LIST OF APPENDICES

NOTE: Appendices A-S are associated with *NCHRP Web-Only Document 304: Criteria for Restoration of Longitudinal Barriers, Phase II* (found on the TRB website [www.trb.org] by searching for *NCHRP Web-Only Document 304)*.

APPENDIX A

A Guide for W-Beam Guardrail Assessment – A Field Manual for Highway Maintenance Personnel

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A Guide for W-Beam Guardrail Damage Assessment

A Field Manual for

Highway Maintenance Personnel

June 2015

National Cooperative Highway Research Program

Project 22-28

ACKNOWLEDGEMENT

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Introduction

This document provides guidance to aid highway maintenance personnel in assessing damage and repair priority of the most widely used strong-post w-beam guardrails – namely the modified G4(1S) and the G4(2W). These systems are also identified as SGR04 in the *Standardized Highway Barrier Guide*. The evaluation procedures are presented in graphical format to facilitate the assessment process. For each damage mode, a commentary is also provided to support the evaluation criteria. A worksheet is provided at the end of this Manual to be used in assessing guardrail condition and reporting materials to be repaired.

While this manual categorizes the various problems individually requiring repair, the field inspector should also look into all problems collectively during the field inspection and report all items requiring attention.

There are many risk factors, in addition to guardrail condition, that state agencies must consider in deciding which systems most warrant repair, such as traffic exposure, operating speeds, site conditions and crash history. The guidance presented herein is based solely on the effectiveness of the damaged guardrail to safely contain and redirect errant vehicles.

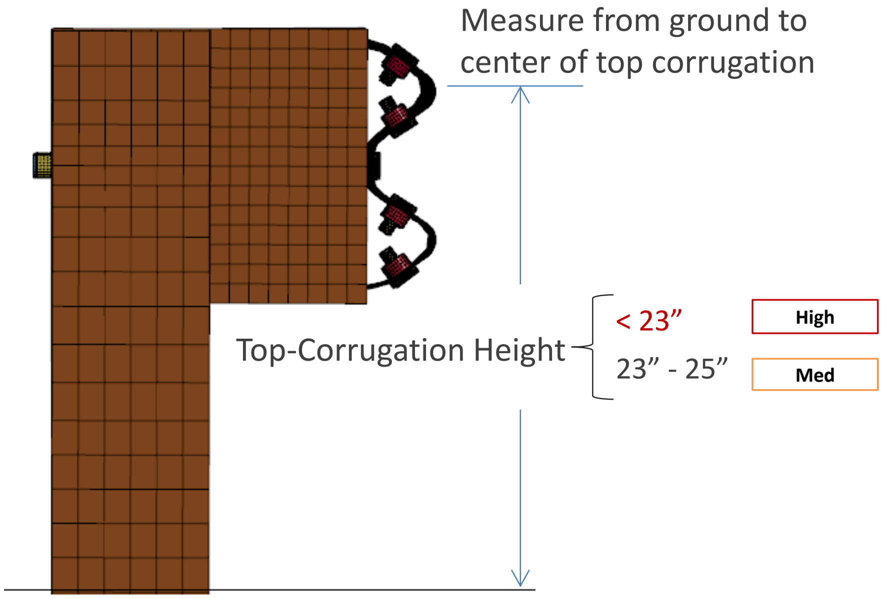
Three classifications are used to denote the relative priority for repair – High, Medium and Low. These were adopted from NCHRP Report 656 and are defined as follows:

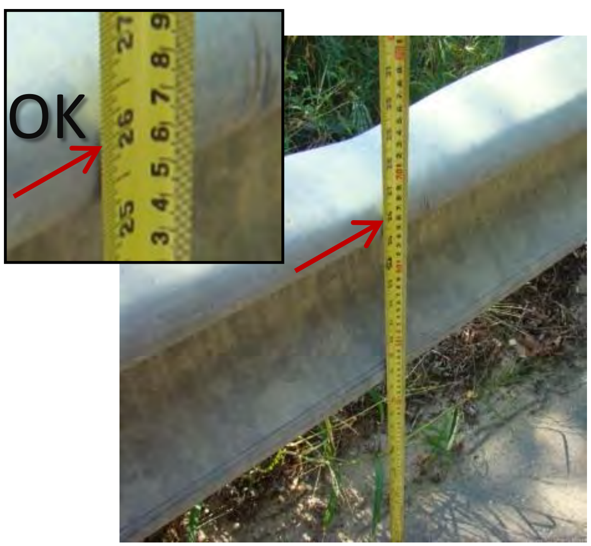
- **High Priority:** Indicates severe damage. The crash performance of the barrier has been compromised to such a degree that a second impact to the damaged barrier would likely result in unacceptable performance.
- **Medium Priority:** Indicates moderate damage. The crash performance of the barrier has likely been compromised to some degree, but the system should perform effectively for a majority of impact conditions.
- **Low Priority:** Indicates that the damaged guardrail is expected to remain fully functional and applies to all damage that is not classified as medium or high.

Online Version

An on-line version of this guide is available at:
http://www.roadsafellc.com/GCA/index.php

Rail Height Condition





Field Example

Commentary

Rail height has traditionally been measured with respect to the top of the rail; however, for crash damaged guardrail it may be more appropriate to measure height with respect to the top corrugation of the rail. For example, a guardrail with standard top-of-rail height of 27 ⅝ inch with a dent on the top of the rail that reduces (locally) the top-of-rail height by 4 inches may not significantly affect guardrail performance as long as the top corrugation is more than 23 inches above grade (also see Rail Crush criterion).

Analyses and full-scale tests have shown that there is a high probability for vaulting over the rail when rail height, as measured from the ground to the center of the top corrugation of the w-beam, is less than 23 inches. Therefore, when the top-corrugation-height is less than 23 inches the relative priority for repair is high.

In the FHWA memorandum issued on May 17, 2010 it was stated that,

> *“Transportation agencies should ensure the minimum height of newly-installed G4(1S) W-beam guardrail is at least 27¾ inches (minimum) to the top of the rail, including construction tolerance. A nominal installation height of 29 inches, plus or minus one inch, may be specified and is acceptable for use on the NHS.”*

Note that a top-of-rail height of 27¾ inches corresponds to a top-corrugation-height of 25 ¼ inches. Thus, based on the memorandum, when the top-corrugation-height 23 to 25 inches, the relative priority for repair is classified as medium.

Lateral Rail Deflection

Maximum lateral deflection =
- > 9 inches — **High**
- 6 – 9 inches — **Med**
- < 6 inches — **Low**

Commentary

Although the effects of rail damage differ between the modified G4(1S) steel post guardrail and the G4(2W) wood post guardrail, the threshold of damage that constitutes the need for repair is essentially the same for both systems; thus the relative repair thresholds defined by Gabler *et al.* in NCHRP Report 656 are considered valid for both systems and are adopted here.

Rail deflections exceeding 9 inches may significantly affect the ability of the guardrail systems to contain and redirect vehicles. Beyond this critical deflection, the G4(2W) was shown to be susceptible to rail rupture, while the modified G4(1S) had an increased probability of barrier override. The relative priority for repair is high for those cases.

Rail deflections of 6 to 9 inches were found to compromise system performance, but the guardrails should function adequately under a majority of impacts. The relative priority for repair is medium for those cases.

At rail deflections less than 6 inches, the guardrails are expected to remain fully functional.

Splice Damage

Field Example

Damage Modes

- Missing bolt
- Visibly missing underlying rail material at bolt location
- Bolt severely gouging rail
- Bolt torn through rail
- Loose bolt

Assessment Criteria

- Damage at two or more splice-bolt locations **High**
- Damage at a single splice-bolt location **Medium**

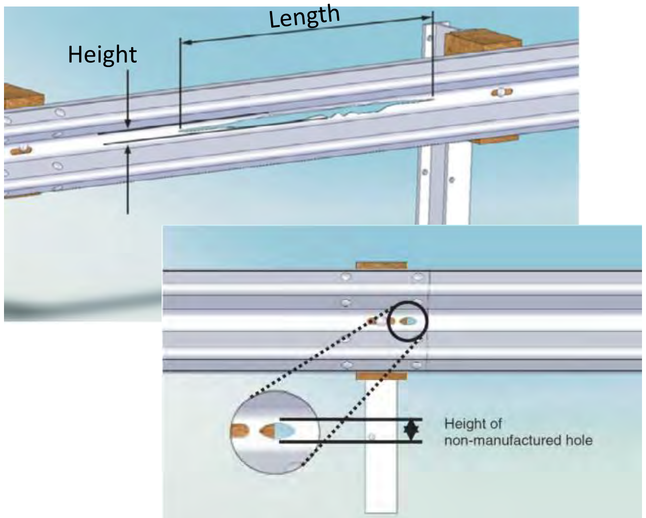
Commentary

It is recommend that the repair threshold for splice damage include splice-bolts: missing, loose, damaged, severely gouging or torn through the rail, or visibly missing any rail material under the bolt. When any of these damages occur at a single splice-bolt location the recommended repair priority is medium. When any of these conditions occur at two or more splice-bolt locations the recommended repair priority is high.

Further, all other damage assessment criteria presented throughout this field guide related to w-beam railing also apply to the w-beam splices; including rail height, rail flattening, rail crush, lateral rail deflection, holes in the rail, horizontal tears and vertical tears.

Since *loose splice-bolts* are not evidenced by obvious signs such as crash damage, they are therefore not easy to identify in the field without conducting close, detailed inspections of the splice. It is not feasible to perform such inspections on a routine basis, care should be taken to ensure that the splice-bolts are properly tightened when installing or repairing w-beam rails.

Rail Holes / Horizontal Tears



- Any size hole or tear at top or bottom edge
- Hole with height > 1”
- Three or more holes or tears on a panel

High

- 1 to 2 holes with height < 1”
- Horz. Tears with Length > 12”
- Horz. Tears with height 0.5 – 1”

Med

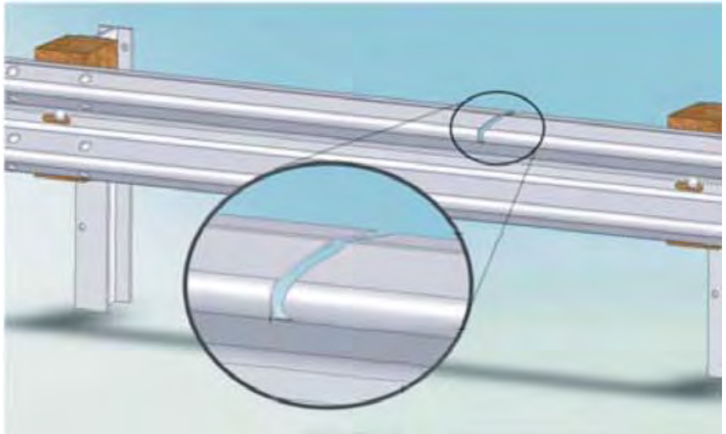
Commentary

Any size hole or horizontal tear (e.g., from weathering, rust, or impact damage) located at the top or bottom edge of the rail has the potential for causing a tear to propagate vertically and is therefore considered high priority for repair. Also, for holes with heights greater than 1 inch, or when there are three or more holes or horizontal tears on a w-beam panel, the relative priority for repair is classified as high.

Pendulum tests have shown that horizontal tears located between the top and bottom corrugations of a w-beam rail do not notably reduce the tensile capacity of the rail. Such tears, however, can result in a part of the vehicle (e.g., front bumper) passing through the tear, exposing the component to direct impact against the guardrail posts, or further extending the tear as the vehicle progresses forward along the rail, increasing the potential for rail rupture.

For horizontal tears located between the top and bottom corrugations with lengths greater than 12 inches, or with heights between 0.5 – 1 inch, or when there are 1 to 2 holes with height less than 1 inch on a single panel, the performance of the guardrail may be compromised but should function adequately under a majority of impacts. Thus the relative priority for repair is classified as medium for those cases.

Vertical Tears

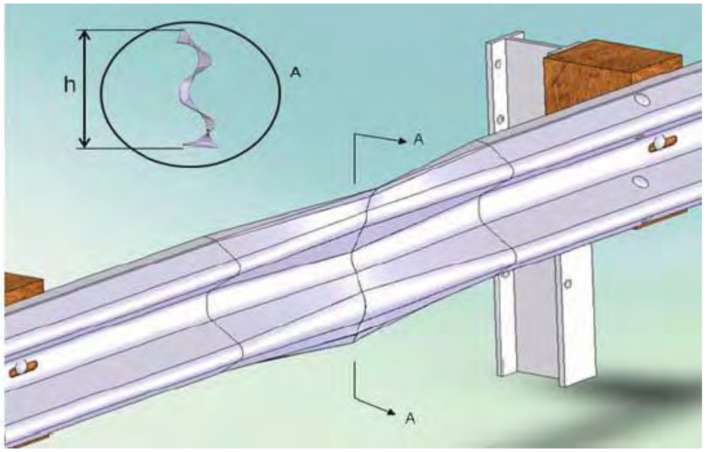


Any size vertical tear → **High**

Commentary

A vertical tear on any part of a w-beam rail may significantly affect the ability of the guardrail system to contain and redirect vehicles. A vertical tear, particularly on or near the edge of the rail, has a high probability of propagating (i.e., extending/growing) during impact and resulting in complete rupture of the rail. All vertical rail tears, therefore, indicate high priority for repair.

Rail Flattening and Rail Crush



Height of Rail Cross-Section	
> 17”	**Med**
9 - 17”	**Low**
< 9”	**Med**

Field Example of Rail Flattening

Field Example of Rail Crush

Commentary

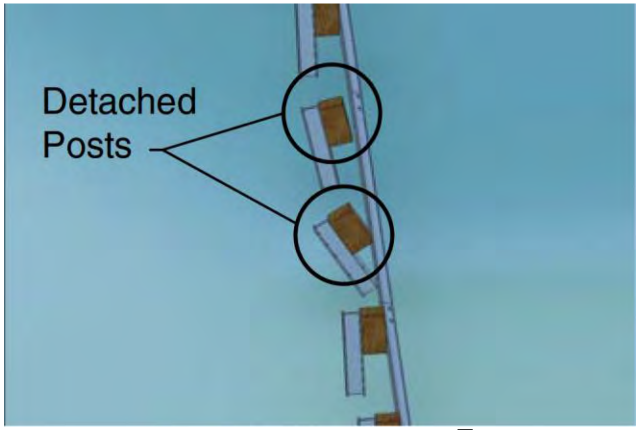
Rail flattening and rail crush have not been shown to significantly affect guardrail performance, and therefore are <u>not</u> considered as high priority for repair.

However, when the cross-section height of the rail, as illustrated in the figure to the left, is less than 9 inches (e.g., crushed) or greater than 17 inches (e.g., flattened), the performance of the guardrail is likely reduced, but it should function adequately under a majority of impacts. The priority for repair is classified as medium for these cases.

For rail damage resulting in a cross-section height of 9 to 17 inches, the guardrail is expected to remain fully functional; thus these cases are considered as low priority for repair.

Note that the baseline cross-section height of an undamaged w-beam rail is 12 inches.

Posts Separated from Rail



- Post/rail separation > 3”
- 2 or more posts separated from rail

Med

Field Example

Note:

1. If the blockout is not firmly attached to the post, count as missing blockout.
2. Lateral deflection guidelines may apply for this damage mode.

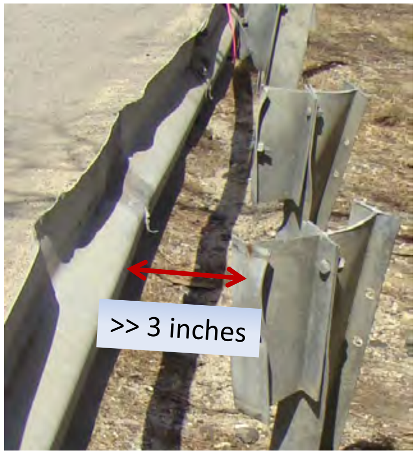
Commentary

This damage mode has not been shown to significantly affect guardrail performance and, therefore, is not considered to warrant high priority for repair. However, engineering judgment should be used on a case by case basis.

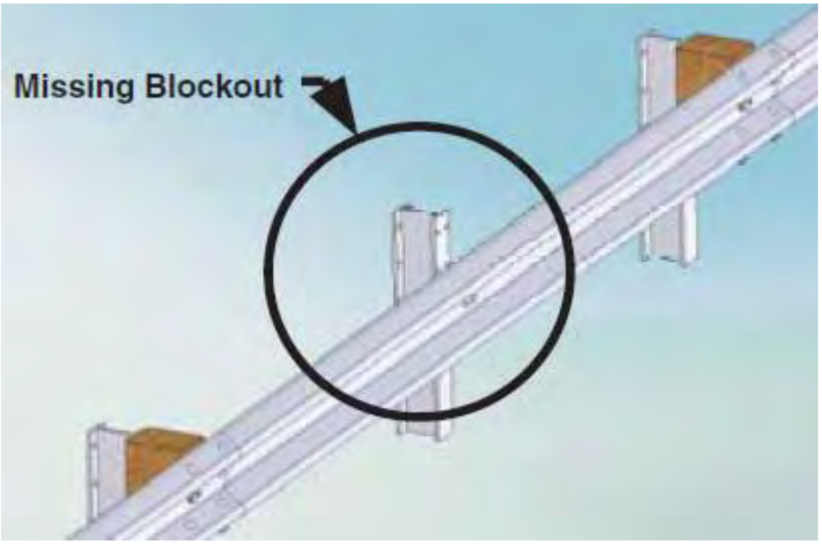
For the case of a single post separated less than 3 inches from the rail, the system should remain fully functional. However, when two or more consecutive posts are separated, or when post/rail separation for a single post exceeds 3 inches, guardrail performance may be compromised. The relative priority for repair in such cases is generally medium; however, such damage often denotes the existence of other damage modes.

Post and rail separation rarely occurs without post and rail deflection or damage to other components. When post/rail separation greatly exceeds 3 inches or if multiple posts are separated from the rail, it is recommended that other aspects of the system be critically evaluated (e.g., lateral deflection, missing or damaged blockouts, etc.).

The photo shown to the right is an example of rail-post separation that warrants high priority for repair. Although the rail deflection is negligible, the extreme deformation and separation of the posts in this case render them nonfunctional.



Blockout Condition



Any blockouts:

- Missing
- Cracked across grain
- Split through post hole
- Rotted

Med

Field Example

Commentary

This damage mode has not been shown to significantly affect guardrail performance and, therefore, is not considered to warrant high priority for repair. However, when one or more blockouts are missing, cracked across the grain, split vertically through the post-bolt hole or rotted, there is an increased potential for the rail to directly contact the posts during a collision, which may increase the propensity for rail tears (particularly for rail contact with steel wide-flange posts).

For this damage mode, the guardrail is expected to perform adequately for the majority of impact cases. The relative priority for repair is classified as medium.

Wood Post Deterioration

Damage Levels (using Strength and Deterioration Mesurement Tools)

	8-inch Round Posts (nominal)			General
	Capacity		Resi Score	
Damage Level	Peak Force (kips)	Strain Energy (kip-in)	S_U or S_{MOR}	Relative Capacity
0 (new)	> 14	> 35	>1	100%
1	12 - 15	26 - 40	0.83 - 1.0	83%
2	7 - 13	20 - 30	0.57 - 0.83	57%
3	< 9	< 20	< 0.57	< 57%

Visual Cues (see Commentary)

DL3

	Score	Criteria
Force (k):	3.8	< 9
Energy (k-in):	5.3	< 20
Resi:	0.24	< 0.57

DL2

Score	Criteria
7.6	7-13
21.3	20-30
0.67	0.57 - 0.83

DL1

Score	Criteria
14.8	12-15
32	26-40
0.95	0.83 - 1.0

Commentary

Note: The information provided on this page is for how to assess the deterioration level of wooden guardrail posts. Repair criteria are provided on the following pages.

Four levels of deterioration for wood guardrail posts are defined in terms of load and energy capacity of the post data, as well as in terms of relative capacity. Therefore, if post strength is measured or otherwise determined in the field (e.g., stress wave techniques, force-deflection techniques, resistograph, etc.) then the relative capacity may be used to identify damage level.

If strength and/or deterioration measurement tools are not available, then visual inspection and “sounding” procedures should be utilized by experienced maintenance personnel to assess the soundness of the posts.

Visual and Auditory Cues

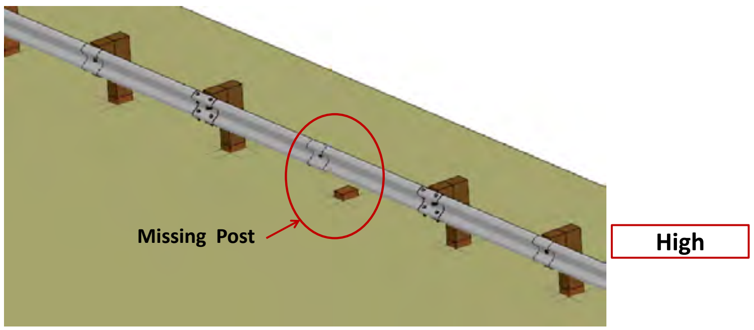
DL3**:** Significant deterioration at top of post is usually evident. Deterioration is often deep (>1”) and covers the full cross-section of the post. Mildew or mold is often present on the side of the post near the ground line; and the post is audibly very soft (punky) when struck with a hammer near the groundline.

DL2**:** Often marked by shallow deterioration at top of post (<1”), extending over most if not all the cross-section. Post is audibly soft but not punky when struck by a hammer.

DL1**:** Generally there is no deterioration evident at the top of the post. In some cases, however, signs of deterioration may exist near the top-center of post, but will not extend to the outer shell. The post is relatively sound when struck with a hammer.

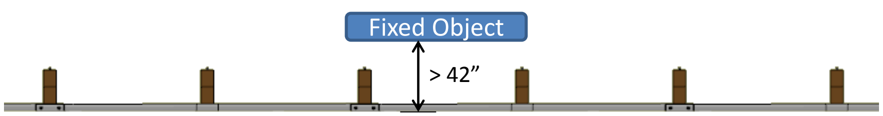
Wood Post Condition

Missing / Broken:



Deteriorated Wood Posts:

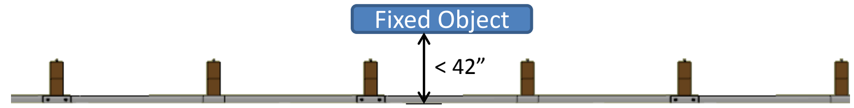
If a fixed-object is located more than 42” behind face of rail:



Post Condition =

DL3	**High**
DL2	**Med**
DL1	**Low**

If a fixed-object is located less than 42” behind face of rail:



Post Condition =

DL2 or DL3	**High**
DL1	**Med**

Commentary

If any wood posts are missing, broken or cracked across the grain the guardrail will not function properly and should be replaced. Also, any posts with deterioration level 3 (DL3) are essentially non-functional and are considered to be of high priority for replacement.

When a fixed object is located within 42 inches behind the guardrail, then wood posts with damage level DL2 or greater should be replaced with high priority, due to potential for large rail deflection leading to vehicle contact with the object.

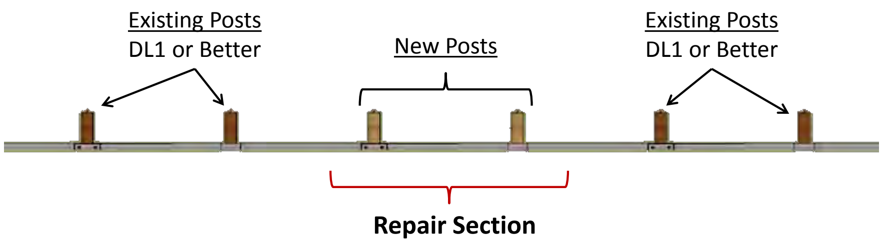
Otherwise, posts with damage level DL2 should function adequately under a majority of impacts and are thus considered to be of medium priority for replacement.

Posts with damage level 1 (DL1) are considered fully functional.

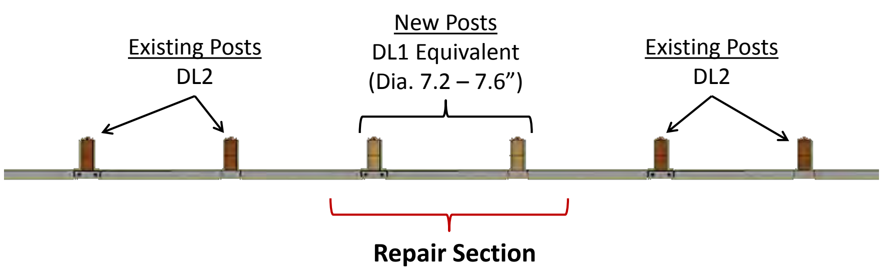
Wood Post Condition (Continued)

<u>If Replacement of Posts is Warranted:</u>

If posts adjacent to the repair section are DL1 or better:



If posts adjacent to the repair section are DL2:



Commentary

If it is determined that replacement of guardrail post(s) is warranted, (e.g., in a crash damaged section), then the posts immediately upstream and downstream of the repair section should be checked for deterioration to ensure stiffness compatibility between the repair section and the existing guardrail.

- If the adjacent posts are DL1 or better, then only the posts in the damage region need to be replaced.
- If the adjacent posts are DL2, then either: (1) all posts in the system should be replaced with new posts or (2) the damaged posts in the immediate repair section should be replaced with posts of equivalent strength to DL1 (e.g., new posts with reduced cross-section). From available test data, new <u>round</u> posts with a diameter of 7.2 to 7.6 inches meet this condition. Moreover, these reduced post diameters also meet the minimum size criteria for round posts (i.e., 8 ± 1 inches).
- If the adjacent posts are DL3, then according to the aforementioned criteria, those posts should also be included in the repair since they render the guardrail non-functional.

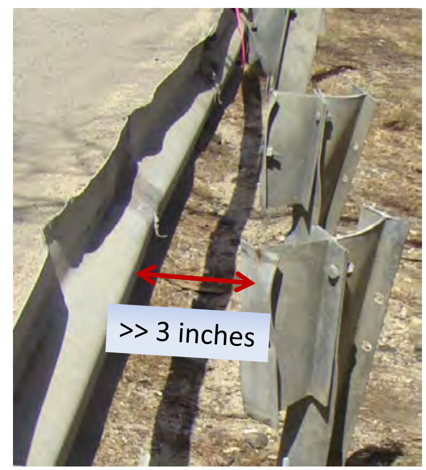
Steel Post Condition

One or more posts missing or with metal tears **High**

Commentary

For the steel posts of the G4(1S) guardrail, the relative priority for repair is classified as high when any posts are missing or have metal tears in them. The guardrail will not function properly with these damages and the posts must be replaced.

The case of bent or twisted posts has not been evaluated as an isolated damage mode, thus engineering judgement must be used for those cases. (See also the criteria for rail deformation and for post-rail separation on pages 4 and 9, respectively.) The photo below was shown earlier on page 9 and is shown again here for its relevancy to this damage mode. The deformation of the posts, as well as their separation distance from the rail as shown in this photo, renders them nonfunctional. Thus, this damage would warrant high priority for repair.



Soil Erosion Condition

Erosion at a Single Post within a Four-Post Span:

Erosion = { ≥ 12” **High**; 9 - 12” **Med** }

Erosion at Multiple Posts within a Four-Post Span:

Erosion = { ≥ 6” **High**; 4 - 6” **Med** }

Commentary

Erosion at a Single Post within a Four-Post Span:

Erosion depth of 12 inches or greater around the post indicates high priority for repair due to increased potential for excessive pocketing and rail rupture.

Erosion depths of 9 to 12 inches were found to compromise system performance, but the guardrail should function adequately under a majority of impacts. This damage level is classified as medium.

When erosion is less than 6 inches, the guardrail is expected to remain fully functional.

Erosion at Multiple Posts within a Four-Post Span:

Soil erosion depth of 6 inches or greater at two or more posts within a four-post span indicates high priority for repair, due to increased potential for pocketing and rail rupture.

Erosion depth of 4 to 6 inches at two or more posts was found to compromise system performance, but the guardrail should function adequately under a majority of impacts at those erosion levels. The lower bound value of 4 inches was based on engineering judgment, since the study did not include erosion depths less than 6 inches. The upper bound value of 6-inches erosion was based on high magnitude strains around the splice-bolt holes in the w-beam, which were considered borderline regarding high potential for rail rupture.

When erosion is less than 4 inches, the guardrail is expected to remain fully functional.

End-Terminal Condition

Impact Head

Misaligned or missing screws:

High

Note: Attachment hardware for the impact head will vary depending on manufacturer.

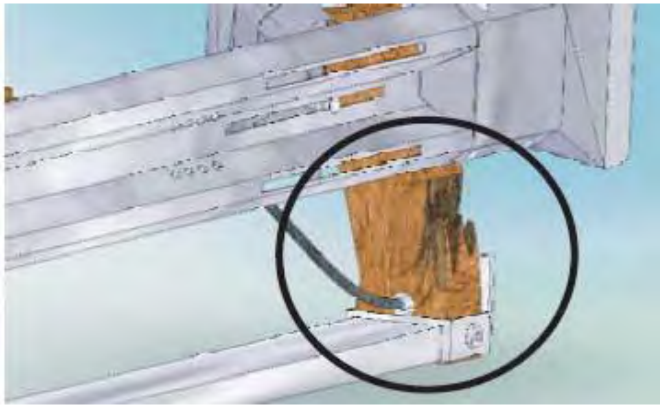
Commentary

The alignment of the impact head on an energy absorbing end-terminal is crucial to the functioning of the system during end-on impacts. Thus, if the terminal head is misaligned or not properly attached to the end-post, then the system should be repaired immediately. In most cases the impact head is attached to steel posts using bolts, whereas lag screws are used for attachment to wood posts.

End-Terminal Condition (Continued)

Damaged End-Post

Damaged, Severely Cracked, Rotted or Missing End-Post:



High

High

Commentary

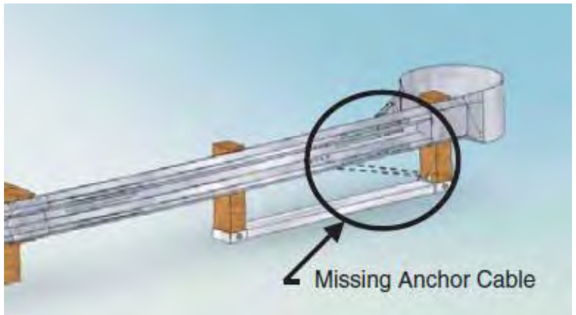
Although the end-terminal of a guardrail serves many purposes, one of its primary functions is to "anchor" the ends of the guardrail so that the resulting tension in the rail can help to limit lateral deflection of the guardrail during downstream impacts.

The anchor mechanism (for most end-terminals) relies on the end-post to hold the anchor cable in place and transfer the loads from the rail to the foundation tubes. Therefore, any end-posts that are damaged, severely cracked, rotted or missing are considered high priority for repair.

End-Terminal Condition (Continued)

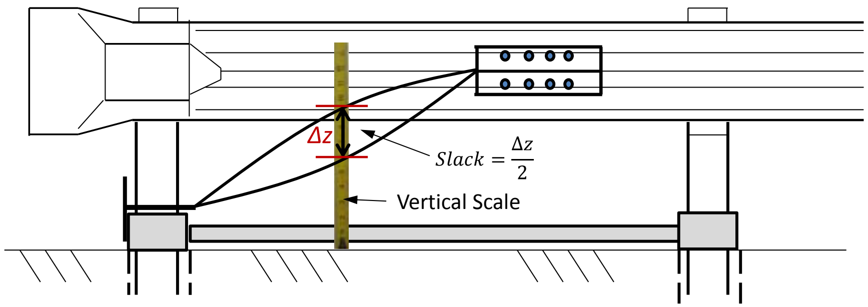
Anchor Cable:

Missing Cable:

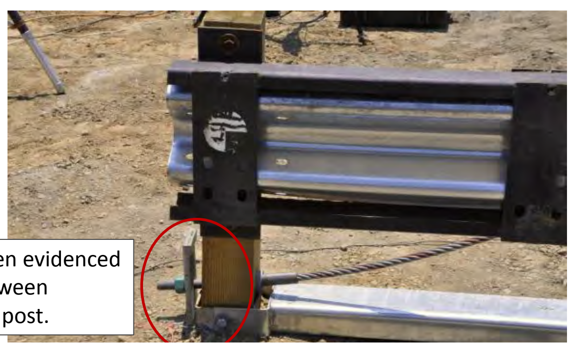


High

Loose Cable:



$$\textbf{Slack} = \frac{\Delta z}{2} = \begin{cases} >3'' & \textbf{High} \\ 2''\text{-}3'' & \textbf{Med} \end{cases}$$



Loose cable is often evidenced by separation between bearing plate and post.

Bearing Plate:

High

Med

Commentary

A missing or unattached anchor cable or a missing bearing plate would result in complete loss of anchorage for the guardrail and render the guardrail non-functional for downstream impacts. Such damages are therefore considered high priority for repair.

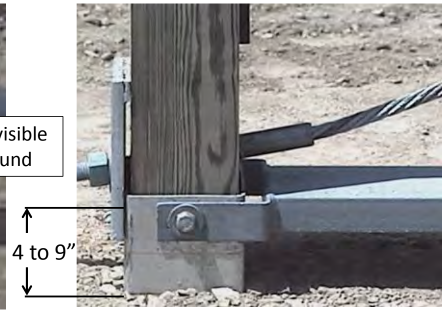
Also, when the anchor cable has more than 3 inches of slack, the performance of the guardrail is significantly compromised and is considered to be high priority for repair. For downstream impacts on the guardrail, a slack anchor cable results in increased lateral rail deflection and increases the potential for pocketing and rail rupture.

A loose cable could also lead to misalignment or loss of the cable bearing plate, as shown above. According to the repair guidelines specified by most end-terminal manufacturers, more than 2 inches of slack in the anchor cable is warrant for repair and is therefore considered to be of medium priority.

End-Terminal Condition (Continued)

Foundation Tube:

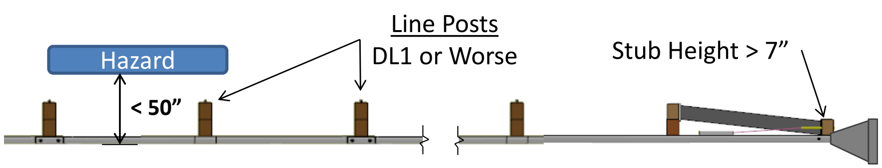
Stub Height:



High **Med**

Stub Height = >9" **High**; 4-9" **Med**

Combination Mode:



Combination Mode = Hazard within 50" behind rail, and Stub height > 7" and Line posts DL1 or worse → **High**

Commentary

A properly installed foundation tube normally protrudes approximately 2-3 inches above the finished ground surface to facilitate connection of the groundline strut and for proper positioning of the bearing plate against tube. Stub heights have been observed to exceed this limit due to incorrect installation and, in some areas, due to frost heave.

A stub height exceeding 9 inches above the ground surface corresponds to excessive reduction in anchor strength and is therefore considered <u>high priority for repair</u>. This condition is evident when the soil plate on the foundation tube protrudes more than 1 inch above grade.

Stub heights extending from 4-9 inches above ground are considered to be <u>medium priority for repair</u>. When stub heights extend more than 4 inches above ground there is an increased potential for small vehicles to snag on the foundation tube. Also, further increases in stub height may prevent proper activation of the breakaway mechanism of the end-terminal during end-on crashes.

Additionally, for wood post guardrail systems such as the G4(2W), when a fixed/rigid object is located within 50 inches behind the face of the guardrail, then a stub height greater than 7 inches is considered <u>high priority for repair</u> if the guardrail line posts have deterioration level of DL1 or greater. This is due to potential for large rail deflection leading to vehicle contact with the fixed-object.

Worksheet for Guardrail Damage Assessment

This guardrail condition questionnaire was developed to aid highway maintenance personnel in assessing damage to guardrails and identifying materials needed for repair. The guidance presented herein applies to two of the most widely used strong-post w-beam guardrails – namely the modified G4(1S) and the G4(2W). If the answer to any of the questions in the questionnaire below is "yes" then it is highly unlikely that the barrier will perform acceptably in subsequent impacts, and the relative priority for repair is considered "high".

Name	
Date of Assessment	
State	
Route number	
Side of road	
Mile post at start of damage	
Date Repairs Completed	
Repairs Completed by	

Notes:____

____

____

____

____

____

GUARDRAIL DAMAGE QUESTIONAIRE

Level 1: System Damage

If the answer is YES to any of the Level 1 questions, replace all visibly damaged components of the system within the limits of the end anchors and reset the undamaged components to a minimum height of 27 ⅝ inches (measured from the top of rail to the ground surface).

___ Q1. Are there more than 9 inches of lateral deflection to the posts and/or rails?

___ Q2. Is the height measured from the ground to the center of the top corrugation of the w-beam less than 23 inches?

Level 2: Splice Damage

If the answer is YES to the Level 2 question, replace the missing or damaged bolts.

___ Q3. Are there any rail splices with two or more splice-bolt deficiencies? Do not count more than one deficiency per splice bolt.

- Missing splice-bolt
- Visibly missing rail material under splice-bolt
- Splice-bolt torn through rail
- Loose bolt
- Bolt severely gouging rail

Level 3: Rail Panel Damage

If the answer is YES to any of the Level 3 questions, replace the damaged rails.

___ Q4. Are there any non-manufactured holes or horizontal tears that meet one or more of the following conditions?

- Intersect either the top or bottom edge of the rail
- Height > 1"
- Three or more non-manufactured holes or horizontal tears on a single panel

___ Q5. Does the rail have any vertical tears?

Level 4: Post Damage

If the answer is YES to any of the Level 4 questions, the missing and damaged posts should be replaced. The displaced and eroded posts should be reset. Any missing or damaged blockouts and/or post bolts should also be replaced.

___ Q6. Are one or more wooden posts missing, broken, rotted, or cracked across the grain?

___ Q7. Are one or more metal posts missing, or have metal tears?

___ Q8. Are the posts in good condition, but displaced?

___ Q9. Do two or more posts within a four post span length have soil eroded from them at a depth of 6 inches or more, as measured at the back of the post, or does one post have 12 or more inches or erosion?

Note: If there are any rectangular washers under the post-rail bolt heads anywhere in the system, they should be removed.

Level 5: End-Terminal Component Damage

If the answer is YES to any of the Level 5 questions, the damaged or missing components should be replaced. Remember to check both upstream and downstream anchors.

___ Q10. Is the end post sheared, rotted, cracked across the grain, bent, deformed, or has metal tears?

___ Q11. Is the anchor cable missing?

___ Q12. Is there more than 3 inches of vertical slack in the anchor cable?

___ Q13. Is the terminal bearing plate missing?

___ Q14. For energy absorbing terminal, are there any missing or failed lag screws?

___ Q15. Does the foundation tube stub height exceed 9 inches?

___ Q16. Is the groundline strut missing or otherwise non-functional?

___ Q17. Is there any other end-terminal damage that would result in more than 50% reduction in anchor capacity?

___ Q18. (*If system has wood posts*) Is there a combination of:

- Fixed-object located within 50 inches behind w-beam rail
- Stub height exceeds 7 inches
- Line posts have deterioration level of DL1 or greater

Level 6: Steel blockouts

If the answer is YES to the Level 6 question, you should consider upgrading all the blockouts to composite or wood. FHWA encourages agencies to upgrade existing highway safety hardware that has not been accepted under NCHRP Report 350 or MASH when the system is damaged beyond repair.

___ Q19. Does your system have steel blockouts AND have you answered yes to any question above?

Document Damaged Components

If the answer to any of the questions in the questionnaire is "yes" then repair is warranted. Include all damaged components in the repair list below.

Panel Type	# of damaged straight panels	# of damaged curved panels
galvanized steel		
painted		
powder coated steel		
weathering steel		

Bolts	# of bolts needed
Post Bolts	
Splice Bolts	
Other	

Post Type	Size	# of posts to be replaced	# of posts to be reset
galvanized steel			
powder coated steel			
weathering steel			
wood			

Block out Type	# of damaged block outs
composite	
steel	
wood	

End Terminal Type	Missing Components

APPENDIX B

SURVEY OF PRACTICE

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April 9, 2013

SURVEY OF PRACTICE

Introduction

A survey was conducted to determine Transportation Agency plans for implementing NCHRP Report 656 and to identify damage modes and other system elements (e.g., wood posts, transitions, end treatments) that should be added to those covered by Report 656. This information will be important for several reasons. First, it is essential to understand the issues facing the user base of the Field Guide. Additionally, it is essential to understand what obstacles users have or may face when implementing the research recommendation into practice. Identifying these challenges will enable the research team to tailor the Field Guide to meet those identified concerns.

The survey had two target audiences (1) those with direct maintenance responsibilities in the state DOT's and (2) those involved in barrier design and evaluation. Each of these groups will likely have very different perspectives on the performance of these systems, but only the maintenance group will be able to provide feedback regarding the usefulness of the field guide. In particular, only certain entities in the DOT maintenance groups will have any reasonable knowledge of the existence of Report 656 and whether its recommendations have been implemented in their states' maintenance practices.

Two separate surveys were developed and sent to two separate groups with questions designed according to their respective fields and expected knowledge base. Survey 1 was designed to target maintenance engineers with the states and providences; therefore the survey was sent to the member list for the AASHTO Subcommittee on Maintenance, which has 104 members on their email list. Survey 2 was designed to target researchers familiar with ongoing and recently completed research in this field. The second survey was sent to the chair of TRB AFB20 to forward to the TRB AFB20 committee members and friends list as well as the subcommittees and friends lists. It is unknown exactly how many people are on these lists although the number is in the many hundreds. Each recipient was asked to forward the survey to a more appropriate respondent, if the recipient was reached in error.

The surveys were assembled and made available using the on-line tool surveymonkey.com (i.e., www.surveymonkey.com). The advantage to using an internet-based facility like Survey Monkey is that very sophisticated surveys can be developed and easily disseminated to recipients by email.

The following sections list each question from the survey and provide a summary of the results. The intent of the two surveys was to analyze the unique perspectives from these separate functional fields (i.e., maintenance and research); however, since the TRB AFB20 committee and subcommittees encompass many professional groups, the respondents to Survey 2 included a significant proportion of maintenance engineers, as well as researchers, policy makers, manufacturers and others. Therefore, where appropriate the results of the two surveys were combined and reorganized into two profession groups: (1) Maintenance and (2) Research/Policy/Other. These categories are used for survey questions that were common to both surveys.

Contact Information

Question 1 (Survey Groups 1 and 2) – Please provide the following optional information about yourself.

Respondents were asked to provide contact information. All respondents provided their company name (i.e, State DOT, private companies, etc.). Respondents were primarily from the United States, with one from Quebec, Canada, one from the United Kingdom, and one from Spain. Those respondents from within the U.S. represented sixteen states from various regions across the country. The states represented and the number of respondents from each of those states is located in Table 1.

Table 1. U.S. Respondent State and Regional Locations.

State	Region	# of Respondents
New York	Eastern	4
Tennessee	Southern	3
Washington	Western	3
Iowa	Midwestern	2
North Carolina	Southern	2
Connecticut	Eastern	1
Delaware	Eastern	1
Florida	Southern	1
Louisiana	Southern	1
Michigan	Midwestern	1
Minnesota	Midwestern	1
Missouri	Midwestern	1
Ohio	Midwestern	1
South Carolina	Southern	1
Utah	Western	1
Virginia	Eastern	1

Table 2. Regional Locations of U.S. Survey Respondents.

Region	# of Respondents
Southern	8
Eastern	7
Midwestern	6
Western	4

Table 2 shows the regional affiliation for the U.S. respondents. The region represented by the most respondents is the Southern region, while the region represented by the least number of respondents is the Western region.

The regional definitions used for Table 1 and Table 2 are located in Figure 1.

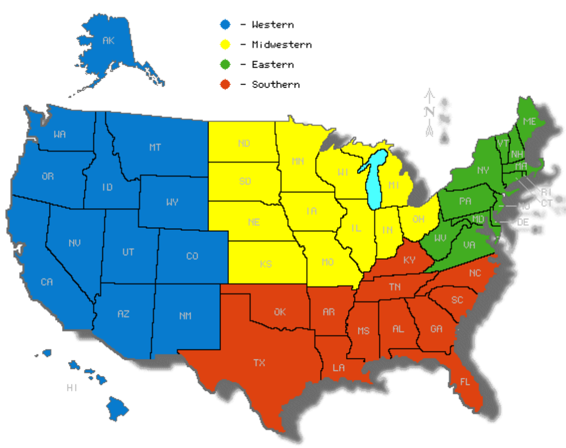


Figure 1. Regional Boundaries for Respondent Locations.

Field of Work

Question 2 (Survey Groups 1 and 2) – What is your field of work?

Respondents were asked the type of work they perform and instructed to check all that apply; therefore, respondents may have checked more than one field. Table 3 contains the amounts of respondents from both survey groups that considered at least some aspect of their field of work to be in the provided fields of work. The respondents who describe themselves as doing "other" work are engaged in activities including:

- Maintenance Operations Superintendent
- Highway/Roadside Standards
- Maintenance Design Engineer
- Central Maintenance Unit

- State Maintenance Methods Engineer
- Director of Maintenance

The respondents' fields of work can be grouped together into two categories: "Maintenance" and "Research/Policy/Other"; based on the most predominant role of each of the respondent's field of work. Table 4 gives a summary of the number of respondents from both survey groups in their prospective categories.

Table 3. Survey Groups 1 & 2 Combined Profession Response Count.

What is your field of work?			
Answer Options	Response Count		
	Survey Group 1	Survey Group 2	Both
Maintenance Supervisor	2	2	4
Maintenance Engineer	8	3	11
Roadside Safety Research	0	4	4
Highway Safety Research	1	0	1
Manufacturing (Product Development)	0	1	1
Manufacturing (Marketing and Sales)	0	1	1
Highway/Roadside Design	2	3	5
Highway/Roadside Policy	3	3	6
Other (please specify)	3	3	6
answered question	15	14	29
skipped question	0	0	0

Table 4. Respondent Profession Groupings.

Maintenance	20
Research/Policy/Other	9

As it was the intent of the surveyors to analyze the unique perspectives from these separate functional fields, it was determined these groupings may help the researchers of this study to better understand the separate needs of the different field categories. These categories are used for survey questions that were included in both surveys for response analysis in this manner, as well as the simple combination of survey responses. When these groups are referenced herein, they are not referred to as "survey groups" but instead as "profession groups" or "reorganized groups". The term "survey groups" as it is used in this research refers to the groups that completed either survey 1 or 2, before the respondents were categorized as having their fields of work as either "Maintenance" or "Research/Policy/Other".

NCHRP Report 656 Relevance

Question 3 (Survey Group 1) – NCHRP Report 656 developed a guide for assessing damage to w-beam barriers and prioritizing maintenance efforts for damaged w-beam barriers. Has your organization implemented or modified its repair policies based on this guide?

The responses from Survey Group 1 are listed in Table 5 and shown graphically in Figure 2. With two-thirds of respondents answering that no changes have been made to any policies, this was by far the most popular answer. Approximately seven percent answered that their organization has *implemented new policies* based on NCHRP Report 656, while none of the respondents indicated that their organizations has *updated existing policies* based on the NCHRP Report 656 guide.

Table 5. Survey Group 1, Question 3 Responses.

NCHRP Report 656 developed a guide for assessing damage to w-beam barriers and prioritizing maintenance efforts for damaged w-beam barriers. Has your organization implemented or modified its repair policies based on this guide?		
Answer Options	**Response Percent**	**Response Count**
I don't know	26.7%	4
My organization has IMPLEMENTED NEW policies based on this guide.	6.7%	1
My organization has UPDATED EXISTING policies based on this guide.	0.0%	0
No, changes have not been made to any policies.	66.7%	10
Please share any comments you may have.		4
answered question		**15**
skipped question		**0**

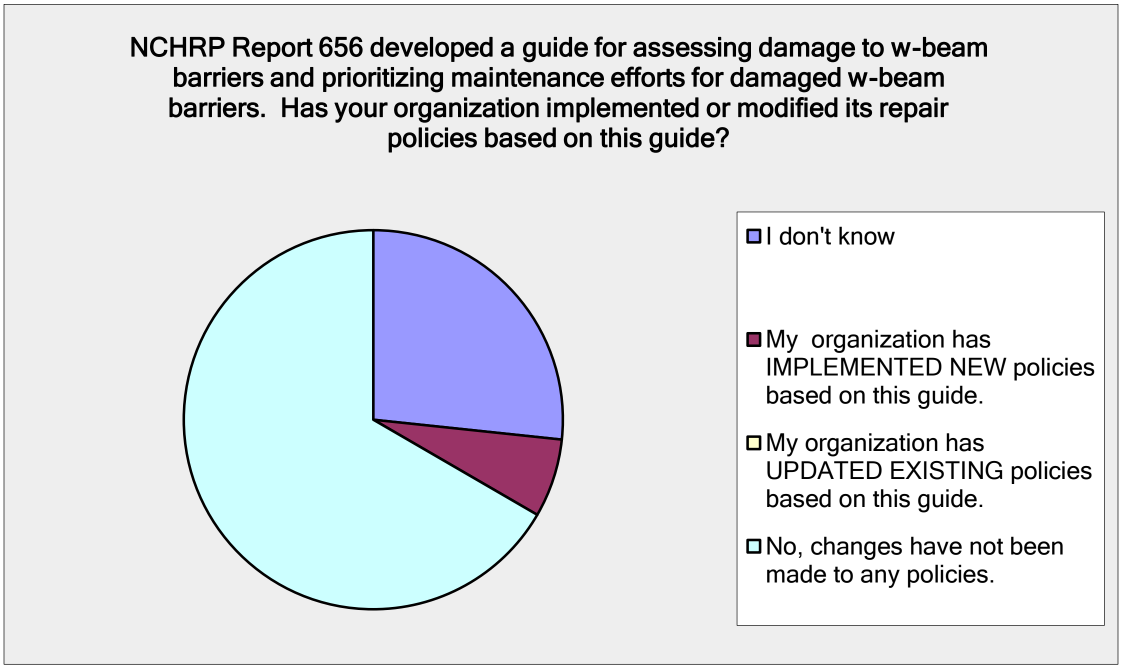


Figure 2. Survey Group 1, Question 3 Responses.

Field Guide Exposure

Question 4 (Survey Group 1) – In the conduct of your work, have you encountered the field guide in use?

Table 6 shows the responses from Survey Group 1, and Figure 3 shows the percentages of the responses graphically. Most respondents have never encountered the field guide in use at all, and none of the respondents have used the field guide themselves. The one respondent that chose to express their impressions with the guide responded with simply, "I have reviewed the Field Guide."

Table 6. Survey Group 1, Question 4 Responses.

