	554		3-042	2-102									AC03
5	95	5	2-08	TB	17	265		0-07	2-01									AC03
6	40	5	2-07	UB	S11	108		2-07						1-03			0-033	AC
7	12	5	40-00	R5		501												ST
	572.					3939.												
8	160	4	7-01	TL-4	17	757		4-00	3-012									AC02
9	70	4	40-00	R4		1870												ST
	230.					2627.												
10	170	3	2-06	P	S11	160		2-06						1-022			0-023	AC
	170.					160.												

Total Weight: 8,533 Lbs

Longest Length: 40-00

WEIGHT SUMMARY

Rebar, Grade 60, Black

SIZE	TOTAL ITEMS	TOTAL PIECES	TOTAL LBS	STRAIGHT ITEMS	STRAIGHT PIECES	STRAIGHT LBS	LIGHT BENDING ITEMS	LIGHT BENDING PIECES	LIGHT BENDING LBS	HEAVY BENDING ITEMS	HEAVY BENDING PIECES	HEAVY BENDING LBS
3	1	170	160	0	0	0	1	170	160	0	0	0
4	2	230	2,627	1	70	1,870	0	0	0	1	160	757
5	5	572	3,939	1	12	501	1	40	108	3	520	3,330
6	1	170	1,767	0	0	0	1	170	1,767	0	0	0
8	1	3	40	1	3	40	0	0	0	0	0	0
	10	1145	8,533	3	85	2,411	3	380	2,035	4	680	4,087

Total Weight: 8,533 Lbs

Longest Length: 40-00

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Mid American Steel & Wire

MATERIAL TEST REPORT

PAGE 1

Date Printed: 03/14/2018

Bill to:
CMC REBAR
P O BOX 139094
DALLAS, TX 75313

Ship to:
CMC REBAR
2001 BRITTMOORE
HOUSTON, TX 77043

Customer No: 000000006015
PO Number: 4501198093
Ship Date: 03/14/2018
Order Number: 91943
Load Number: 116288

Item Number: 3REBAR

Description: #3 GRADE 60 COILED REBAR

CHEMICAL ANALYSIS

Heat Number	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Sn	V	Al	N	Nb
3076185	0.3700	0.8000	0.0120	0.0320	0.2100	0.2800	0.2200	0.2100	0.0910	0.0130	0.0200	0.0010	0.0000	0.0000

MECHANICAL PROPERTIES

Heat Number	Yield (Psi/Mpa)	Tensile (Psi/Mpa)	Elongation (% 8" guage)	Bend Test Pass/Fail
3076185	76007 psi / 524 Mpa	111338 psi / 768 Mpa	12.50	Pass

I hereby certify that the above test results are correct as contained in the records of the company. All Manufacturing processes of the steel materials in this product, including melting have occurred in the United States. The material was produced and tested according to ASTM A615/A615M-065.

Quality Assurance: ____________

MATERIAL TEST REPORT

PAGE 1

Date Printed: 03/29/2018

Mid American Steel & Wire

Customer No: 000000006015
PO Number: 4501201423
Ship Date: 03/29/2018
Order Number: 92181
Load Number: 116521

Bill to:
CMC REBAR
P O BOX 139094
DALLAS, TX 75313

Ship to:
CMC REBAR
2001 BRITTMOORE
HOUSTON, TX 77043

Item Number	Description
4REBAR	# 4 GRADE 60 COILED REBAR

CHEMICAL ANALYSIS

Heat Number	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Sn	V	Al	N	Nb
1820636	0.4400	0.9100	0.0160	0.0240	0.2400	0.2300	0.1700	0.2400	0.0600	0.0110	0.0020	0.0040	0.0077	0.0003

MECHANICAL PROPERTIES

Heat Number	Yield (Psi/Mpa)	Tensile (Psi/Mpa)	Elongation (% 8" guage)	Bend Test Pass/Fail
1820636	66470 psi / 458 Mpa	114647 psi / 791 Mpa	10.00	Pass

I hereby certify that the above test results are correct as contained in the records of the company. All Manufacturing processes of the steel materials in this product, including melting have occurred in the United States. The material was produced and tested according to ASTM A615/A615M-065.