In the conduct of your work, have you encountered the field guide in use? (check all that apply)		
Answer Options	Response Percent	Response Count
I don't know	14.3%	2
Yes, I've used the guide myself.	0.0%	0
Yes, I've seen the guide used by others.	7.1%	1
No	78.6%	11
If yes, please explain your experience and impressions with the guide.		1
answered question		14
skipped question		1

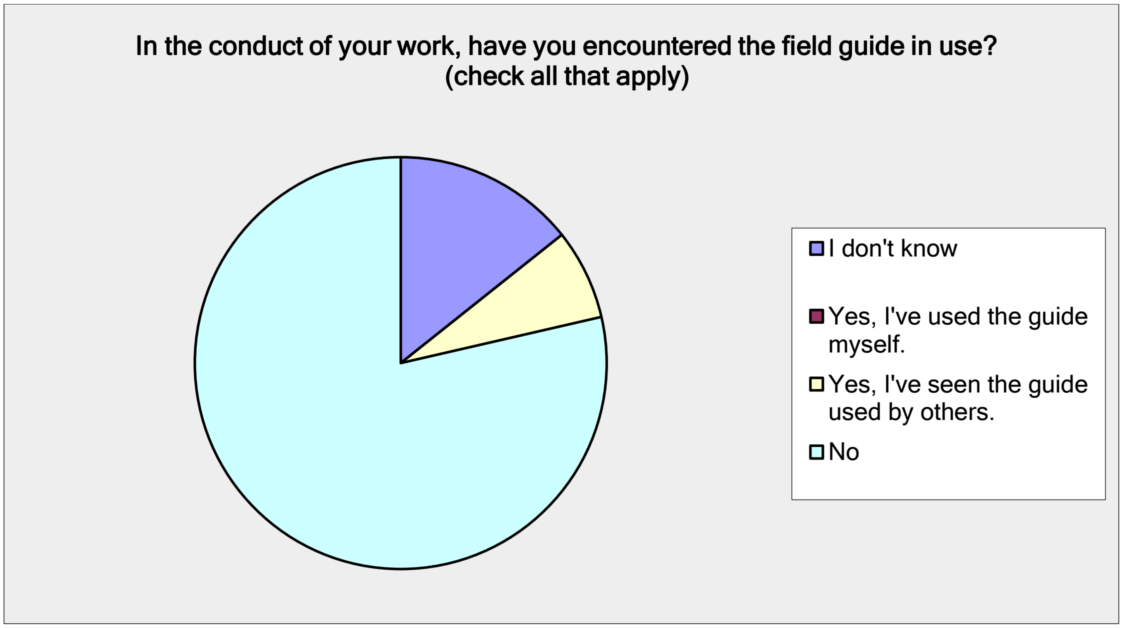


Figure 3. Survey Group 1, Question 4 Responses.

Contact Information for Field Testing Efforts

Question 5 (Survey Group 1) – This research will also include field-testing the expanded guide. If you would like your department to participate in the field-testing efforts, please provide appropriate contact information below. Thank you for your time.

Table 7 shows the response count from Survey Group 1. Most of the respondents did not provide contact information. The three respondents that did provide their contact information were from Tennessee DOT, Virginia DOT, and Utah DOT.

Table 7. Survey Group 1, Question 5 Responses.

This research will also include field-testing the expanded guide. If you would like your department to participate in the field-testing efforts, please provide appropriate contact information below. Thank you for your time.	
Answer Options	**Response Count**
	3
answered question	**3**
skipped question	**12**

Barrier Type Interest

Question 6 (Survey Group 1), Question 3 (Survey Group 2) – Strong steel post w-beam (i.e., Modified G4(1S)) was the focus of Report 656. Additional research is being conducted to expand this guide by including a limited number of additional guardrail systems (excluding cable barriers, bridge rails and concrete barriers). Note that rigid barriers, such as concrete median barriers and bridge rails, generally do not experience minor or moderate damage that would compromise the barrier and restoration guidelines for cable guardrails are being developed in NCHRP Project 22-25. Please rate the types of barriers that you would like to see included in the updated guide. Your response will aid the research team in selecting the barrier types that will be focused on in the current study. [NOTE: Do not include the strong steel-post w-beam guardrail as other, since that system was included in Report 656.]

Respondents were asked to rate their interest in each barrier type using the scale of "very low", 'low", "medium", "high", and "very high". The responses from both reorganized groups were then averaged using a weighted scale where "very low" = 1 and "very high" = 5. The results can be seen below in Figure 4 and Figure 5.

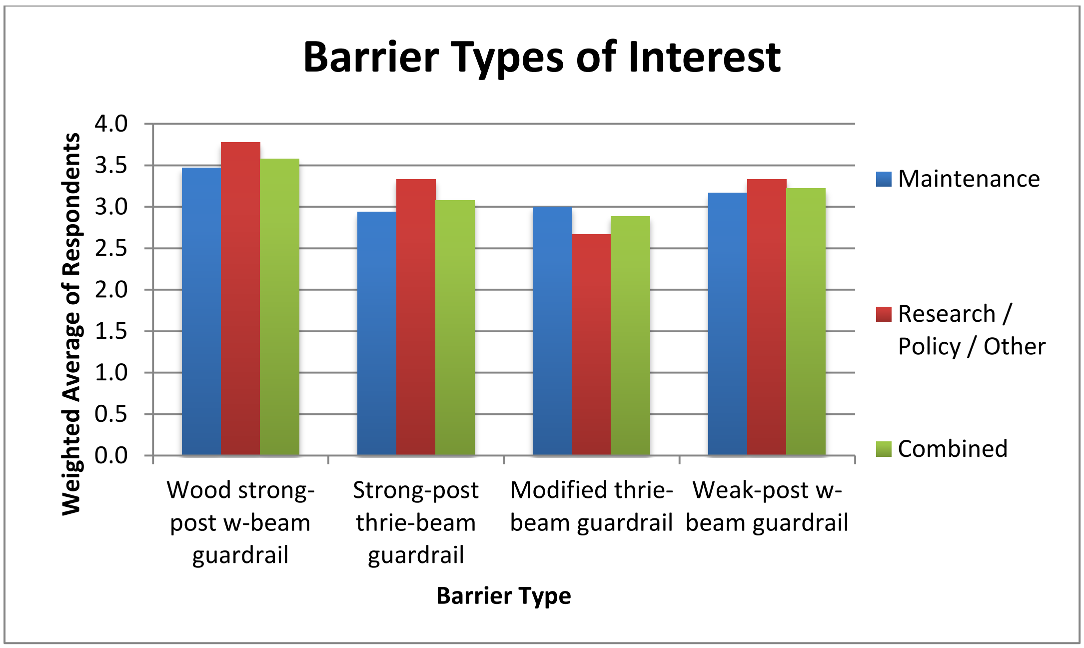


Figure 4. Barrier Types of Interest 1, Reorganized Groups.

From Figure 4, it can be seen that the Research/Policy/Other group has more interest in the wood strong-post w-beam, strong-post thrie-beam, and weak-post w-beam guardrails than the Maintenance group, while the Maintenance group showed more interest in the modified thrie-beam guardrail than the Research/Policy/Other group.

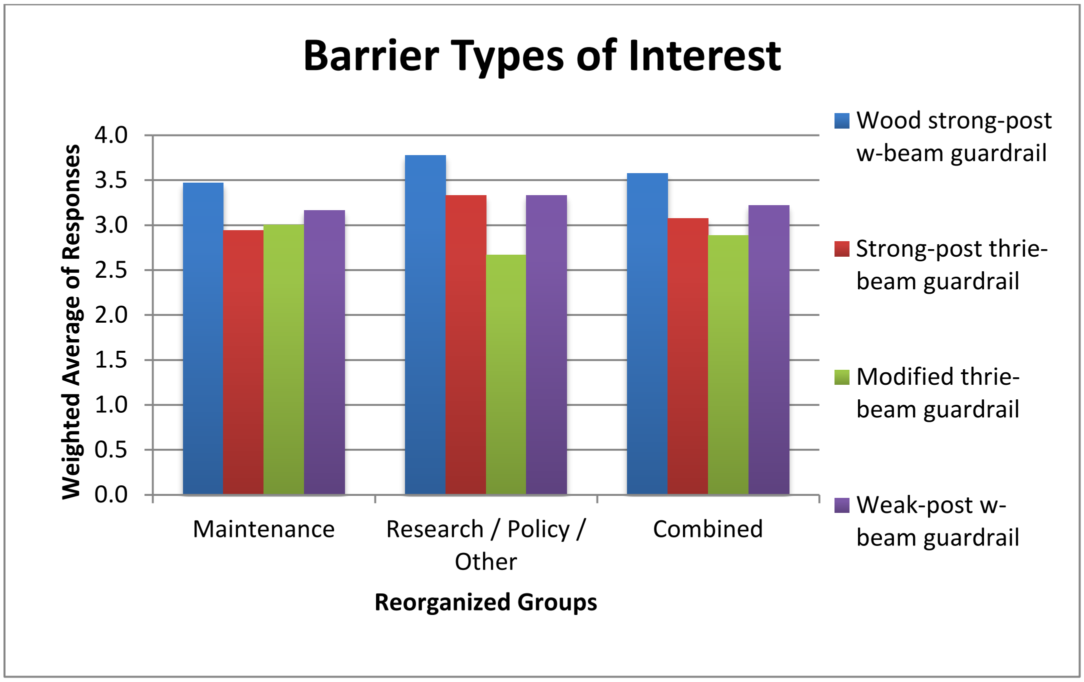


Figure 5. Barrier Types of Interest 2, Reorganized Groups.

From Figure 5, it is evident that the wood strong-post w-beam is the guardrail that both profession groups are the most interested in, followed by the weak-post w-beam guardrail. The Maintenance group was interested in the strong-post thrie-beam guardrail the least, while the Research/Policy/Other group had the least interest in the modified thrie-beam guardrail. The modified thrie-beam guardrail was the barrier with the least amount of interest when the two reorganized groups were combined.

Damage Modes for Guardrail Posts

Question 7 (Survey Group 1), Question 4 (Survey Group 2) - Please identify the damage modes that you feel are most common for each guardrail type by selecting the appropriate rating scale using the pull-down menu. PLEASE ONLY PROVIDE RESPONSES FOR THE GUARDRAIL SYSTEMS THAT YOU ARE FAMILIAR WITH. A blank response indicates that you don't know.

Figure 6 through Figure 13 show the results of the reorganized group responses for each barrier type, while Figure 14 through Figure 19 show the results for each of the guardrail post damage modes. The same weighted average scale that was used for the barrier type interest responses was also used for all of the following damage mode questions.

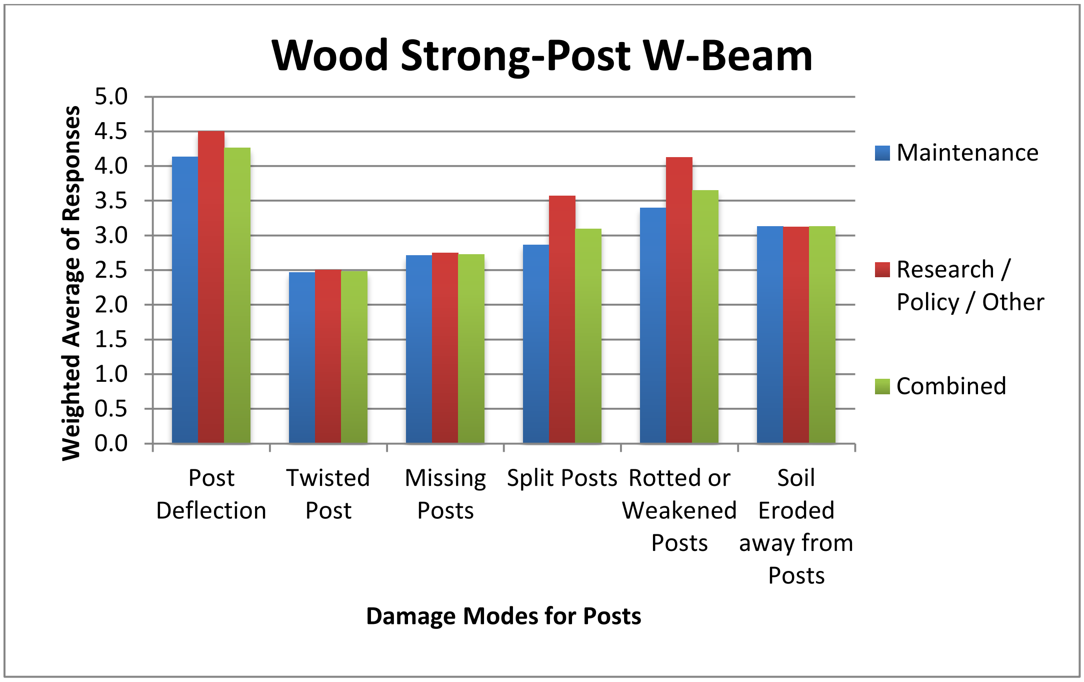


Figure 6. Wood Strong-Post W-Beam Damage Modes for Posts 1, Reorganized Groups.

From Figure 6 it can be seen that the Research/Policy/Other group showed more concern than the Maintenance group for every type of damage mode for posts in the wood strong-post w-beam guardrail except for "soil eroded away from posts". The weighted average of responses for the reorganized groups were very close to one another for three of the damage modes; "twisted posts", "missing posts", and "soil eroded away from posts".

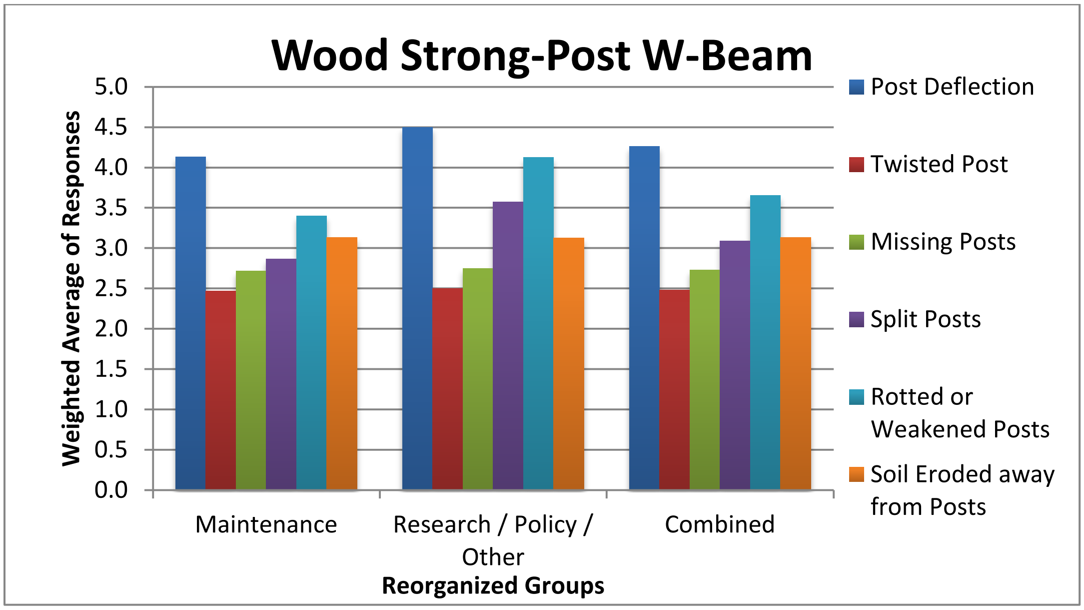


Figure 7. Wood Strong-Post W-Beam Damage Modes for Posts 2, Reorganized Groups.

From Figure 7, "post deflection" is clearly the damage mode considered most common for the wood strong-post w-beam guardrail by both profession groups, followed by "rotted or weakened posts". "Twisted post" and "missing posts" were the two damage modes of least common occurrence for both groups. Those were the only two damage modes that the two groups did not agree on; the Maintenance group felt that "soil eroded away from posts" was more common than "split posts", while the Research/Policy/Other group felt it was the other way around. When combining the two groups, the weighted averages of responses for those two damage modes were about the same.

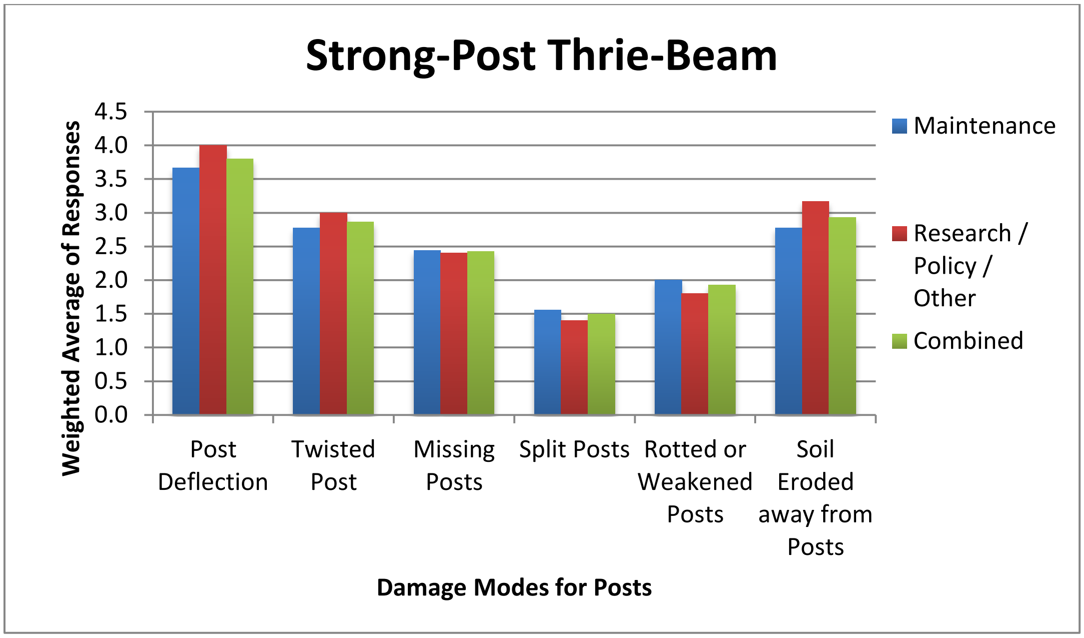


Figure 8. Strong-Post Thrie-Beam Damage Modes for Posts 1, Reorganized Groups.

With regards to the strong-post thrie-beam barrier, Figure 8 shows that the Research/Policy/Other group had more concern for "post deflection", "twisted post", and "soil eroded away from posts" than the Maintenance group. The Maintenance group showed more concern than the Research/Policy/Other group for "split posts" and "rotted or weakened posts", and the results were about the same for both groups in regards to "missing posts".

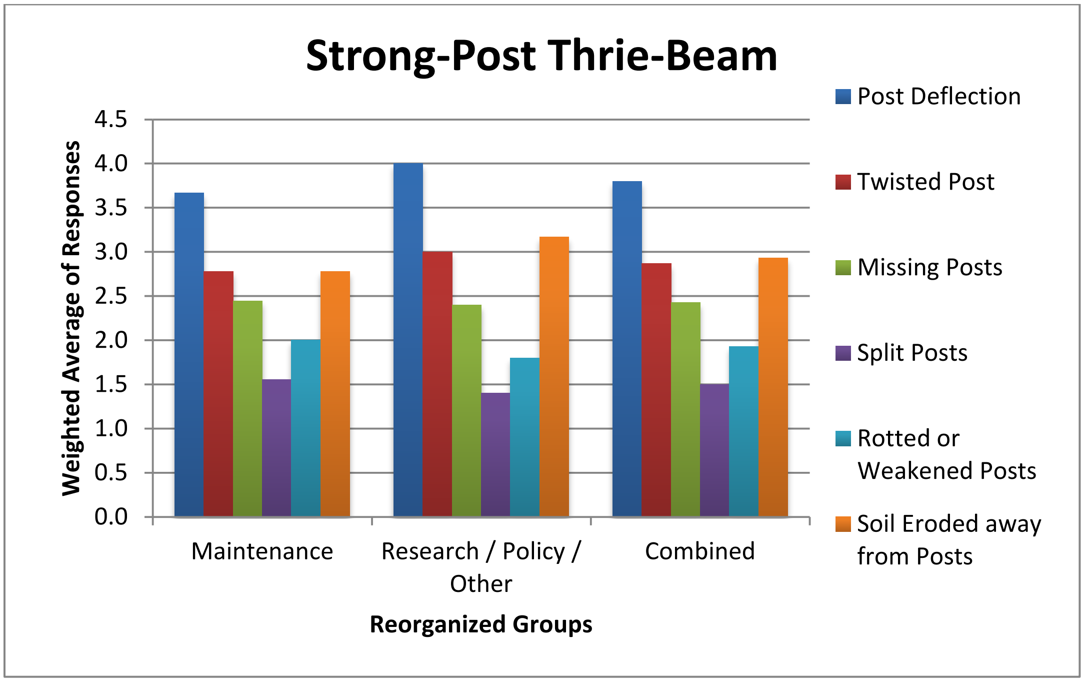


Figure 9. Strong-Post Thrie-Beam Damage Modes for Posts 2, Reorganized Groups.

Figure 9 shows that both profession groups mostly agree with each other as to the frequency of each damage mode for the strong-post thrie-beam barrier. In descending order of occurrence frequency, the damage modes identified were: "post deflection", "soil eroded away from posts", "twisted post", "missing posts", "rotted or weakened posts", and "split posts".

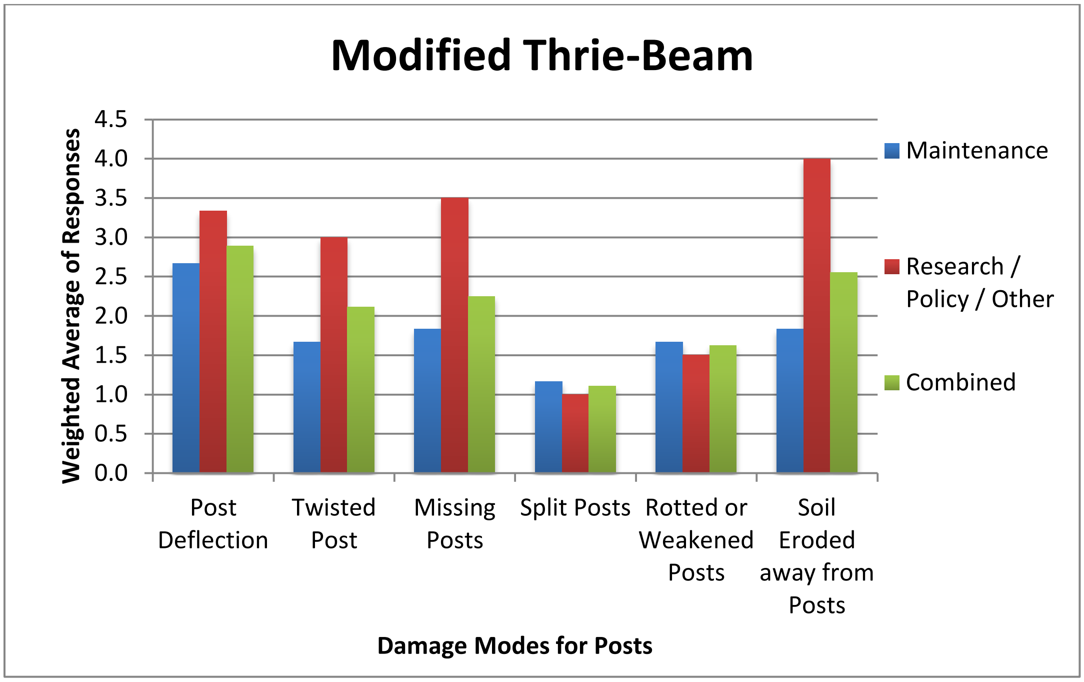


Figure 10. Modified Thrie-Beam Damage Modes for Posts 1, Reorganized Groups.

With regards to damage modes for guardrail posts of the modified thrie-beam, the responses from the different profession groups (Figure 10) were very similar to those for the strong-post thrie-beam (Figure 8), only more skewed. The Research/Policy/Other group showed much more concern for the “post deflection”, “twisted post”, “missing posts”, and “soil eroded away from posts” than the Maintenance group, who showed more concern with “split posts” and “rotted or weakened posts”.

Figure 11 shows that the Maintenance group considered “post deflection” to be the most frequently occurring damage mode for posts in regards to the modified thrie-beam guardrail, while the Research/Policy/Other group considered “soil eroded away from posts” to be the most frequently occurring damage mode. Both profession groups felt “split posts” was the least frequently occurring damage mode, followed by “rotted or weakened posts” as the second least frequently occurring damage mode.

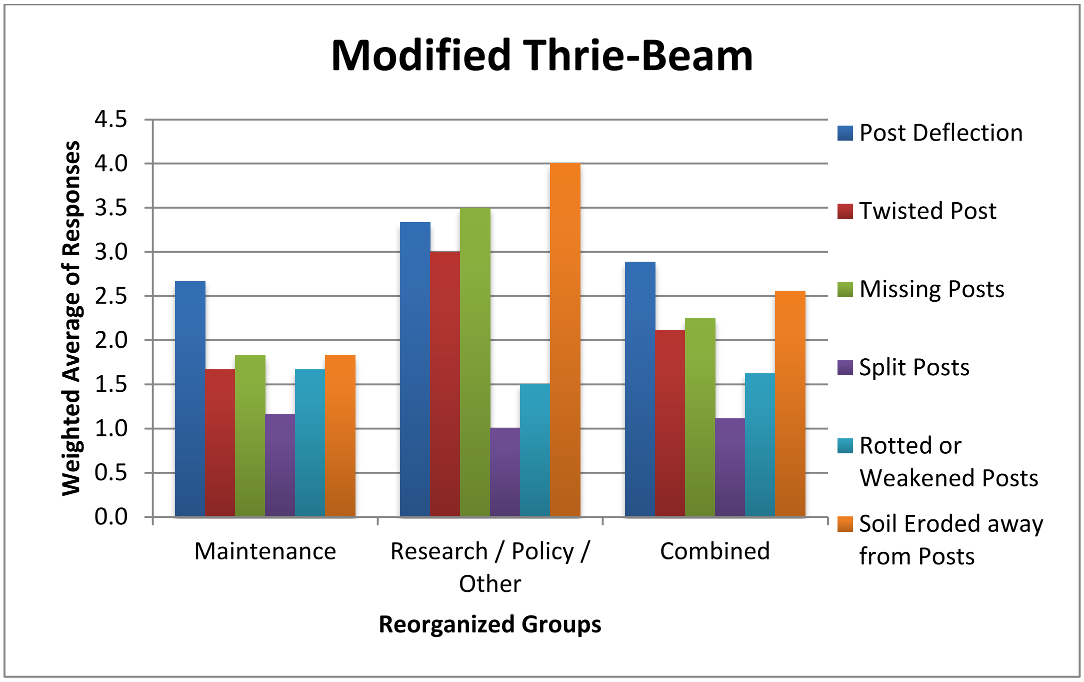


Figure 11. Modified Thrie-Beam Damage Modes for Posts 2, Reorganized Groups.

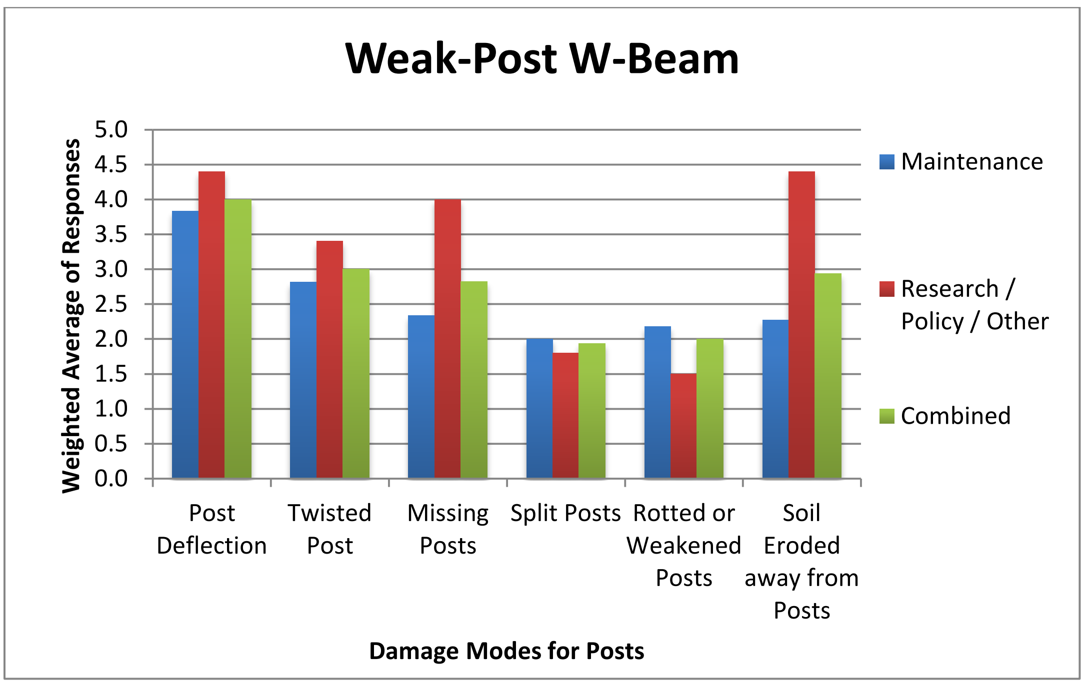


Figure 12. Weak-Post W-Beam Damage Modes for Posts 1, Reorganized Groups.

With regards to damage modes for posts of the weak-post w-beam guardrail, the responses from the different profession groups (Figure 10) were very similar to those for the strong-post thrie-beam (Figure 8) and modified thrie-beam (Figure 10). The Research/Policy/Other group showed more concern for the “post deflection”, “twisted post”, “missing posts”, and “soil eroded away from posts" than the Maintenance group, who showed more concern with "split posts" and "rotted or weakened posts".

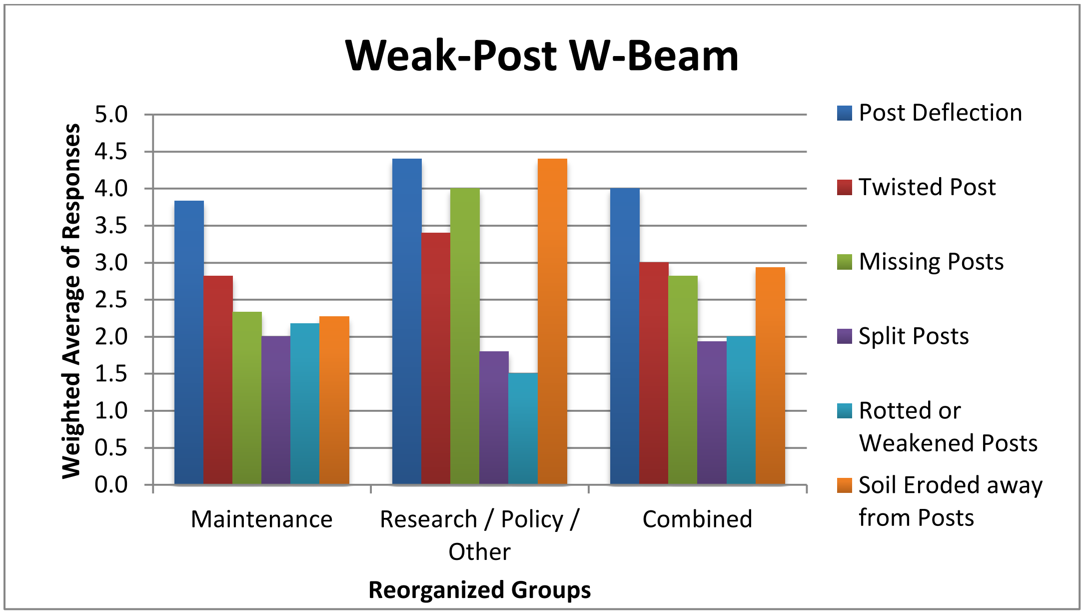


Figure 13. Weak-Post W-Beam Damage Modes for Posts 2, Reorganized Groups.

For the weak-post w-beam barrier (Figure 13), the Maintenance group considered "post deflection" to be the most frequently occurring damage mode for posts. The Research/Policy/Other group considered both "post deflection" and "soil eroded away from posts" to be the most frequently occurring damage mode for posts, and both profession groups considered both "split posts" and "rotted or weakened posts" to be the two least-occurring damage modes.

When looking at just the "post deflection" damage mode (Figure 14), both groups considered this mode of damage to occur more frequently in the wood strong-post w-beam guardrail, followed by the weak-post w-beam, the strong-post thrie-beam, and finally the modified thrie-beam guardrail.

The Maintenance group considered both the strong-post thrie-beam and weak-post w-beam guardrails to have the highest occurrence of twisted posts, while the Research/Policy/Other group considered the weak-post w-beam guardrail alone to be the barrier that experienced this damage mode the most often.

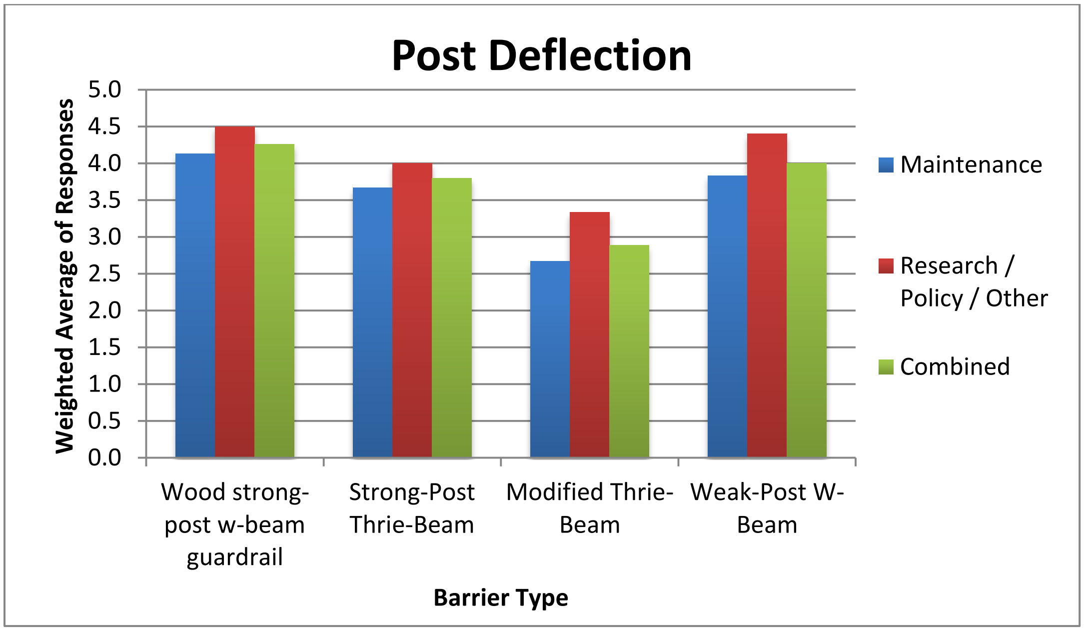


Figure 14. Post Deflection Damage Mode Frequency for Barrier Types, Reorganized Groups.

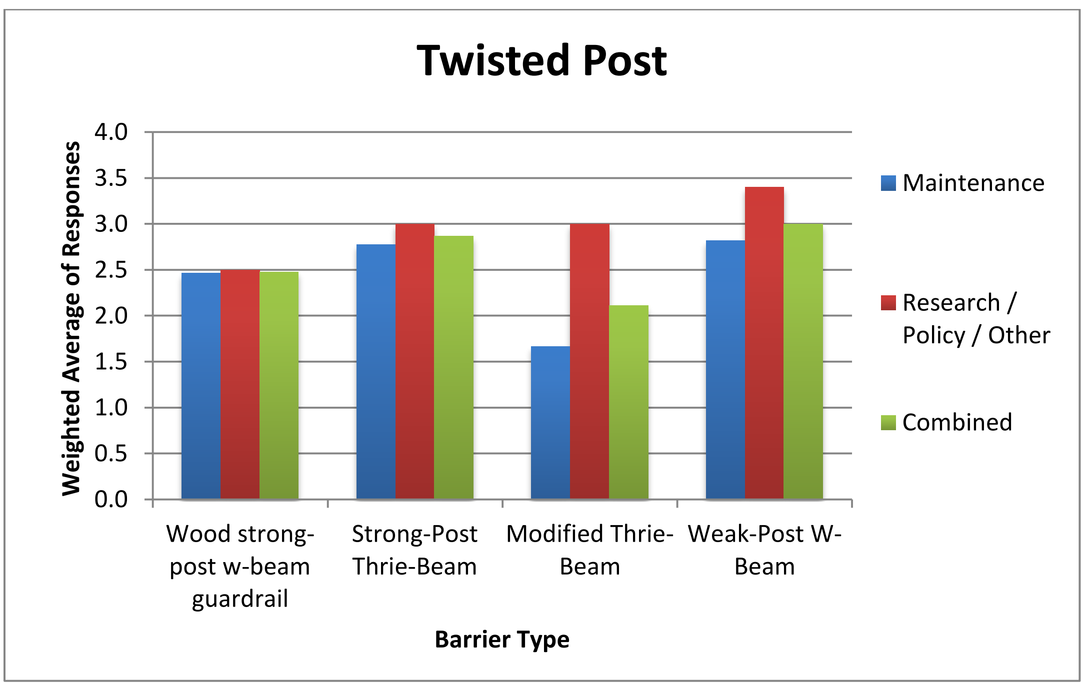


Figure 15. Twisted Post Damage Mode Frequency for Barrier Types, Reorganized Groups.

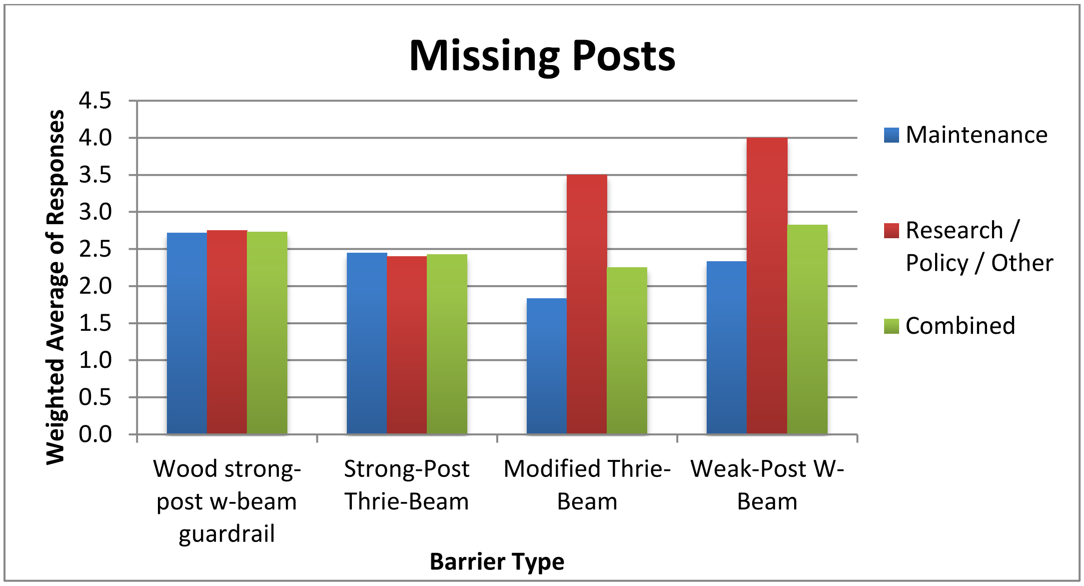


Figure 16. Missing Posts Damage Mode Frequency for Barrier Types, Reorganized Groups.

For the "missing posts" damage mode (Figure 16), the two profession groups were in complete disagreement as to which barrier types experienced the highest frequency of this damage mode. The Maintenance group thought this damage mode occurred mostly with the wood strong-post w-beam and strong-post thrie-beam guardrails, while the Research/Policy/Other group thought it occurred most frequently with the modified thrie-beam and weak-post w-beam guardrails.

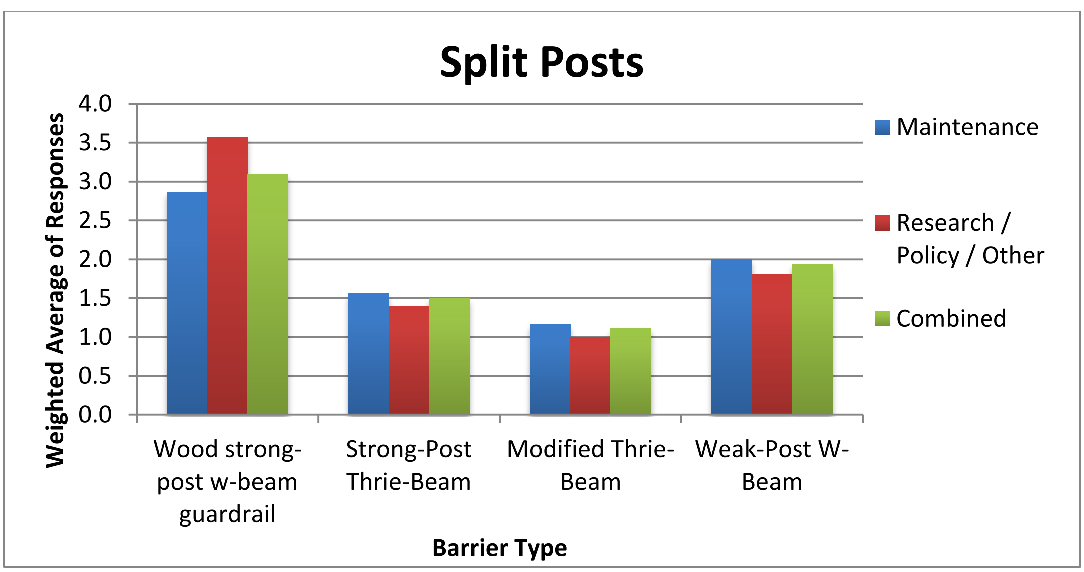


Figure 17. Split Posts Damage Mode Frequency for Barrier Types, Reorganized Groups.

For the “split posts” damage mode (Figure 17), both profession groups agreed with each other on every barrier type. They felt that the wood strong-post w-beam guardrail was the barrier that experienced this damage mode the most often. It is surprising that the modified thrie-beam guardrail received any responses, since this system does not have wooden posts; however, it may be that those respondents confused the wood-post thrie-beam with the modified thrie-beam system. Similarly, the TL-3 weak-post w-beam system also only has steel posts, although there are several TL-2 wooden weak-post guardrail systems.

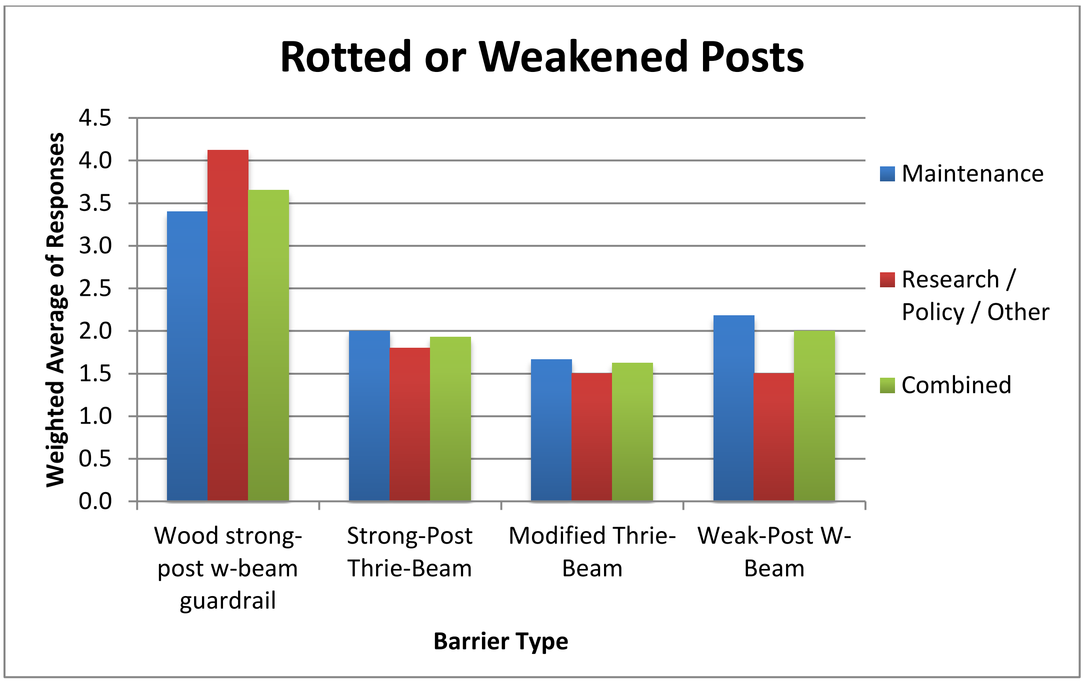


Figure 18. Rotted or Weakened Posts Damage Mode Frequency for Barrier Types, Reorganized Groups.

As with the “split posts” damage mode, the “rotted or weakened posts” damage mode (Figure 18) also had both profession groups cite the wood strong-post w-beam guardrail as the barrier having the highest frequency of occurrence.

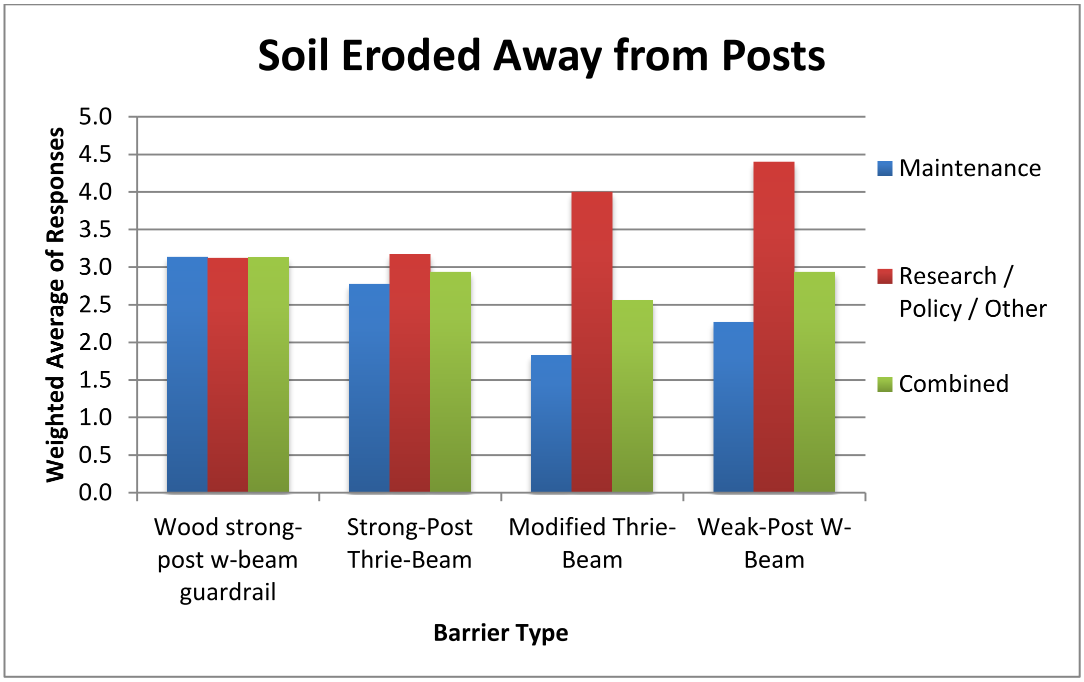


Figure 19. Soil Eroded Away from Posts Damage Mode Frequency for Barrier Types, Reorganized Groups.

"Soil eroded away from posts" (Figure 19) was another damage mode for posts that the two reorganized groups disagreed on in respect to barrier type frequency of occurrence. The Maintenance group identified the wood strong-post w-beam and the strong-post thrie-beam guardrails as the two barriers with the highest frequency of occurrence for this damage mode, whereas the Research/Policy/Other group identified the weak-post w-beam and the modified thrie-beam guardrails.

Damage Modes for Rail Element

Question 8 (Survey Group 1), Question 5 (Survey Group 2) – Please identify the damage modes that you feel are most common for each guardrail type by selecting the appropriate rating scale using the pull-down menu. PLEASE ONLY PROVIDE RESPONSES FOR THE GUARDRAIL SYSTEMS THAT YOU ARE FAMILIAR WITH. A blank response indicates that you don't know.

Figure 20, Figure 21, Figure 22, Figure 23, Figure 24, Figure 25, Figure 26, and Figure 27 show the results of the reorganized group responses for each barrier type, while Figure 28, Figure 29, Figure 30, Figure 31, Figure 32, and Figure 33 show the results for each of the rail element damage modes.

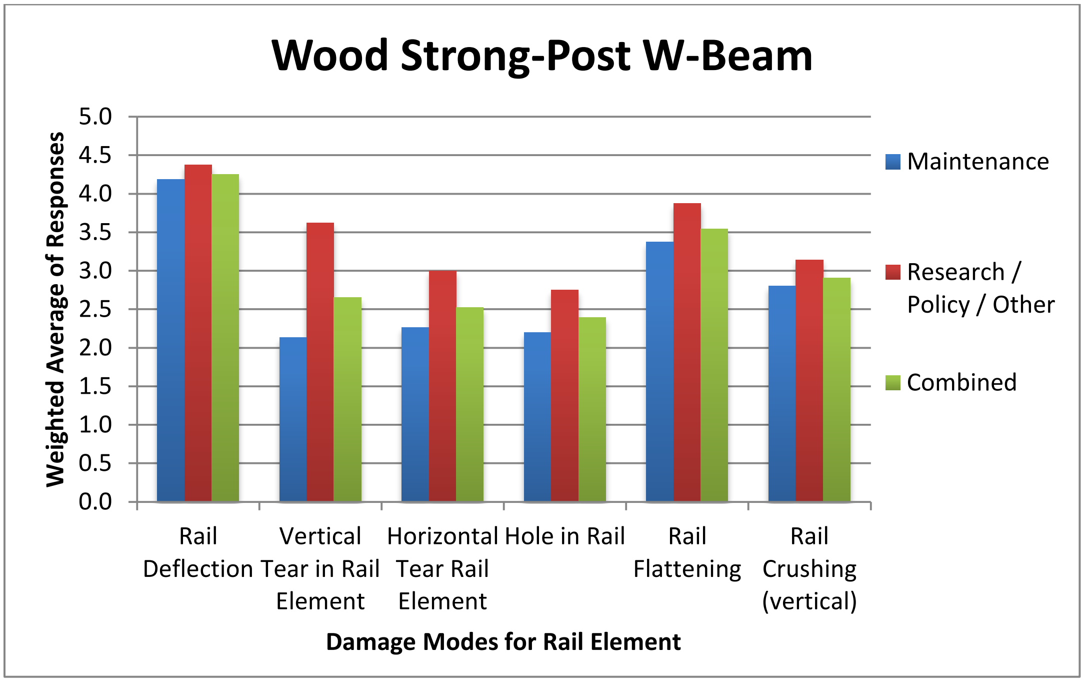


Figure 20. Wood Strong-Post W-Beam Damage Modes for Rail Element 1, Reorganized Groups.