Quality Assurance: ____________

CMC STEEL TEXAS
1 STEEL MILL DRIVE
SEGUIN TX 78155-7510

CERTIFIED MILL TEST REPORT

For additional copies call
830-372-8771

We hereby certify that the test results presented here are accurate and conform to the reported grade specification

TOMMY HEWITT
Quality Assurance Manager

HEAT NO.:3078175
SECTION: REBAR 13MM (#4) 40'0" 420/60
GRADE: ASTM A615-16 Gr 420/60
ROLL DATE: 03/03/2018
MELT DATE: 02/27/2018
Cert. No.: 02/27/2018 / 078175A371

SOLD TO

SHIP TO

Delivery#:
BOL#:
CUST PO#:
CUST P/N:
DLVRY LBS / HEAT:
DLVRY PCS / HEAT:

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.43%				
Mn	0.73%				
P	0.009%				
S	0.046%				
Si	0.19%				
Cu	0.33%				
Cr	0.10%				
Ni	0.21%				
Mo	0.079%				
V	0.000%				
Cb	0.002%				
Sn	0.014%				
Al	0.001%				
Yield Strength test 1	62.0ksi				
Tensile Strength test 1	99.2ksi				
Elongation test 1	17%				
Elongation Gage Lgth test 1	8IN				
Bend Test Diameter	1.750IN				
Bend Test 1	Passed				

The Following is true of the material represented by this MTR:

*Material is fully killed
*100% melted and rolled in the USA
*EN10204:2004 3.1 compliant
*Contains no weld repair
*Contains no Mercury contamination
*Manufactured in accordance with the latest version of the plant quality manual
*Meets the "Buy America" requirements of 23 CFR635.410

REMARKS :

04/02/2018 20:57:52
Page 1 OF 1

Mid American Steel & Wire

MATERIAL TEST REPORT

Date Printed: 03/28/2018

PAGE 1

Customer No: 000000006015
PO Number: 4501201440
Ship Date: 03/28/2018
Order Number: 92187
Load Number: 116527

Bill to:
CMC REBAR
P O BOX 139094
DALLAS, TX 75313

Ship to:
CMC REBAR
2001 BRITTMOORE
HOUSTON, TX 77043

Item Number: 5REBAR

Description: # 5 GRADE 60 COILED REBAR

CHEMICAL ANALYSIS

Heat Number	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Sn	V	Al	N	Nb
1723630	0.4600	0.8700	0.0170	0.0260	0.2000	0.2100	0.1100	0.1900	0.0300	0.0110	0.0030	0.0010	0.0067	0.0005

MECHANICAL PROPERTIES

Heat Number	Yield (Psi/Mpa)	Tensile (Psi/Mpa)	Elongation (% 8" guage)	Bend Test Pass/Fail
1723630	62474 psi / 431 Mpa	108254 psi / 747 Mpa	11.71	Pass

I hereby certify that the above test results are correct as contained in the records of the company. All Manufacturing processes of the steel materials in this product, including melting have occurred in the United States. The material was produced and tested according to ASTM A615/A615M-065.