As can be seen in Figure 20, the Research/Policy/Other group had a higher weighted average value of responses for every damage mode for rail element than the Maintenance group for the wood strong-post w-beam guardrail. “Rail deflection” had the least amount of difference, while “vertical tear in rail element” had the most.

From Figure 21, both profession groups considered “rail deflection” to be the most frequently occurring damage mode for rail elements in regards to the wood strong-post w-beam guardrail. They also agree that “rail flattening” was the second most frequently occurring damage mode for the barrier but did not agree on “vertical tear in rail element”, which was considered more common by the Research/Policy/Other group than the Maintenance group.

The Research/Policy/Other group rated every rail element damage mode higher for this barrier than the Maintenance group (Figure 22). The two profession groups agreed the most on the frequency of occurrence for the “rail deflection” rail element damage mode for the strong-post thrie-beam guardrail, and both groups rated it as the most common of the damage modes.

As with the wood strong-post w-beam guardrail, respondents from both profession groups considered “rail deflection” to be the most commonly occurring damage mode for rail elements for the strong-post thrie-beam guardrail (Figure 23). “Rail flattening” was also once again considered the second most common damage mode for rail elements, but the two groups did not agree on two of the damage modes. The Maintenance groups felt that “horizontal tear in rail element” occurred more frequently than the “vertical tear in rail element”, while the Research/Policy/Other group felt the opposite.

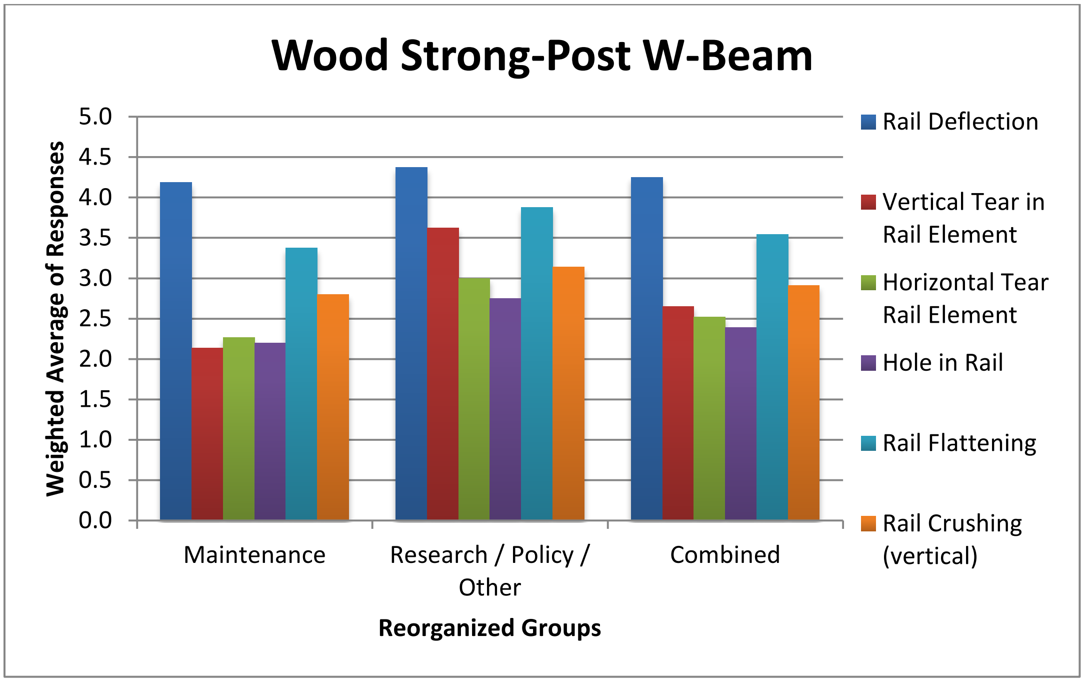


Figure 21. Wood Strong-Post W-Beam Damage Modes for Rail Element 2, Reorganized Groups.

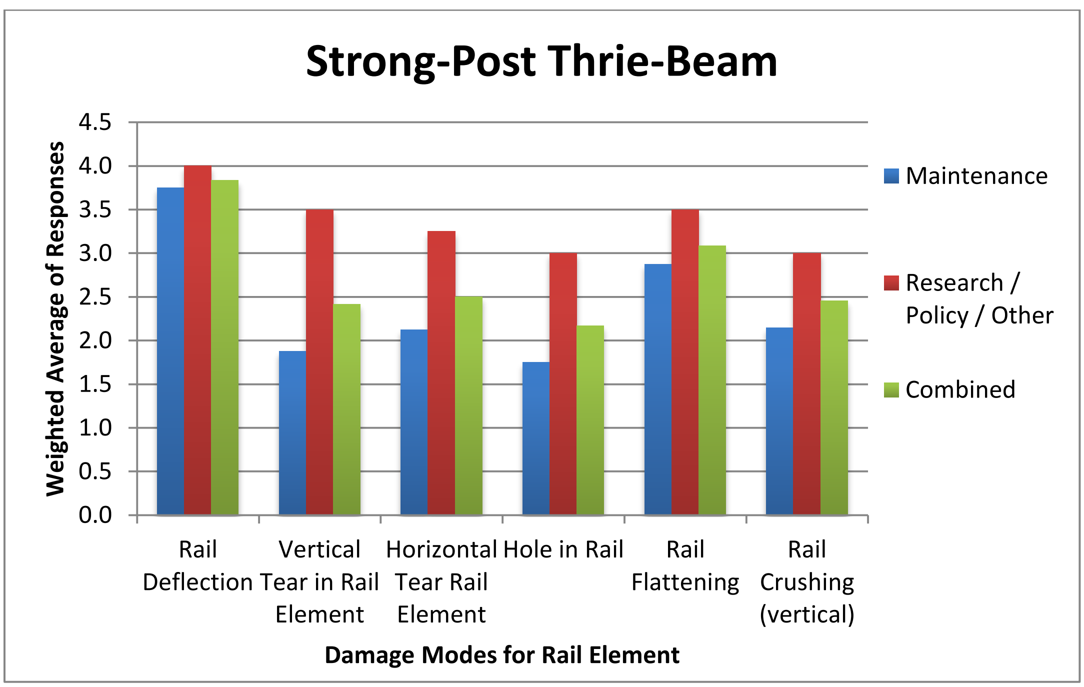


Figure 22. Strong-Post Thrie-Beam Damage Modes for Rail Element 1, Reorganized Groups.

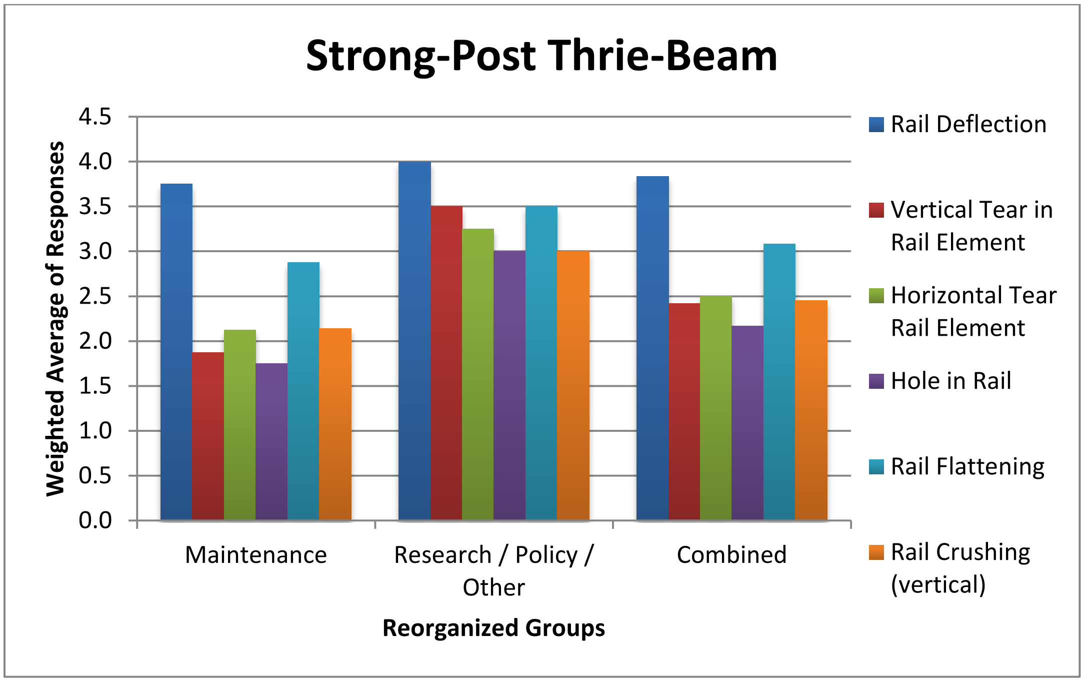


Figure 23. Strong-Post Thrie-Beam Damage Modes for Rail Element 2, Reorganized Groups.

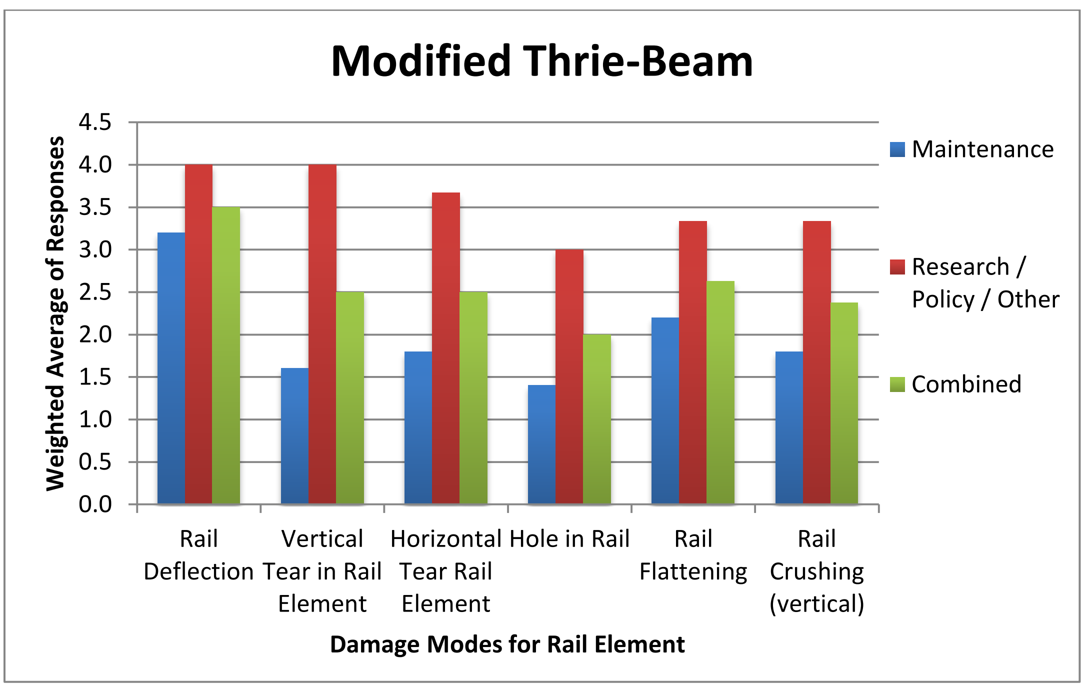


Figure 24. Modified Thrie-Beam Damage Modes for Rail Element 1, Reorganized Groups.

For the rail element damage modes for the modified thrie-beam guardrail (Figure 24), the Maintenance and Research/Policy/Other groups agreed the most on the “rail deflection” and the least on the “vertical tear in rail element” damage modes. The Research/Policy/Other group rated “vertical tear in rail element as tied with “rail deflection” as the most frequent damage mode for rail elements, while the Maintenance group rated it as the second least frequent.

Figure 25 shows the reorganized groups’ weighted averages of responses for rail element damage modes for the modified thrie-beam guardrail. The Maintenance group clearly considered “rail deflection” to be the rail element damage mode that occurred with the highest frequency, while the Research/Policy/Other group considered both “rail deflection” and “vertical tear in rail element” to be the most common damage modes. Both groups considered “hole in rail” to be the least common of the rail element damage modes for this barrier type.

Figure 26 shows the reorganized groups’ responses regarding the damage modes for rail element on the weak-post w-beam guardrail. The two profession groups mostly agree on the frequency of “rail deflection” and “rail flattening”, somewhat agree on the frequency of “rail crushing (vertical)”, and disagree on the frequency of “vertical tear in rail element”, “horizontal tear in rail element”, and “hole in rail”.

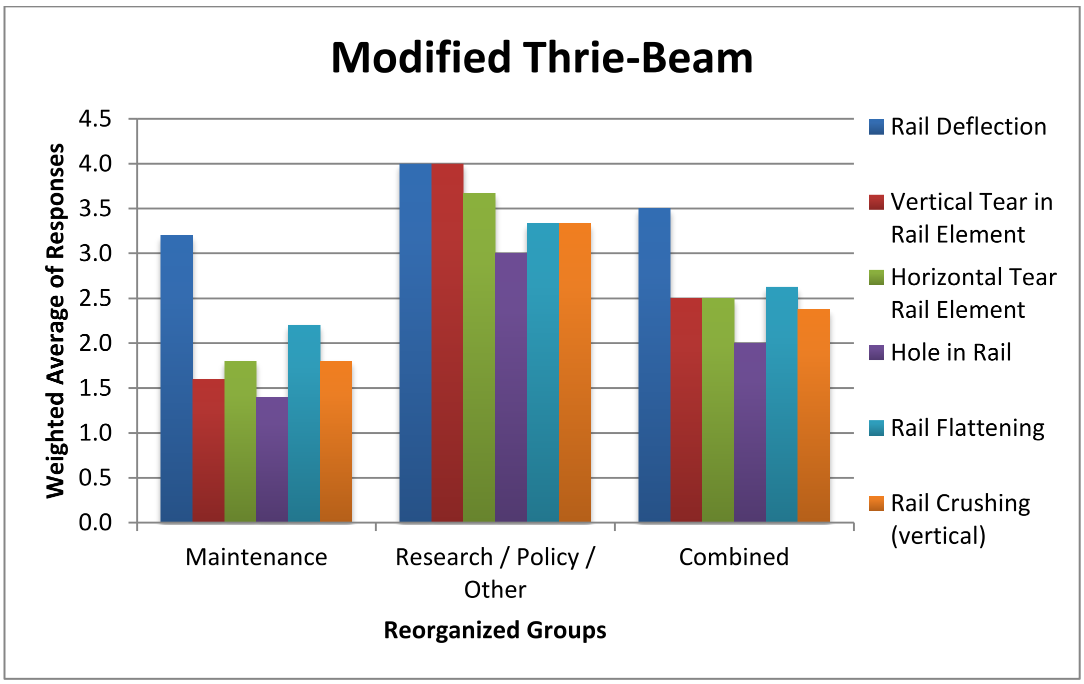


Figure 25. Modified Thrie-Beam Damage Modes for Rail Element 2, Reorganized Groups.

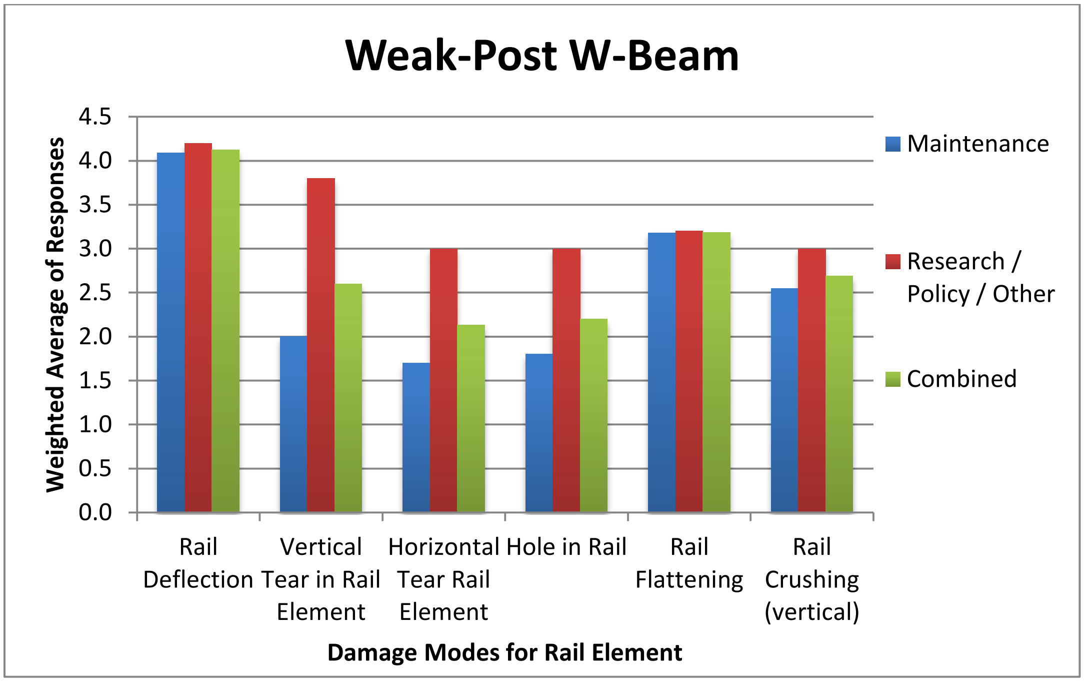


Figure 26. Weak-Post W-Beam Damage Modes for Rail Element 1, Reorganized Groups.

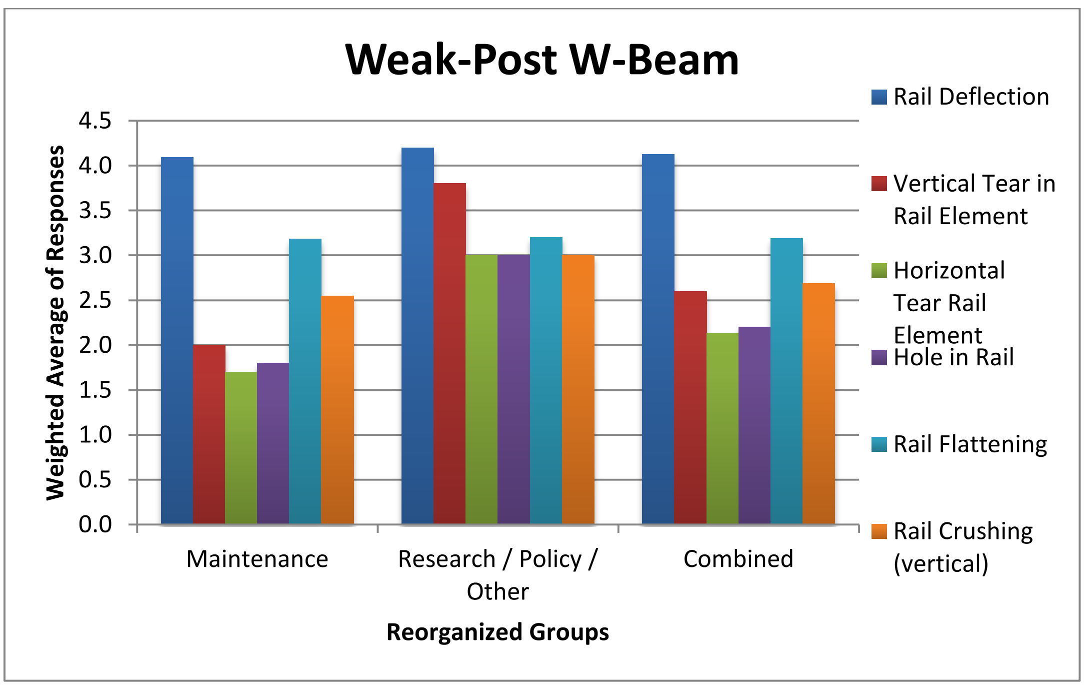


Figure 27. Weak-Post W-Beam Damage Modes for Rail Element 2, Reorganized Groups.

Both the Maintenance group and the Research/Policy/Other group considered “rail deflection” to be the most frequently occurring rail element damage mode for the weak-post w-beam guardrail (Figure 27). Once again, “vertical tear in rail element” was considered more common by the Research/Policy/Other group than by the Maintenance group.

Both profession groups consider the frequency of occurrence for “rail deflection” to be highest in the wood strong-post w-beam and weak-post w-beam guardrails (Figure 28). Although the weighted averages from both groups are lower for the two thrie-beam barriers than they are for the w-beam barriers, the weighted-average scores are high enough in all cases to signify that this damage mode is the most frequently occurring damage mode for all guardrail types.

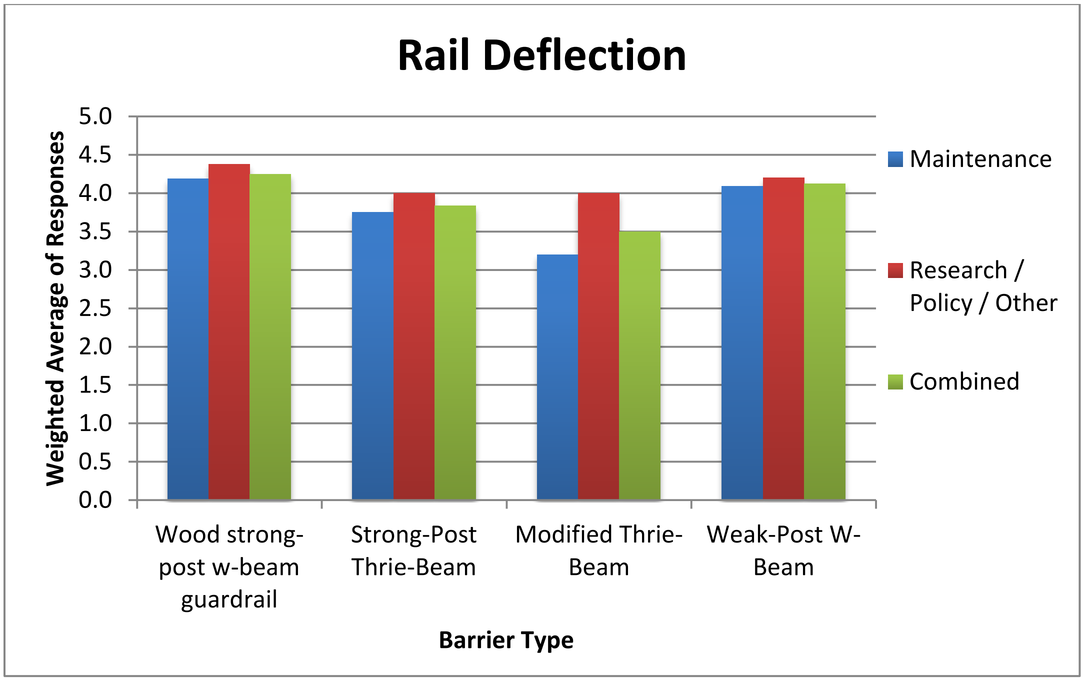


Figure 28. Rail Deflection Damage Mode Frequency for Barrier Types, Reorganized Groups.

The “vertical tear in rail element” was considered a much more common damage mode by the Research/Policy/Other group than it was by the Maintenance group. Also, the modified thrie-beam guardrail was rated as the barrier with the highest frequency of occurrence by the Research/Policy/Other group, while it was rated the barrier type with the lowest frequency of occurrence by the Maintenance group (Figure 29). When the responses from the two reorganized groups are combined, the weighted average values are essentially the same for all the barrier types, which indicates that vertical rail tear is equally common among all the barrier types explored in the survey.

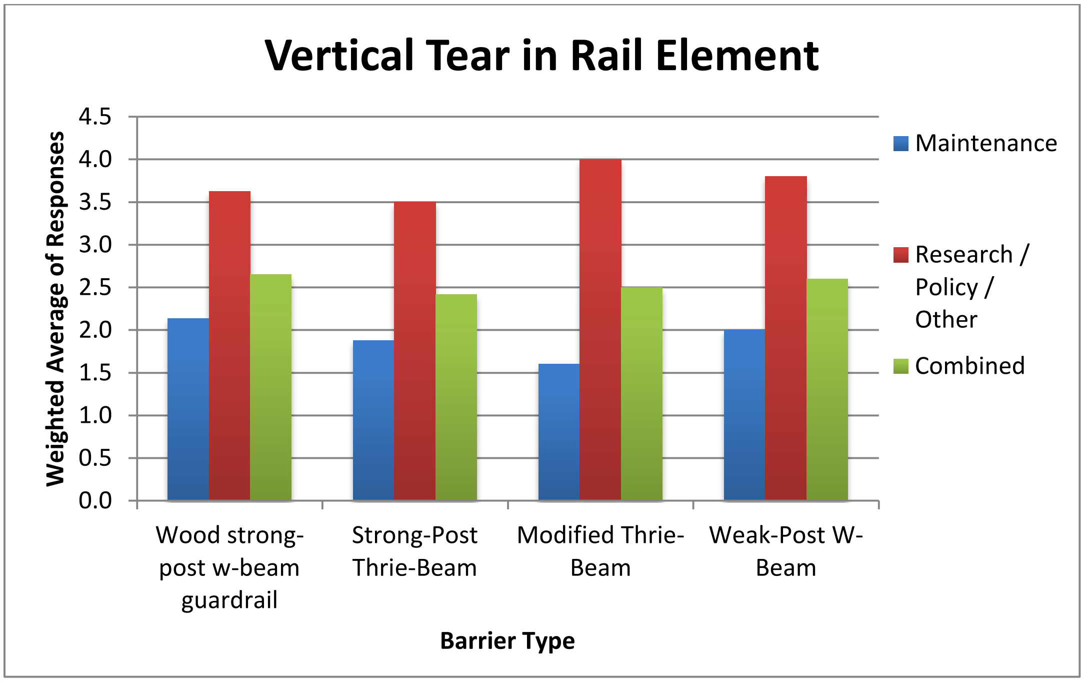


Figure 29. Vertical Tear in Rail Element Damage Mode Frequency for Barrier Types, Reorganized Groups.

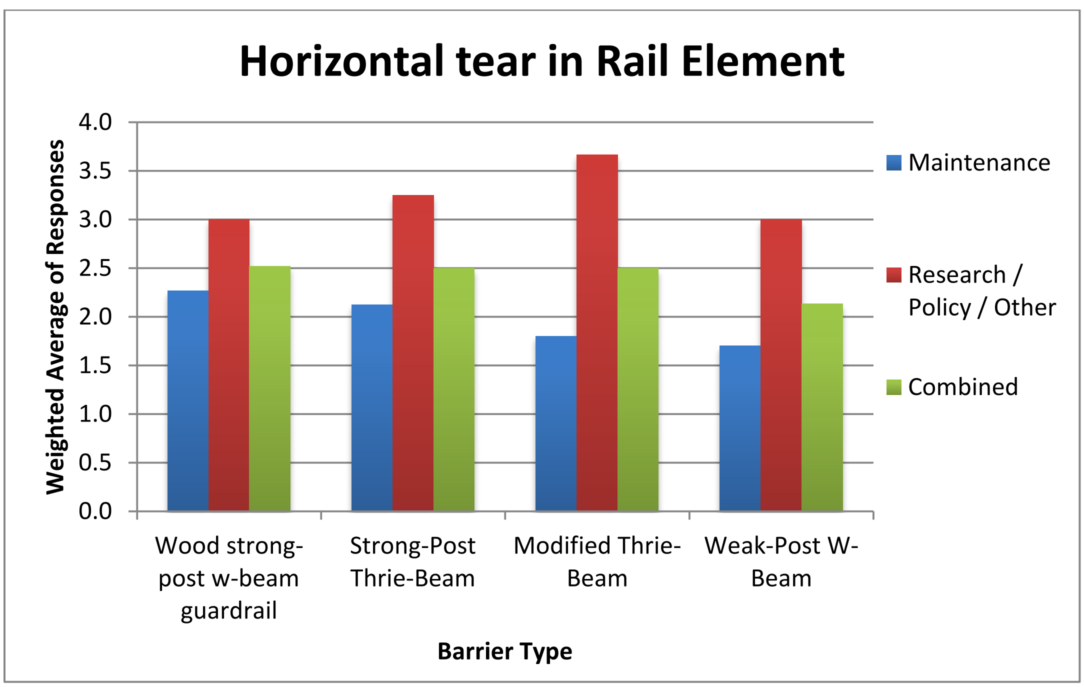


Figure 30. Horizontal Tear in Rail Element Damage Mode Frequency for Barrier Types, Reorganized Groups.

As with the "vertical tear in rail element," the largest difference in perceived frequency of occurrence between the two profession groups was in regards to the modified thrie-beam guardrail (Figure 30). The Research/Policy/Other group identified this barrier type to have the highest frequency of horizontal rail tears, while the Maintenance group considered this barrier type to have the second lowest frequency of occurrence.

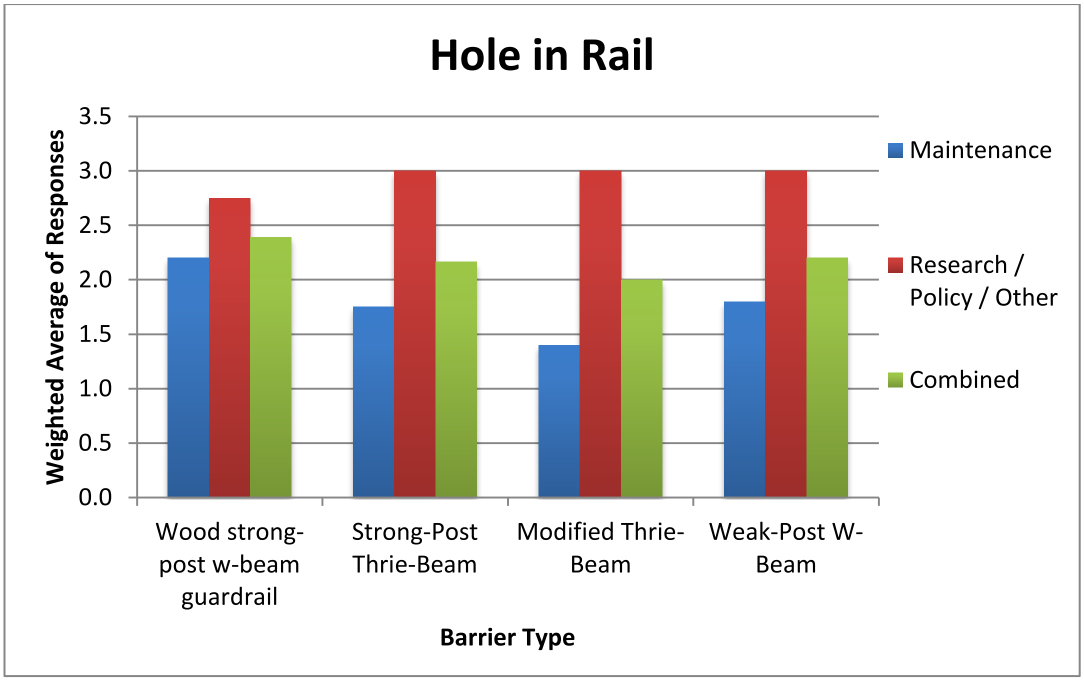


Figure 31. Hole in Rail Element Damage Mode Frequency for Barrier Types, Reorganized Groups.

The Research/Policy/Other group rated the "hole in rail" damage mode to be of roughly the same frequency of occurrence for all barrier types, with the wood strong-post w-beam barrier as having a slightly lower frequency. Conversely, the Maintenance group rated the wood strong-post w-beam guardrail as having the highest frequency of occurrence of the "hole in rail" damage mode, and the modified thrie-beam as having the lowest. (Figure 31)

Both profession groups rated the wood strong-post w-beam guardrail as the barrier type with the highest frequency of occurrence of the "rail flattening" damage mode. As with other damage modes, the modified thrie-beam was again the barrier type with the biggest discrepancy between the reorganized groups. (Figure 32)

From Figure 33, "rail crushing (vertical)" is another damage mode where the two profession groups disagree on frequency of occurrence across barrier types. Where the Research/Policy/Other group thought the modified thrie-beam was the barrier that experienced the highest frequency of this damage mode, the Maintenance group thought the modified thrie-beam had the lowest frequency.

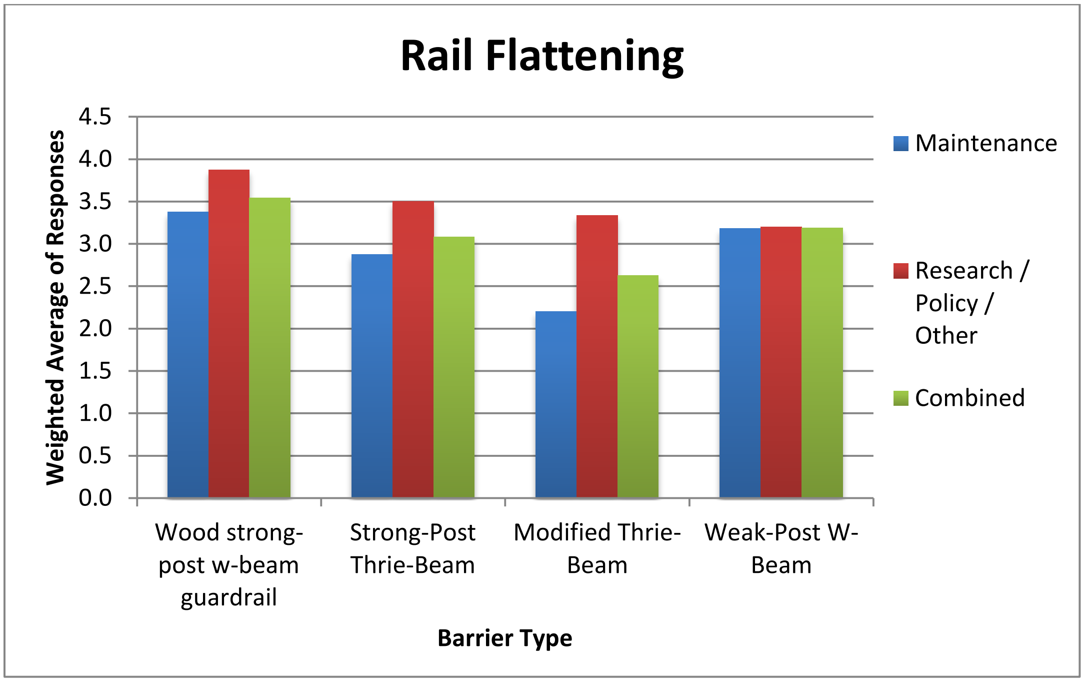


Figure 32. Rail Flattening Damage Mode Frequency for Barrier Types, Reorganized Groups.

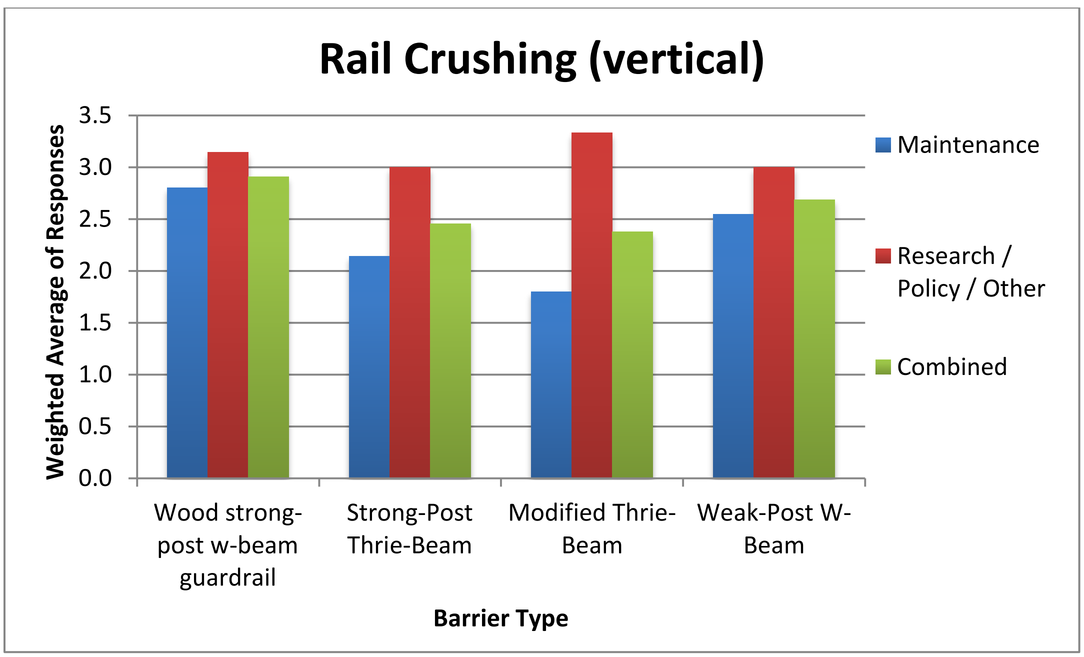


Figure 33. Rail Crushing (vertical) Damage Mode Frequency for Barrier Types, Reorganized Groups.

Damage Modes for Blockouts

Question 9 (Survey Group 1), Question 6 (Survey Group 2) – Please identify the damage modes that you feel are most common for each guardrail type by selecting the appropriate rating scale using the pull-down menu. PLEASE ONLY PROVIDE RESPONSES FOR THE GUARDRAIL SYSTEMS THAT YOU ARE FAMILIAR WITH. A blank response indicates that you don't know.

Figure 34 through Figure 41 show the results of the reorganized group responses for each barrier type, while Figure 42 through Figure 46 show the results for each of the damage modes for blockouts.

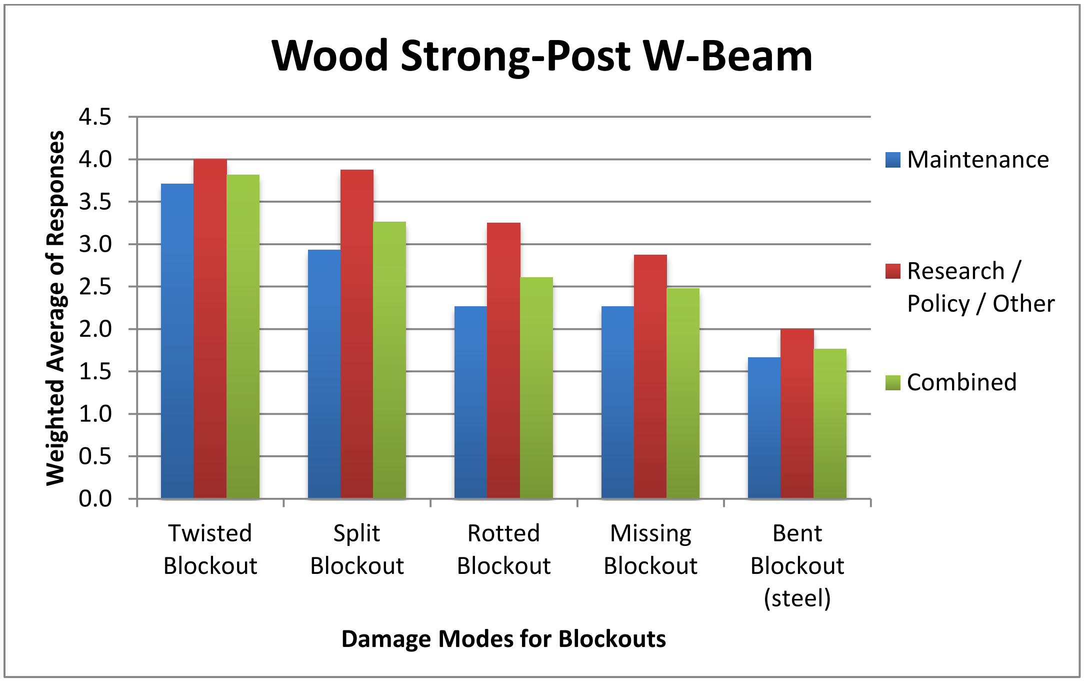


Figure 34. Wood Strong-Post W-Beam Damage Modes for Blockouts 1, Reorganized Groups.

The two profession groups were for the most part in agreement with each other regarding the frequency of the various damage modes for the blockout on the wood strong-post w-beam guardrail. For both groups, "twisted blockout" was rated as having the highest frequency, while "bent blockout (steel)" was rated as having the lowest. (Figure 34, Figure 35)

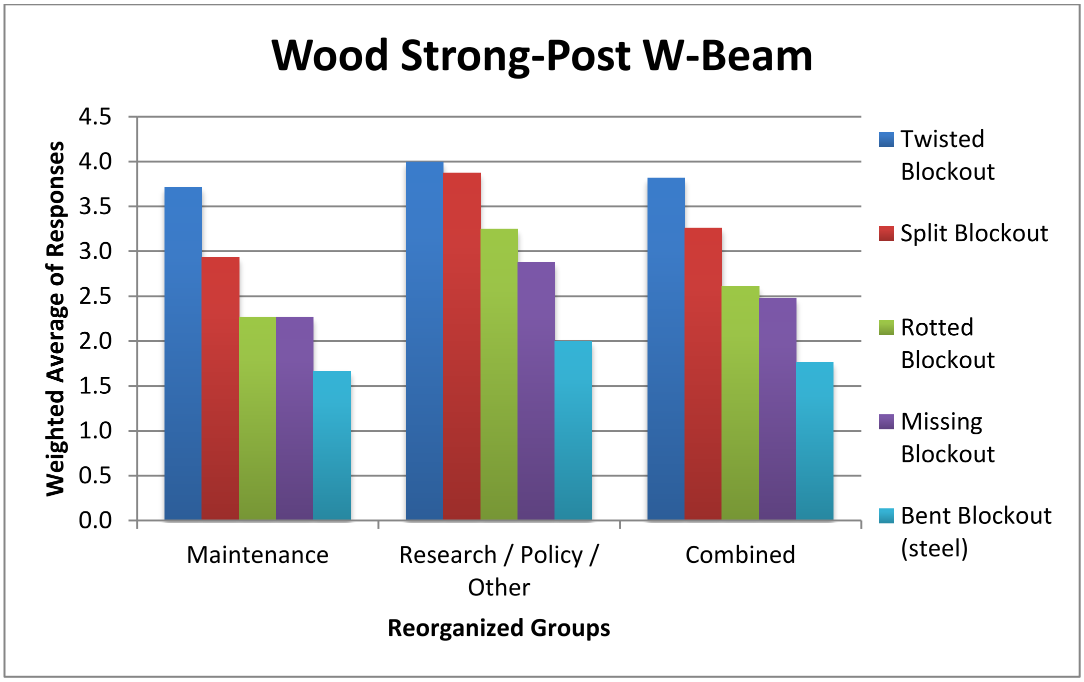


Figure 35. Wood Strong-Post W-Beam Damage Modes for Blockouts 2, Reorganized Groups.

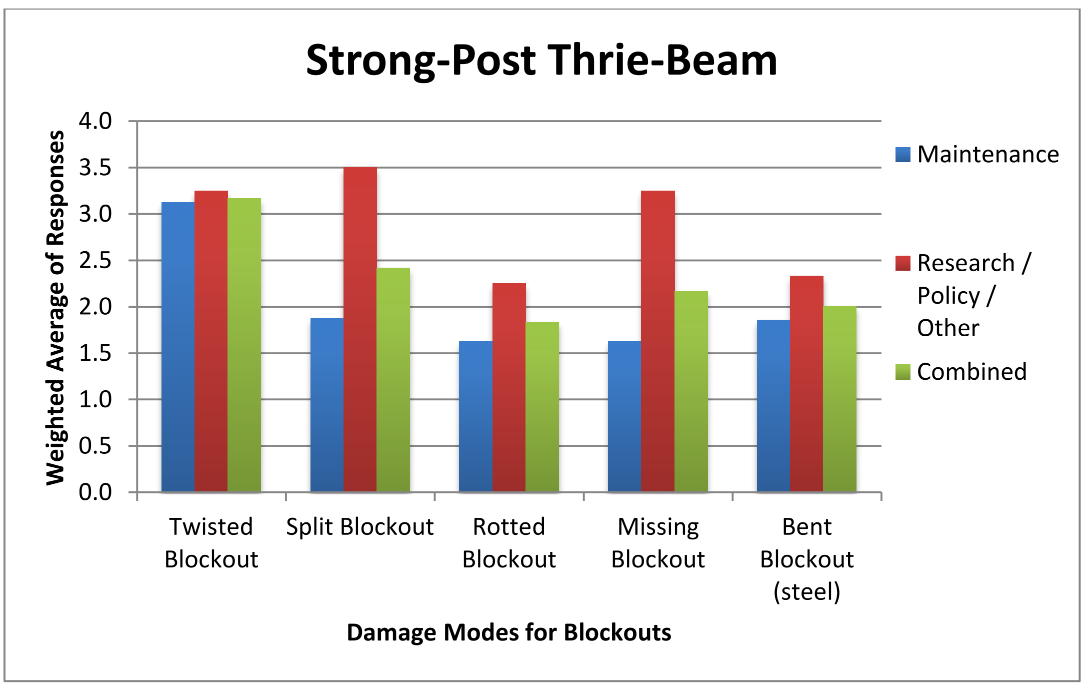


Figure 36. Strong-Post Thrie-Beam Damage Modes for Blockouts 1, Reorganized Groups.

For the strong-post thrie-beam, the both profession groups agreed on the frequency of occurrence for the “twisted blockout” and “rotted blockout” damage modes, but disagreed on the frequency of occurrence for the “split blockout”, “missing blockout”, and “bent blockout” damage modes. (Figure 36)

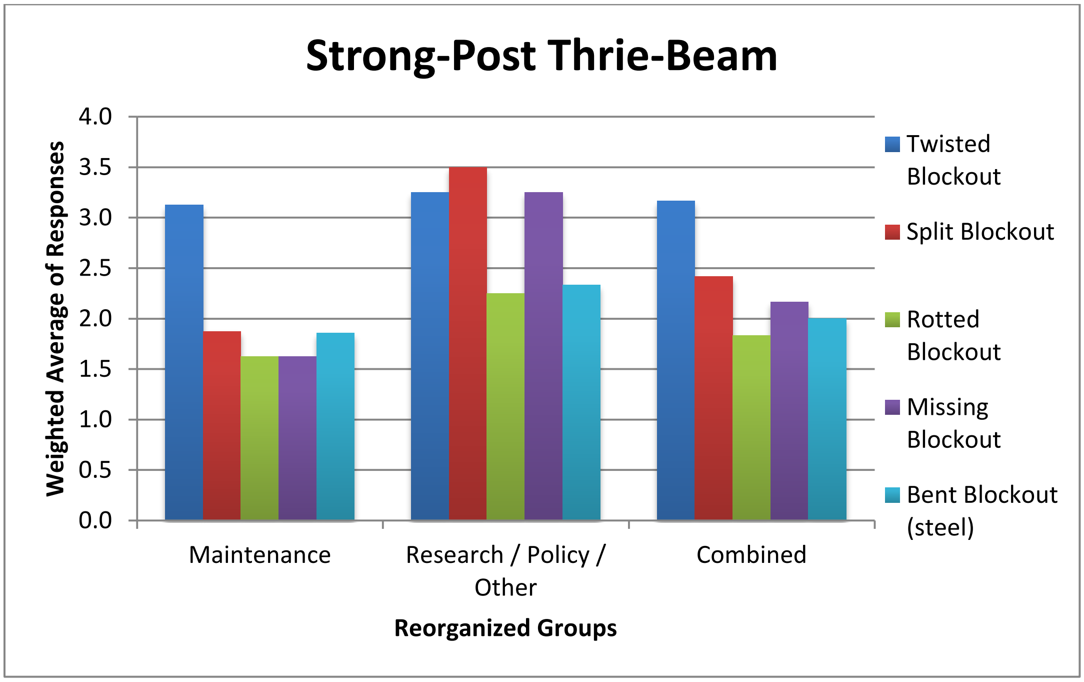


Figure 37. Strong-Post Thrie-Beam Damage Modes for Blockouts 2, Reorganized Groups.

The two groups had somewhat differing opinions regarding damage modes for blockouts in on the strong-post thrie-beam barrier (Figure 37). The Maintenance group rated “twisted blockout” to be the most common damage mode for blockouts, followed by “split blockout” and “bent blockout (steel)”. In contrast, the Research/Policy/Other group rated “split blockout” to be the most common, followed by “twisted blockout” and “missing blockout”. “Missing blockout” was the damage mode that the two groups most strongly disagreed on (Figure 37) .

For the modified thrie-beam guardrail, the two profession groups generally agreed that the “twisted blockout” occurred with moderate frequency and that the “split blockout” and the “rotted blockout” occurred with very low frequency. Regarding “missing blockouts” and “bent blockouts,” however, the Research/Policy/Other group indicated that these damage modes occur with relatively high frequency, while the maintenance group indicated a very low frequency of occurrence (Figure 38).

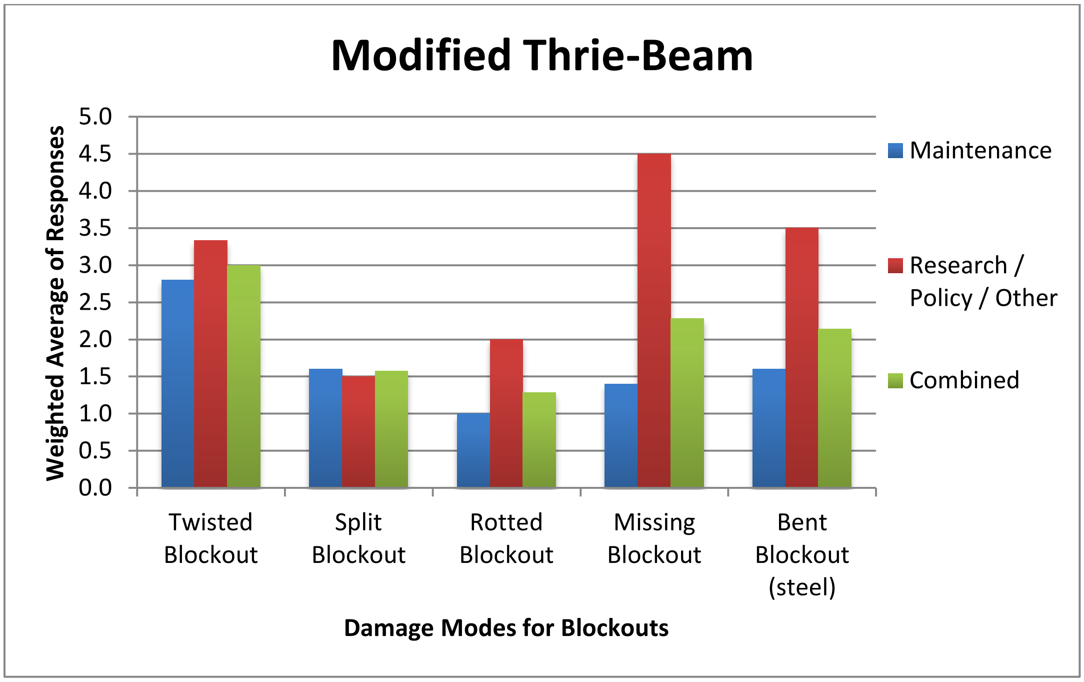


Figure 38. Modified Thrie-Beam Damage Modes for Blockouts 1, Reorganized Groups.

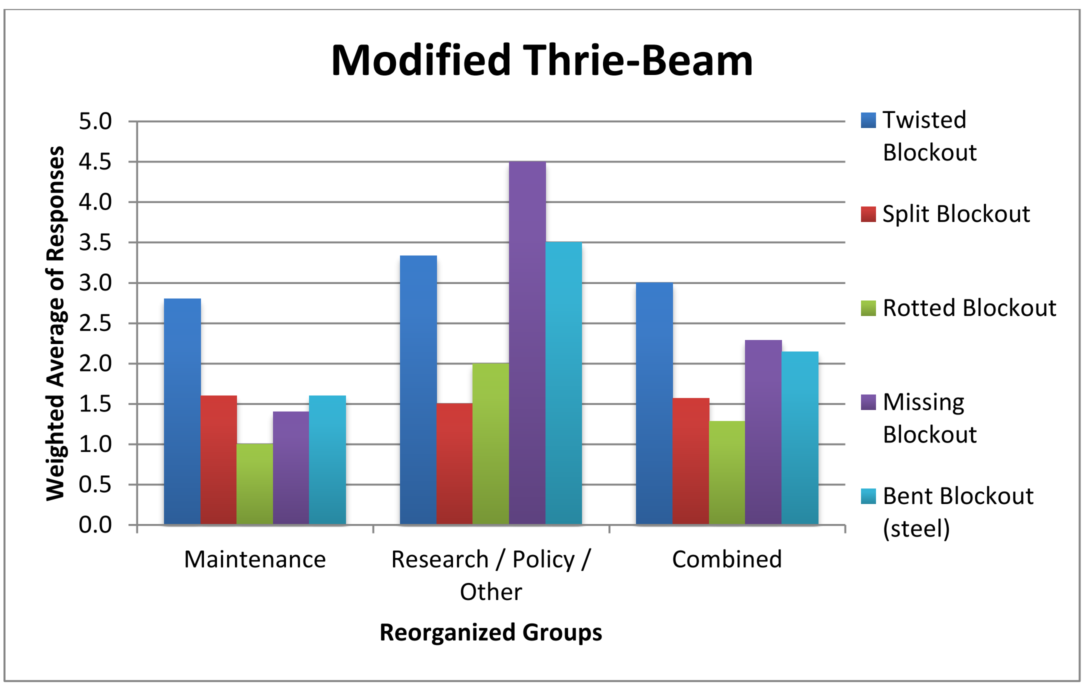


Figure 39. Modified Thrie-Beam Damage Modes for Blockouts 2, Reorganized Groups.

The Maintenance group considered "twisted blockout" to be the most common damage mode for blockouts. The remaining damage modes for blockouts all had low average occurrence ratings by the Maintenance group. The Research/Policy/Other group considered "missing blockout" to be the most frequently occurring damage mode for blockouts, followed by "bent blockout (steel)" and "twisted blockout". Although "twisted blockout" was the third highest rated damage mode for blockouts according to the Research/Policy/Other group, the weighted average rating was still higher than it was for the Maintenance group, who listed this damage mode as the most common (Figure 39).

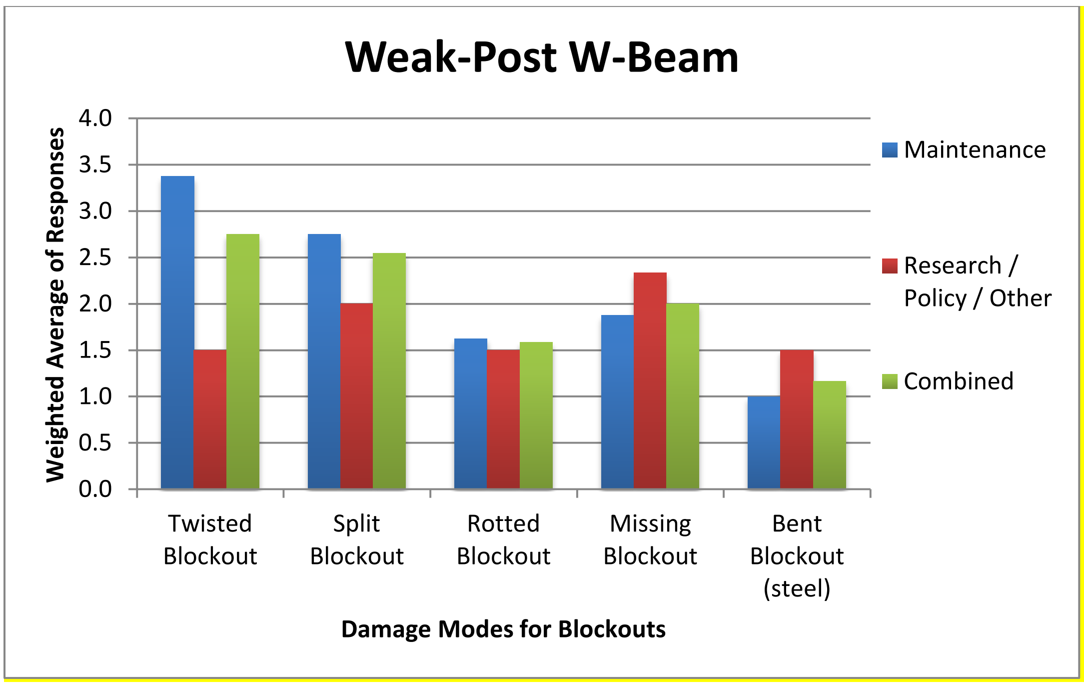


Figure 40. Weak-Post W-Beam Damage Modes for Blockouts 1, Reorganized Groups.

Interestingly, for the weak-post w-beam guardrail (Figure 40), the Maintenance groups rated "twisted blockout" and "split blockout" higher than the Research/Policy/Other group did. The G2 guardrail, however, does not actually include blockouts so it is unclear why the respondents included this information. It may have been due to the manner in which the survey form was constructed but, in any case, the information in Figure 40 and Figure 41 is not correct but is included since these are the responses generated by the survey. The same incorrect results for the weak-post w-beam appear in Figure 42 through Figure 46.

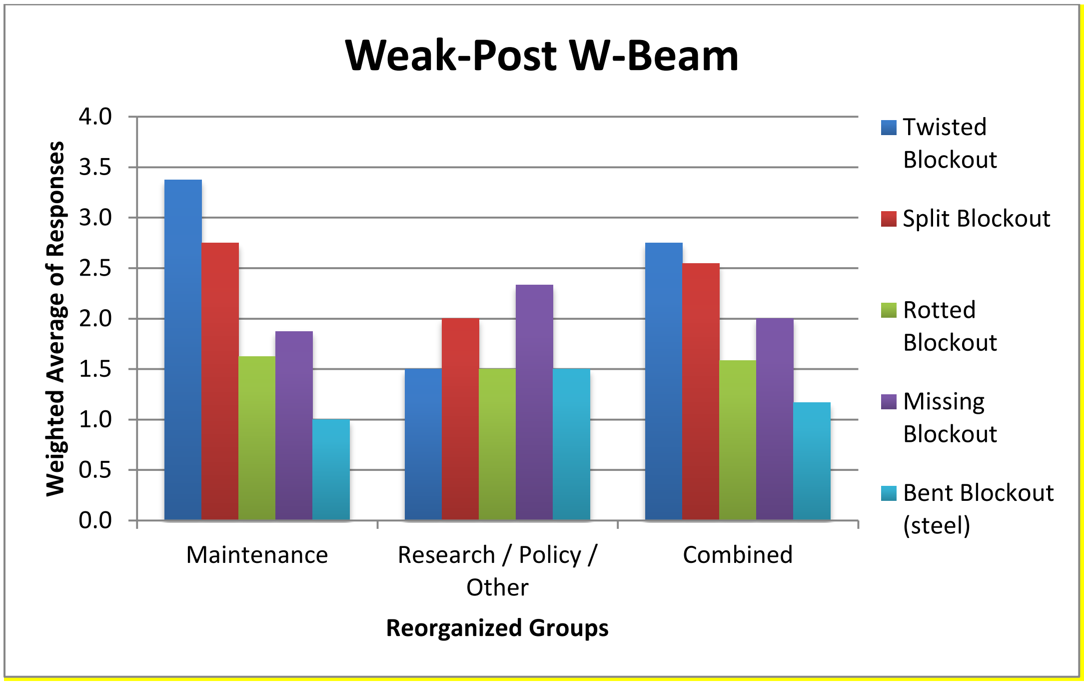


Figure 41. Weak-Post W-Beam Damage Modes for Blockouts 2, Reorganized Groups.

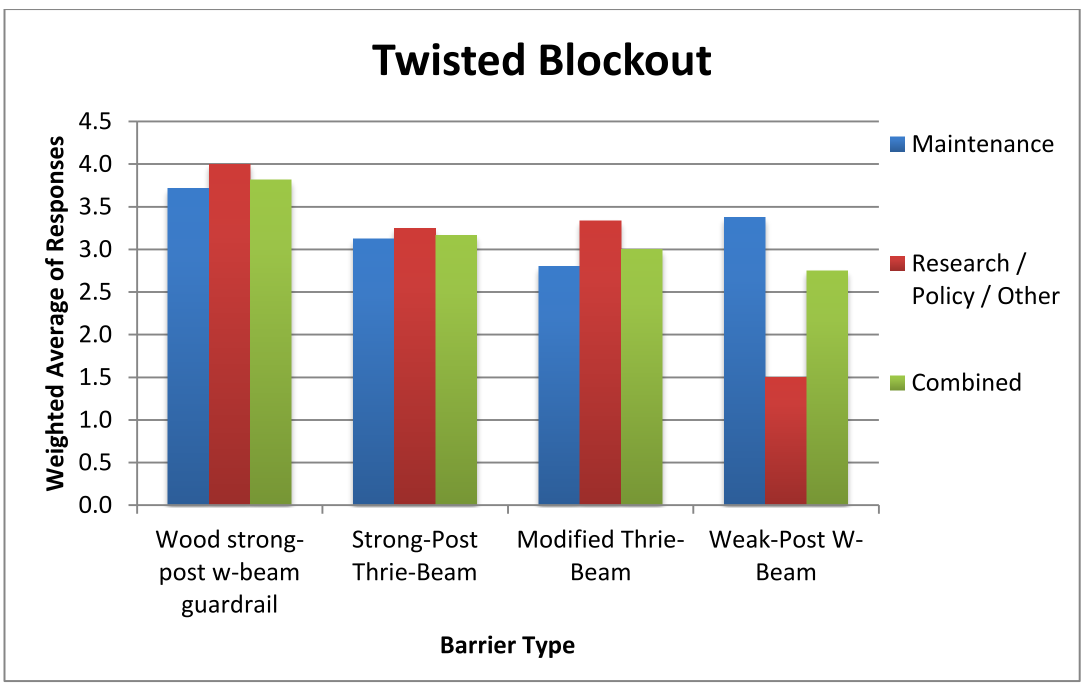


Figure 42. Twisted Blockout Damage Mode Frequency for Barrier Types, Reorganized Groups.

The two profession groups agreed with each other for the most part about the frequency of occurrence of the “twisted blockout” damage mode among the different barrier types. The one barrier type where they disagreed on was the weak-post w-beam guardrail. The Maintenance group felt it occurred more often than the Research/Policy/Other group did. Both groups consider the wood strong-post w-beam guardrail as the barrier type that experiences twisted blockouts the most often (Figure 42).

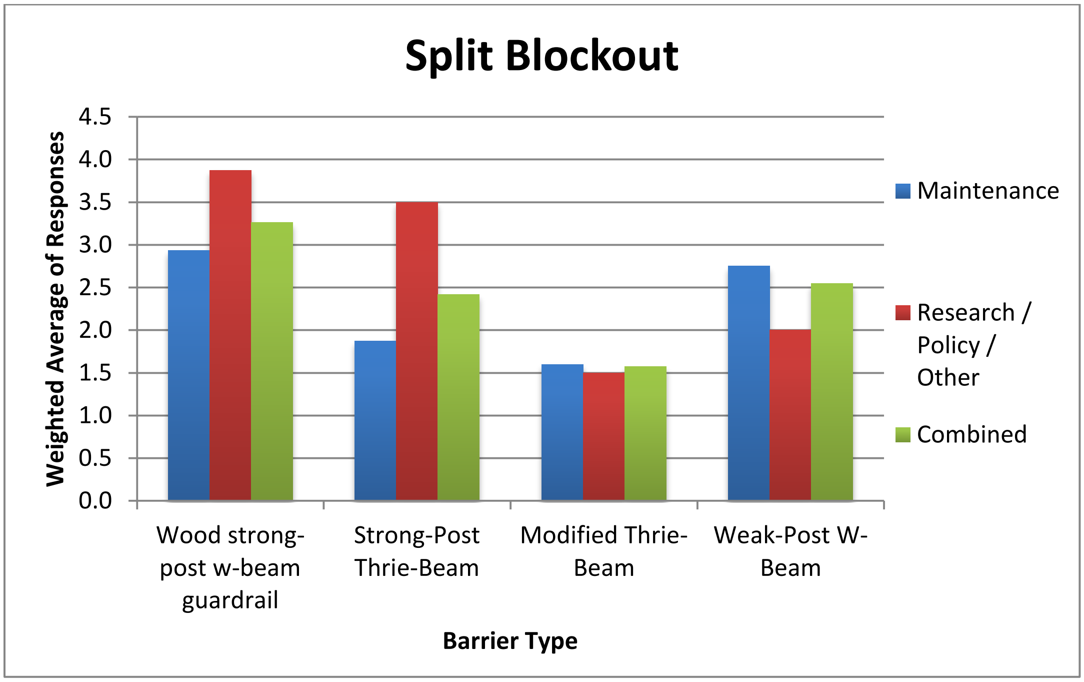


Figure 43. Split Blockout Damage Mode Frequency for Barrier Types, Reorganized Groups.

Both profession groups considered the wood strong-post w-beam guardrail to be the barrier with the highest frequency of occurrence of the “split blockout” damage mode. The Maintenance group thought the weak-post w-beam came next, followed by both types of thrie-beam guardrails. The Research/Policy/Other group thought the strong-post thrie-beam was the barrier with the second highest frequency of occurrence, followed by the weak-post w-beam, and finally the modified thrie-beam guardrail (Figure 43).

Both profession groups considered the wood strong-post w-beam guardrail to be the barrier type that experiences the highest frequency of the “rotted blockout” damage mode. The Research/Policy/Other group considered the weak-post w-beam to be the barrier type that experienced the least amount of this damage mode, while the Maintenance group gave that distinction to the modified thrie-beam guardrail. It is worth noting that both groups had roughly the same weighted average rating of the weak-post w-beam guardrail (Figure 44).

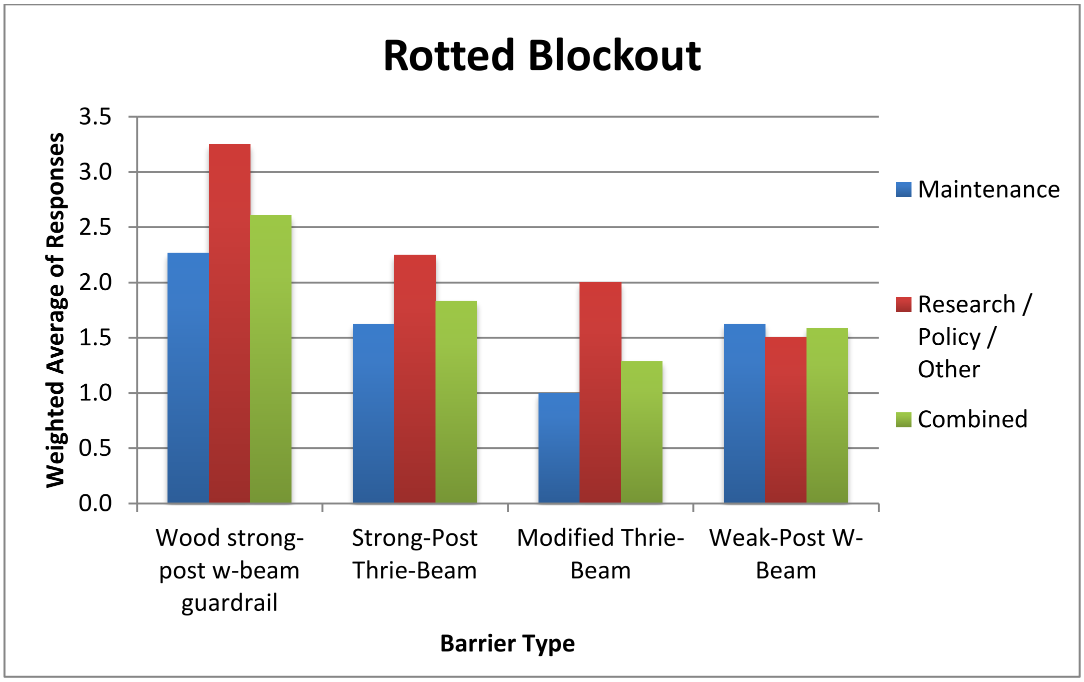


Figure 44. **Rotted Blockout Damage Mode Frequency for Barrier Types, Reorganized Groups.**

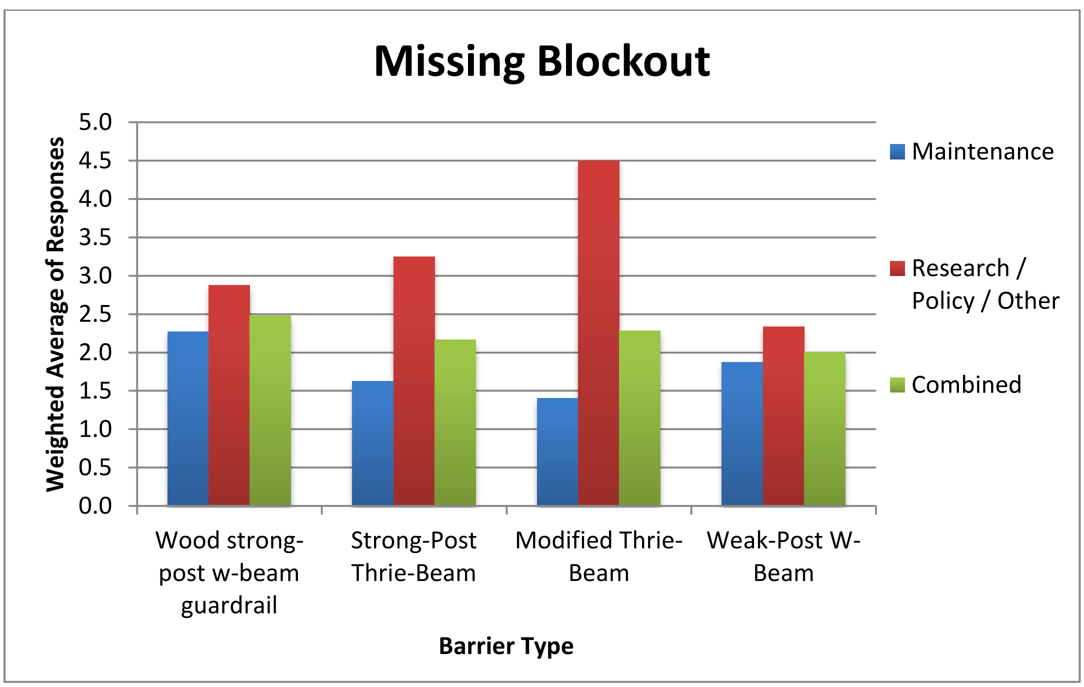


Figure 45. **Missing Blockout Damage Mode Frequency for Barrier Types, Reorganized Groups.**

The “missing blockout” damage mode had a large discrepancy between the ratings given by the two reorganized groups for both of the thrie-beam barriers. The modified thrie-beam guardrail in particular has the greatest difference, as the Research/Policy/Other group rated it as being the barrier type that experienced the highest frequency of occurrence while the Maintenance group rated it as having the lowest frequency of occurrence. (Figure 45)

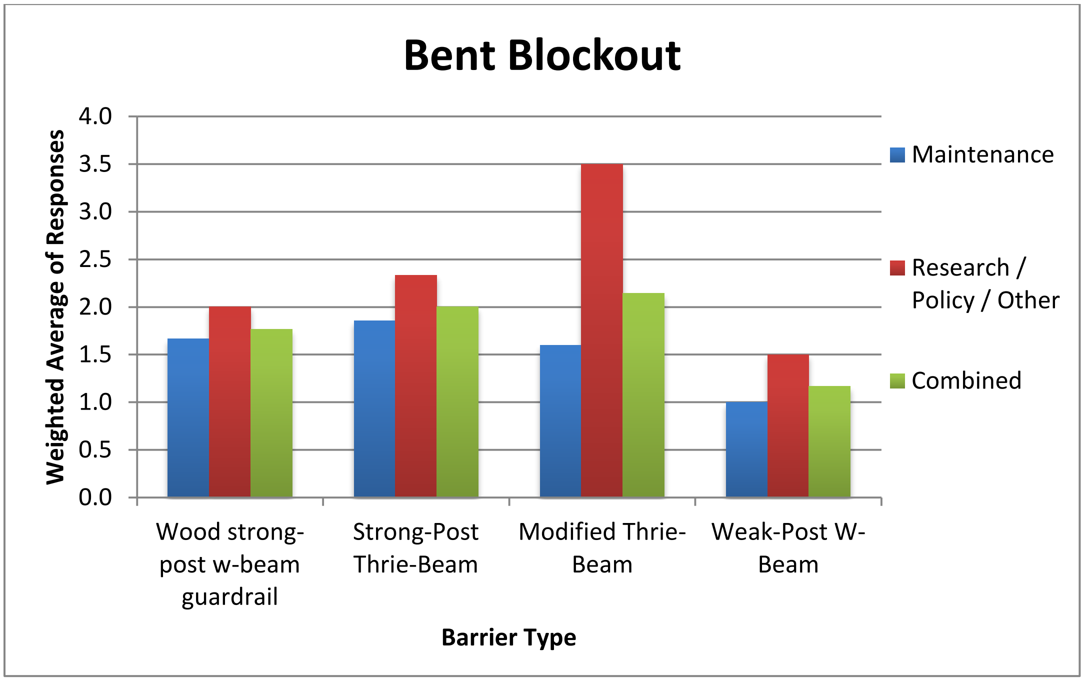


Figure 46. Bent Blockout Damage Mode Frequency for Barrier Types, Reorganized Groups.

As with the “missing blockout” damage mode, the “bent blockout” also shows the largest discrepancy between the two group average ratings for the modified thrie-beam guardrail. The Research/Policy/Other group rated this barrier as having the highest frequency of occurrence of bent blockout, while the Maintenance group considered this barrier type as having the second to lowest frequency of occurrence. The remaining barriers had average ratings from the reorganized groups that were relatively close to each other (Figure 46).

Damage Modes for Connection Elements

Question 10 (Survey Group 1), Question 7 (Survey Group 2) –Please identify the damage modes that you feel are most common for each guardrail type by selecting the appropriate rating scale using the pull-down menu. PLEASE ONLY PROVIDE RESPONSES FOR THE GUARDRAIL SYSTEMS THAT YOU ARE FAMILIAR WITH. A blank response indicates that you don't know.

Figure 47 through Figure 54 show the results of the reorganized group responses for each barrier type, while Figure 55 through Figure 57 show the results for each of the damage modes for connection elements.

The largest discrepancy between the two reorganized groups for damage modes for connection elements with the wood strong-post w-beam guardrail was for “splice damage”. “Guardrail anchor cable damage” was the damage mode that the two groups agreed on the most (Figure 47).

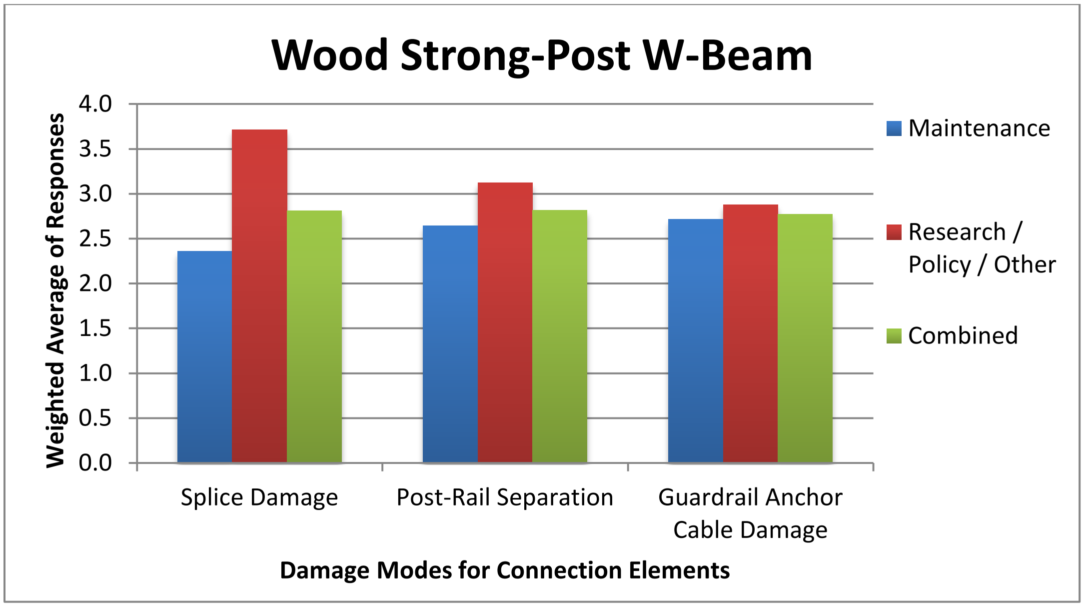


Figure 47. Wood Strong-Post W-Beam Damage Modes for Connection Elements 1, Reorganized Groups.

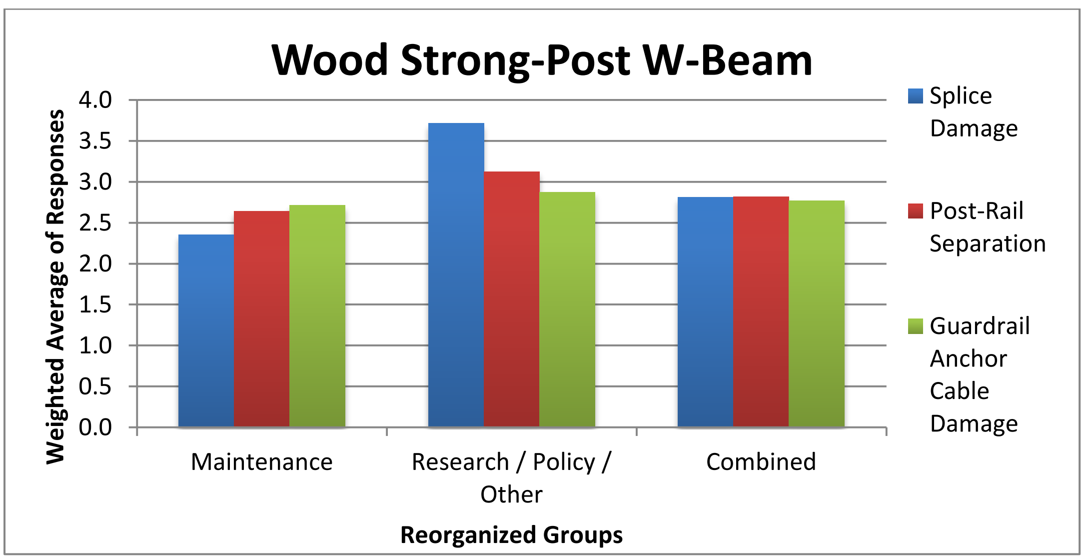


Figure 48. Wood Strong-Post W-Beam Damage Modes for Connection Elements 2, Reorganized Groups.

The Research/Policy/Other group rated "splice damage" as the most common connection element damage mode for the wood strong-post w-beam guardrail. In contrast, the Maintenance group considered "splice damage" the least common; the most common being "guardrail anchor cable damage" in their opinion (Figure 48).

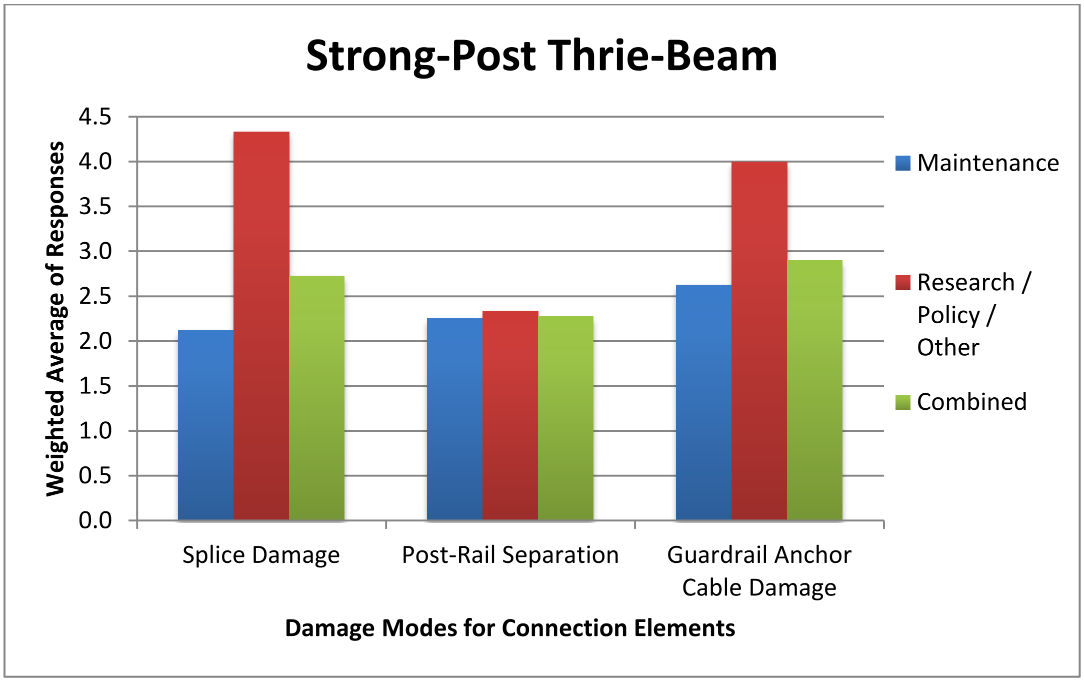


Figure 49. Strong-Post Thrie-Beam Damage Modes for Connection Elements 1, Reorganized Groups.

For the strong-post thrie-beam guardrail, the two profession groups agreed on the frequency of occurrence for the "post-rail separation" damage mode, but disagreed on the "splice damage" and "guardrail anchor cable" damage modes (Figure 49).

For the strong-post thrie-beam guardrail, the Research/Policy/Other group considered the "splice damage" damage mode to be the most common damage mode for connection elements, followed closely by "guardrail anchor cable damage". The Maintenance group considered the "guardrail anchor cable damage" damage mode for connection elements to be the most common, followed by "post-rail separation" and lastly, "splice damage" (Figure 50).

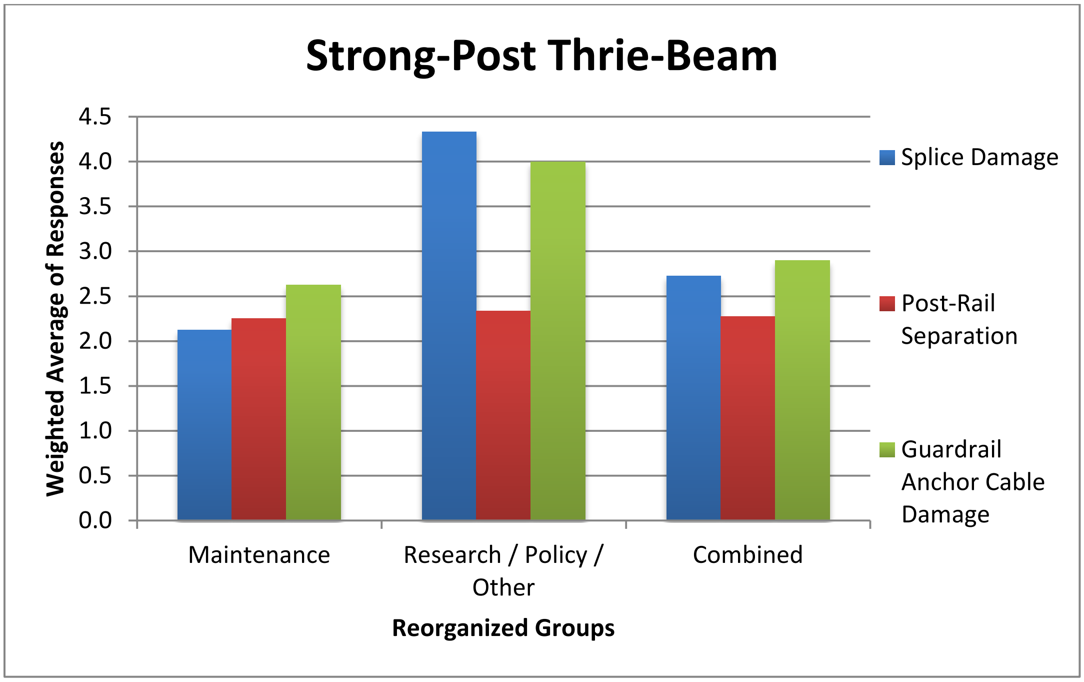


Figure 50. Strong-Post Thrie-Beam Damage Modes for Connection Elements 2, Reorganized Groups.

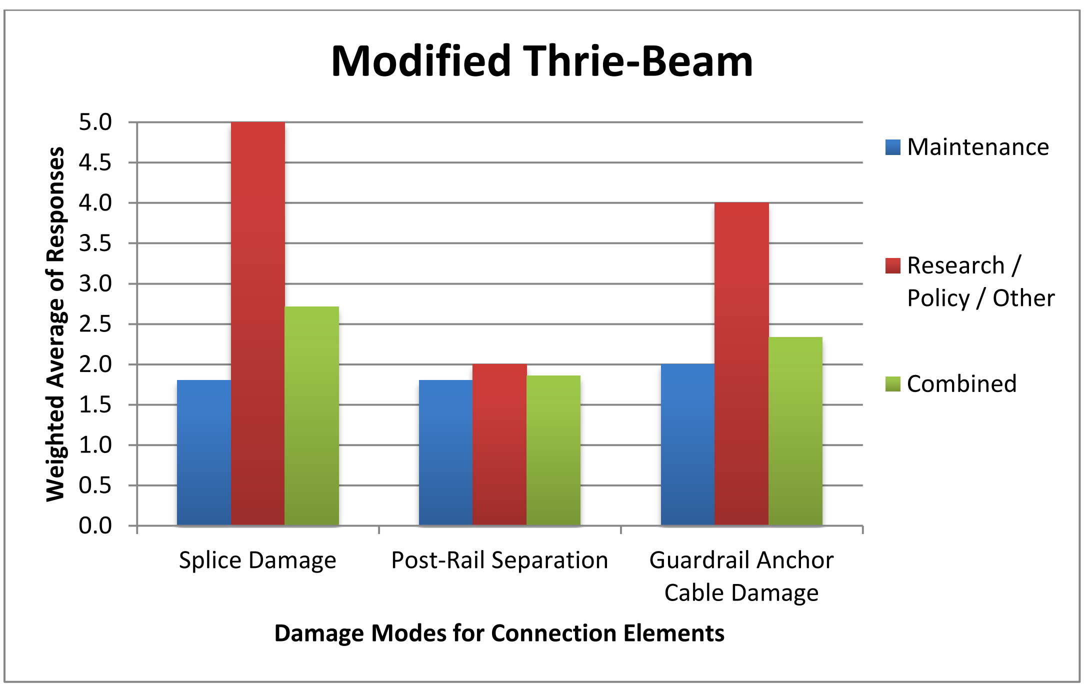


Figure 51. Modified Thrie-Beam Damage Modes for Connection Elements 1, Reorganized Groups.

For the modified thrie-beam guardrail, "post-rail separation" was the only damage mode for connection elements that the reorganized groups agreed on in regards to frequency of occurrence. The Research/Policy/Other group rated both "splice damage" and "guardrail anchor cable damage" higher than the Maintenance group. (Figure 51)

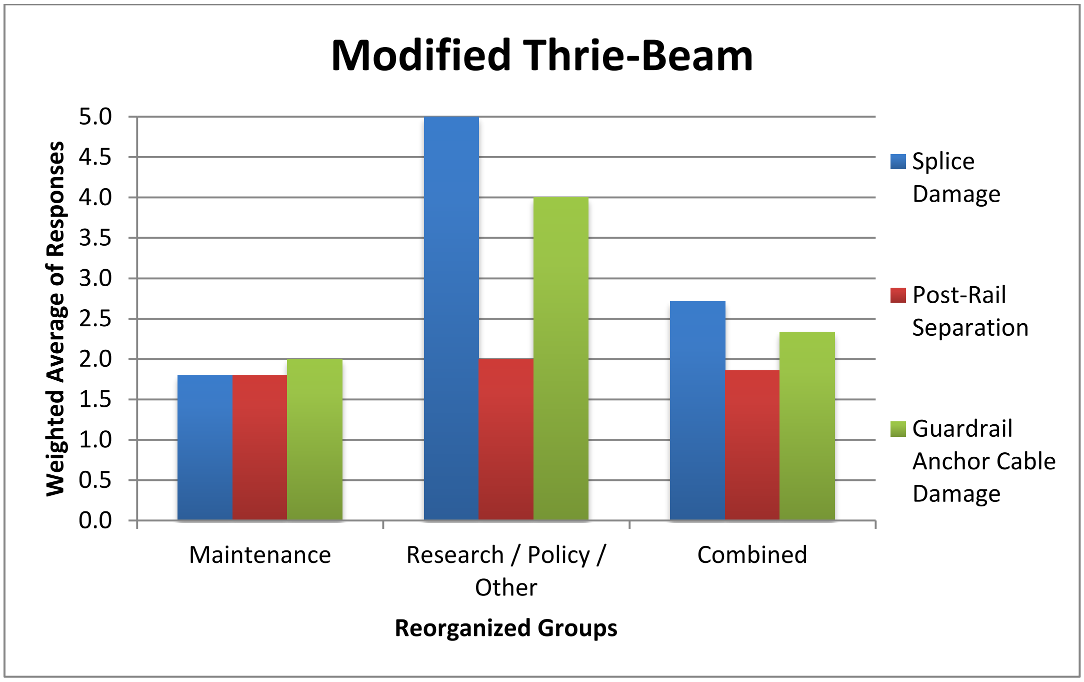


Figure 52. Modified Thrie-Beam Damage Modes for Connection Elements 2, Reorganized Groups.

The Maintenance group indicated that all three damage modes for connection elements were relatively uncommon for the modified thrie-beam guardrail, whereas the Research/Policy/Other group gave the "splice damage" damage mode a rating of 5, which is the highest rating possible. The Research/Policy/Other group also rated the "guardrail anchor cable" damage mode quite high, meaning the group felt this damage mode was also common for the modified thrie-beam guardrail (Figure 52).

For the weak-post w-beam guardrail, the Research/Policy/Other group rated all three connection element damage modes higher than the Maintenance group (Figure 53).

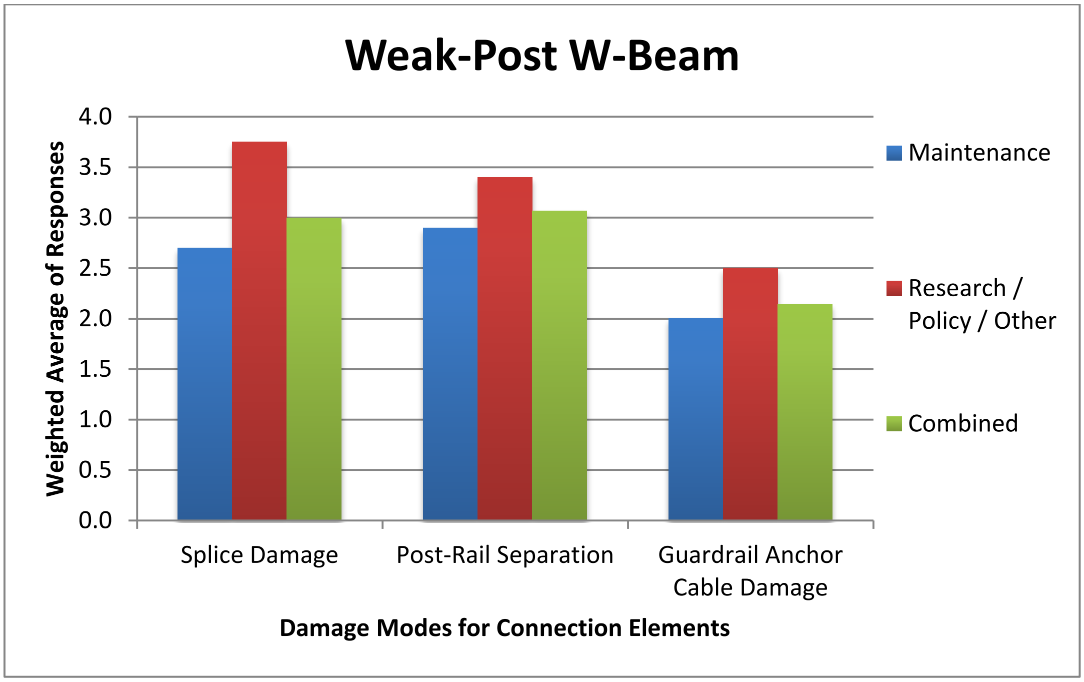


Figure 53. **Weak-Post W-Beam Damage Modes for Connection Elements 1, Reorganized Groups.**

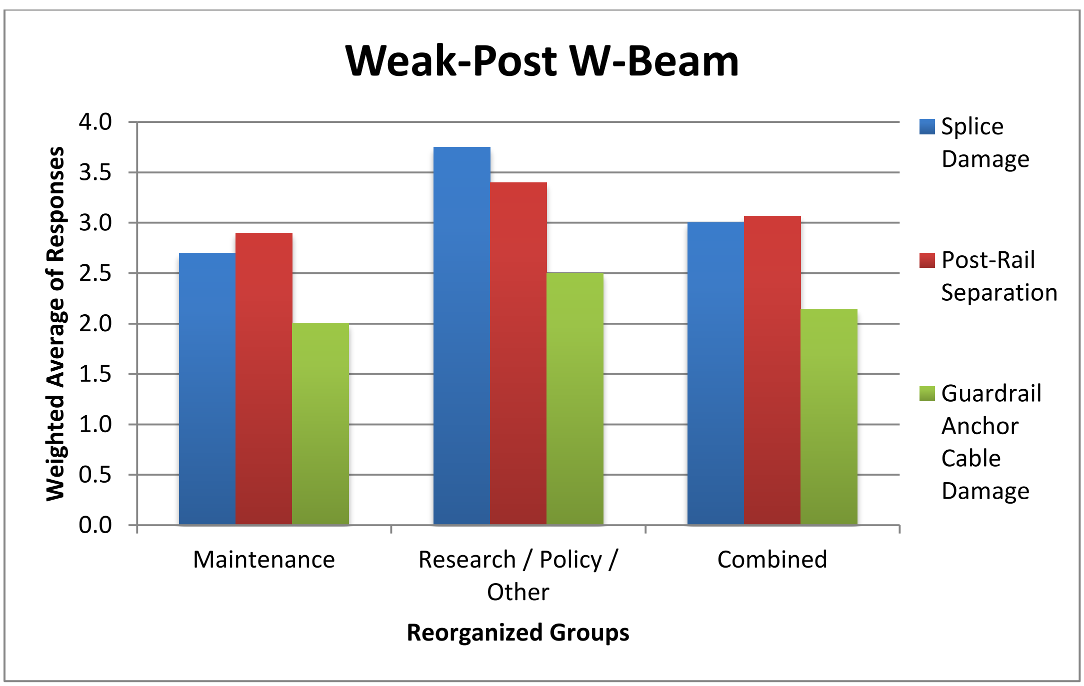


Figure 54. **Weak-Post W-Beam Damage Modes for Connection Elements 2, Reorganized Groups.**

The Research/Policy/Other group rated "splice damage" as the most common connection element damage mode for the weak-post w-beam guardrail, followed by "post-rail separation". The Maintenance group has it the other way around, with "post-rail separation" first, followed by "splice damage". Both profession groups consider "guardrail anchor cable damage" to be the least occurring connection element damage mode for the weak-post w-beam guardrail (Figure 54).

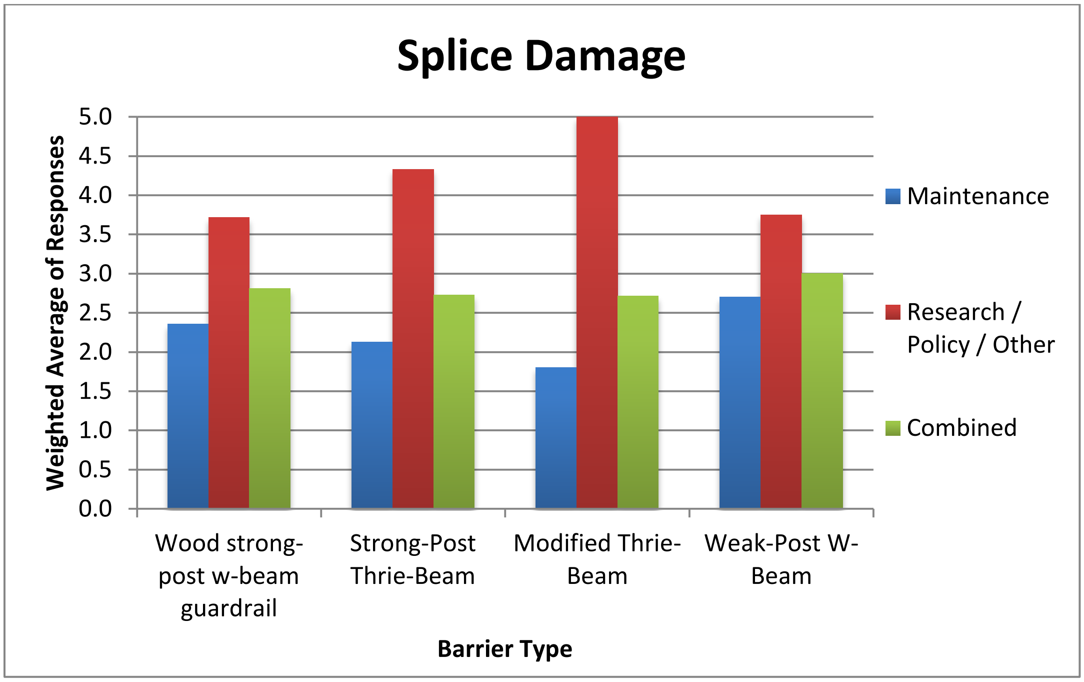


Figure 55. Splice Damage Mode Frequency for Barrier Types, Reorganized Groups.

The Research/Policy/Other group rated all of the barrier types as having a higher frequency of "splice damage" than the Maintenance group did. Of these, they considered this damage mode to be most common for the modified thrie-beam barrier. Conversely, the Maintenance group indicated that "splice damage" was least common with the modified thrie-beam, and most common with the weak-post w-beam guardrail (Figure 55).

"Post-rail separation" is a damage mode that both profession groups agree on completely. They both consider this damage mode most common in the weak-post w-beam guardrail and least common in the modified thrie-beam guardrail (Figure 56).

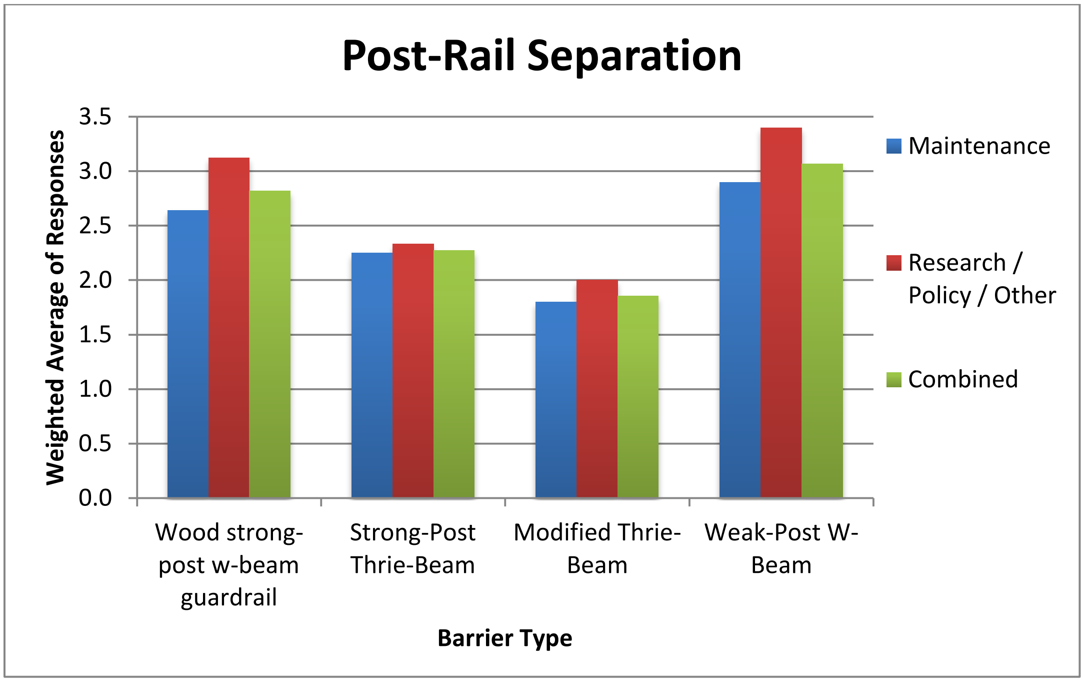


Figure 56. Post-Rail Separation Damage Mode Frequency for Barrier Types, Reorganized Groups.