Quality Assurance: ________

CMC STEEL TEXAS
1 STEEL MILL DRIVE
SEGUIN TX 78155-7510

CERTIFIED MILL TEST REPORT
For additional copies call
830-372-8771

We hereby certify that the test results presented here are accurate and conform to the reported grade specification

TOMMY HEWITT
Quality Assurance Manager

HEAT NO.:3078356 SECTION: REBAR 16MM (#5) 40'0" 420/60 GRADE: ASTM A615-16 Gr 420/60 ROLL DATE: 03/07/2018 MELT DATE: 03/07/2018 Cert. No.: 82333189 / 078356A765	SOLD TO	CMC Rebar Houston-West BRITTMOORE RD. HOUSTON TX US 77043-2208 713-690-0347	SHIP TO	CMC Sterling Steel 2001 Brittmoore Rd Houston TX US 77043-2208 7136900347 7136905758	Delivery#: 82333189 BOL#: 72398632 CUST PO#: CUST P/N: DLVRY LBS / HEAT: 24030.000 LB DLVRY PCS / HEAT: 576 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.42%				
Mn	0.86%				
P	0.008%				
S	0.045%				
Si	0.18%				
Cu	0.33%				
Cr	0.10%				
Ni	0.17%				
Mo	0.088%				
V	0.000%				
Cb	0.002%				
Sn	0.010%				
Al	0.002%				
Yield Strength test 1	64.9ksi				
Tensile Strength test 1	102.5ksi				
Elongation test 1	14%				
Elongation Gage Lgth test 1	8IN				
Bend Test Diameter	2.188IN				
Bend Test 1	Passed				

The Following is true of the material represented by this MTR:
- *Material is fully killed*
- *100% melted and rolled in the USA*
- *EN10204:2004 3.1 compliant*
- *Contains no weld repair*
- *Contains no Mercury contamination*
- *Manufactured in accordance with the latest version of the plant quality manual*
- *Meets the "Buy America" requirements of 23 CFR635.410*

REMARKS :

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Page 1 OF 1

CMC STEEL TEXAS
1 STEEL MILL DRIVE
SEGUIN TX 78155-7510

CERTIFIED MILL TEST REPORT
For additional copies call
830-372-8771

We hereby certify that the test results presented here are accurate and conform to the reported grade specification.

TOMMY HEWITT
Quality Assurance Manager

HEAT NO.:3077775
SECTION: REBAR 19MM (#6) 60'0" 420/60
GRADE: ASTM A615-16 Gr 420/60
ROLL DATE: 02/21/2018
MELT DATE: 02/11/2018
Cert. No.: 82326504 / 077775A053

SOLD TO: CMC Rebar Houston-West
BRITTMOORE RD.
HOUSTON TX
US 77043-2208
713-690-0347

SHIP TO: CMC Sterling Steel
2001 Brittmoore Rd
Houston TX
US 77043-2208
7136900347
7136905758

Delivery#: 82326504
BOL#: 72388853
CUST PO#:
CUST P/N:
DLVRY LBS / HEAT: 43526.000 LB
DLVRY PCS / HEAT: 483 EA

Characteristic	Value
C	0.44%
Mn	0.87%
P	0.009%
S	0.049%
Si	0.17%
Cu	0.29%
Cr	0.12%
Ni	0.16%
Mo	0.048%
V	0.001%
Cb	0.002%
Sn	0.011%
Al	0.001%
Yield Strength test 1	62.7ksi
Tensile Strength test 1	103.1ksi
Elongation test 1	16%
Elongation Gage Lgth test 1	8IN
Bend Test Diameter	3.750IN
Bend Test 1	Passed

Characteristic	Value

Characteristic	Value

The Following is true of the material represented by this MTR:
- *Material is fully killed*
- *100% melted and rolled in the USA*
- *EN10204:2004 3.1 compliant*
- *Contains no weld repair*
- *Contains no Mercury contamination*
- *Manufactured in accordance with the latest version of the plant quality manual*
- *Meets the "Buy America" requirements of 23 CFR635.410*

REMARKS :

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Page 1 OF 1

CMC STEEL TEXAS
1 STEEL MILL DRIVE
SEGUIN TX 78155-7510

CERTIFIED MILL TEST REPORT
For additional copies call
830-372-8771

We hereby certify that the test results presented here are accurate and conform to the reported grade specification