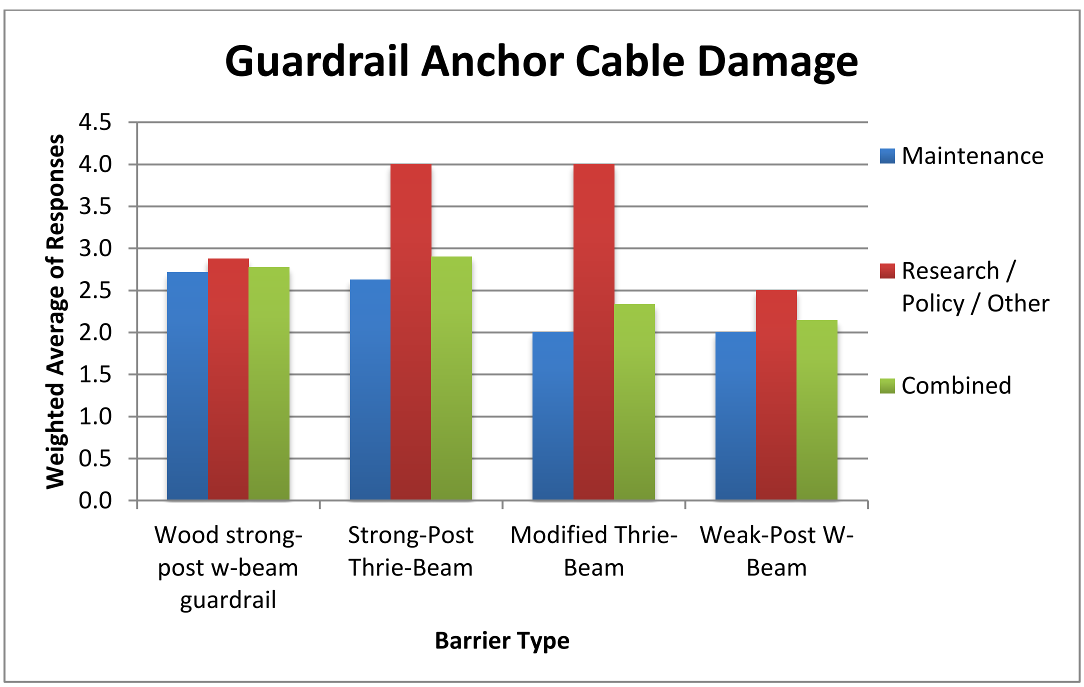


Figure 57. Guardrail Anchor Cable Damage Mode Frequency for Barrier Types, Reorganized Groups

The Maintenance group considers "guardrail anchor cable damage" to be most common damage mode for the strong-post thrie-beam guardrail and the wood strong-post w-beam guardrails. The Research/Policy/Other group indicated that the strong-post thrie-beam and the modified thrie-beam guardrails had a very high occurrence of anchor cable damage. (Figure 57)

Reasoning / Logic

Question 11 (Survey Group 1), Question 8 (Survey Group 2) – It is important for the research team to better understand the reasoning/logic behind your selections in the questions above. For example, your selection may have been derived from knowledge of a full-scale test that resulted in a failure because a component was missing or damaged (e.g., the weak-post w-beam test which resulted in a rail-tear when the back-up plate was not installed); or your selections may have been based on knowledge of field installations that performed poorly with certain pre-existing damage modes; or maybe your selections were based purely on engineering judgment or general knowledge. Please indicate your reasoning by selecting all that apply.

The responses from the reorganized groups can be seen in Figure 58 and Figure 59. In previous sections, the responses of these reorganized groups were compared to each other by means of the weighted averages of their responses. Since these weighted averages cannot be calculated here, and the size of the groups differs (Maintenance = 20, Research/Policy/Other = 9), direct comparison between these groups is not performed here. Instead, the following figures are used to help visualize how each group responded.

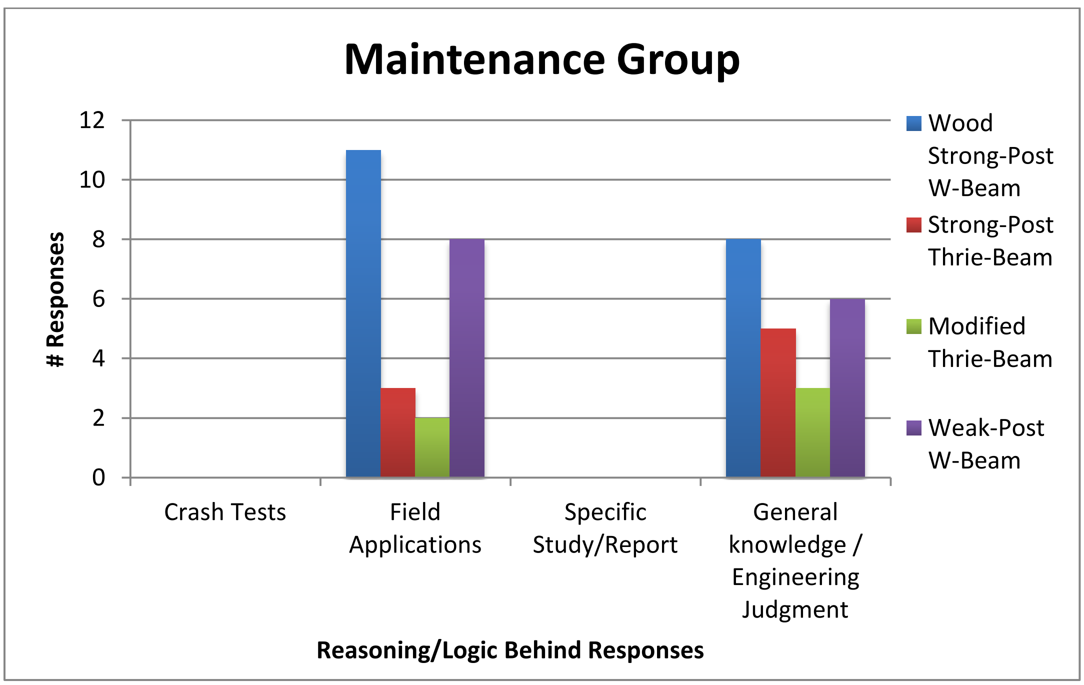


Figure 58. Reasoning/Logic Responses, Maintenance Group.

The Maintenance group did not cite crash tests or any specific studies or reports as reasoning behind their previous answers for any of the barrier types in the survey. They expressed that they are more familiar with the wood strong-post w-beam and weak-post w-beam guardrails from both field applications and general knowledge / engineering judgment than they are with the two thrie-beam guardrails. They appear to have more knowledge of the w-beam barriers from field experience, whereas their knowledge of thrie-beam guardrail comes more from general knowledge and engineering judgment (Figure 58).

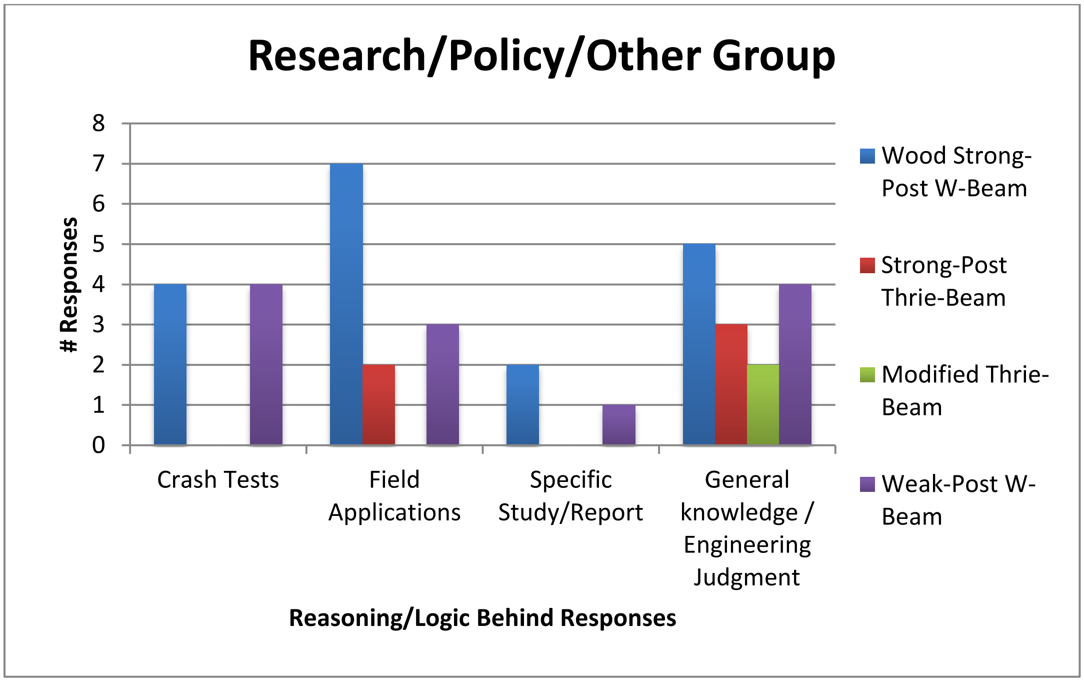


Figure 59. Reasoning/Logic Responses, Research/Policy/Other Group.

The Research/Policy/Other group has used, at least to some degree, all of the reasoning examples presented while answering the above questions in regards to both the wood strong-post w-beam and the weak-post w-beam guardrails. The group used experience from field applications and general knowledge / engineering judgment to answer the questions regarding the strong-post thrie-beam, and relied entirely on general knowledge / engineering judgment to answer questions regarding the modified thrie-beam guardrail. (Figure 59)

Damage Mode Extrapolation Compatibility

Question 9 (Survey Group 2) – Quantitative assessment of several damage modes is included in Report 656 for the steel strong-post guardrail. The current study does not intend to re-do any of the work already included in Report 656, but it is not ascertained which, if any, of the damage modes for the steel-post guardrail can be extrapolated to other guardrail systems. Which of the damage modes included in Report 656 for the steel strong-post guardrail do you feel would have the same or similar effect on the systems listed below? Please rate the similarity by selecting the appropriate rating scale using the pull-down menus. PLEASE ONLY PROVIDE RESPONSES FOR THE GUARDRAIL SYSTEMS THAT YOU ARE FAMILIAR WITH. A blank response indicates that you don't know.

The answers given by Survey Group 2 were converted to a weighted average, using a value of 3 for Very Similar, 2 for Similar, 1 for Somewhat Similar, and 0 for Not Similar. The results are provided in Table 8 and are presented graphically in Figure 60 and Figure 61.

Table 8. Survey Group 2, Question 9 Weighted Averages.

Question #9	Weighted Average		Weighted Average
Midwest Guardrail		**Modified Thrie-Beam**	
Rail / Post deflection	2.00	Rail / Post deflection	NA
Vertical tear in rail	2.00	Vertical tear in rail	1.00
Horizontal tear in rail	2.00	Horizontal tear in rail	NA
Twisted blockout	2.00	Twisted blockout	2.00
Missing blockout	1.50	Missing blockout	2.00
Splice damage	2.00	Splice damage	NA
Hole in rail	2.00	Hole in rail	NA
Missing posts	2.00	Missing posts	3.00
Post-rail separation	1.00	Post-rail separation	NA
Rail flattening	2.00	Rail flattening	2.00
Guardrail anchor damage	2.00	Guardrail anchor damage	2.00
Wood Strong-Post W-Beam		**Weak-Post W-Beam**	
Rail / Post deflection	2.14	Rail / Post deflection	1.75
Vertical tear in rail	2.33	Vertical tear in rail	1.75
Horizontal tear in rail	1.80	Horizontal tear in rail	1.33
Twisted blockout	1.57	Twisted blockout	1.25
Missing blockout	1.43	Missing blockout	1.25
Splice damage	2.00	Splice damage	1.75
Hole in rail	1.80	Hole in rail	1.67
Missing posts	1.33	Missing posts	1.50
Post-rail separation	1.33	Post-rail separation	2.25
Rail flattening	2.14	Rail flattening	2.25
Guardrail anchor damage	2.29	Guardrail anchor damage	2.50
Strong-Post Thrie-Beam			
Rail / Post deflection	3.00		
Vertical tear in rail	3.00		
Horizontal tear in rail	NA		
Twisted blockout	2.00		
Missing blockout	2.00		
Splice damage	NA		
Hole in rail	NA		
Missing posts	2.00		
Post-rail separation	NA		
Rail flattening	2.00		
Guardrail anchor damage	2.00		

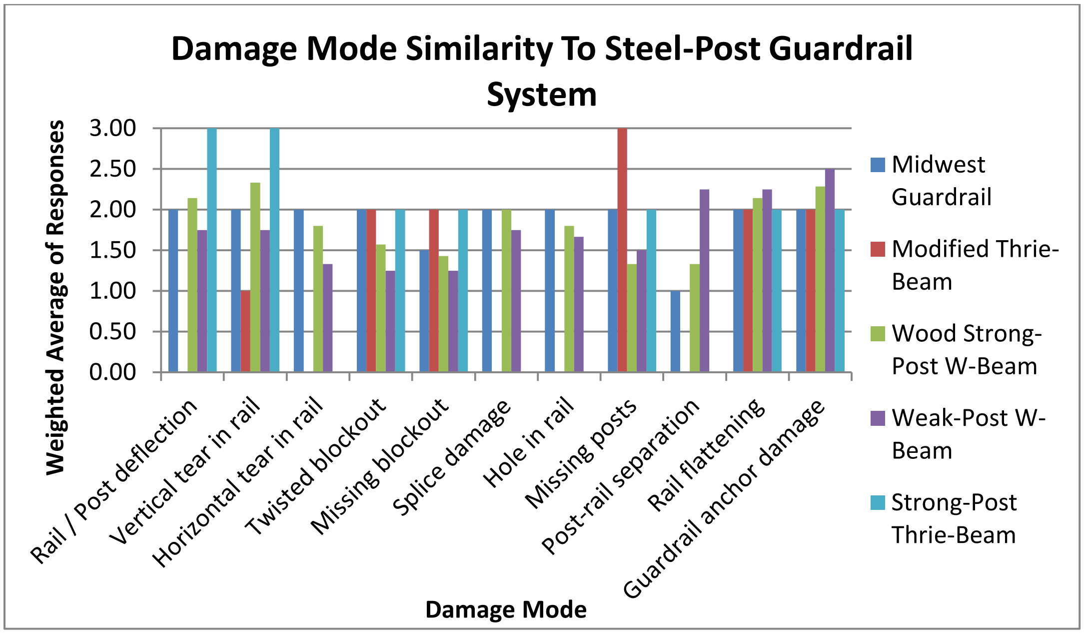


Figure 60. Damage Mode Similarity To Report 656 Field Guide (1)

From Figure 60, it can be seen that the Survey Group 2 respondents felt that "rail flattening" and "guardrail anchor damage" were two damage modes that would have similar behavior as the steel strong-post w-beam barrier used in Report 656; regardless of barrier type.

The wood strong-post w-beam and the weak-post w-beam were two barrier types that the respondents felt would not generally behave similarly to the steel strong-post w-beam, as can be seen in Figure 61.

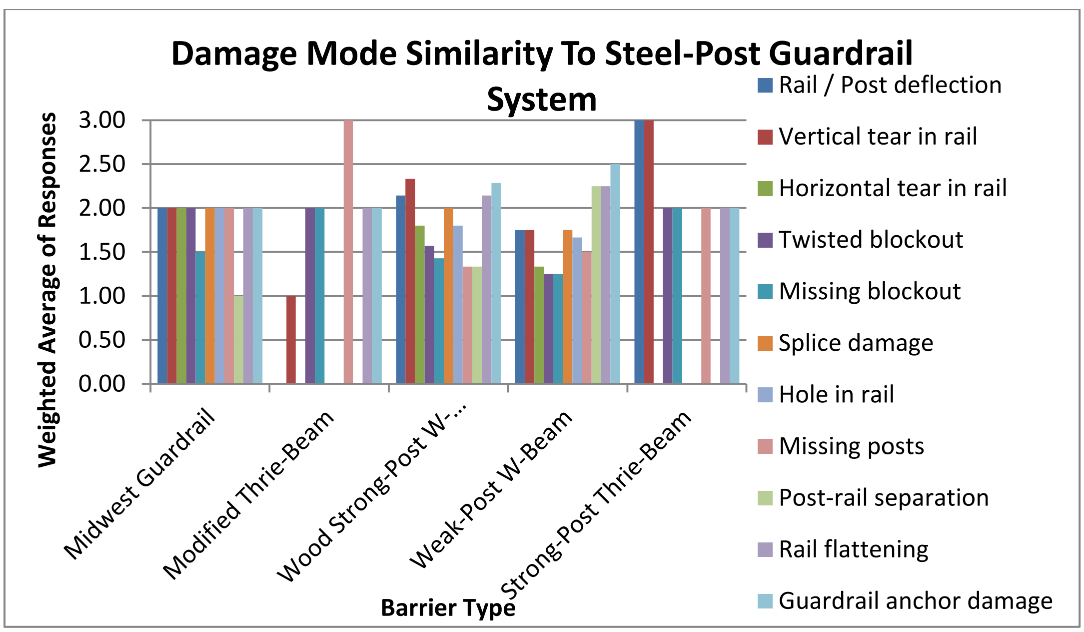


Figure 61. Damage Mode Similarity To Report 656 Field Guide. (2)

Combination Damage Modes for Steel Strong-Post Guardrail

Question 12 (Survey Group 1), Question 10 (Survey Group 2) – When a guardrail system is damaged, say for example in a low-speed impact, the damage is usually characterized by several minor damage modes such as a flattened and deflected rail, deflected and twisted posts, loose soil around posts, damaged bolt connection, etc. The scope of work in Report 656 was limited to a single guardrail type (i.e., the modified G4(1S)) with performance assessments based on the assumption that each damage mode exists in isolation. It is anticipated that the effects of multiple damage modes on guardrail performance will be considered in this study (e.g., flattened rail leading up to missing or damaged post). Please identify ONE or MORE damage-combination cases that you consider important for investigation in this study by selecting all that apply. KEEP IN MIND that only a limited number of damage-combination cases may be included in the current study and that cases involving a high number of damage modes may not be feasible. IF MORE THAN ONE CASE IS ENTERED, please list them in priority order, with Case 1 rated as highest priority.

The responses for each damage mode and case number given by the reorganized groups are located in Table 9. Since damage modes listed in "Case 1" are considered more important than the damage modes listed in "Case 6", each damage mode was assigned a weighted value score, based on how many times they were included and by the priority of the combination damage case as listed by the respondents. The formula used to calculate the weighted value for each damage mode is as follows:

Weighted Value = (Case1*6 + Case2*5 + Case3*4 + Case4*3 + Case5*2 + Case6*1)

All of the weighted values for the damage modes by each profession group, as well as a combination of the two are provided in Table 10.

Table 9. Combination Damage Modes, Reorganized Groups.

		Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Post Deflection	Maintenance	10	2	1	2	1	2
	Research / Policy / Other	6	1	0	0	0	0
	Combined	16	3	1	2	1	2
Twisted Posts	Maintenance	0	3	2	0	1	1
	Research / Policy / Other	2	0	2	0	0	0
	Combined	2	3	4	0	1	1
Missing Posts	Maintenance	3	2	1	0	1	1
	Research / Policy / Other	1	0	0	0	0	1
	Combined	4	2	1	0	1	2
Soil Eroded away from Posts	Maintenance	1	1	2	1	2	0
	Research / Policy / Other	3	0	1	1	0	0
	Combined	4	1	3	2	2	0
Rail Deflection	Maintenance	9	5	2	1	1	1
	Research / Policy / Other	4	3	0	0	0	0

	Combined	13	8	2	1	1	1
Vertical Tear in W-Beam	Maintenance	1	1	2	0	0	1
	Research / Policy / Other	2	1	0	1	0	0
	Combined	3	2	2	1	0	1
Horizontal Tear W-Beam	Maintenance	1	1	1	0	0	0
	Research / Policy / Other	0	2	0	1	0	0
	Combined	1	3	1	1	0	0
Hole in Rail	Maintenance	0	0	1	0	0	1
	Research / Policy / Other	0	0	1	0	1	0
	Combined	0	0	2	0	1	1
Rail Flattening	Maintenance	6	1	2	1	1	1
	Research / Policy / Other	2	3	1	0	0	0
	Combined	8	4	3	1	1	1
Rail Crushing (vertical)	Maintenance	2	0	0	0	0	0
	Research / Policy / Other	0	0	2	0	0	0
	Combined	2	0	2	0	0	0
Twisted Blockout	Maintenance	0	2	1	1	0	0
	Research / Policy / Other	2	0	1	1	0	0
	Combined	2	2	2	2	0	0
Split Blockout	Maintenance	0	1	1	0	1	0
	Research / Policy / Other	1	1	0	1	0	0
	Combined	1	2	1	1	1	0
Rotted Blockout	Maintenance	0	1	0	0	2	0
	Research / Policy / Other	0	0	0	2	0	0
	Combined	0	1	0	2	2	0
Missing Blockout	Maintenance	0	0	0	1	0	2
	Research / Policy / Other	1	1	0	1	0	1
	Combined	1	1	0	2	0	3
Splice Damage	Maintenance	2	0	1	1	0	0
	Research / Policy / Other	3	1	0	1	0	1
	Combined	5	1	1	2	0	1
Post-Rail Separation	Maintenance	3	2	1	2	0	1
	Research / Policy / Other	0	2	0	1	1	0
	Combined	3	4	1	3	1	1
Anchor Damage	Maintenance	3	3	1	1	0	0
	Research / Policy / Other	0	1	1	0	2	1
	Combined	3	4	2	1	2	1

Table 10. Combination Damage Modes Weighted Values, Reorganized Groups.

	Maintenance	Research / Policy / Other	Combined
Post Deflection	84	41	125
Twisted Posts	26	20	46
Missing Posts	35	7	42
Soil Eroded away from Posts	26	25	51
Rail Deflection	93	39	132
Vertical Tear in W-Beam	20	20	40
Horizontal Tear W-Beam	15	13	28
Hole in Rail	5	6	11
Rail Flattening	55	31	86
Rail Crushing (vertical)	12	8	20
Twisted Blockout	17	19	36
Split Blockout	11	14	25
Rotted Blockout	9	6	15
Missing Blockout	5	15	20
Splice Damage	19	27	46
Post-Rail Separation	39	15	54
Anchor Damage	40	14	54

It was difficult to process and synthesize the survey results regarding combination damage modes directly, because many of the respondents included too many damage modes (e.g., anywhere from two to seven) in each combination case. With the current funding level in the project, it will not be feasible to conduct a parametric study of combination mode cases with more than three variables. An alternative approach for processing and presenting the data was used where the survey responses were weighted based on each respondent's priority, then summed to establish overall priority. This method provided a simple way of presenting the data that was also reflective of the information garnered directly from the survey results.

Table 11 contains the weighted values for the combination damage modes for the Maintenance group, sorted from highest to lowest value. Table 12 contains the weighted values for the combination damage modes for the Research/Policy/Other group, sorted from highest to lowest value. Table 13 contains the weighted values for the combination damage modes for the combined groups, sorted from highest to lowest value.

For example, Rail deflection and post deflection where listed together as a combination mode more than 50 percent of the time by the respondents as their highest priority case. This is reflected in Table 11, Table 12, and Table 13 with the top highest rating scores. In the combination cases that included rail deflection and post deflection, one or more of the damage modes listed next in these tables were also included in the combination cases.

Table 11. Combination Damage Modes Weighted Values, Maintenance Group.

	Maintenance
Rail Deflection	93
Post Deflection	84
Rail Flattening	55
Anchor Damage	40
Post-Rail Separation	39
Missing Posts	35
Twisted Posts	26
Soil Eroded away from Posts	26
Vertical Tear in W-Beam	20
Splice Damage	19
Twisted Blockout	17
Horizontal Tear W-Beam	15
Rail Crushing (vertical)	12
Split Blockout	11
Rotted Blockout	9
Hole in Rail	5
Missing Blockout	5

Table 12. Combination Damage Modes Weighted Values, Research/Policy/Other Group.

	Research / Policy / Other
Post Deflection	41
Rail Deflection	39
Rail Flattening	31
Splice Damage	27
Soil Eroded away from Posts	25
Twisted Posts	20
Vertical Tear in W-Beam	20
Twisted Blockout	19
Post-Rail Separation	15
Missing Blockout	15
Anchor Damage	14
Split Blockout	14
Horizontal Tear W-Beam	13
Rail Crushing (vertical)	8
Missing Posts	7
Rotted Blockout	6
Hole in Rail	6

Both groups listed "rail deflection", "post deflection", and "rail flattening" as the three damage modes they are the most interested in.

Additional System Element Interest

Question 13 (Survey Group 1), Question 11 (Survey Group 2) – Which additional system elements (if any) would you like to see covered in the expanded guide? Please rate the following guardrail element options.

Table 14 shows the additional system elements of interest, rated for importance by the reorganized groups.

Table 13. Combination Damage Modes Weighted Values, Combined Profession Groups.

	Combined
Rail Deflection	132
Post Deflection	125
Rail Flattening	86
Post-Rail Separation	54
Anchor Damage	54
Soil Eroded away from Posts	51
Splice Damage	46
Twisted Posts	46
Missing Posts	42
Vertical Tear in W-Beam	40
Twisted Blockout	36
Horizontal Tear W-Beam	28
Split Blockout	25
Missing Blockout	20
Rail Crushing (vertical)	20
Rotted Blockout	15
Hole in Rail	11

Table 14. Additional System Element Interest, Reorganized Groups.

Which additional system elements (if any) would you like to see covered in the expanded guide? Please rate the following guardrail element options.						
Answer Options		Very Important	Important	Somewhat Important	Not Important	Rating Average
Guardrail Transitions	Maintenance	6	5	4	1	2.00
	Research / Policy / Other	5	1	2	0	2.38
	Combined	11	6	6	1	2.13
Generic Guardrail End Treatments	Maintenance	9	4	2	1	2.31
	Research / Policy / Other	7	1	0	0	2.88
	Combined	16	5	2	1	2.50

The values used for the weighted averages of responses are as follows: very important = 3, important = 2, somewhat important = 1, and not important = 0.

The Research/Policy/Other group expressed more concerned with both transitions and end treatments than the Maintenance group, and both profession groups expressed more interest in end treatments than guardrail transitions.

Guardrail Transitions

Question 14 (Survey Group 1), Question 12 (Survey Group 2) – Length-of-need sections of guardrail are the primary focus of this study; however, if the study is expanded to include transition elements, which types of systems would you like to see included?   Please rate the types of transition element types that you would like to see included in the updated guide.

The responses for the guardrail transition elements of interest from the reorganized groups are located in Table 15. The values used for the weighted averages of responses are as follows: high importance = 3, medium importance = 2, and low importance = 1.

Table 15. Guardrail Transition Elements of Interest, Reorganized Groups.

GUARDRAIL TRANSITIONS: Length-of-need sections of guardrail are the primary focus of this study; however, if the study is expanded to include transition elements, which types of systems would you like to see included? Please rate the types of transition element types that you would like to see included in the updated guide.					
Answer Options		High Importance	Medium Importance	Low Importance	Weighted Average
W-Beam to Thrie-Beam	Maintenance	6	6	3	2.20
	Research / Policy / Other	4	2	2	2.25
	Combined	10	8	5	2.22
Wood-Post W-beam to Rigid Barrier	Maintenance	7	4	5	2.13
	Research / Policy / Other	4	2	3	2.11
	Combined	11	6	8	2.12
Steel-Post W-Beam to Rigid Barrier	Maintenance	12	2	1	2.73
	Research / Policy / Other	5	3	1	2.44
	Combined	17	5	2	2.63
Thrie-Beam to Rigid Barrier (e.g., Bridge Rail)	Maintenance	5	6	3	2.14
	Research / Policy / Other	5	2	0	2.71
	Combined	10	8	3	2.33
Weak-Post W-Beam to Rigid Barrier	Maintenance	6	1	7	1.93
	Research / Policy / Other	4	0	3	2.14
	Combined	10	1	10	2.00
Weak-Post W-Beam to Strong-Post W-Beam	Maintenance	4	4	5	1.92
	Research / Policy / Other	2	3	3	1.88
	Combined	6	7	8	1.90
Low-Tension Cable to W-Beam	Maintenance	3	2	6	1.73
	Research / Policy / Other	1	2	4	1.57
	Combined	4	4	10	1.67

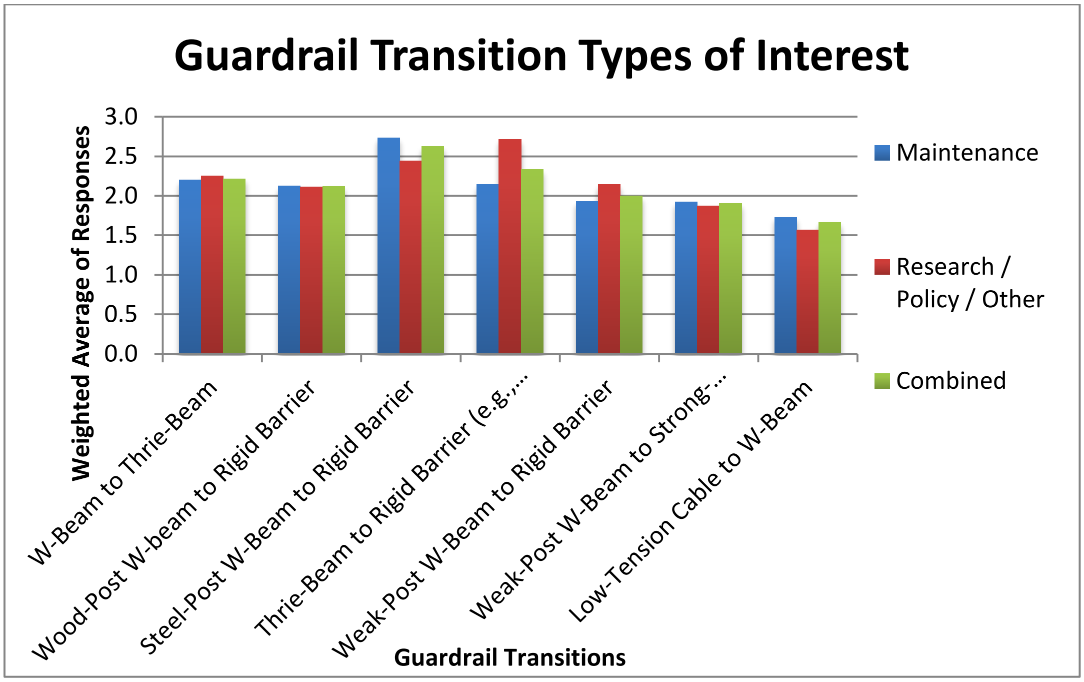


Figure 62. Guardrail Transition Types of Interest 1, Reorganized Groups.

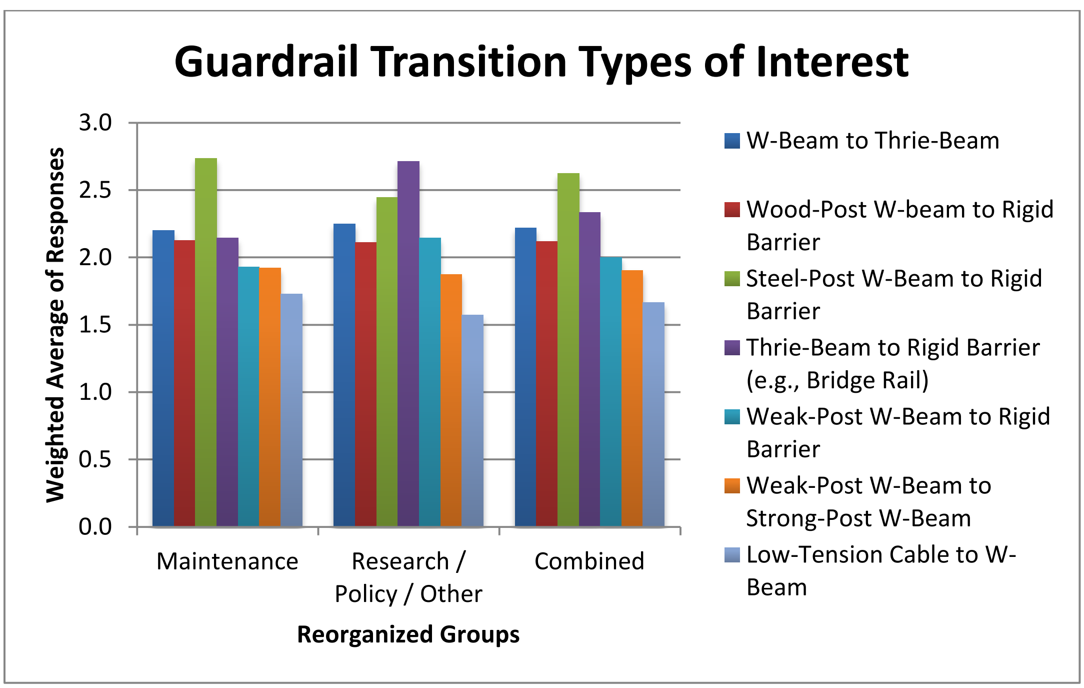


Figure 63. Guardrail Transition Types of Interest 2, Reorganized Groups.

The Maintenance group expressed the most interest in the steel-post w-beam to rigid barrier transition, while the Research/Policy/Other group expressed the most interest in the thrie-beam to rigid barrier (e.g., bridge rail) transition. Both groups expressed the least amount of interest in the low-tension cable to w-beam transition. (Figure 62 and Figure 63)

Guardrail End-Treatments

Question 15 (Survey Group 1), Question 13 (Survey Group 2) – If the study is expanded to include guardrail end-treatments, which systems would you like to see included? Note that proprietary systems are not being considered for this study and there are currently no non-proprietary systems that meet FHWA approval. However, there are many field installations that are still in service which may have incurred some amount of damage. Also, there are several system aspects that are common for many of these types of systems (e.g., post release, anchor connections, etc.), thus damage effects on certain elements may extrapolate to other similar systems. Please rate the types of guardrail end-treatment elements that you would like to see included in the updated guide.

The responses for the guardrail end treatments of interest from the reorganized groups are located in Table 16. The values used for the weighted averages of responses are as follows: high importance = 3, medium importance = 2, and low importance = 1.

Table 16. Guardrail End-Treatment Types of Interest, Reorganized Groups.

Answer Options		High Importance	Medium Importance	Low Importance	Weighted Average
BCT	Maintenance	6	7	3	2.19
	Research / Policy / Other	4	4	1	2.33
	Combined	10	11	4	2.24
MELT	Maintenance	5	7	4	2.06
	Research / Policy / Other	1	5	3	1.78
	Combined	6	12	7	1.96
Buried in Backslope	Maintenance	3	4	8	1.67
	Research / Policy / Other	6	2	1	2.56
	Combined	9	6	9	2.00

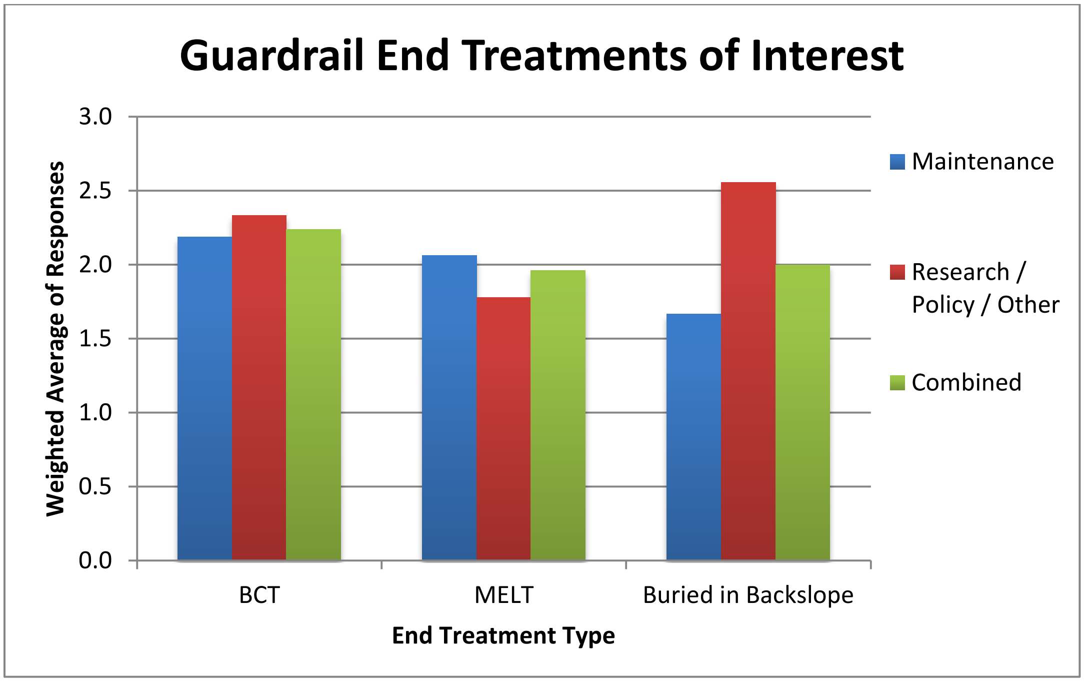


Figure 64. Guardrail End Treatment Types of Interest 1, Reorganized Groups.

The two profession groups disagreed the most on the "buried in backslope" end treatment; the Research/Policy/Other group expressed much more interest in this end treatment than the Maintenance group did. (Figure 64)

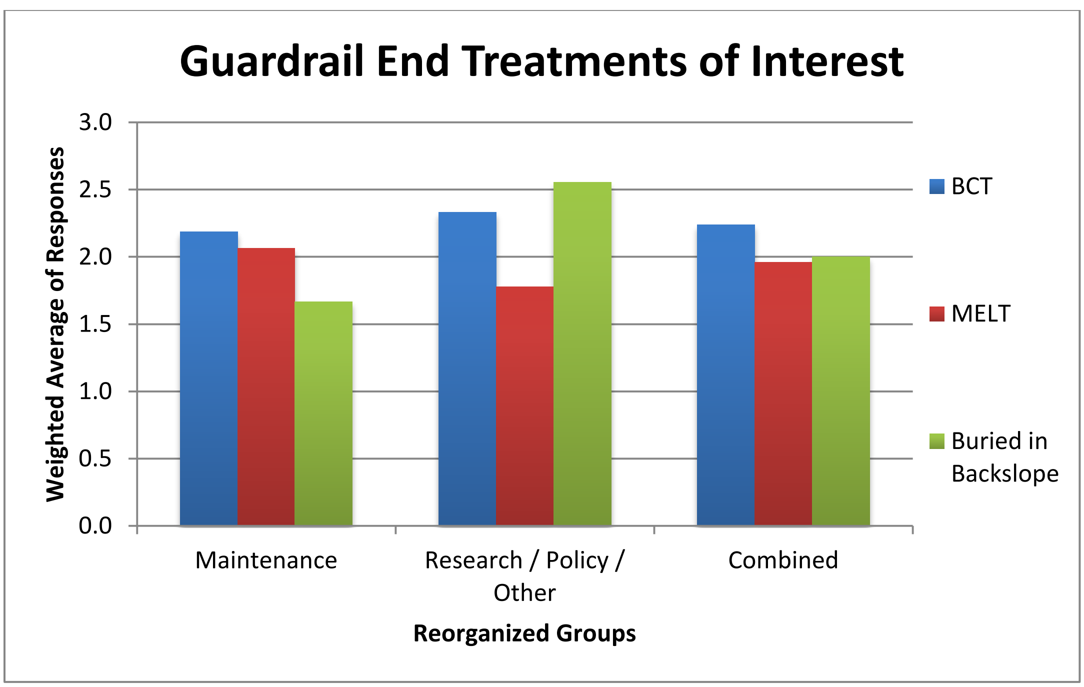


Figure 65. Guardrail End Treatment Types of Interest 2, Reorganized Groups.

The Maintenance group considered the BCT end treatment to be of the most interest and expressed the least amount of interest in the “buried in backslope” end treatment. The Research/Policy/Other group however, expressed the most interest in the “buried in backslope” end treatment and the least amount of interest in the MELT end treatment. (Figure 65)

Summary

A survey was conducted to determine Transportation Agency plans for implementing NCHRP Report 656 and to identify damage modes and other system elements (e.g., wood posts, transitions, end treatments) that should be added to those covered by Report 656. The survey had two target audiences (1) those with direct maintenance responsibilities in the state DOT’s and (2) those involved in barrier design and evaluation (i.e., research/policy/other in this report). Unfortunately, with only 29 respondents, the response rate on the survey was relatively low. There were a total of twenty respondents with a field of work related to maintenance and nine respondents with field of work related to research/policy/other.

The survey results were presented graphically and included the average response from each of the two individual groups, as well as, the overall average response of the combined groups. The two groups generally agreed on questions related to the G4(2W) and the standard thrie-beam guardrails, which are both widely used systems; but often disagreed on the answers to questions related to the modified thrie-beam and the weak-post w-beam guardrail systems. It is assumed that these differences were due to the different perspectives of the two groups; however, it is also possible that there was confusion regarding those two particular guardrail systems. For example, as shown in the Background section, the blockout on the standard G9 thrie-beam guardrail was changed to a wooden blockout in the late 90’s to improve crash performance, thus some respondents may have considered the wood-block thrie-beam system to be a modified thrie-beam guardrail. Likewise, the weak-post w-beam guardrail, which is a TL-3 system that is very common throughout the northeastern States, may have been confused with other so-called “weak-post” systems that use *standard strong-posts* (i.e., W6x9 steel posts or 6x8-inch wood posts), with *wider post spacing* (i.e., 12.5-ft post spacing) and *no blockouts*. These so-called “weak-post” systems are very common throughout the country, but are generally installed on low-speed roadways since they are rated as TL-2, or lower.

It is also possible that respondents from the research field may have rated damage modes based on their perceived “effect on performance” rather than how common the damage mode was for the system. For example, in almost every case the research/policy/other group gave higher ratings for damage modes, regardless of system, compared to the maintenance group.

Overall, the results of the survey were not too surprising. With such a low number of respondents it is not clear, however, how much merit can be given to the results. Where appropriate, the results of the survey in combination with the information garnered from the literature review will be used to prioritize the guardrail system(s) and damage modes that will be considered for investigation in this study. The prioritization task is the focus of the following sections.

APPENDIX C

Validation/Verification Report Forms

Chuck A. Plaxico, Ph.D.

October 10, 2013

FEA VALIDATION/VERIFICATION REPORT FORM FOR THE G4(2W) MODEL

A ____REPORT 350 TEST 3-11____

(Report 350 or MASH08 or EN1317 Vehicle Type)

Striking a _____G4(2W)____

(roadside hardware type and name)

Report Date: ____10/02/2013____

Type of Report (check one)

☐ Verification (known numerical solution compared to new numerical solution) or

☒ Validation (full-scale crash test compared to a numerical solution).

General Information	**Known Solution**	**Analysis Solution**
Performing Organization	TTI	Roadsafe
Test/Run Number:	471470-26	471470-26_R8
Vehicle:	1989 Chevrolet C-2500	C2500D-v5 (modified)
Reference:	2000-P	2000P
Impact Conditions		
Vehicle Mass:	4,572 lb	4,568 lb
Speed:	62.6 mph	62.2 mph
Angle:	24.3 degrees	24.3 degrees
Impact Point:	2 ft upstream of Post 14	2 ft upstream of Post 14

Composite Validation/Verification Score

List the Report 350/MASH08 or EN1317 Test Number	
Part I	Did all solution verification criteria in Table E-1 pass?
Part II	Do all the time history evaluation scores from Table E-2 result in a satisfactory comparison (i.e., the comparison passes the criterion)? If all the values in Table E-2 did not pass, did the weighted procedure shown in Table E-3 result in an acceptable comparison. If all the criteria in Table E-2 pass, enter "yes." If all the criteria in Table E-2 did not pass but Table E-3 resulted in a passing score, enter "yes."
Part III	All the criteria in Table E-4 (Test-PIRT) passed?
	Are the results of Steps I through III all affirmative (i.e., YES)? If all three steps result in a "YES" answer, the comparison can be considered validated or verified. If one of the steps results in a negative response, the result cannot be considered validated or verified.

The analysis solution (check one) ☐ is ☒ is NOT verified/validated against the known solution.

PART I: BASIC INFORMATION

These forms may be used for validation or verification of roadside hardware crash tests. If the known solution is a full-scale crash test (i.e., physical experiment) which is being compared to a numerical solution (e.g., LSDYNA analysis) then the procedure is a validation exercise. If the known solution is a numerical solution (e.g., a prior finite element model using a different program or earlier version of the software) then the procedure is a verification exercise. This form can also be used to verify the repeatability of crash tests by comparing two full-scale crash test experiments. Provide the following basic information for the validation/verification comparison:

1. What type of roadside hardware is being evaluated (check one)?
   - ☒ Longitudinal barrier or transition
   - ☐ Terminal or crash cushion
   - ☐ Breakaway support or work zone traffic control device
   - ☐ Truck-mounted attenuator
   - ☐ Other hardware: ____________________

2. What test guidelines were used to perform the full-scale crash test (check one)?
   - ☒ NCHRP Report 350
   - ☐ MASH08
   - ☐ EN1317
   - ☐ Other: ____________________

3. Indicate the test level and number being evaluated (fill in the blank). __Test 3-11__________

4. Indicate the vehicle type appropriate for the test level and number indicated in item 3 according to the testing guidelines indicated in item 2.

   NCHRP Report 350/MASH08

☐ 700C	☐ 820C	☐ 1100C
☒ 2000P	☐ 2270P	☐ Other:____________
☐ 8000S	☐ 10000S	
☐ 36000V		
☐ 36000T		

   EN1317

☐ Car (900 kg)	☐ Car (1300 kg)	☐ Car (1500 kg)
☐ Rigid HGV (10 ton)	☐ Rigid HGV (16 ton)	☐ Rigid HGV (30 ton)
☐ Bus (13 ton)	☐ Articulated HGV (38 ton)	☐ Other:____________

PART II: ANALYSIS SOLUTION VERIFICATION

Using the results of the analysis solution, fill in the values for Table E-1. These values are indications of whether the analysis solution produced a numerically stable result and do not necessarily mean that the result is a good comparison to the known solution. The purpose of this table is to ensure that the numerical solution produces results that are numerically stable and conform to the conservation laws (e.g., energy, mass and momentum).

Table A-1. Analysis Solution Verification Table.

Verification Evaluation Criteria	Change (%)	Pass?
Total energy of the analysis solution (i.e., kinetic, potential, contact, etc.) must not vary more than 10 percent from the beginning of the run to the end of the run.	5%	**Y**
Hourglass Energy of the analysis solution at the end of the run is less than *five percent* of the total *initial energy* at the *beginning* of the run.	5.2%	**N**
Hourglass Energy of the analysis solution at the end of the run is less than *ten percent* of the total *internal energy* at the *end* of the run.	9.7%	**Y**
The part/material with the highest amount of hourglass energy at the end of the run is less than ten percent of the total internal energy of the part/material at the end of the run.	Blockout (9.7%) Truck Frame (50%)	**N**
Mass added to the total model is less than five percent of the total model mass at the beginning of the run.	39 lb	**Y**
The part/material with the most mass added had less than 10 percent of its initial mass added.		**Y**
The moving parts/materials in the model have less than five percent of mass added to the initial moving mass of the model.	0.3%	**Y**
There are no shooting nodes in the solution?	Y	**Y**
There are no solid elements with negative volumes?	Y	**Y**

If all the analysis solution verification criteria are scored as passing, the analysis solution can be verified or validated against the known solution. If any criterion in Table E-1 does not pass one of the verification criterion listed in Table E-1, the analysis solution cannot be used to verify or validate the known solution. If there are exceptions that the analyst things are relevant these should be footnoted in the table and explained below the table.

The Analysis Solution (check one) ☒ passes ☐ does NOT pass <u>all</u> the criteria in Table E1-1

☒with ☐without exceptions as noted.

PART III: TIME HISTORY EVALUATION TABLE

Using the RSVVP computer program ('Single channel' option), compute the Sprague-Geers MPC metrics and ANOVA metrics using time-history data from the known and analysis solutions for a time period starting at the beginning of the contact and ending at the loss of contact. Both the Sprague-Geers and ANOVA metrics must be calculated based on the original units the data was collected in (e.g., if accelerations were measured in the experiment with accelerometers then the comparison should be between accelerations. If rate gyros were used in the experiment, the comparison should be between rotation rates). If all six data channels are not available for both the known and analysis solutions, enter "N/A" in the column corresponding to the missing data. Enter the values obtained from the RSVVP program in Table E-2 and indicate if the comparison was acceptable or not by entering a "yes" or "no" in the "Agree?" column. Attach a graph of each channel for which the metrics have been compared at the end of the report.

Enter the filter, synchronization method and shift/drift options used in RSVVP to perform the comparison so that it is clear to the reviewer what options were used. Normally, SAE J211 filter class 180 is used to compare vehicle kinematics in full-scale crash tests. Either synchronization option in RSVVP is acceptable and both should result in a similar start point. The shift and drift options should generally only be used for the experimental curve (i.e., true curve) since shift and drift are characteristics of sensors. For example, the zero point for an accelerometer sometimes "drifts" as the accelerometer sits out in the open environment of the crash test pad whereas there is no sensor to "drift" or "shift" in a numerical solution.

In order for the analysis solution to be considered in agreement with the known solution (i.e., verified or validated), <u>all</u> the criteria scored in Table E-2 must pass. If all the channels in Table E-2 do not pass, fill out Table E-3, the multi-channel weighted procedure.

If one or more channels do not satisfy the criteria in Table E-2, the multi-channel weighting option may be used. Using the RSVVP computer program ('Multiple channel' option), compute the Sprague-Geers MPC metrics and ANOVA metrics using all the time histories data from the known and analysis solutions for a time period starting at the beginning of the contact and ending at the loss of contact. If all six data channels are not available for both the known and analysis solutions, enter "N/A" in the column corresponding to the missing data.

For some types of roadside hardware impacts, some of the channels are not as important as others. An example might be a breakaway sign support test where the lateral (i.e., Y) and vertical (i.e., Z) accelerations are insignificant to the dynamics of the crash event. The weighting procedure provides a way to weight the most important channels more highly than less important channels. The procedure used is based on the area under the curve, therefore, the weighing scheme will weight channels with large areas more highly than those with smaller areas. In general, using the "Area (II)" method is acceptable although if the complete inertial properties of the vehicle are available the "inertial" method may be used. Enter the values obtained from the RSVVP program in Table E-3 and indicate if the comparison was acceptable or not by entering a "yes" or "no" in the "Agree?" column.

In order for the analysis solution to be considered in agreement with the known solution (i.e., verified or validated), <u>all</u> the criteria scored in Table E-3 must pass.

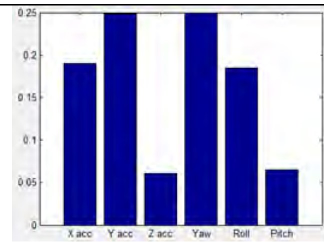
Table A-2. Roadside Safety Validation Metrics Rating Table – Time History Comparisons (single channel option).