TOMMY HEWITT
Quality Assurance Manager

HEAT NO.:3078084 SECTION: REBAR 22MM (#7) 60'0" 420/60 GRADE: ASTM A615-16 Gr 420/60 ROLL DATE: 02/24/2018 MELT DATE: 02/24/2018 Cert. No.: 82346478 / 078084A625	SOLD TO	CMC Rebar Houston-West BRITTMOORE RD. HOUSTON TX US 77043-2208 713-690-0347	SHIP TO	CMC Sterling Steel 2001 Brittmoore Rd Houston TX US 77043-2208 7136900347 7136905758

Delivery#: 82346478
BOL#: 72417710
CUST PO#:
CUST P/N:
DLVRY LBS / HEAT: 38020.000 LB
DLVRY PCS / HEAT: 310 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.42%				
Mn	0.92%				
P	0.013%				
S	0.056%				
Si	0.15%				
Cu	0.34%				
Cr	0.19%				
Ni	0.17%				
Mo	0.081%				
V	0.001%				
Cb	0.003%				
Sn	0.014%				
Al	0.002%				
Yield Strength test 1	67.9ksi				
Tensile Strength test 1	106.5ksi				
Elongation test 1	13%				
Elongation Gage Lgth test 1	8IN				
Bend Test Diameter	4.375IN				
Bend Test 1	Passed				

The Following is true of the material represented by this MTR:
- *Material is fully killed*
- *100% melted and rolled in the USA*
- *EN10204:2004 3.1 compliant*
- *Contains no weld repair*
- *Contains no Mercury contamination*
- *Manufactured in accordance with the latest version of the plant quality manual*
- *Meets the "Buy America" requirements of 23 CFR635.410*

REMARKS :

03/27/2018 00:13:07
Page 1 OF 1

CMC STEEL TEXAS
1 STEEL MILL DRIVE
SEGUIN TX 78155-7510

CERTIFIED MILL TEST REPORT
For additional copies call
830-372-8771

We hereby certify that the test results presented here are accurate and conform to the reported grade specification

TOMMY HEWITT
Quality Assurance Manager

HEAT NO.:3078559 SECTION: REBAR 25MM (#8) 50'0" 420/60 GRADE: ASTM A615-16 Gr 420/60 ROLL DATE: 03/17/2018 MELT DATE: 03/14/2018 Cert. No.: 82343437 / 078559A061	SOLD TO: CMC Rebar Houston-West BRITTMOORE RD. HOUSTON TX US 77043-2208 713-690-0347	SHIP TO: CMC Sterling Steel 2001 Brittmoore Rd Houston TX US 77043-2208 7136900347 7136905758	Delivery#: 82343437 BOL#: 72412704 CUST PO#: CUST P/N: DLVRY LBS / HEAT: 21360.000 LB DLVRY PCS / HEAT: 160 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.43%				
Mn	0.93%				
P	0.011%				
S	0.045%				
Si	0.21%				
Cu	0.29%				
Cr	0.20%				
Ni	0.23%				
Mo	0.082%				
V	0.001%				
Cb	0.002%				
Sn	0.011%				
Al	0.002%				
Yield Strength test 1	70.3ksi				
Tensile Strength test 1	109.8ksi				
Elongation test 1	14%				
Elongation Gage Lgth test 1	8IN				
Bend Test Diameter	5.000IN				
Bend Test 1	Passed				

The Following is true of the material represented by this MTR:

- *Material is fully killed*
- *100% melted and rolled in the USA*
- *EN10204:2004 3.1 compliant*
- *Contains no weld repair*
- *Contains no Mercury contamination*
- *Manufactured in accordance with the latest version of the plant quality manual*
- *Meets the "Buy America" requirements of 23 CFR635.410*

REMARKS :

03/20/2018 18:55:38
Page 1 OF 1

APPENDIX C. CRASH TEST NO. 469688-2-1

C.1 VEHICLE PROPERTIES AND INFORMATION

Table C.1. Vehicle Properties for Test No. 469688-2-1.

Vehicle Inventory Number: 1319

Date: 2018-7-5 Test No.: 469688-2-1 VIN No.: JKAEXMJ17CDA97577

Year: 2012 Make: Kawasaki Model: 250 Ninja

Tire Size: F110/70 R17, R130/70R17 Tire Inflation Pressure: 28 psi

Tread Type: Highway Odometer: 29475

Note any damage to the vehicle prior to test: ______

● Denotes accelerometer location.

NOTES: ______

Engine Type: 2 cyl
Engine CID: 249cc

Transmission Type:
___ Auto or X Manual
___ FWD X RWD ___ 4WD

Optional Equipment: ______

Dummy Data:
Type: ______
Mass: 190 lb
Seat Position: ______

Geometry: inches

A	30.1	C	78.5	E	12.5	G	5
B	45.8	D	55	F	30.5	H	26.5

Wheel Center Height Front	11.3	Wheel Well Clearance (Front)	1.5	Bottom Frame Height - Front	8
Wheel Center Height Rear	11.8	Wheel Well Clearance (Rear)	6.75	Bottom Frame Height - Rear	9

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	265	M_{front}		180	250
Back	485	M_{rear}		230	350
Total	750	M_{Total}	374	410	600

Mass Distribution:
lb F: 180 R: 230

C.2 SEQUENTIAL PHOTOGRAPHS

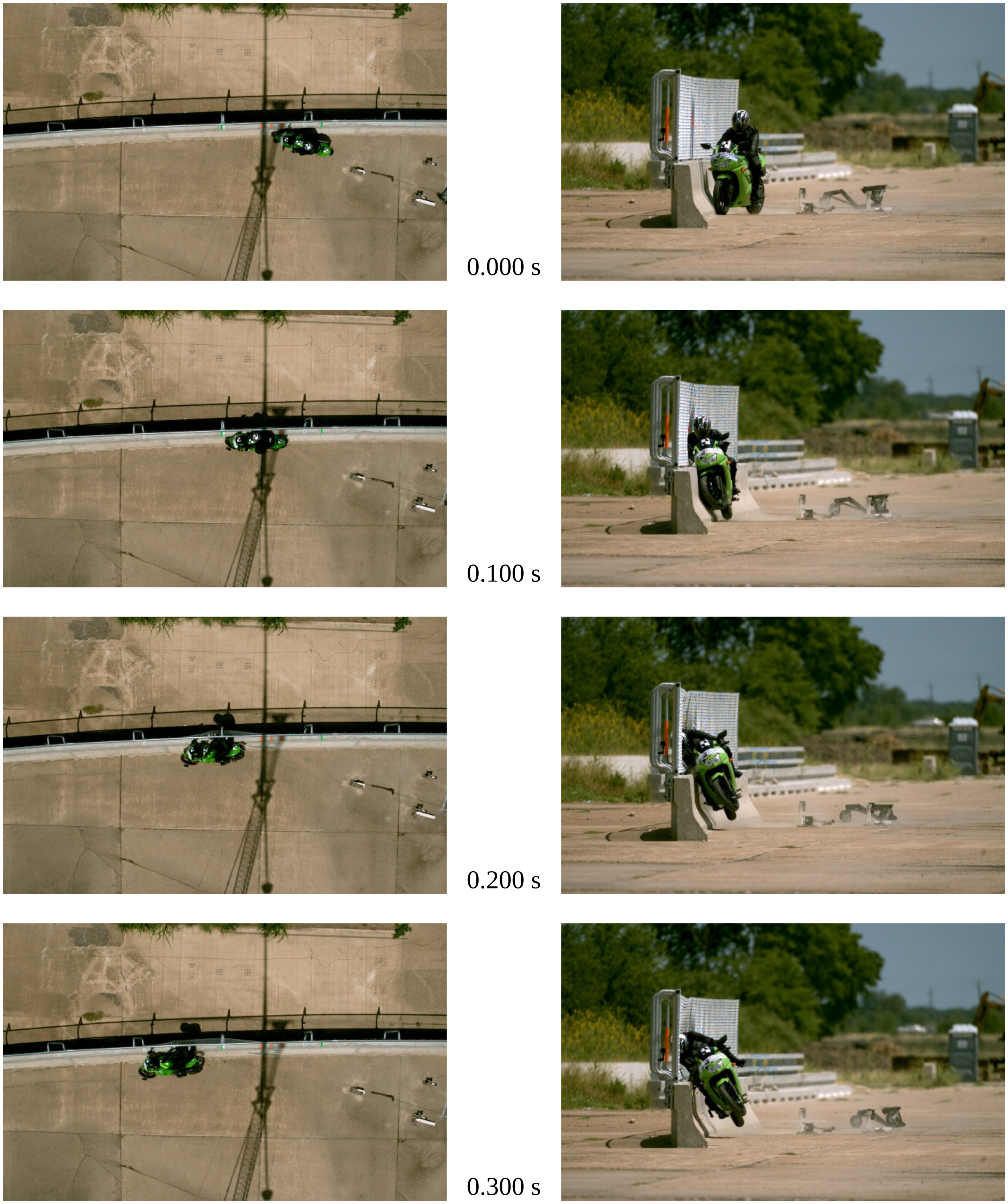


Figure C.1. Sequential Photographs for Test No. 469688-2-1 (Overhead and Frontal).