<table>
<tr><th colspan="9">Evaluation Criteria</th><th colspan="3" rowspan="2">Time interval
[0.00 – 0.6 sec]</th></tr>
<tr><td rowspan="9">O</td><td colspan="8">Sprague-Geers Metrics
List all the data channels being compared. Calculate the M and P metrics using RSVVP and enter the results. Values less than or equal to 40 are acceptable.</td></tr>
<tr><td rowspan="3"></td><td colspan="6">RSVVP Curve Preprocessing Options</td><td rowspan="3">M</td><td rowspan="3">P</td><td rowspan="3">Pass?</td></tr>
<tr><td rowspan="2">Filter Option</td><td rowspan="2">Sync. Option</td><td colspan="2">Shift</td><td colspan="2">Drift</td></tr>
<tr><td>True Curve</td><td>Test Curve</td><td>True Curve</td><td>Test Curve</td></tr>
<tr><td>X acceleration</td><td>CFC 60</td><td>none</td><td>none</td><td>none</td><td>none</td><td>none</td><td>1.3</td><td>33.7</td><td>Y</td></tr>
<tr><td>Y acceleration</td><td>CFC 60</td><td>none</td><td>none</td><td>none</td><td>none</td><td>none</td><td>6.0</td><td>31.7</td><td>Y</td></tr>
<tr><td>Z acceleration</td><td>CFC 60</td><td>none</td><td>none</td><td>none</td><td>none</td><td>none</td><td>59.6</td><td>51.1</td><td>N</td></tr>
<tr><td>Roll rate</td><td>CFC 60</td><td>none</td><td>none</td><td>none</td><td>none</td><td>none</td><td>51.7</td><td>41.1</td><td>N</td></tr>
<tr><td>Pitch rate</td><td>CFC 60</td><td>none</td><td>none</td><td>none</td><td>none</td><td>none</td><td>4.0</td><td>23.3</td><td>Y</td></tr>
<tr><td></td><td>Yaw rate</td><td>CFC 60</td><td>none</td><td>none</td><td>none</td><td>none</td><td>none</td><td>15.7</td><td>8.3</td><td>Y</td></tr>
<tr><td rowspan="7">P</td><td colspan="8">ANOVA Metrics
List all the data channels being compared. Calculate the ANOVA metrics using RSVVP and enter the results. Both of the following criteria must be met:
• The mean residual error must be less than five percent of the peak acceleration ($\bar{e} \leq 0.05 \cdot a_{Peak}$) and
• The standard deviation of the residuals must be less than 35 percent of the peak acceleration ($\sigma \leq 0.35 \cdot a_{Peak}$)</td><td>Mean Residual</td><td>Standard Deviation of Residuals</td><td>Pass?</td></tr>
<tr><td colspan="8">X acceleration/Peak</td><td>1.4</td><td>26.4</td><td>Y</td></tr>
<tr><td colspan="8">Y acceleration/Peak</td><td>1.29</td><td>27.3</td><td>Y</td></tr>
<tr><td colspan="8">Z acceleration/Peak</td><td>0.92</td><td>17.4</td><td>Y</td></tr>
<tr><td colspan="8">Roll rate</td><td>4.0</td><td>23.3</td><td>Y</td></tr>
<tr><td colspan="8">Pitch rate</td><td>1.7</td><td>28.0</td><td>Y</td></tr>
<tr><td colspan="8">Yaw rate</td><td>9.0</td><td>11.83</td><td>N</td></tr>
</table>

The Analysis Solution (check one) ☐ passes ☒ does NOT pass <u>all</u> the criteria in Table E-2 (single-channel time history comparison). If the Analysis Solution does NOT pass, perform the analysis in Table E-3 (multi-channel time history comparison).

Table A-3. Roadside Safety Validation Metrics Rating Table – Time History Comparisons (multi-channel option).

<table>
<tr><td colspan="6">Evaluation Criteria (time interval [0.0 – 0.6 seconds])</td></tr>
<tr><td colspan="6">Channels (Select which were used)</td></tr>
<tr><td colspan="2">☐ X Acceleration</td><td>☐ Y Acceleration</td><td colspan="3">☐ Z Acceleration</td></tr>
<tr><td colspan="2">☐ Roll rate</td><td>☐ Pitch rate</td><td colspan="3">☐ Yaw rate</td></tr>
<tr><td colspan="2">Multi-Channel Weights

- Area II method -</td><td>X Channel: 0.190
Y Channel: 0.249
Z Channel: 0.061
Yaw Channel: 0.249
Roll Channel: 0.185
Pitch Channel: 0.065</td><td colspan="3">
</td></tr>
<tr><td rowspan="2">O</td><td colspan="2" rowspan="2">Sprague-Geer Metrics
Values less or equal to 40 are acceptable.</td><td>M</td><td>P</td><td>Pass?</td></tr>
<tr><td>13.4</td><td>26.5</td><td>Y</td></tr>
<tr><td rowspan="2">P</td><td colspan="2" rowspan="2">ANOVA Metrics
Both of the following criteria must be met:
• The mean residual error must be less than five percent of the peak acceleration ($\bar{e} \le 0.05 \cdot a_{Peak}$)
• The standard deviation of the residuals must be less than 35 percent of the peak acceleration ($\sigma \le 0.35 \cdot a_{Peak}$)</td><td>Mean Residual</td><td>Standard Deviation of Residuals</td><td>Pass?</td></tr>
<tr><td>2.8</td><td>21.4</td><td>Y</td></tr>
</table>

The Analysis Solution (check one) ☒ passes ☐ does NOT pass all the criteria in Table E-3.

PART IV: PHENOMENA IMPORTANCE RANKING TABLE

Table E-4 is similar to the evaluation tables in Report 350 and MASH. For the Report 350 or MASH test number identified in Part I (e.g., test 3-10, 5-12, etc.), circle all the evaluation criteria applicable to that test in Table E-4. The tests that apply to each criterion are listed in the far right column without the test level designator. For example, if a Report 350 test 3-11 is being compared (i.e., a pickup truck striking a barrier at 25 degrees and 100 km/hr), circle all the criteria in the second column where the number "11" appears in the far right column. Some of the Report 350 evaluation criteria have been removed (i.e., J and K) since they are not generally useful in assessing the comparison between the known and analysis solutions.

Table A-4. Evaluation Criteria Test Applicability Table.

<table>
<tr><th>Evaluation Factors</th><th colspan="2">Evaluation Criteria</th><th>Applicable Tests</th></tr>
<tr><td rowspan="2">Structural Adequacy</td><td>A</td><td>Test article should contain and redirect the vehicle; the vehicle should not penetrate, under-ride, or override the installation although controlled lateral deflection of the test article is acceptable.</td><td>10, 11, 12, 20, 21, 22, 35, 36, 37, 38</td></tr>
<tr><td>B</td><td>The test article should readily activate in a predictable manner by breaking away, fracturing or yielding.</td><td>60, 61, 70, 71, 80, 81</td></tr>
<tr><td></td><td>C</td><td>Acceptable test article performance may be by redirection, controlled penetration or controlled stopping of the vehicle.</td><td>30, 31,, 32, 33, 34, 39, 40, 41, 42, 43, 44, 50, 51, 52, 53</td></tr>
<tr><td rowspan="7">Occupant Risk</td><td>D</td><td>Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians or personnel in a work zone.</td><td>All</td></tr>
<tr><td>E</td><td>Detached elements, fragments or other debris from the test article, or vehicular damage should not block the driver's vision or otherwise cause the driver to lose control of the vehicle. (Answer Yes or No)</td><td>70, 71</td></tr>
<tr><td>F</td><td>The vehicle should remain upright during and after the collision although moderate roll, pitching and yawing are acceptable.</td><td>All except those listed in criterion G</td></tr>
<tr><td>G</td><td>It is preferable, although not essential, that the vehicle remain upright during and after collision.</td><td>12, 22 (for test level 1 – 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44)</td></tr>
<tr><td rowspan="2">H</td><td>Occupant impact velocities should satisfy the following:<table><tr><th colspan="3">Occupant Impact Velocity Limits (m/s)</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal and Lateral</td><td>9</td><td>12</td></tr></table></td><td>10, 20, 30,31, 32, 33, 34, 36, 40, 41, 42, 43, 50, 51, 52, 53, 80, 81</td></tr>
<tr><td><table><tr><td>Longitudinal</td><td>3</td><td>5</td></tr></table></td><td>60, 61, 70, 71</td></tr>
<tr><td>I</td><td>Occupant ridedown accelerations should satisfy the following:<table><tr><th colspan="3">Occupant Ridedown Acceleration Limits (g's)</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal and Lateral</td><td>15</td><td>20</td></tr></table></td><td>10, 20, 30,31, 32, 33, 34, 36, 40, 41, 42, 43, 50, 51, 52, 53, 60, 61, 70, 71, 80, 81</td></tr>
<tr><td rowspan="3">Vehicle Trajectory</td><td>L</td><td>The occupant impact velocity in the longitudinal direction should not exceed 40 ft/sec and the occupant ride-down acceleration in the longitudinal direction should not exceed 20 G's.</td><td>11,21, 35, 37, 38, 39</td></tr>
<tr><td>M</td><td>The exit angle from the test article preferable should be less than 60 percent of test impact angle, measured at the time of vehicle loss of contact with test device.</td><td>10, 11, 12, 20, 21, 22, 35, 36, 37, 38, 39</td></tr>
<tr><td>N</td><td>Vehicle trajectory behind the test article is acceptable.</td><td>30, 31, 32, 33, 34, 39, 42, 43, 44, 60, 61, 70, 71, 80, 81</td></tr>
</table>

Complete Table E-5 according to the results of the known solution (e.g., crash test) and the numerical solution (e.g., simulation). Consistent with Report 350 and MASH, Task E-5 has three parts:

the structural adequacy phenomena listed in Table E-5a, the occupant risk phenomena listed in Table E-5b and the vehicle trajectory criteria listed in Table E-5c. If the result of the analysis solution agrees with the known solution, mark the "agree" column "yes." For example, if the vehicle in both the known and analysis solutions rolls over and, therefore, fails criterion F1, the known and the analysis columns for criterion F1 would be evaluated as "no." Even though both failed the criteria, they agree with each other so the "agree" column is marked as "yes." Any criterion that is <u>not</u> applicable to the test being evaluated (i.e., <u>not</u> circled in Table E-4) should be indicated by entering "NA" in the "agree?" column for that row.

Many of the Report 350 evaluation criteria have been subdivided into more specific phenomenon. For example, criterion A is divided into eight sub-criteria, A1 through A8, that provide more specific and quantifiable phenomena for evaluation. Some of the values are simple yes or no questions while other request numerical values. For the numerical phenomena, the analyst should enter the value for the known and analysis result and then calculate the relative difference. Relative difference is always the absolute value of the difference of the known and analysis solutions divided by the known solution. Enter the value in the "relative difference" column. If the relative difference is less than 20 percent, enter "yes" in the "agree?" column.

Sometimes, when the values are very small, the relative difference might be large while the absolute difference is very small. For example, the longitudinal occupant ride down acceleration (i.e., criterion L2) in a test might be 3 g's and in the corresponding analysis might be 4 g's. The relative difference is 33 percent but the absolute difference is only 1 g and the result for both is well below the 20 g limit. Clearly, the analysis solution in this case is a good match to the experiment and the relative difference is large only because the values are small. The absolute difference, therefore, should also be entered into the "Difference" column in Table E-5.

The experimental and analysis result can be considered to agree as long as either the relative difference <u>or</u> the absolute difference is less than the acceptance limit listed in the criterion. Generally, relative differences of less than 20 percent are acceptable and the absolute difference limits were generally chosen to represent 20 percent of the acceptance limit in Report 350 or MASH. For example, Report 350 limits occupant ride-down accelerations to those less than 20 g's so 20 percent of 20 g's is 4 g's. As shown for criterion L2 in Table E-5, the relative acceptance limit is 20 percent and the absolute acceptance limit is 4 g's.

If a numerical model was not created to represent the phenomenon, a value of "NM" (i.e., not modeled) should be entered in the appropriate column of Table E-5. If the known solution for that phenomenon number is "no" then a "NM" value in the "test result" column can be considered to agree. For example, if the material model for the rail element did not include the possibility of failure, "NM" should be entered for phenomenon number T in Table E-5. If the known solution does not indicate rail rupture or failure (i.e., phenomenon T = "no"), then the known and analysis solutions agree and a "yes" can be entered in the "agree?" column. On the other hand, if the known solution shows that a rail rupture did occur resulting in a phenomenon T entry of "yes" for the known solution, the known and analysis solutions do not agree and "no" should be entered in the "agree?" column. Analysts should seriously consider refining their model to incorporate any phenomena that appears in the known solution and is shown in Table E-5.

All the criteria identified in Table E-4 are expected to agree but if one does not and, in the opinion of the analyst, is not considered important to the overall evaluation for this particular comparison, then a footnote should be provided with a justification for why this particular criteria can be ignored for this particular comparison.

Table A-5(a). Roadside Safety Phenomena Importance Ranking Table (Structural Adequacy).

Evaluation Criteria				Known Result	Analysis Result	Difference Relative/ Absolute	Agree?
Structural Adequacy	A	A1	Test article should contain and redirect the vehicle; the vehicle should not penetrate, under-ride, or override the installation although controlled lateral deflection of the test article is acceptable. (Answer Yes or No)	Y	Y		Y
		A2	Maximum dynamic deflection: - Relative difference is less than 20 percent or - Absolute difference is less than 6 inches	27.2 in	27.2 in	0 % 0 in	Y
		A3	Length of vehicle-barrier contact: - Relative difference is less than 20 percent or - Absolute difference is less than 6.6 ft	22.7 ft	25.1ft	10.6 % 2.4 ft	Y
		A4	Number of broken or significantly bent posts is less than 20 percent.	0	0		Y
		A5	Did the rail element rupture or tear (Answer Yes or No)	No	No		Y
		A6	Number of detached post-rail connections.	2	2		Y
		A7	Was there significant snagging between the vehicle wheels and barrier elements (Answer Yes or No).	Y	Y		Y
		A8	Was there significant snagging between vehicle body components and barrier elements (Answer Yes or No).	N	N		Y

Table A-5(b). Roadside Safety Phenomena Importance Ranking Table (Occupant Risk).

Evaluation Criteria				Known Result	Analysis Result	Difference Relative/ Absolute	Agree?
Occupant Risk	D		Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians or personnel in a work zone. (Answer Yes or No)	N	N		Y
	F	F1	The vehicle should remain upright during and after the collision although moderate roll, pitching and yawing are acceptable. (Answer Yes or No)	Y	Y		Y
		F2	Maximum roll of the vehicle at 0.6 seconds: - Relative difference is less than 20 percent or - Absolute difference is less than 5 degrees.	25 deg	30 deg	20% 5 deg	Y
		F3	Maximum pitch of the vehicle at 0.6 seconds: - Relative difference is less than 20 percent or - Absolute difference is less than 5 degrees.	10.7 deg	9.1 deg	15% 1.6 deg	Y
		F4	Maximum yaw of the vehicle at 0.6 seconds: - Relative difference is less than 20 percent or - Absolute difference is less than 5 degrees.	41.2 deg	50.4 deg	22% 9.2 deg	N
	L	L1	Occupant impact velocities: - Relative difference is less than 20 percent or - Absolute difference is less than 2 m/s.				
			• Longitudinal OIV (m/s)	4.6	5.3	15 0.7 m/s	Y
			• Lateral OIV (m/s)	5.8	5.8	0% 0 m/s	Y
			• THIV (m/s)	6.9	7.4	7.2% 0.5 m/s	Y
		L2	Occupant accelerations: - Relative difference is less than 20 percent or - Absolute difference is less than 4 g's.				
			• Longitudinal ORA	11.5	10.2	11.3 % 1.3 g	Y
			• Lateral ORA	11.2	11.1	0.9 % 0.1 g	Y
			• PHD	11.7	13.6	16.2 % 1.9 g	Y
			• ASI	1.01	0.99	2% 0.02 g	Y

Table A-5(c). Roadside Safety Phenomena Importance Ranking Table (Vehicle Trajectory).

Evaluation Criteria				Known Result	Analysis Result	Difference Relative/ Absolute	Agree?
Vehicle Trajectory	M	M1	The exit angle from the test article preferable should be less than 60 percent of test impact angle, measured at the time of vehicle loss of contact with test device.	55%	106%		N
		M2	Exit angle at loss of contact: - Relative difference is less than 20 percent or - Absolute difference is less than 5 degrees.	13.5 deg	25.7 deg	90% 12.2 deg	N
		M3	Exit velocity at loss of contact: - Relative difference is less than 20 percent or - Absolute difference is less than 6.2 mph.	44 mph	37.3 mph	15% 6.7 mph	Y
		M4	One or more vehicle tires failed or de-beaded during the collision event (Answer Yes or No).	Y	Y		Y

The Analysis Solution (check one) ☒ passes ☐ does NOT pass all the criteria in Tables E-5a through E-5c ☒with exceptions as noted ☐ without exceptions .

The error in yaw angle is thought to be due to the slight increase in pitch angle, which allowed the rear bumper of the pickup model to pass over the top of the rail, resulting in higher yaw angle as the vehicle was exiting the system. This had a minor effect on the overall performance of the system and kinematics of the vehicle.

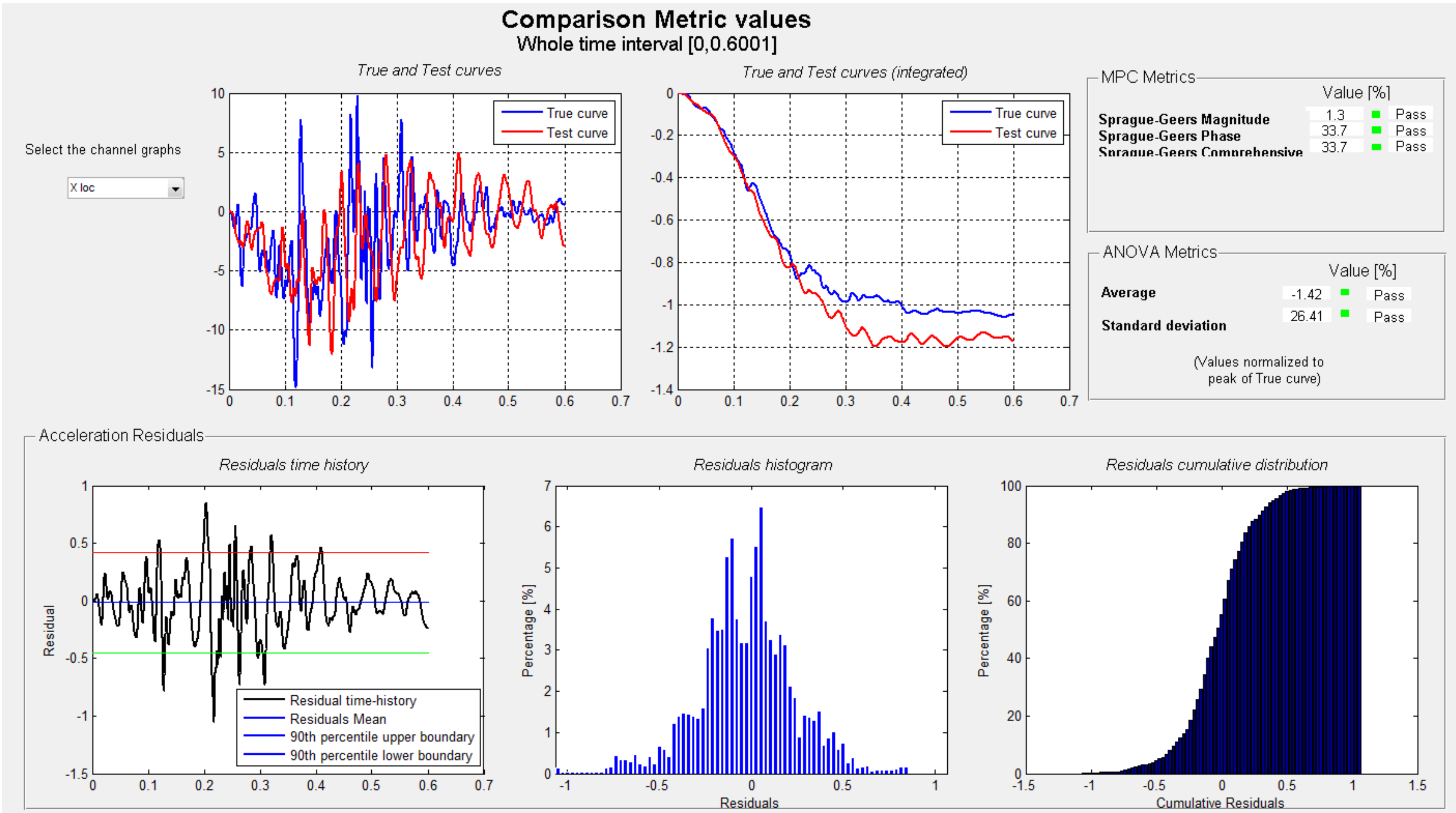


Figure A-1. Comparison metrics for the x-acceleration channel.

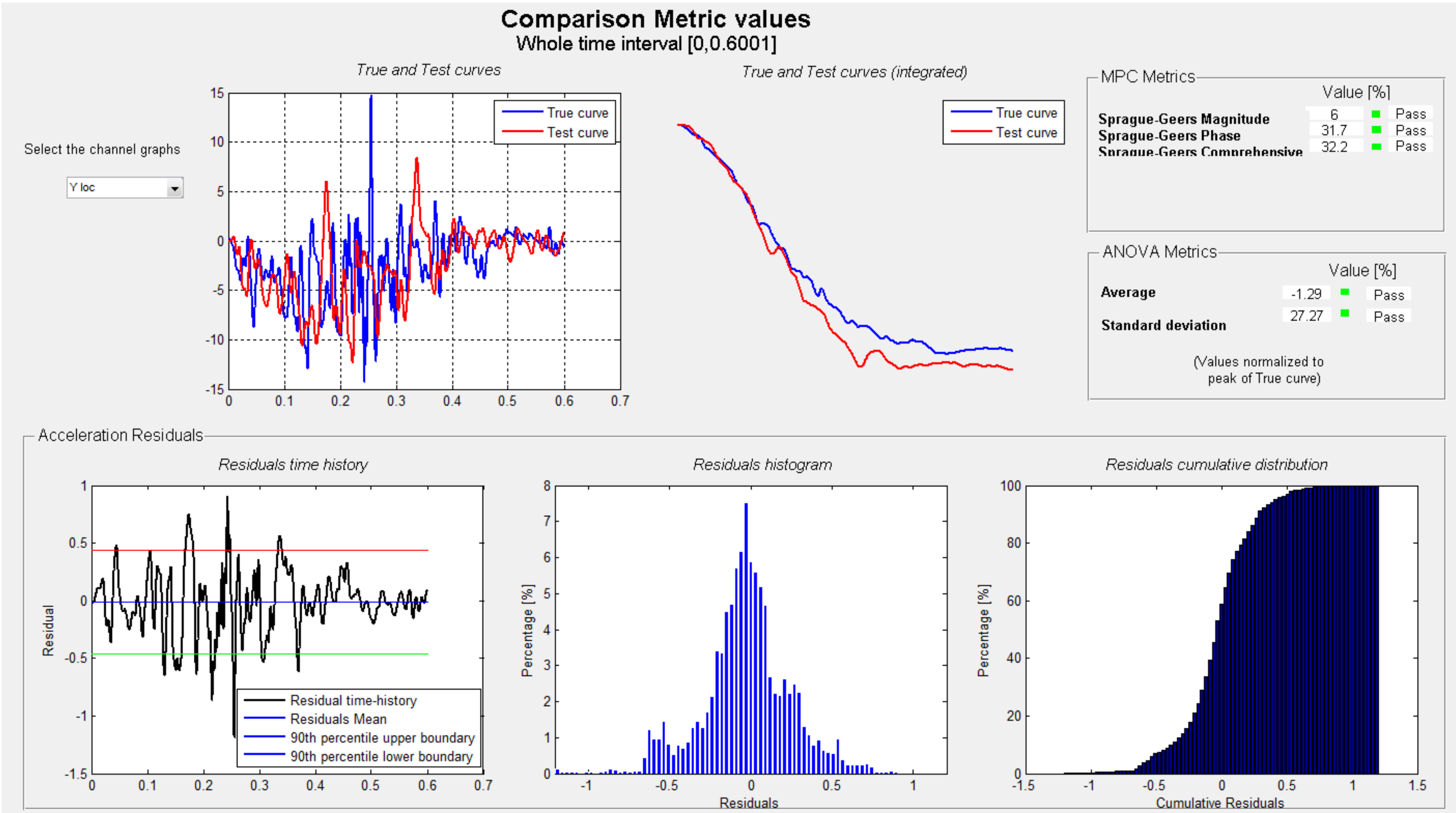


Figure A-2. Comparison metrics for the y-acceleration channel.

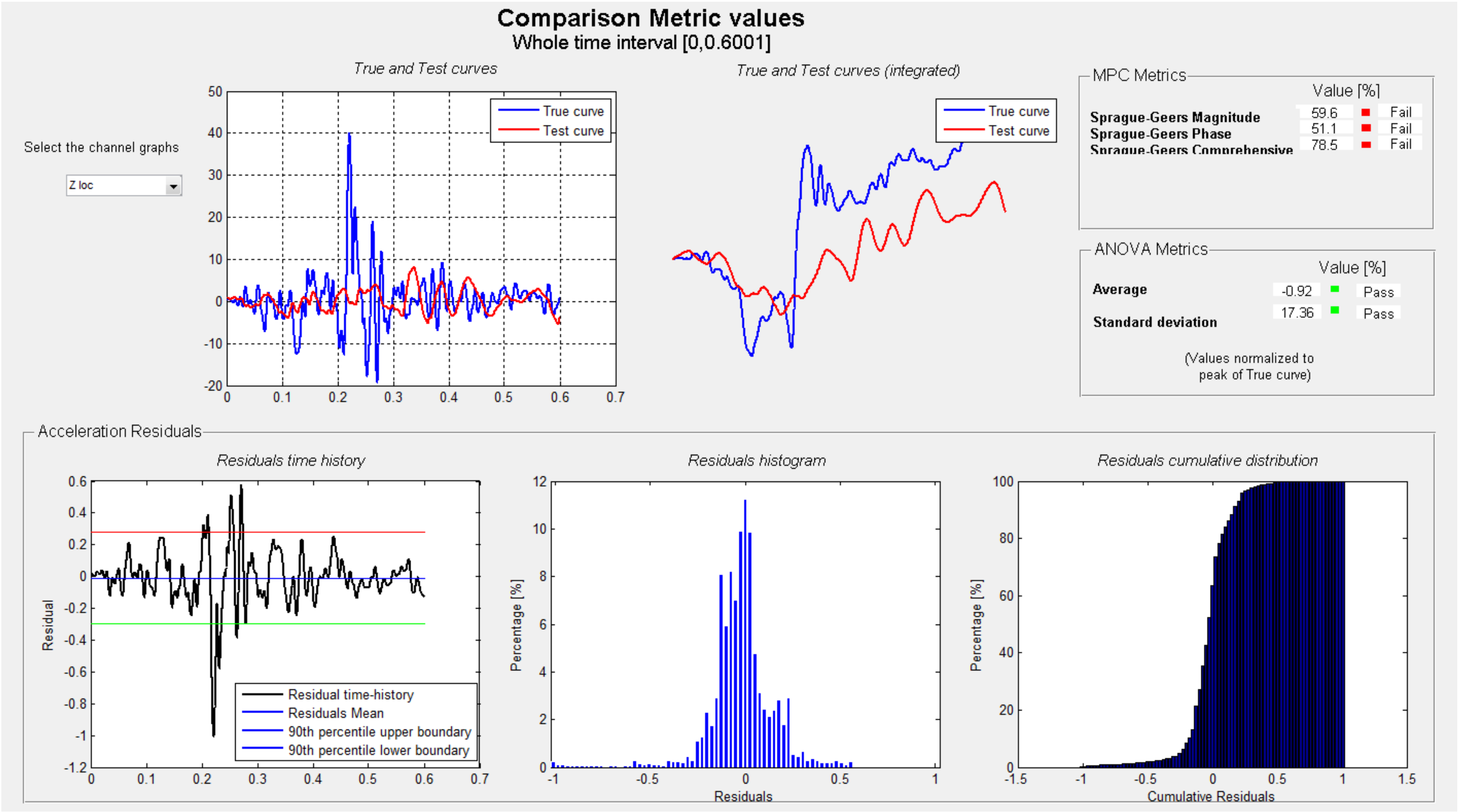


Figure A-3. Comparison metrics for the z-acceleration channel.

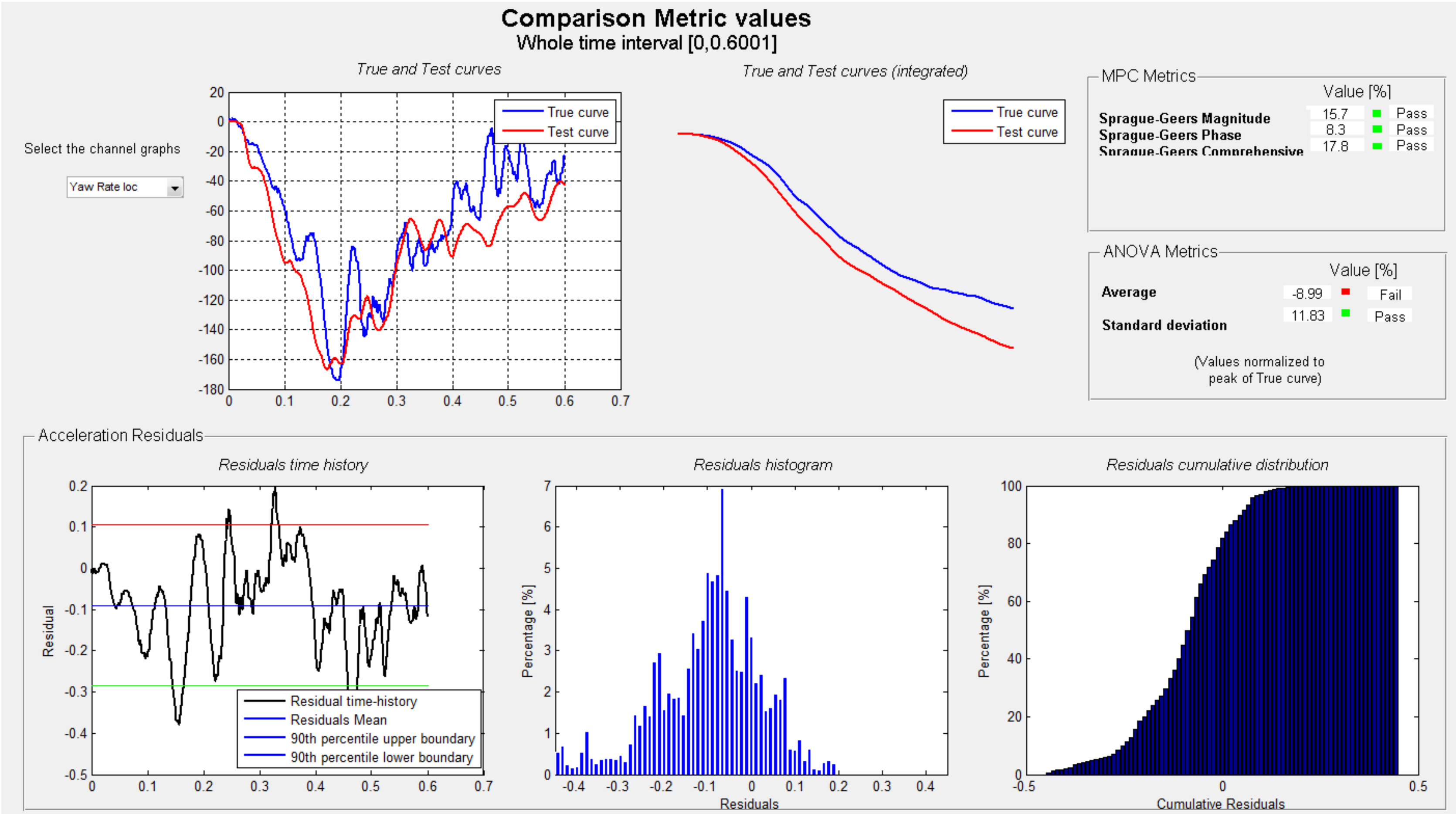


Figure A-4. Comparison metrics for the yaw-rate channel.

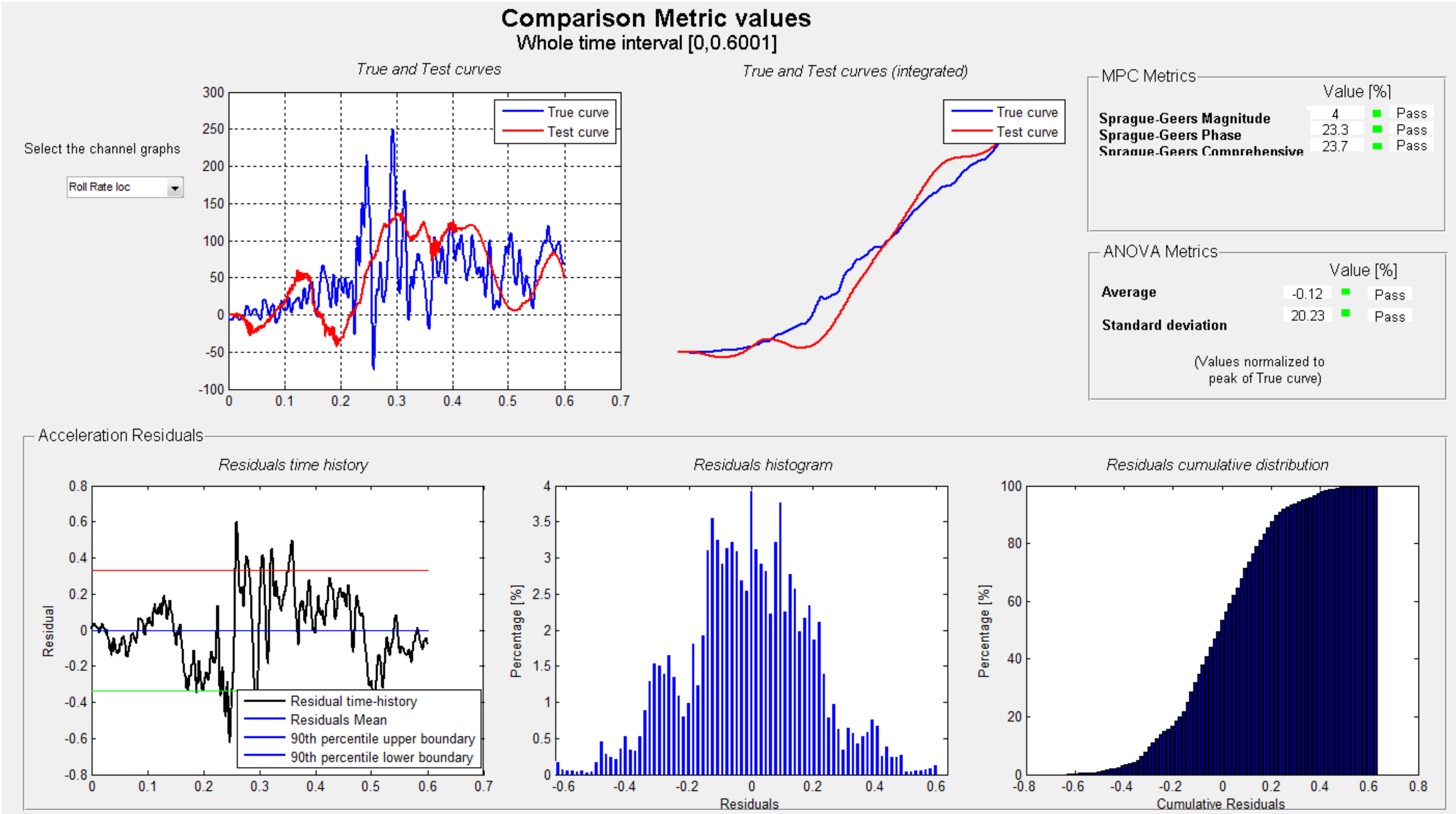


Figure A-5. Comparison metrics for the roll-rate channel.

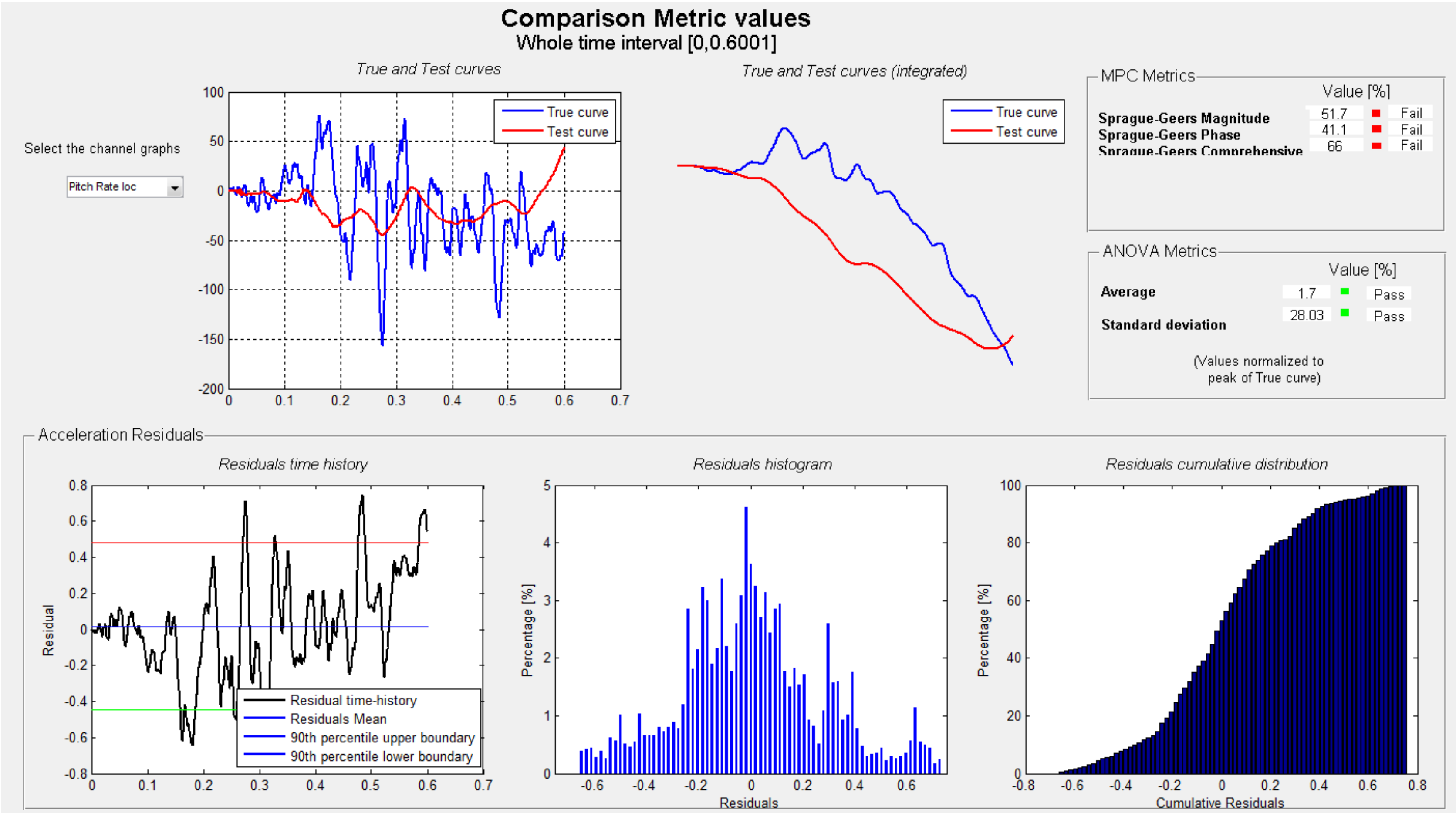


Figure A-6. Comparison metrics for the pitch-rate channel.

APPENDIX D

Task 4A-3
Assess Effects of Guardrail Post Deterioration on Performance of G4(2W)

FOIL Tests 13009 B – W Summary Sheets
Posts in Rigid Foundation

Chuck A. Plaxico, Ph.D.
Archie Ray
Roadsafe LLC

December 2013

Test Information

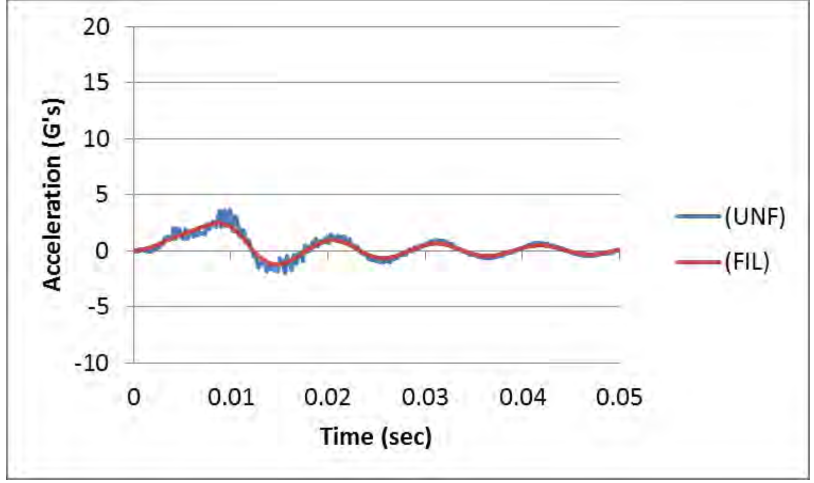
Test Number:	13009B
Test Date:	24-Sept-2013

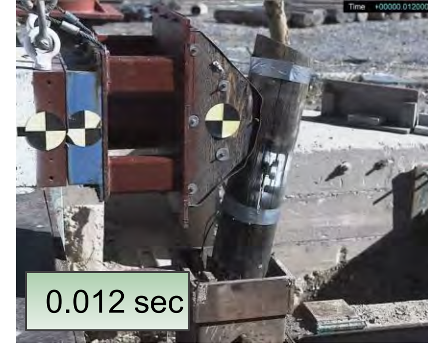
Post Properties

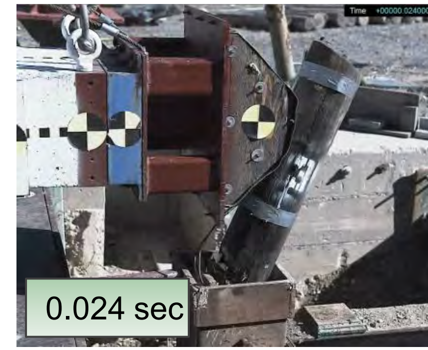
Post Number:	3
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	7.56 inches
Moisture Content:	42.98%
Ring Density (avg.):	5 per inch
Resi Score S_{MOR}:	0.22
Resi Score S_{U}:	0.22

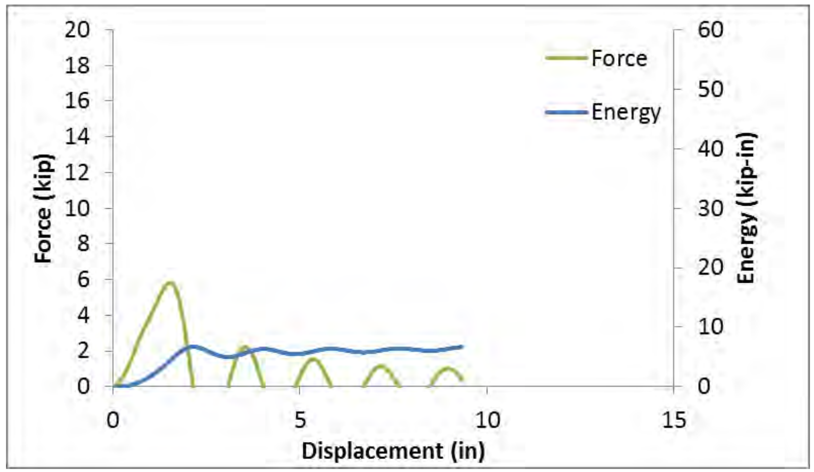
Pendulum Properties

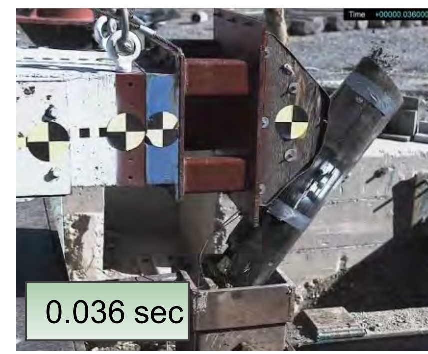
Weight:	2,372 lb
Impact Speed:	20 mph
Impact Height:	21.5 inches

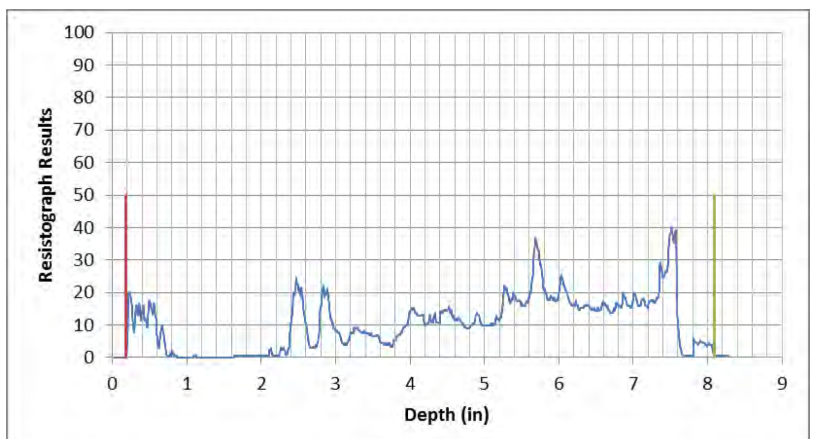












Fractured Post

Test Information

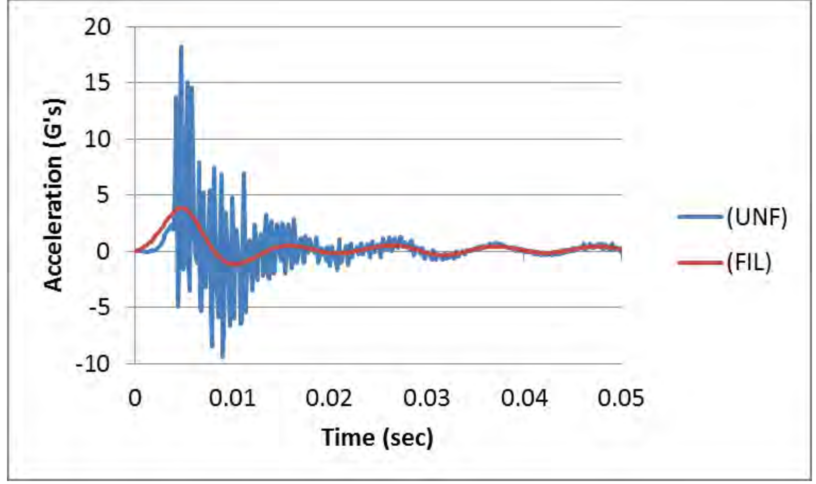
Test Number:	13009C
Test Date:	24-Sept-2013

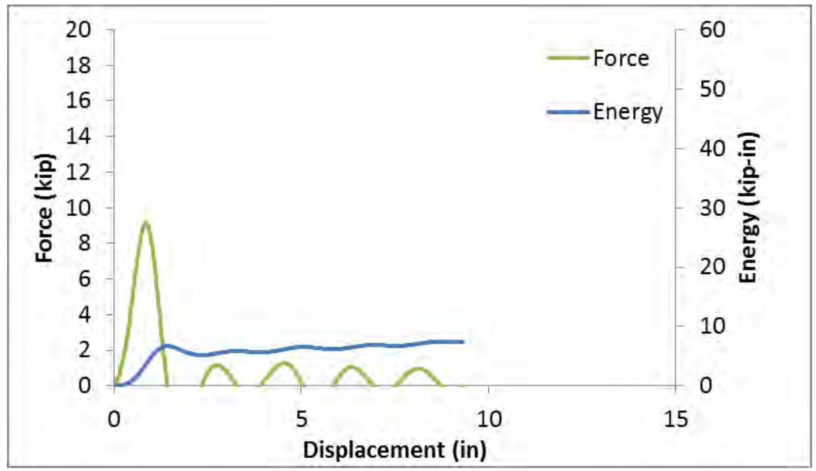
Post Properties

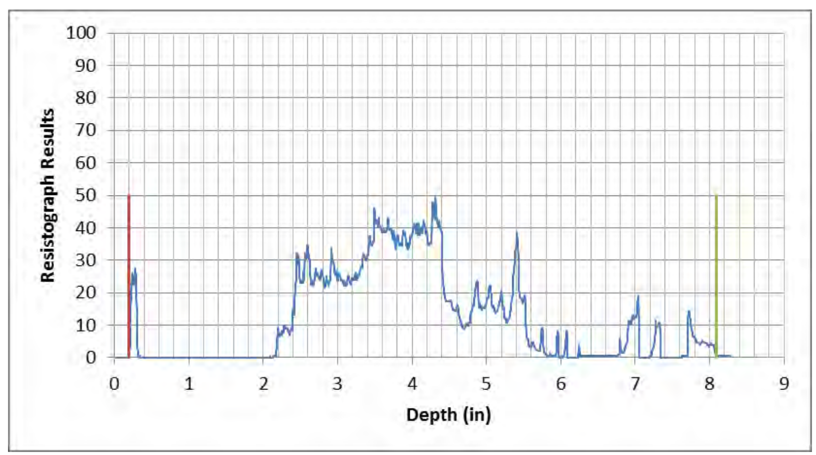
Post Number:	1
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	7.32 inches
Moisture Content:	>50%
Ring Density (avg.):	8.9 per inch
Resi Score S_{MOR}:	0.08
Resi Score S_U:	0.07