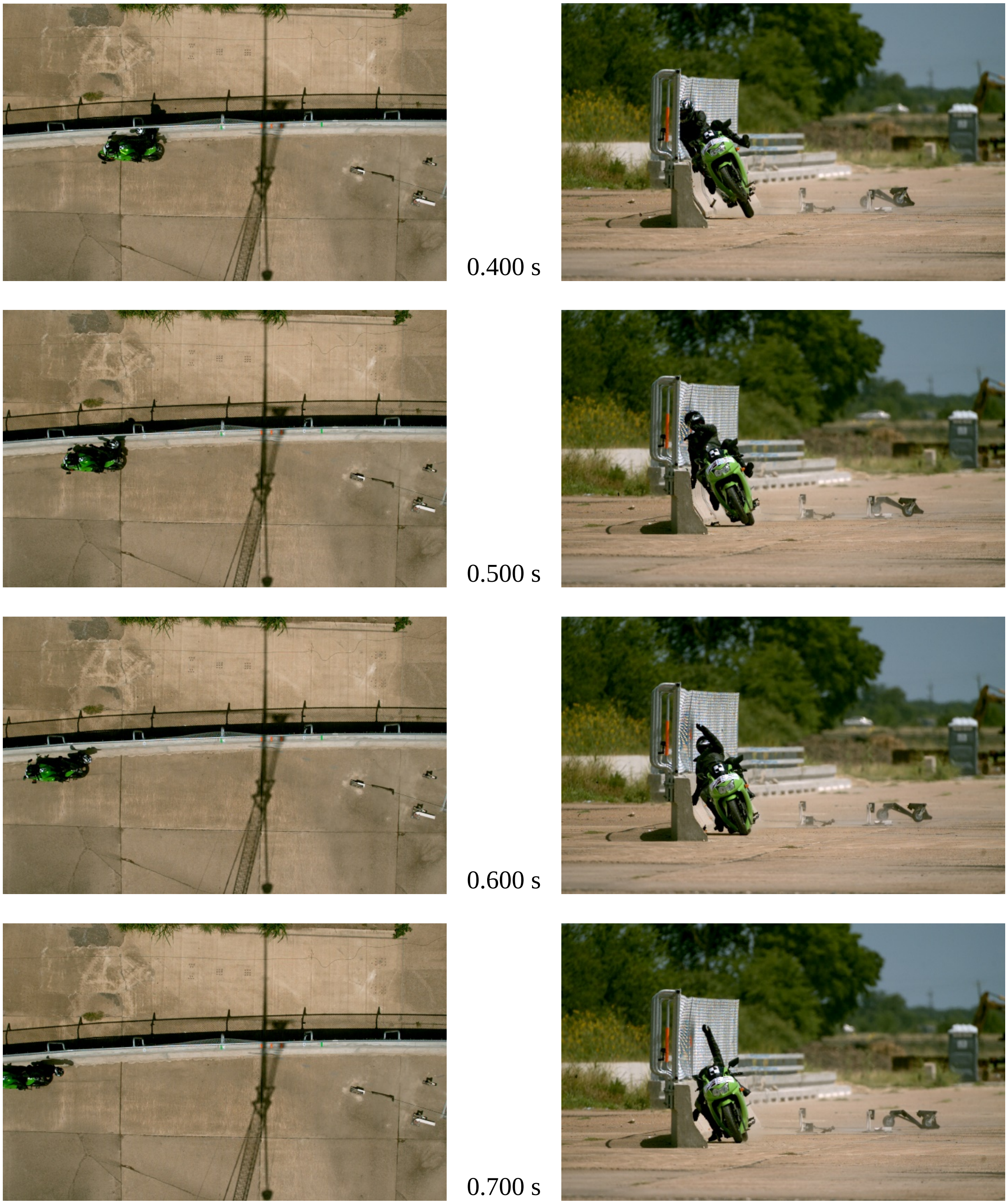
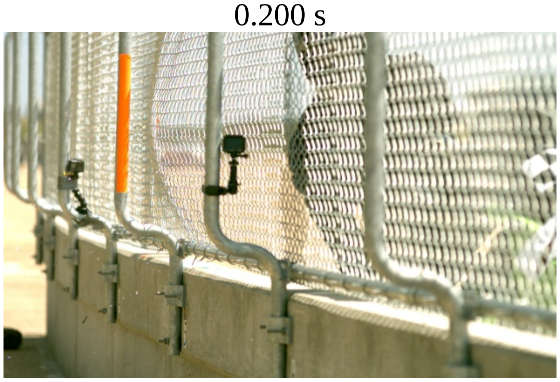
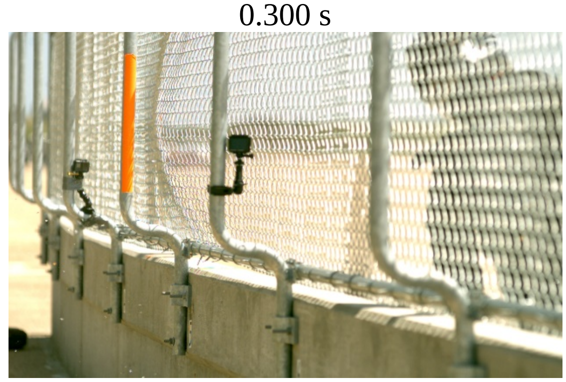


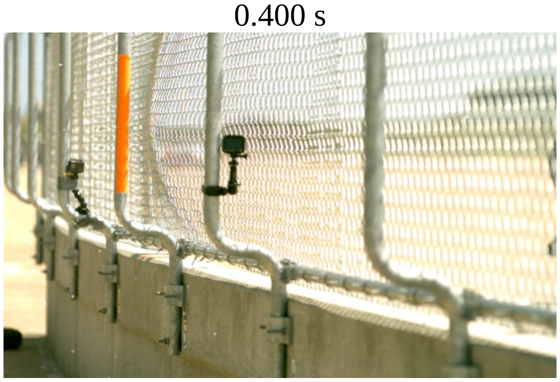
Figure C.1. Sequential Photographs for Test No. 469688-2-1 (Overhead and Frontal Views) (Continued).


0.000 s 0.100 s


0.200 s 0.300 s

0.400 s 0.500 s




0.600 s 0.700 s

Figure C.2. Sequential Photographs for Test No. 469688-2-1 (Rear View).