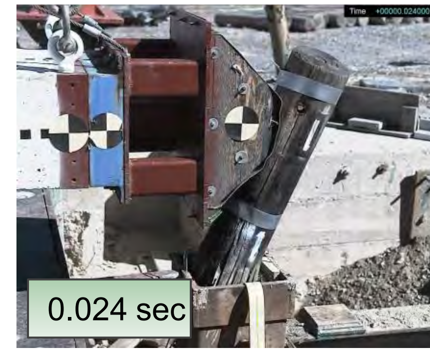
Pendulum Properties

Weight:	2,372 lb
Impact Speed:	20 mph
Impact Height:	21.5 inches









Fractured Post

Test Information

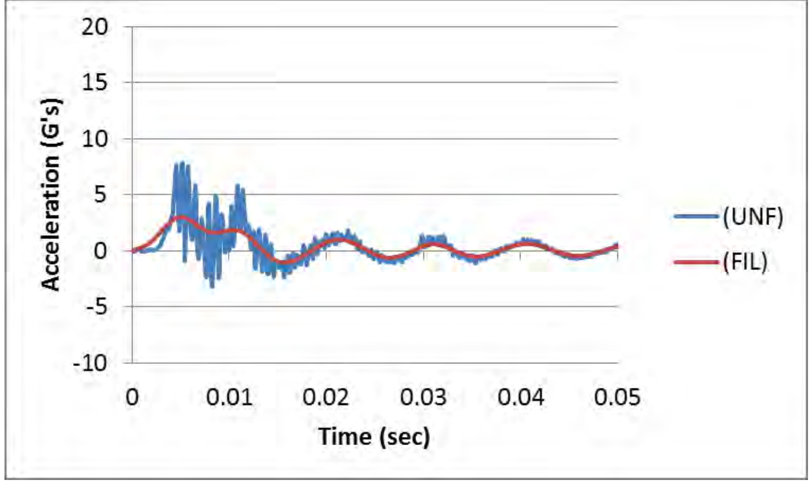
Test Number:	13009D
Test Date:	24-Sept-2013

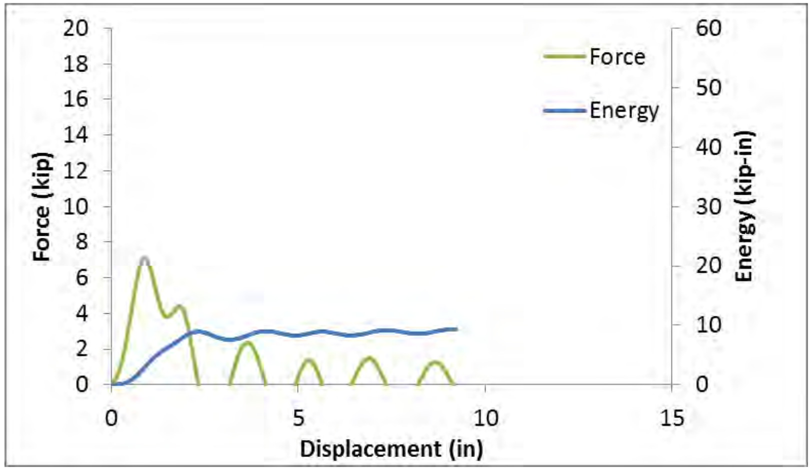
Post Properties

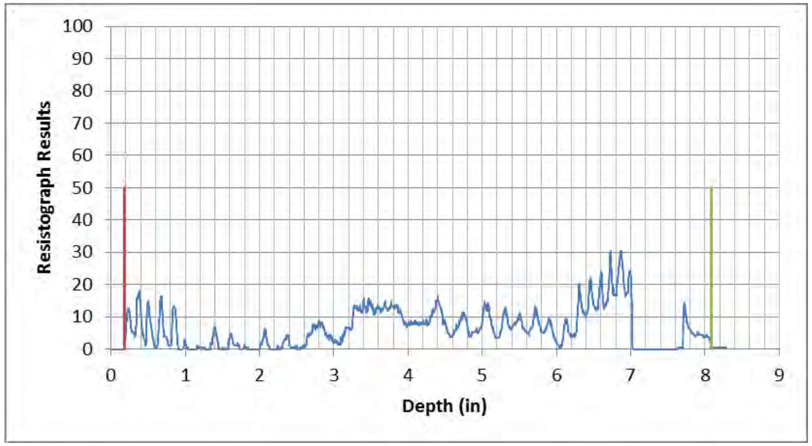
Post Number:	2
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	7.01 inches
Moisture Content:	39.82%
Ring Density (avg.):	3.9 per inch
Resi Score S_{MOR}:	0.12
Resi Score S_U:	0.12

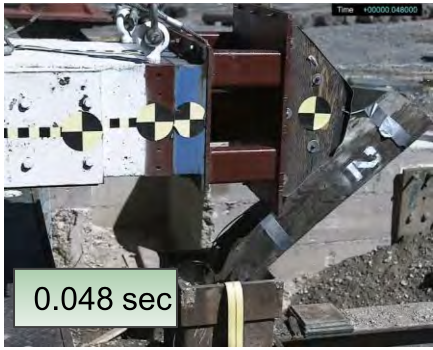
Pendulum Properties

Weight:	2,372 lb
Impact Speed:	20 mph
Impact Height:	21.5 inches









Fractured Post

Test Information

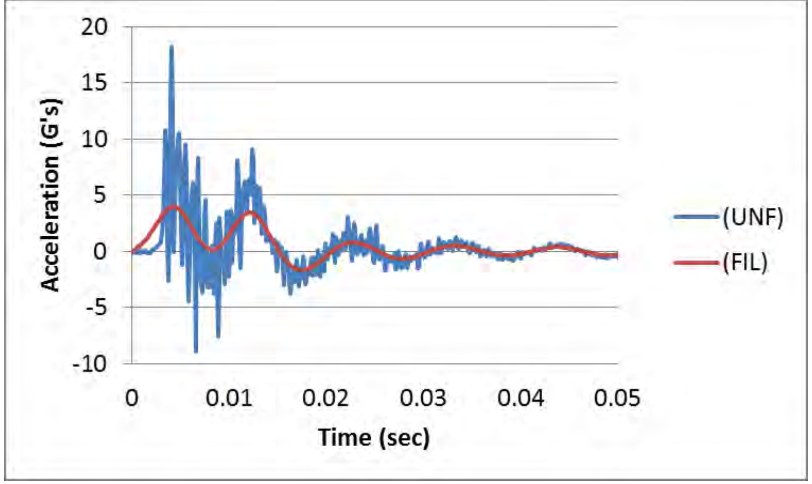
Test Number:	13009E
Test Date:	24-Sept-2013

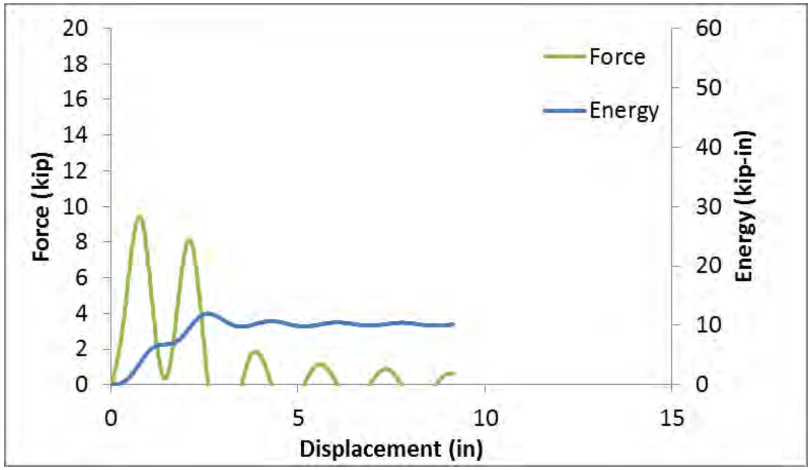
Post Properties

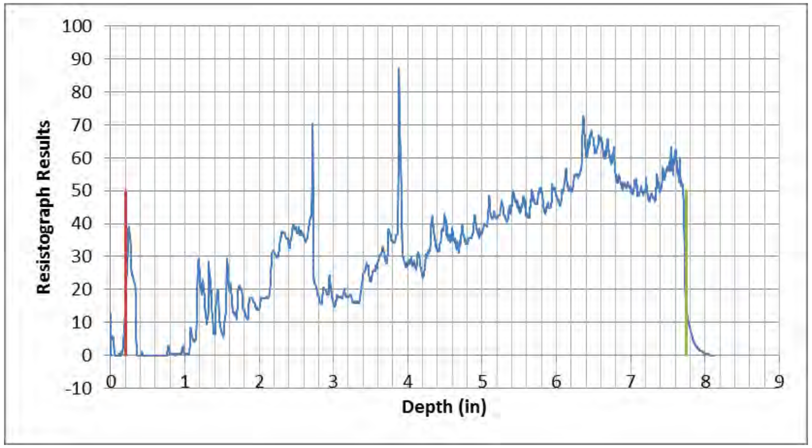
Post Number:	7
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	7.32 inches
Moisture Content:	N/A
Ring Density (avg.):	8 per inch
Resi Score S_{MOR}:	0.63
Resi Score S_U:	0.64

Pendulum Properties

Weight:	2,372 lb
Impact Speed:	20 mph
Impact Height:	21.5 inches

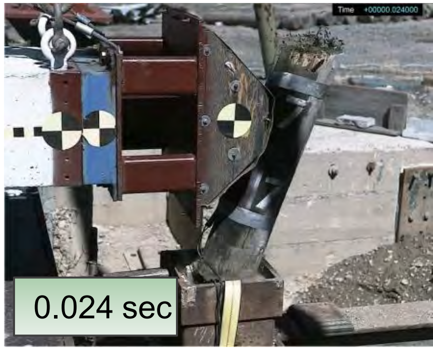


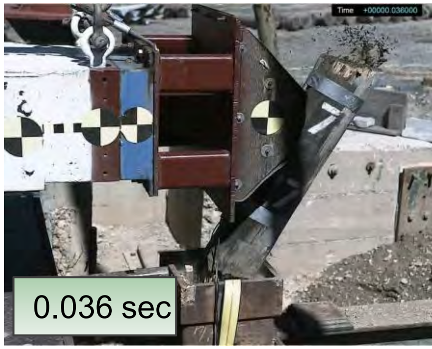


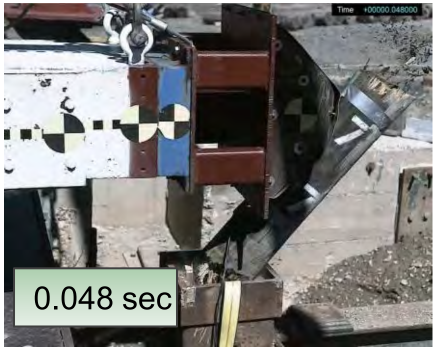


Ring density at bottom of post

Fractured Post







Test Information

Test Number:	13009F
Test Date:	24-Sept-2013

Post Properties

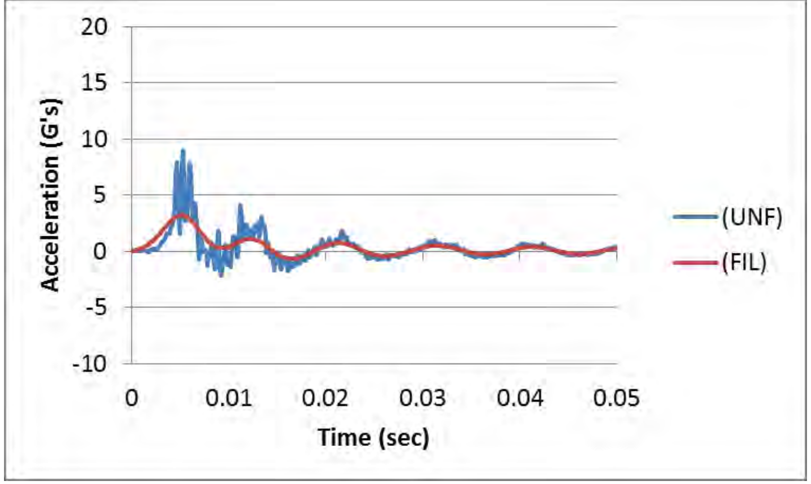
Post Number:	12
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	6.61 inches
Moisture Content:	46.8%
Ring Density (avg.):	7 per inch
Resi Score S_{MOR}:	0.29
Resi Score S_U:	0.33

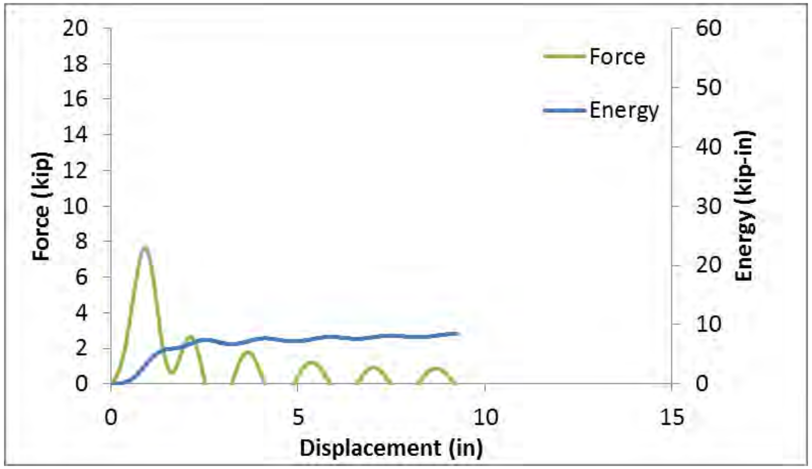
Pendulum Properties

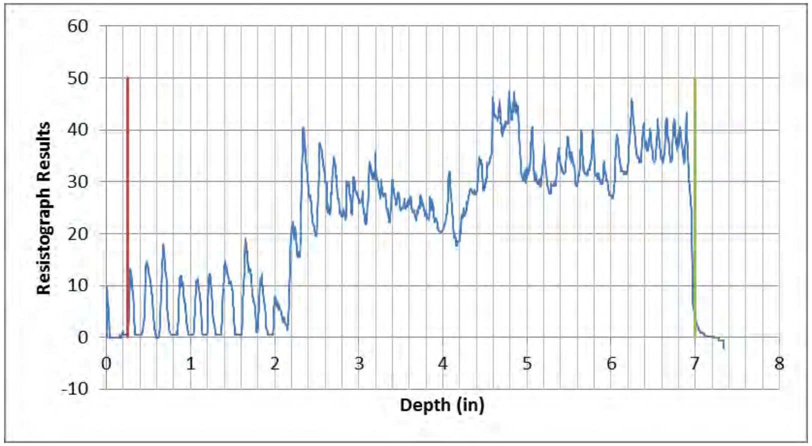
Weight:	2,372 lb
Impact Speed:	20 mph
Impact Height:	21.5 inches

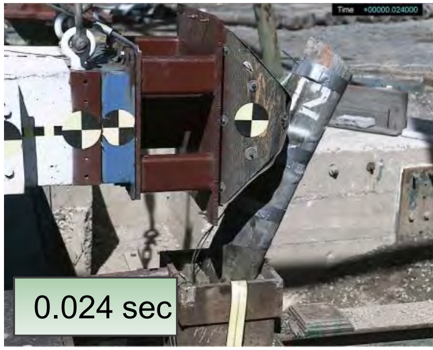
Ring density at bottom of post

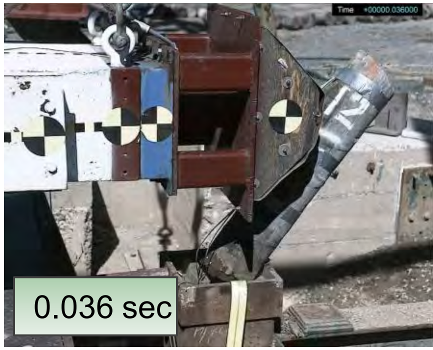
Fractured Post

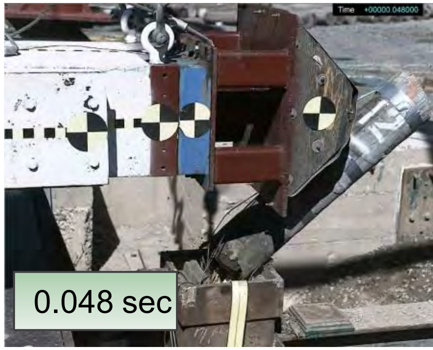












Test Information

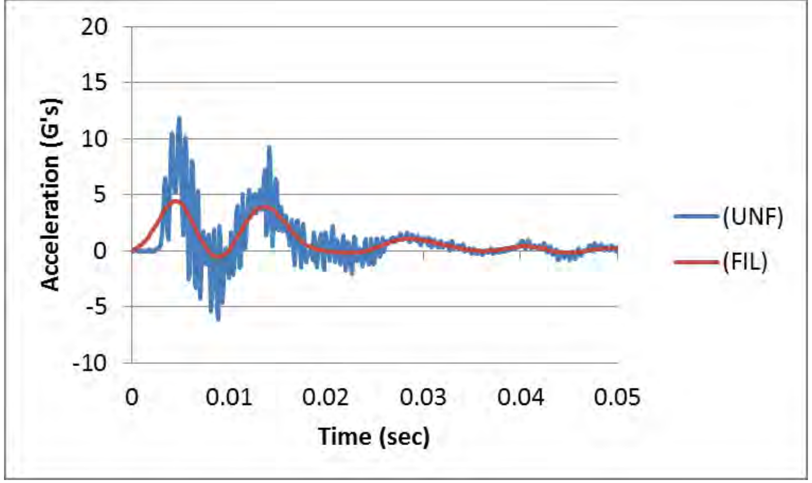
Test Number:	13009G
Test Date:	24-Sept-2013

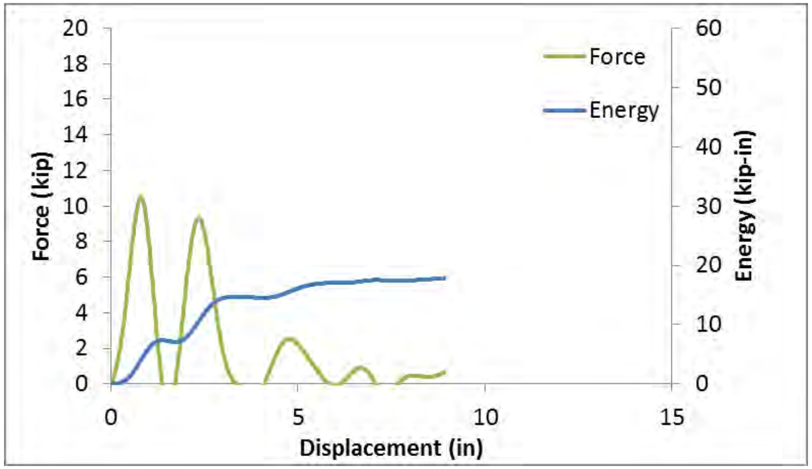
Post Properties

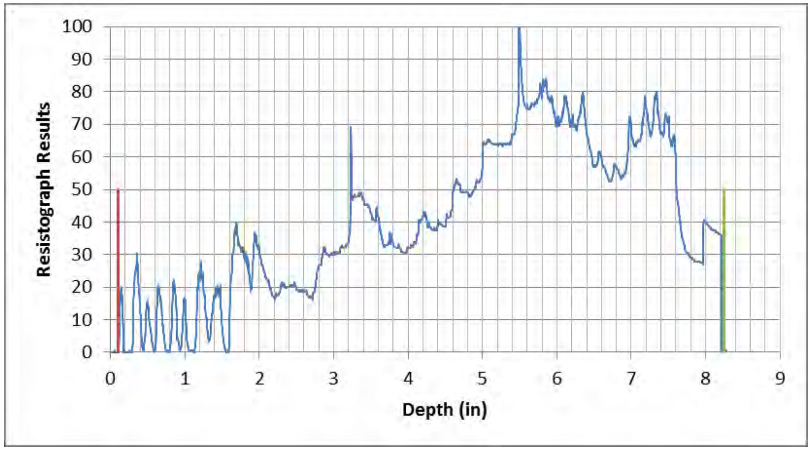
Post Number:	4
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	7.64 inches
Moisture Content:	N/A
Ring Density (avg.):	4.7 per inch
Resi Score S_{MOR}:	0.77
Resi Score S_U:	0.73

Pendulum Properties

Weight:	2,372 lb
Impact Speed:	20 mph
Impact Height:	21.5 inches

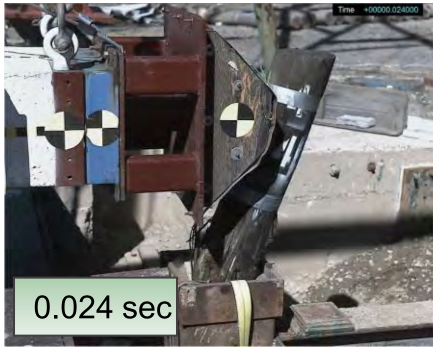


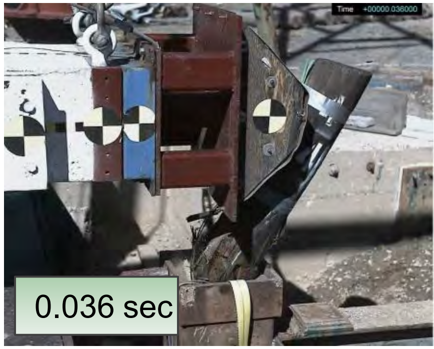


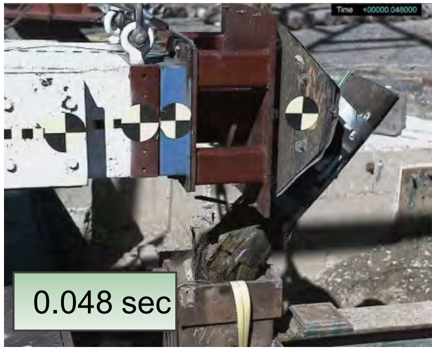


Ring density at bottom of post

Fractured Post







Test Information

Test Number:	13009H
Test Date:	25-Sept-2013

Post Properties

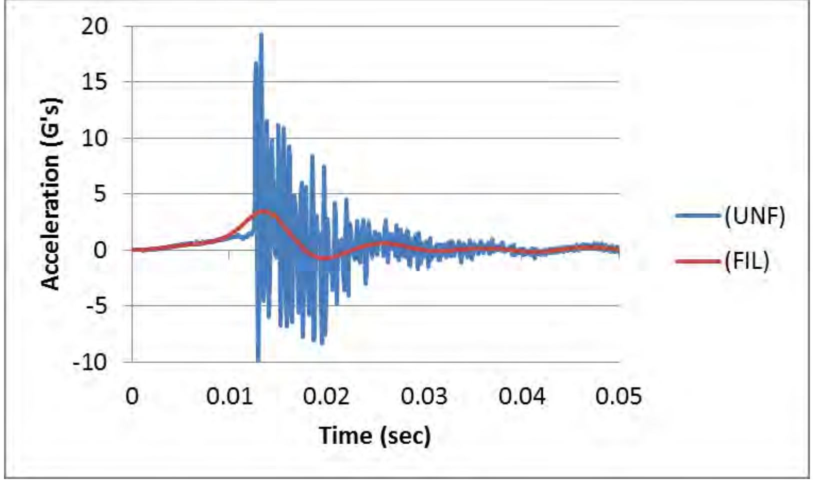
Post Number:	36
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	7.17 inches
Moisture Content:	>50%
Ring Density (avg.):	7.7 per inch
Resi Score S_{MOR}:	0.27
Resi Score S_U:	0.30

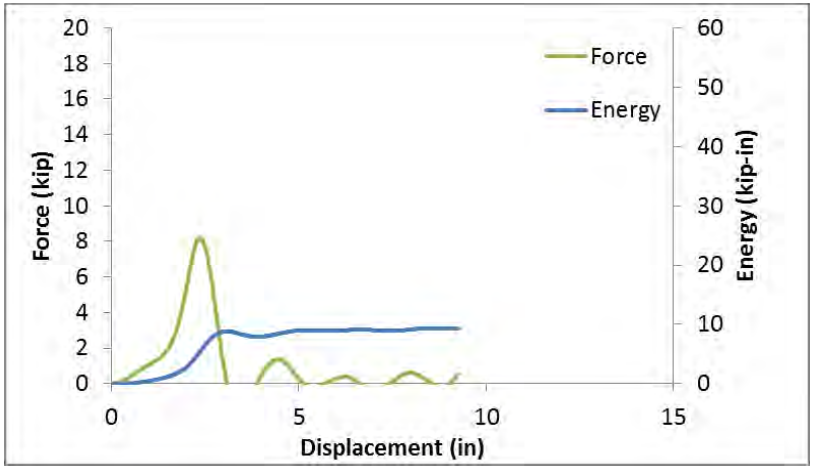
Pendulum Properties

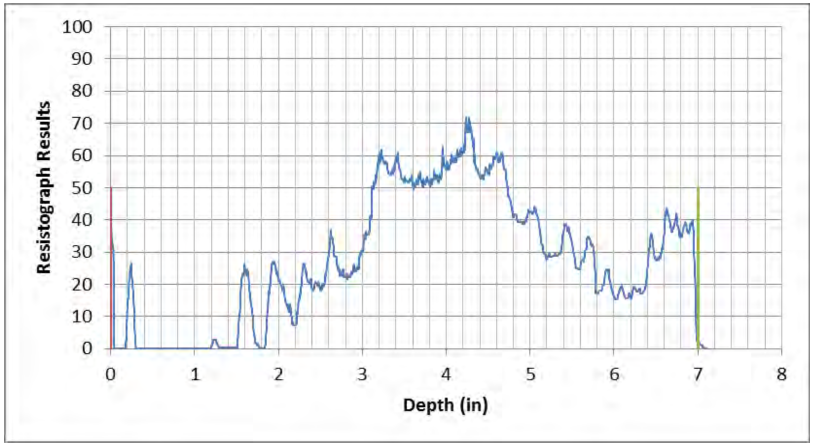
Weight:	2,372 lb
Impact Speed:	20 mph
Impact Height:	21.5 inches

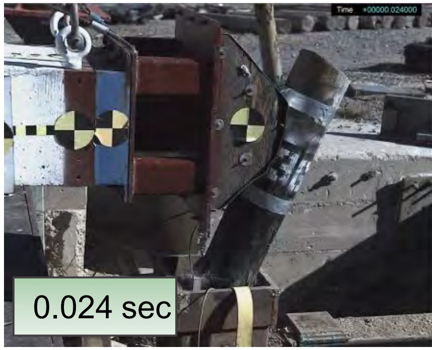
Ring density at bottom of post

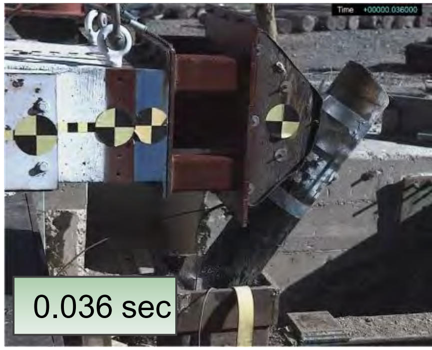
Fractured Post

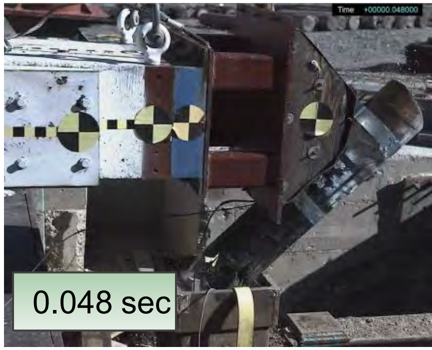












Test Information

Test Number:	13009I
Test Date:	25-Sept-2013

Post Properties

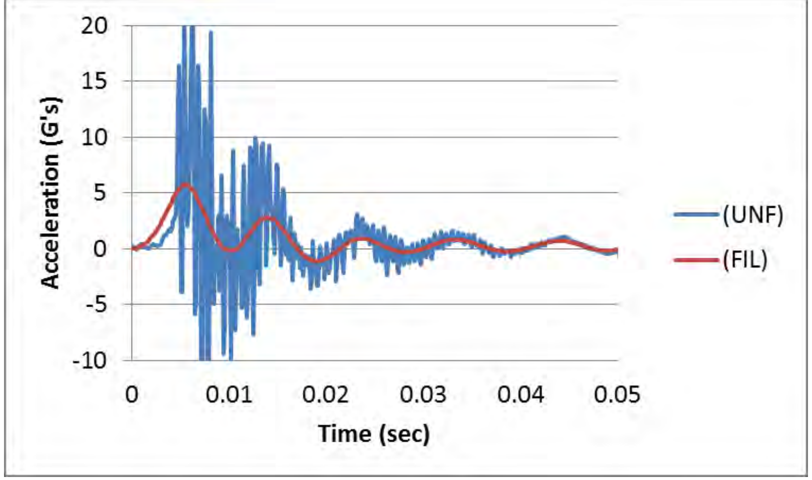
Post Number:	14
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	8.04 inches
Moisture Content:	>50%
Ring Density (avg.):	7.4 per inch
Resi Score S_{MOR}:	0.29
Resi Score S_U:	0.28

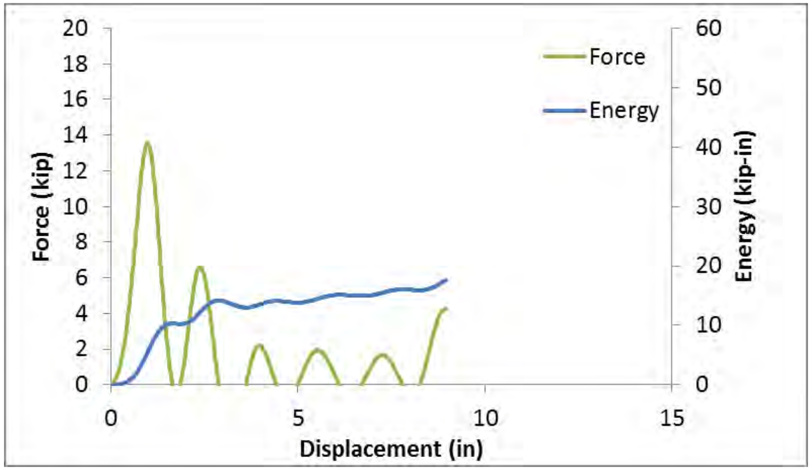
Pendulum Properties

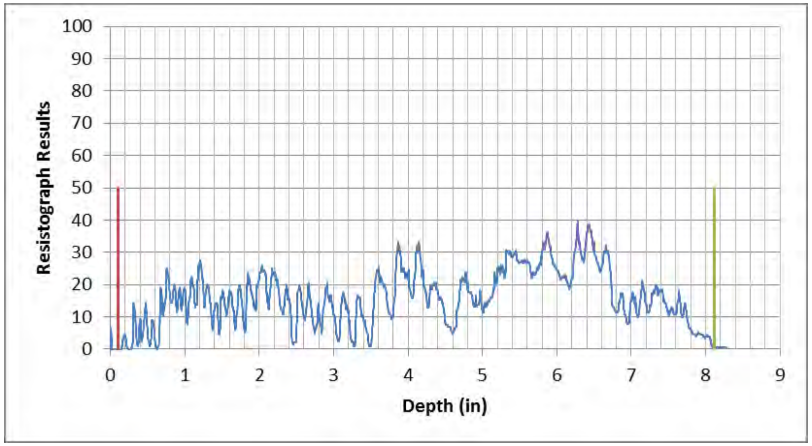
Weight:	2,372 lb
Impact Speed:	20 mph
Impact Height:	21.5 inches

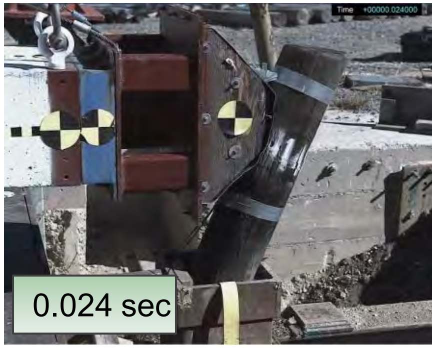
Ring density at bottom of post

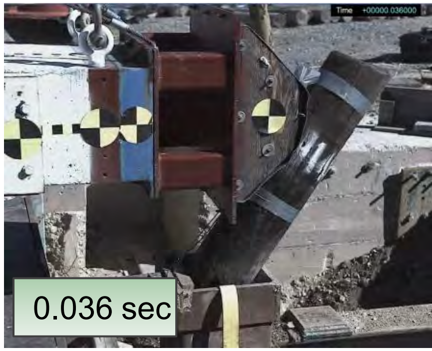
Fractured Post

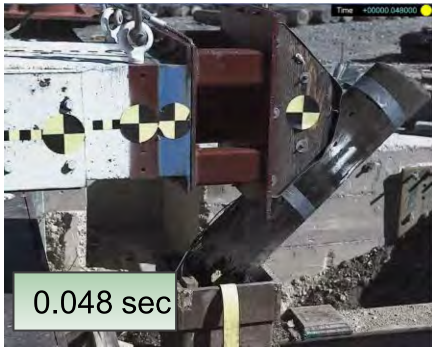












Test Information

Test Number:	13009J
Test Date:	25-Sept-2013

Post Properties

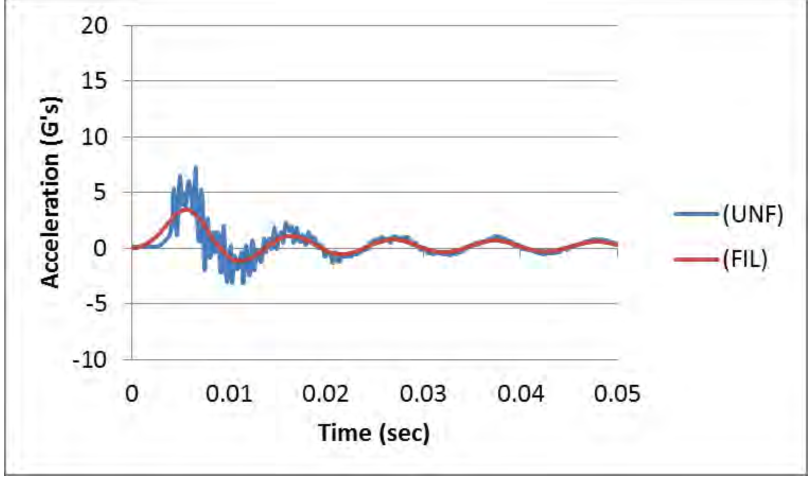
Post Number:	15
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	7.00 inches
Moisture Content:	>50%
Ring Density (avg.):	5.1 per inch
Resi Score S_{MOR}:	0.18
Resi Score S_{U}:	0.21

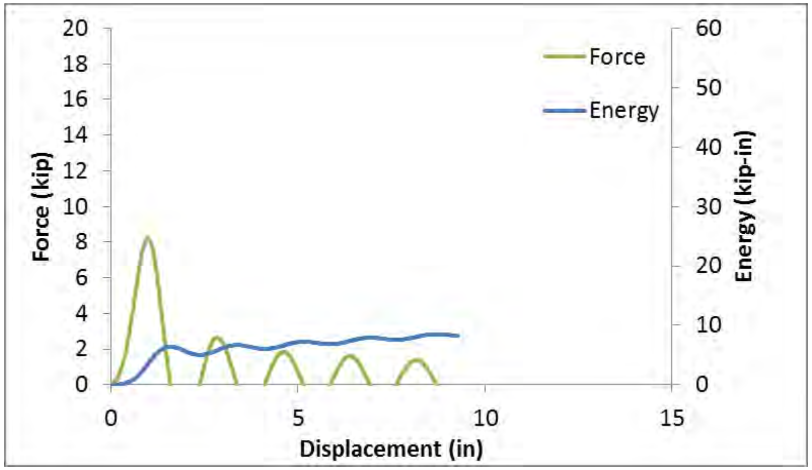
Pendulum Properties

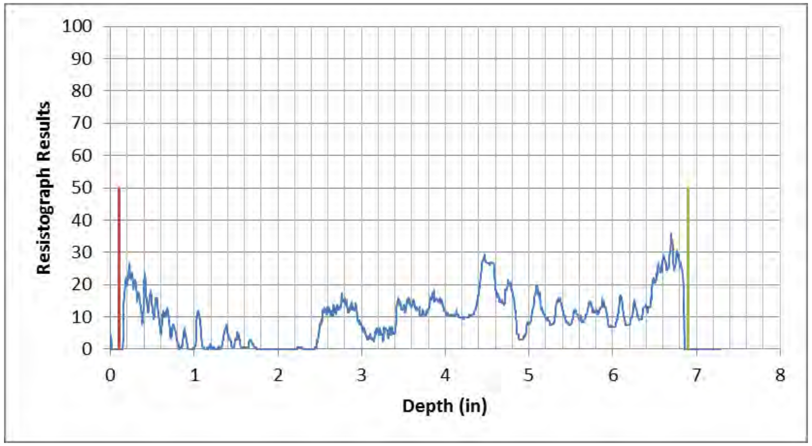
Weight:	2,372 lb
Impact Speed:	20 mph
Impact Height:	21.5 inches

Ring density at bottom of post

Fractured Post







Test Information

Test Number:	13009K
Test Date:	25-Sept-2013

Post Properties

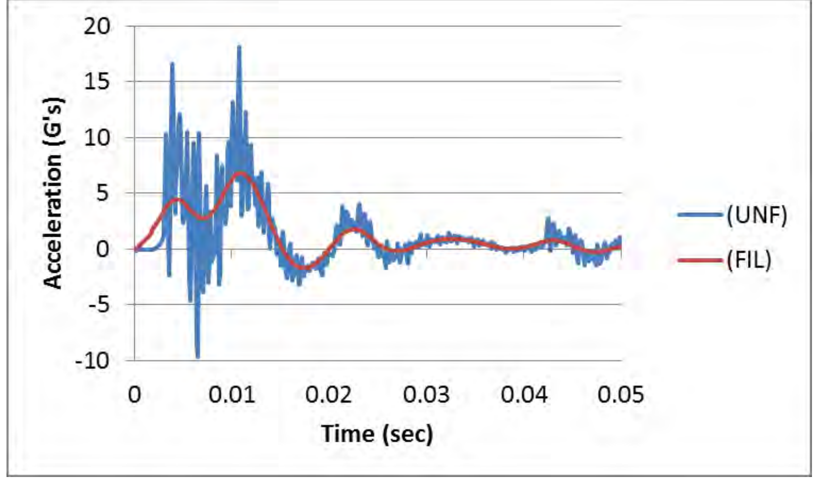
Post Number:	B
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	7.32 inches
Moisture Content:	N/A
Ring Density (avg.):	5.8 per inch
Resi Score S_{MOR}:	0.84
Resi Score S_U:	0.88

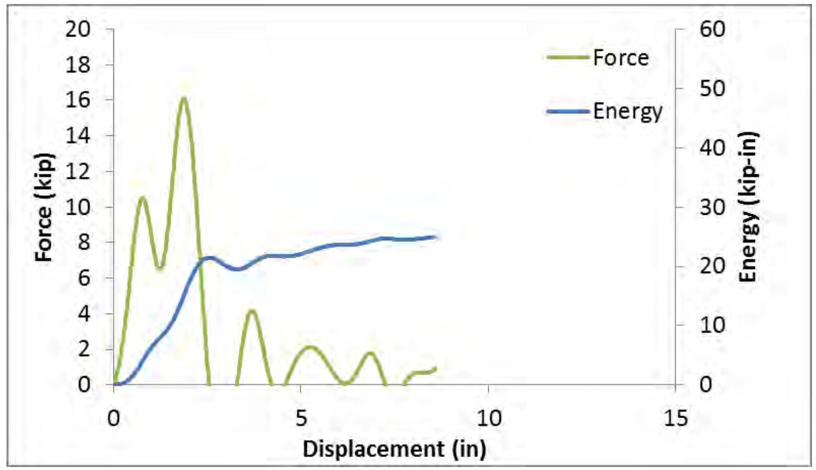
Pendulum Properties

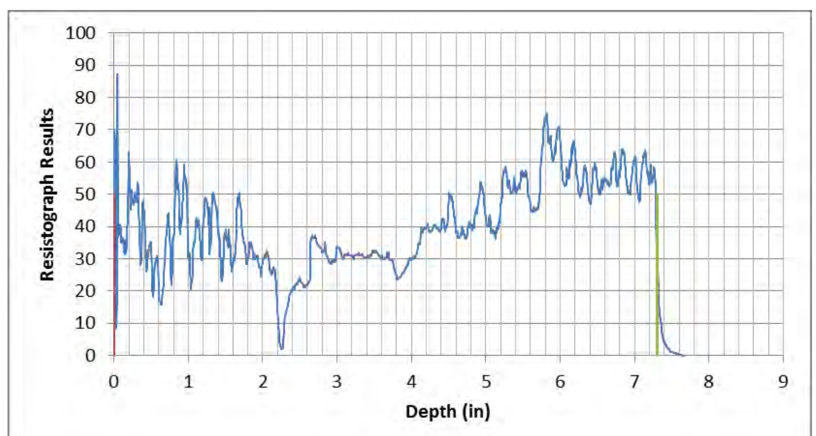
Weight:	2,372 lb
Impact Speed:	20 mph
Impact Height:	21.5 inches

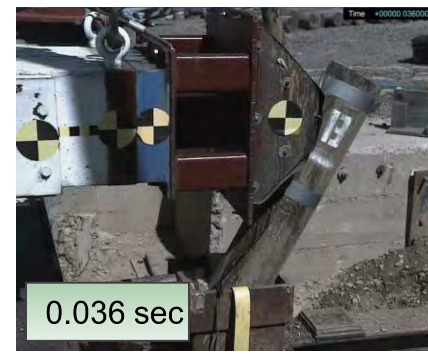
Ring density at bottom of post

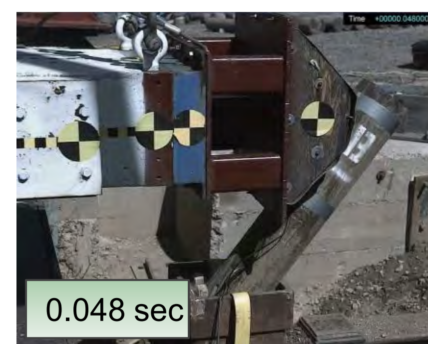
Fractured Post











Test Information

Test Number:	13009L
Test Date:	25-Sept-2013

Post Properties

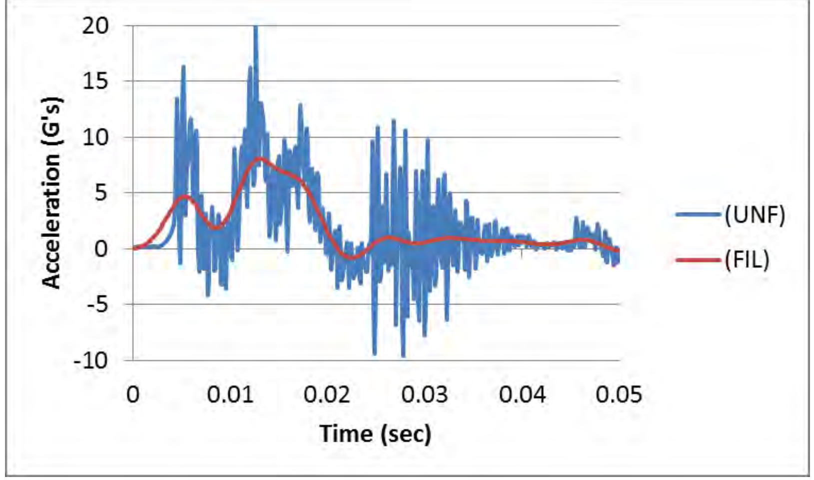
Post Number:	A
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	7.32 inches
Moisture Content:	N/A
Ring Density (avg.):	9.4 per inch
Resi Score S_{MOR}:	0.83
Resi Score S_U:	0.89

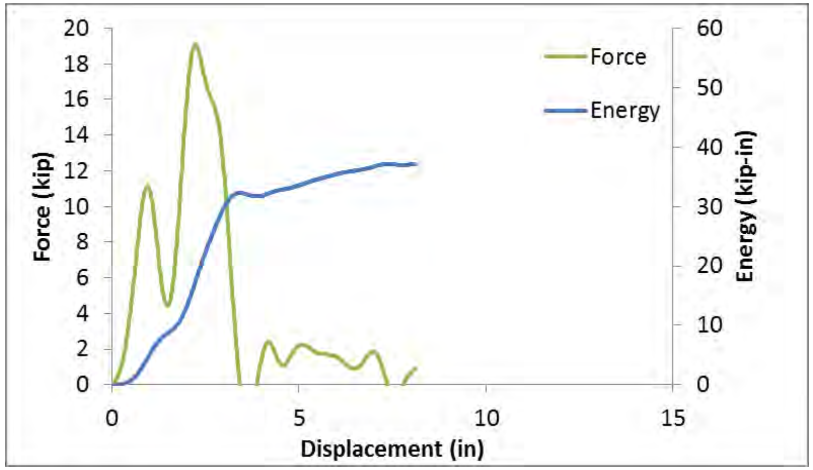
Pendulum Properties

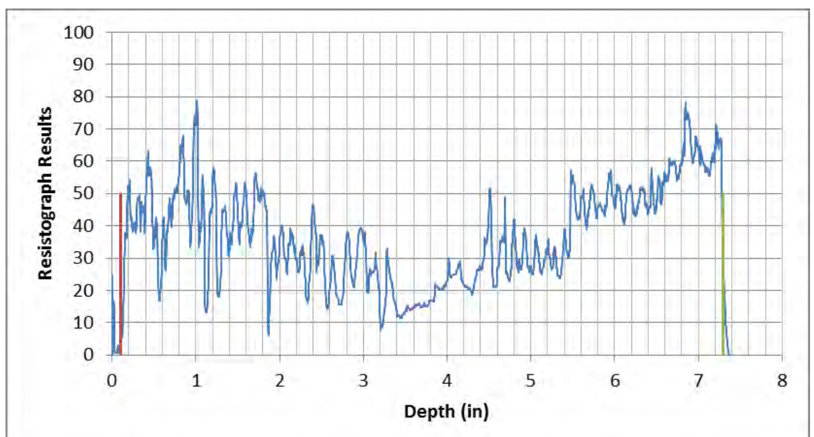
Weight:	2,372 lb
Impact Speed:	20 mph
Impact Height:	21.5 inches

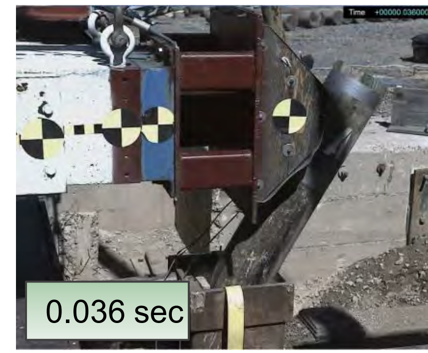
Ring density at bottom of post

Fractured Post









Test Information

Test Number:	13009M
Test Date:	25-Sept-2013

Post Properties

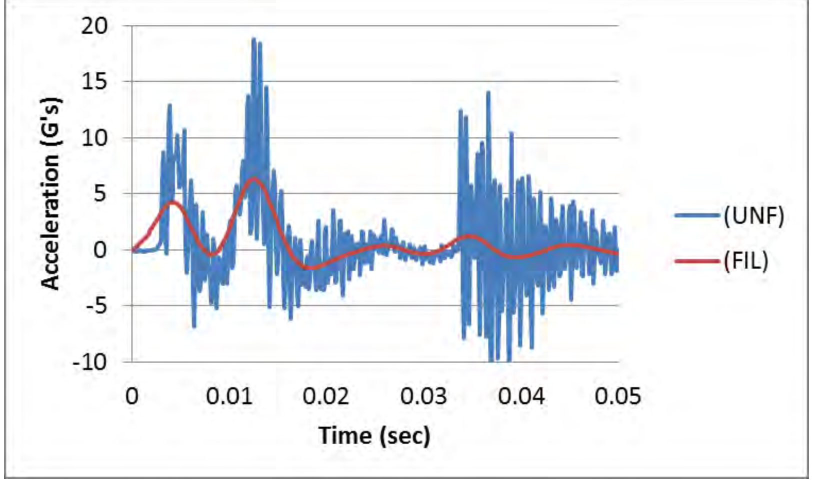
Post Number:	13
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	8.12 inches
Moisture Content:	>50%
Ring Density (avg.):	6.4 per inch
Resi Score S_{MOR}:	0.42
Resi Score S_U:	0.40

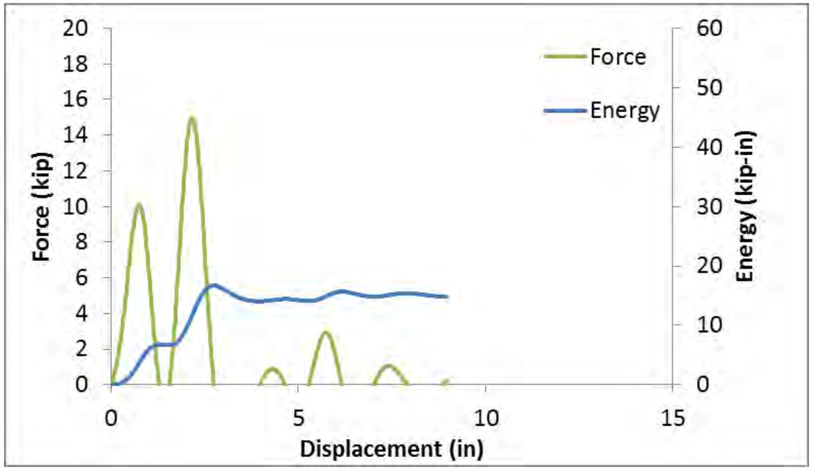
Pendulum Properties

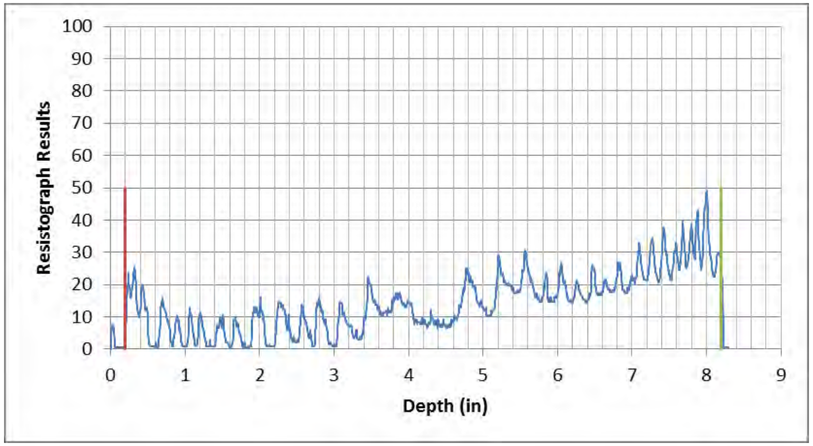
Weight:	2,372 lb
Impact Speed:	20 mph
Impact Height:	21.5 inches

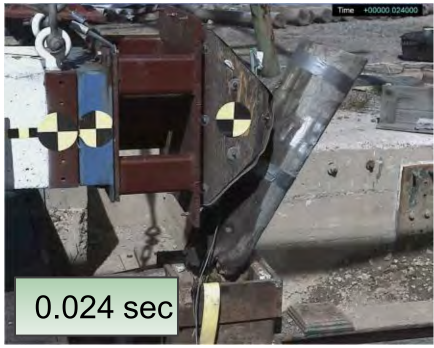
Ring density at bottom of post

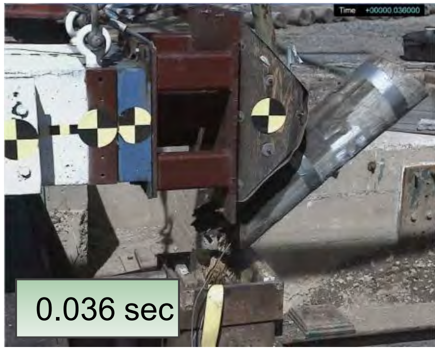
Fractured Post

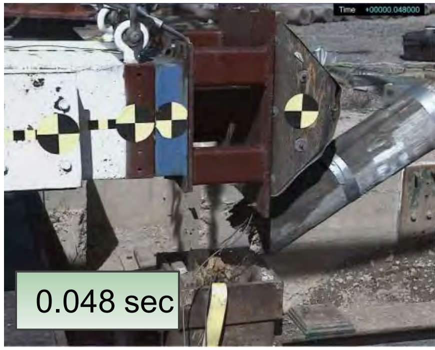












Test Information

Test Number:	13009O
Test Date:	26-Sept-2013

Post Properties

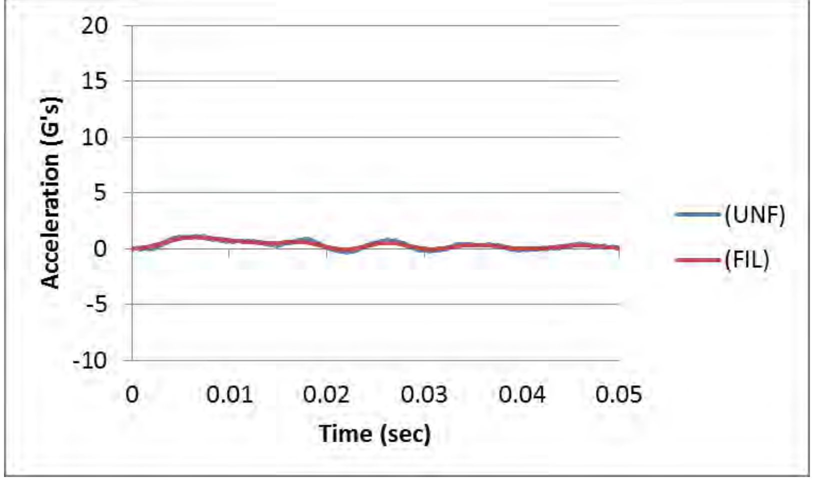
Post Number:	40
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	7.56 inches
Moisture Content:	>50%
Ring Density (avg.):	7.2 per inch
Resi Score S_{MOR}:	0.26
Resi Score S_U:	0.27

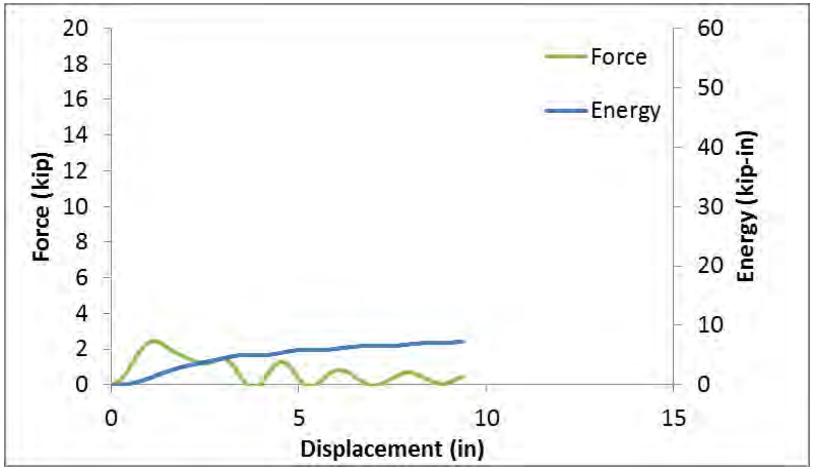
Pendulum Properties

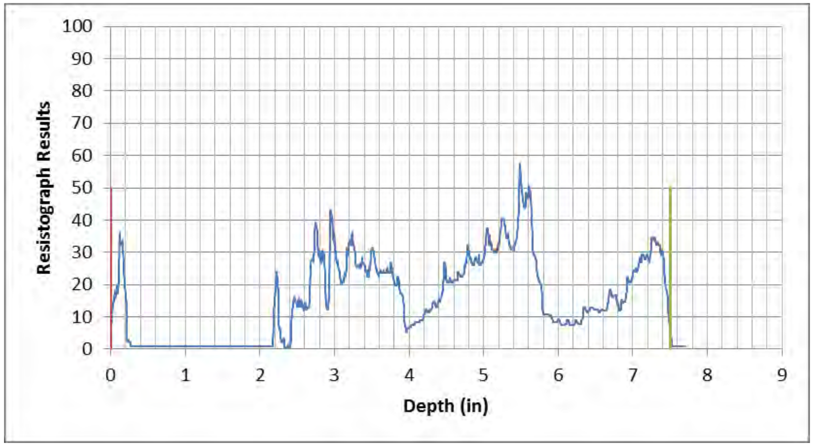
Weight:	2,372 lb
Impact Speed:	20 mph
Impact Height:	21.5 inches

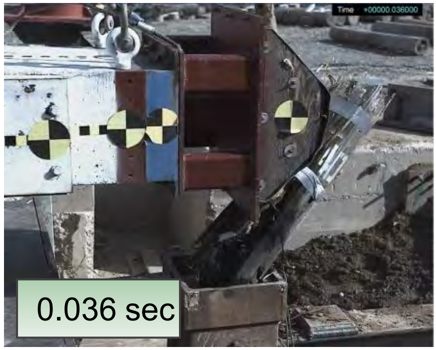
Ring density at bottom of post

Fractured Post









Test Information

Test Number:	13009P
Test Date:	26-Sept-2013

Post Properties

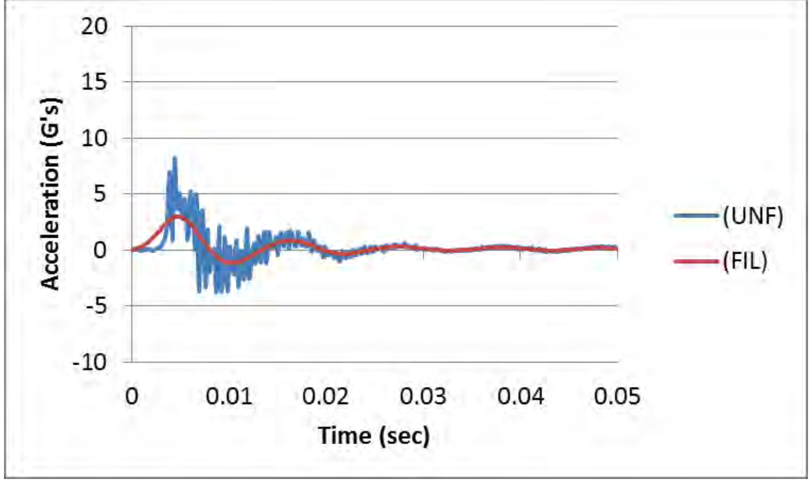
Post Number:	19
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	7.80 inches
Moisture Content:	>50%
Ring Density (avg.):	4.6 per inch
Resi Score S_{MOR}:	0.27
Resi Score S_U:	0.27

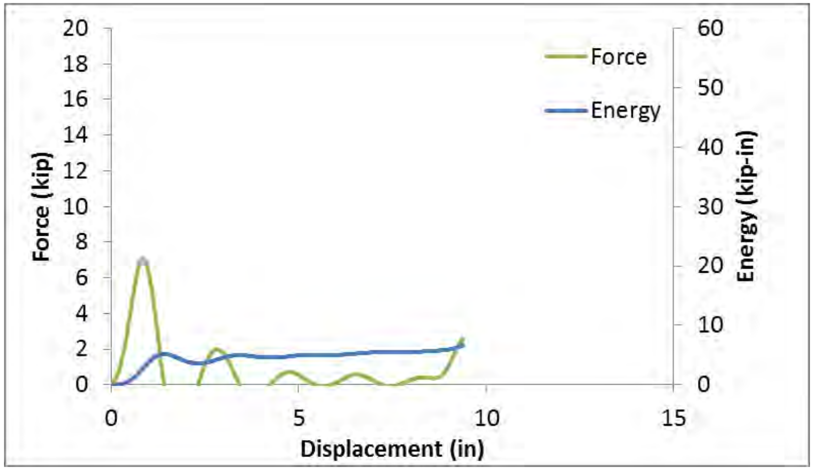
Pendulum Properties

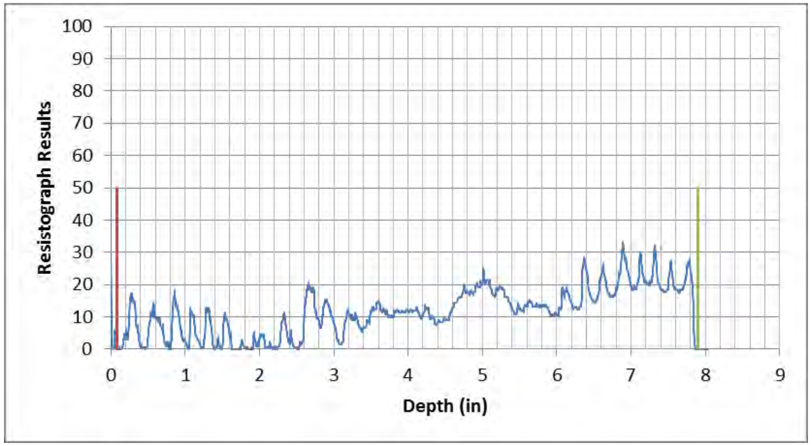
Weight:	2,372 lb
Impact Speed:	20 mph
Impact Height:	21.5 inches

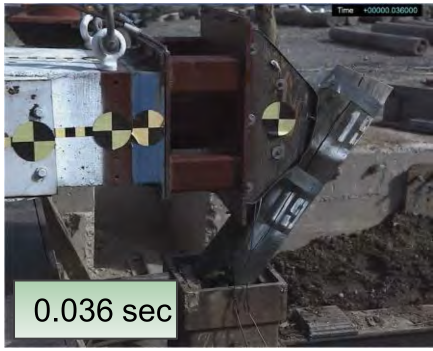
Ring density at bottom of post

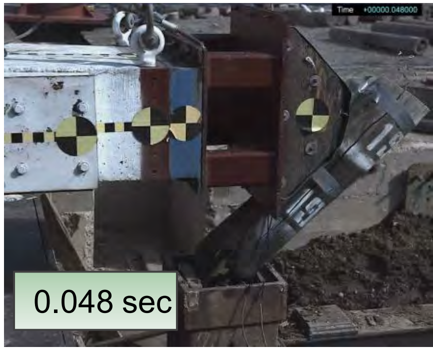
Fractured Post











Test Information

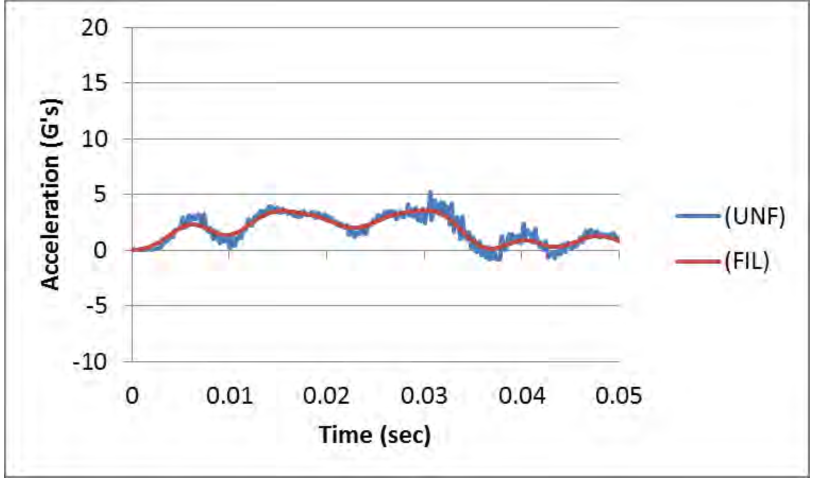
Test Number:	13009Q
Test Date:	26-Sept-2013

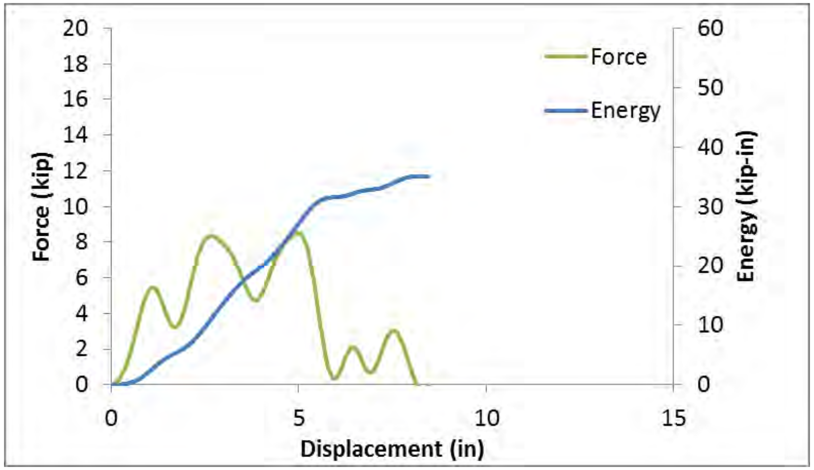
Post Properties

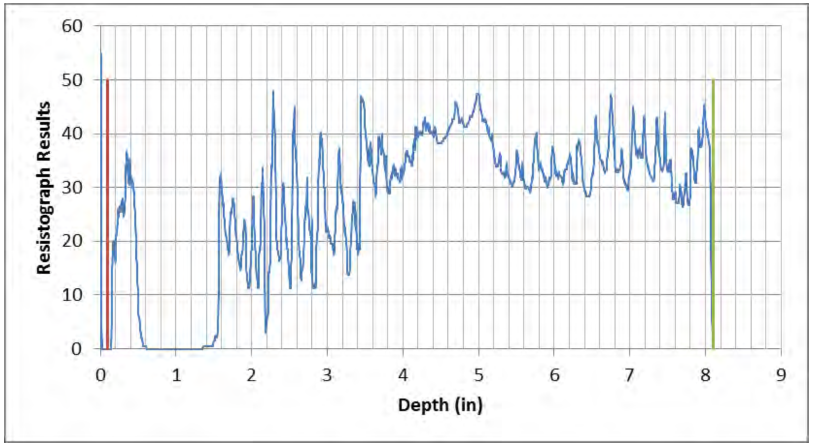
Post Number:	22
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	8.92 inches
Moisture Content:	47.7%
Ring Density (avg.):	6.7 per inch
Resi Score S_{MOR}:	0.54
Resi Score S_U:	0.52

Pendulum Properties

Weight:	2,372 lb
Impact Speed:	20 mph
Impact Height:	21.5 inches

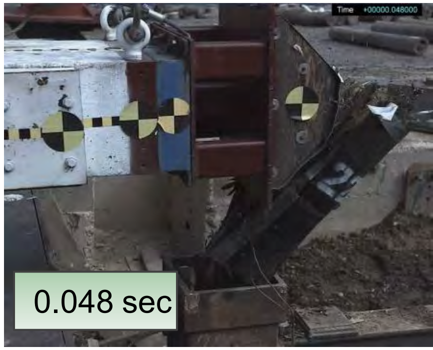






Ring density at bottom of post

Fractured Post



Test Information

Test Number:	13009R
Test Date:	26-Sept-2013

Post Properties

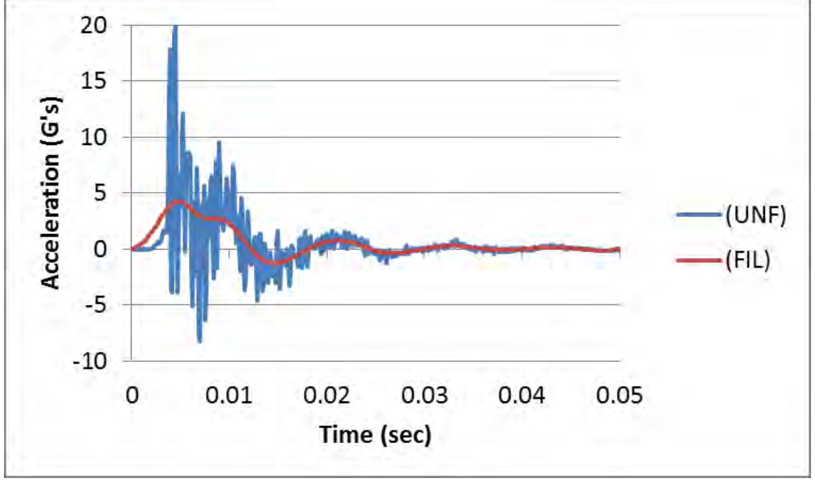
Post Number:	18
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	7.80 inches
Moisture Content:	>50%
Ring Density (avg.):	6.2 per inch
Resi Score S_{MOR}:	0.61
Resi Score S_U:	0.62

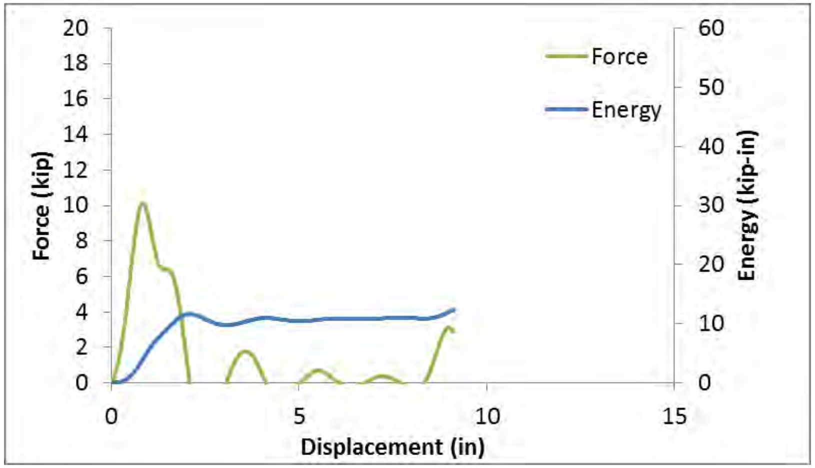
Pendulum Properties

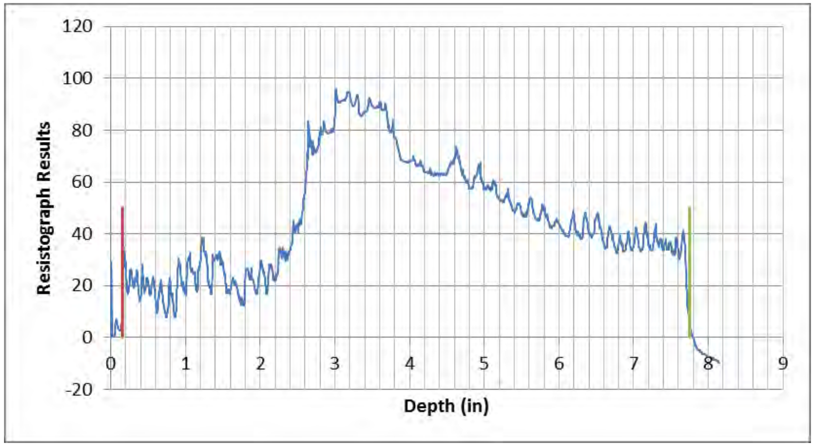
Weight:	2,372 lb
Impact Speed:	20 mph
Impact Height:	21.5 inches

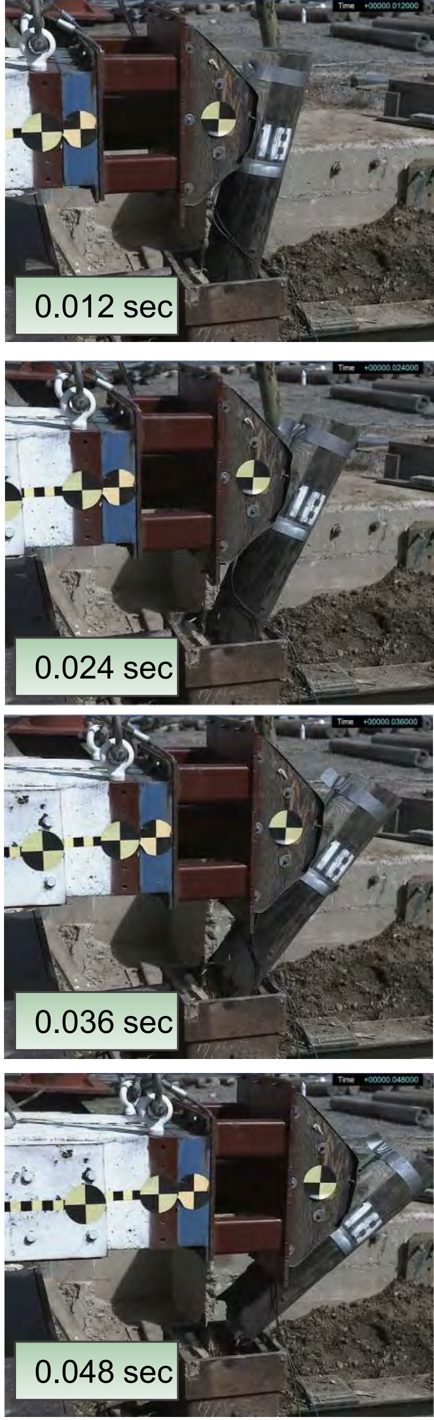
Ring density at bottom of post

Fractured Post









Test Information

Test Number:	13009S
Test Date:	26-Sept-2013

Post Properties

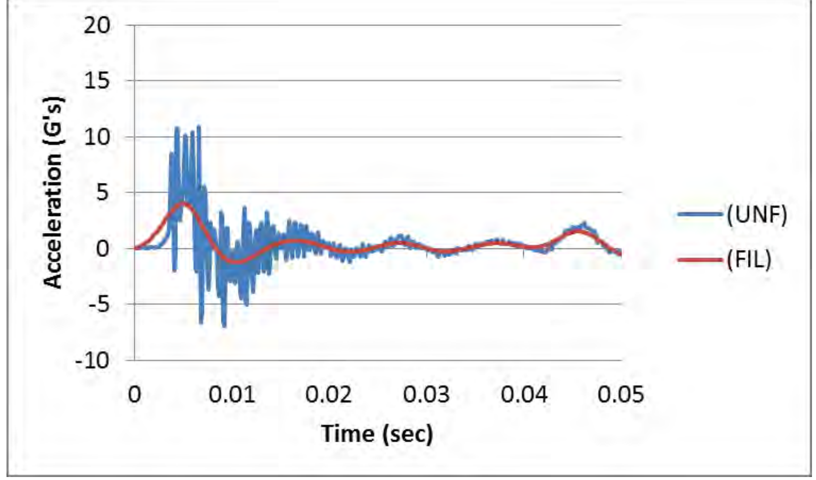
Post Number:	46
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	9.08 inches
Moisture Content:	< 50%
Ring Density (avg.):	8.7 per inch
Resi Score S_{MOR}:	0.60
Resi Score S_U:	0.50

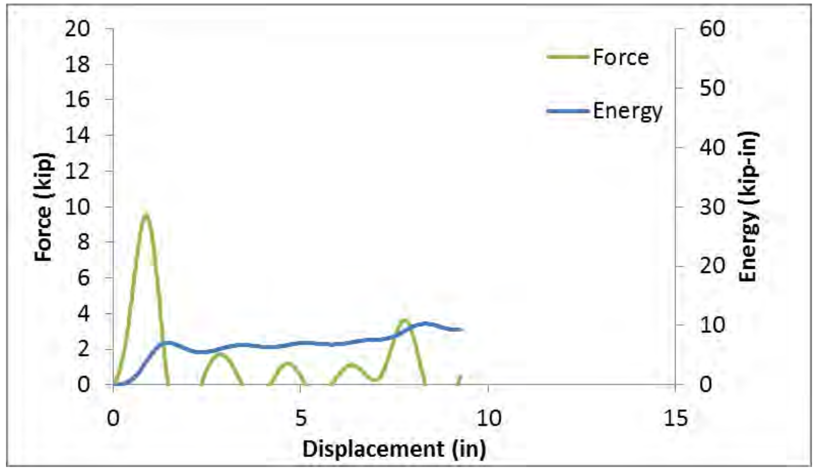
Pendulum Properties

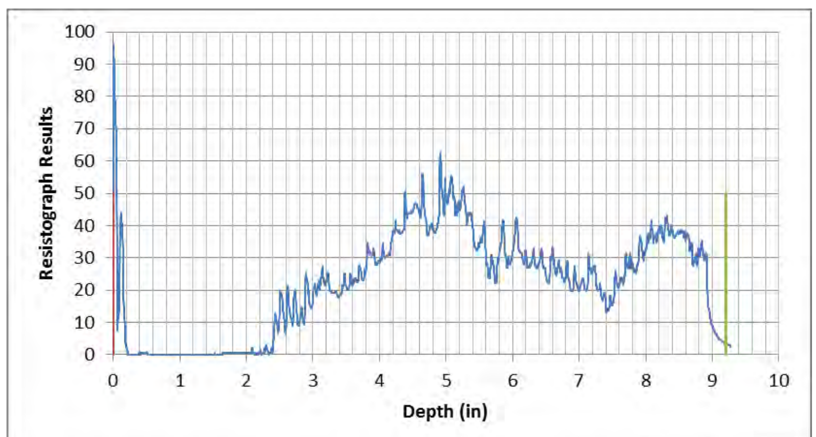
Weight:	2,372 lb
Impact Speed:	20 mph
Impact Height:	21.5 inches

Ring density at bottom of post


Fractured Post







Test Information

Test Number:	13009T
Test Date:	27-Sept-2013

Post Properties

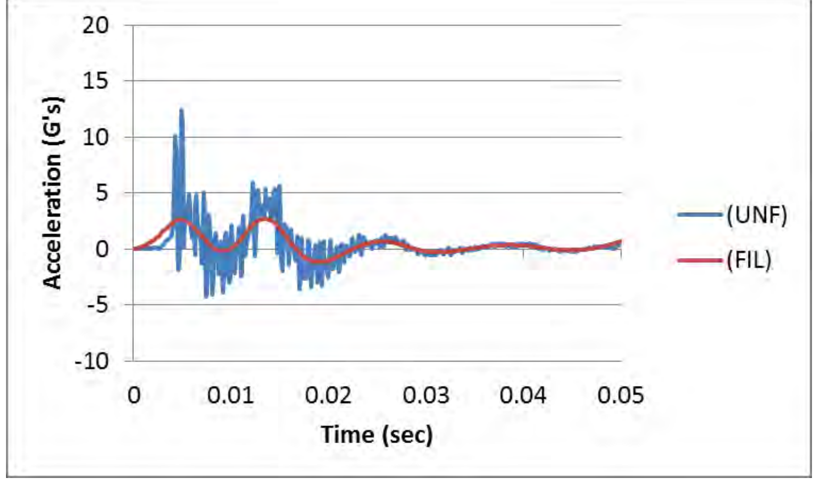
Post Number:	74
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	6.37 inches
Moisture Content:	< 50%
Ring Density (avg.):	7 per inch
Resi Score S_{MOR}:	0.13
Resi Score S_{U}:	0.16

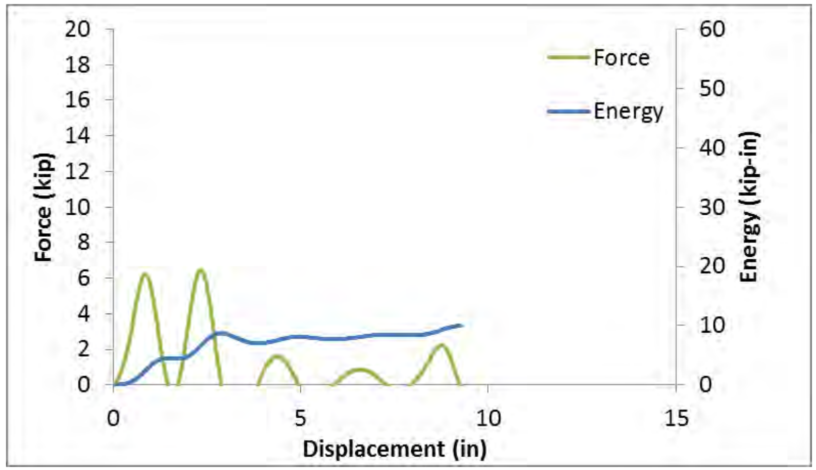
Pendulum Properties

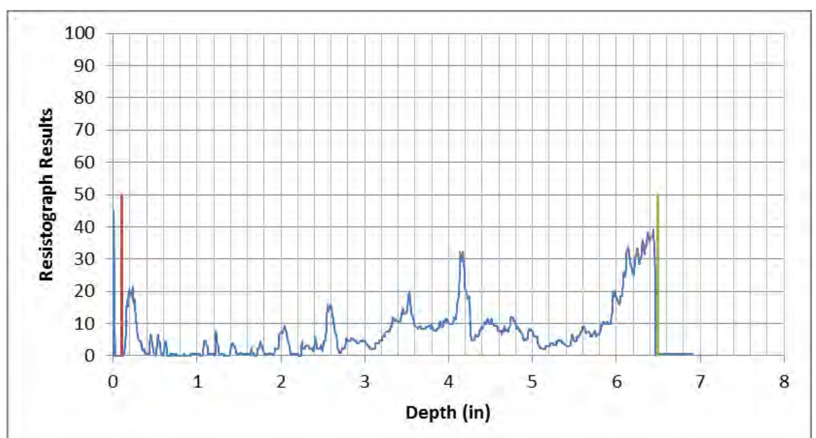
Weight:	2,372 lb
Impact Speed:	20 mph
Impact Height:	21.5 inches

Ring density at bottom of post

Fractured Post







Test Information

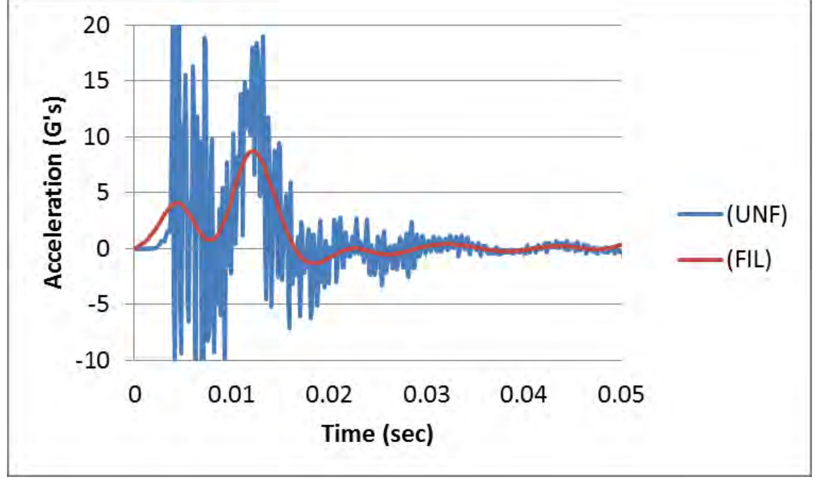
Test Number:	13009U
Test Date:	27-Sept-2013

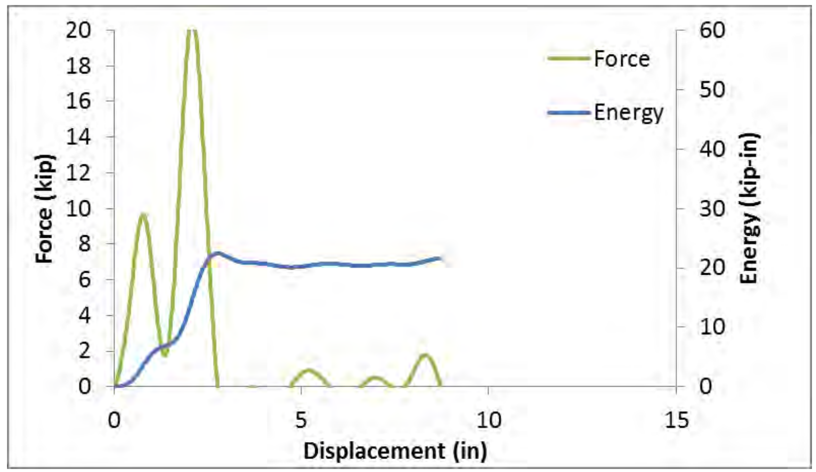
Post Properties

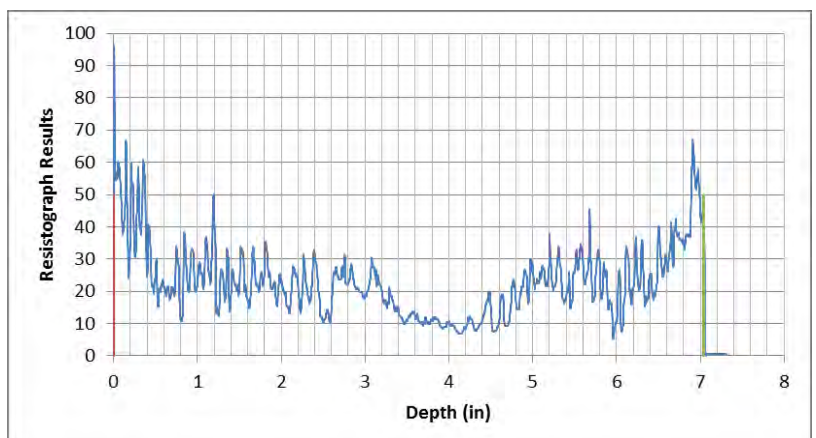
Post Number:	41
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	7.17 inches
Moisture Content:	28.13%
Ring Density (avg.):	7.0 per inch
Resi Score S_{MOR}:	0.52
Resi Score S_U:	0.57

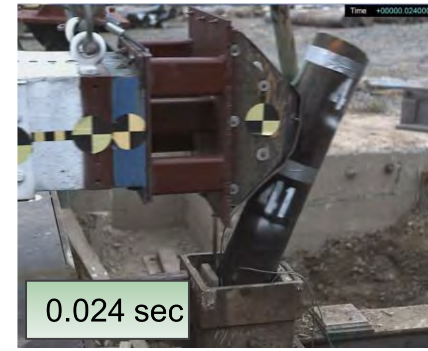
Pendulum Properties

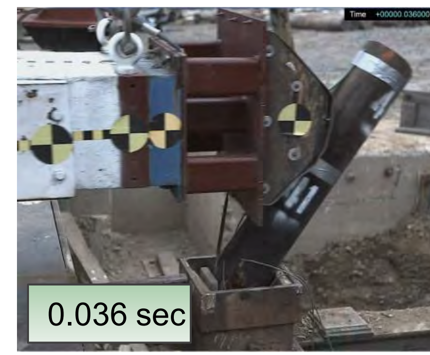
Weight:	2,372 lb
Impact Speed:	20 mph
Impact Height:	21.5 inches

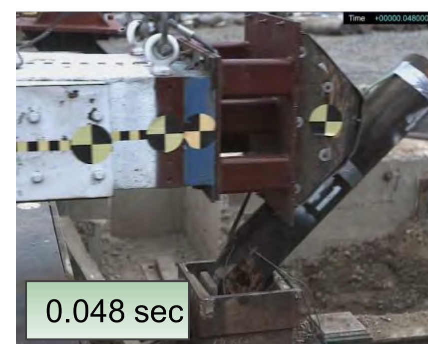












Fractured Post

Test Information

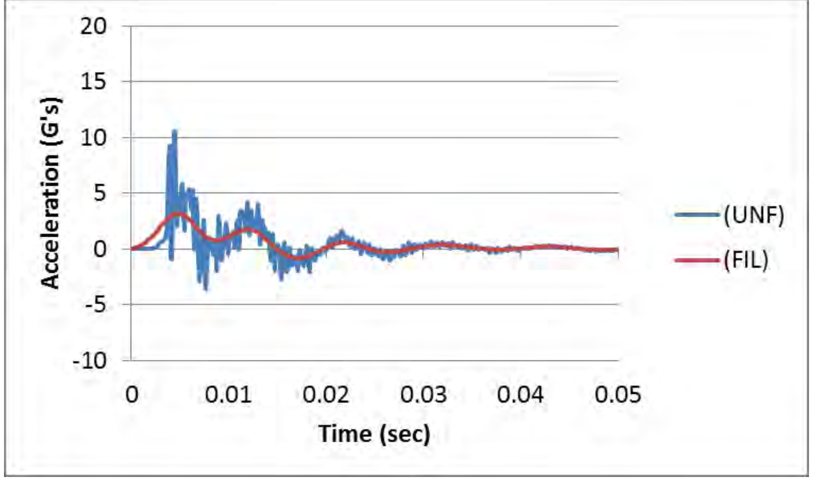
Test Number:	13009V
Test Date:	27-Sept-2013

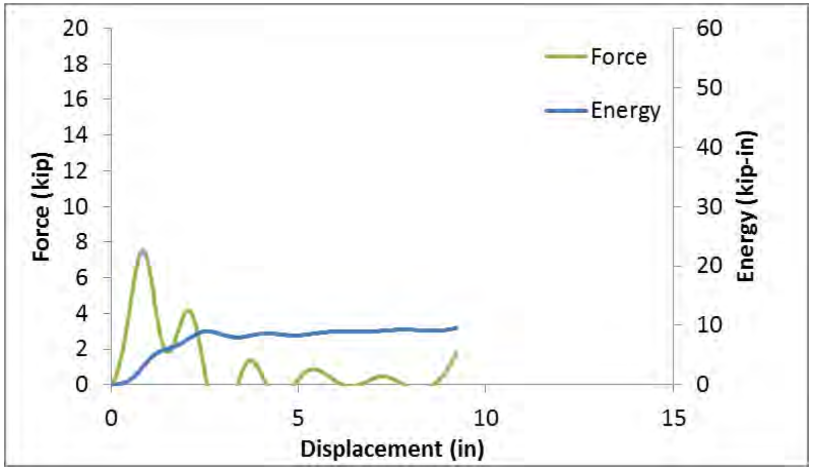
Post Properties

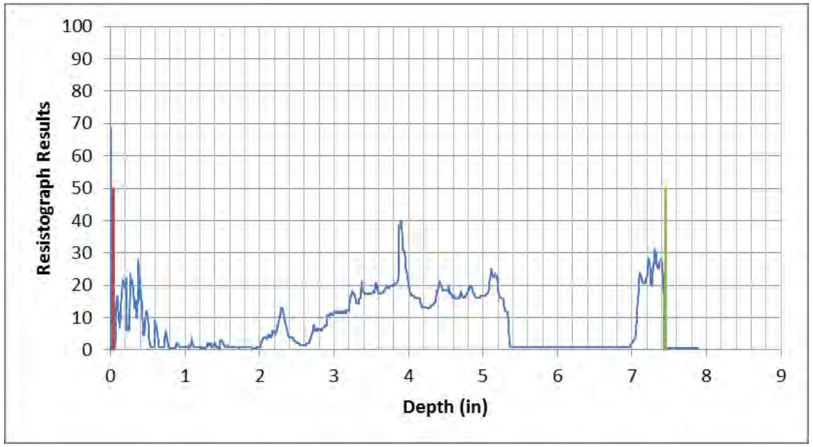
Post Number:	38
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	7.64 inches
Moisture Content:	< 50%
Ring Density (avg.):	5.6 per inch
Resi Score S_{MOR}:	0.15
Resi Score S_U:	0.16

Pendulum Properties

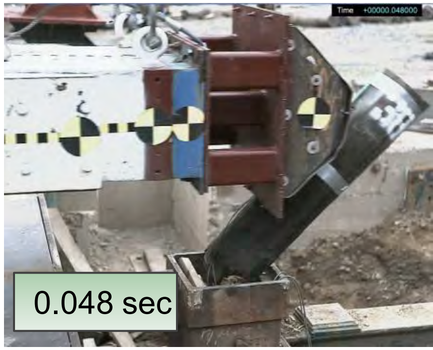
Weight:	2,372 lb
Impact Speed:	20 mph
Impact Height:	21.5 inches







Fractured Post



Test Information

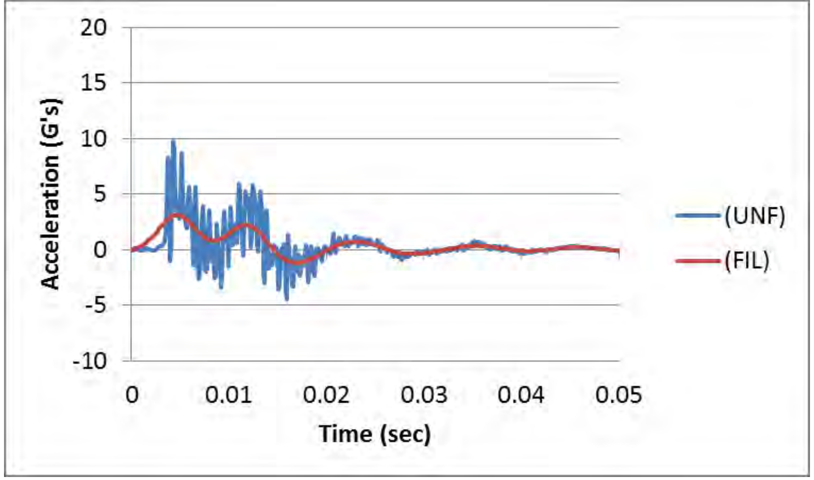
Test Number:	13009W
Test Date:	27-Sept-2013

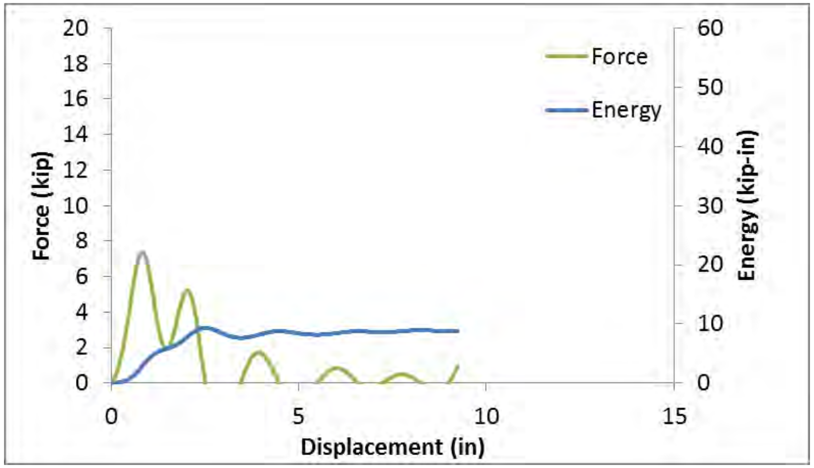
Post Properties

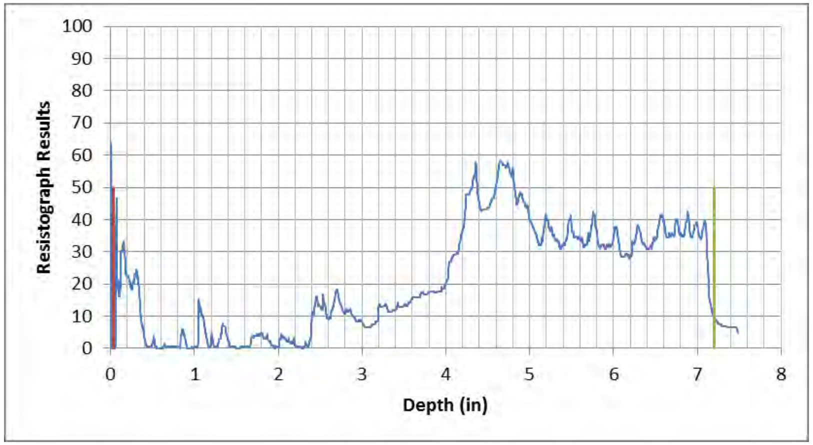
Post Number:	39
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	7.00 inches
Moisture Content:	< 50%
Ring Density (avg.):	4.3 per inch
Resi Score S_{MOR}:	0.36
Resi Score S_U:	0.39

Pendulum Properties

Weight:	2,372 lb
Impact Speed:	20 mph
Impact Height:	21.5 inches

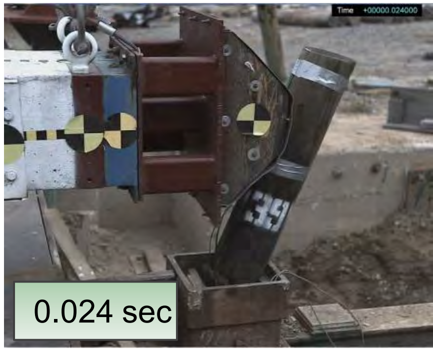


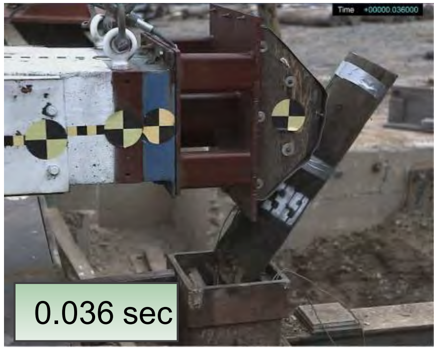




Ring density at bottom of post

Fractured Post





APPENDIX E

Task 4A-3
Assess Effects of Guardrail Post Deterioration on Performance of G4(2W)

FOIL Tests 13009 Y – K2 Summary Sheets
Posts in Rigid Foundation

Chuck A. Plaxico, Ph.D.

Archie Ray

Roadsafe LLC

December 2013

Test Information

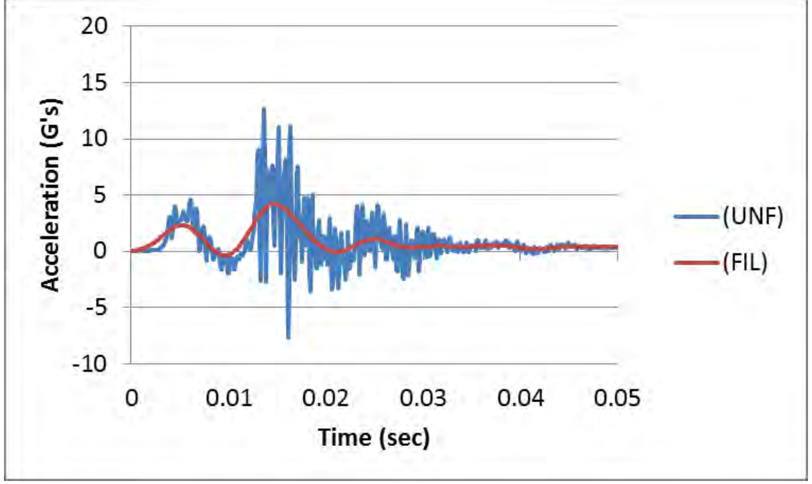
Test Number:	13009Y
Test Date:	01-Oct-2013

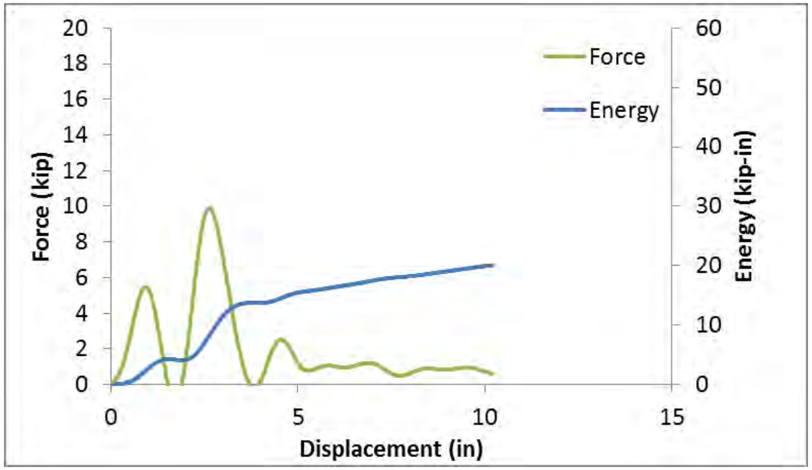
Post Properties

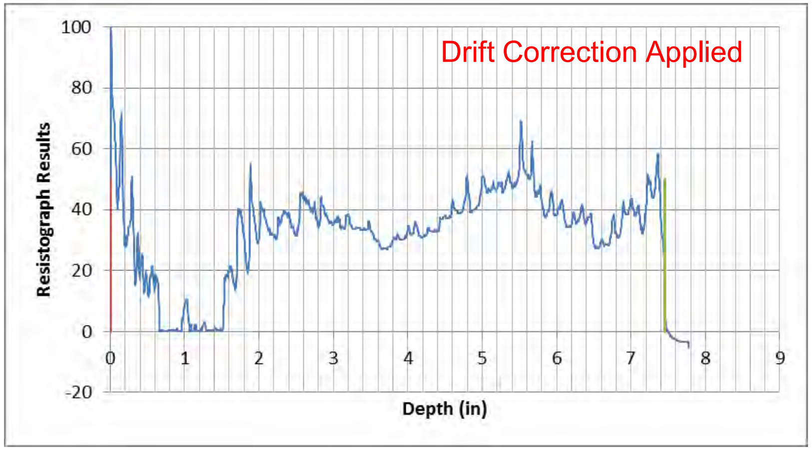
Post Number:	43
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	7.64 inches
Moisture Content:	>50%
Ring Density (avg.):	7.0 per inch
Resi Score S_{MOR}:	0.60
Resi Score S_U:	0.63

Pendulum Properties

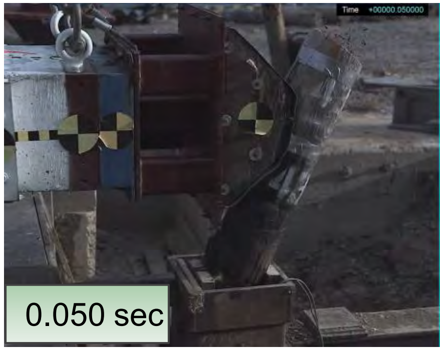
Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches

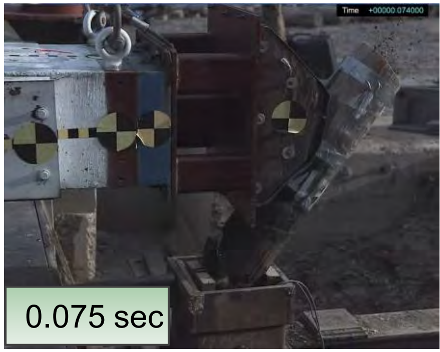


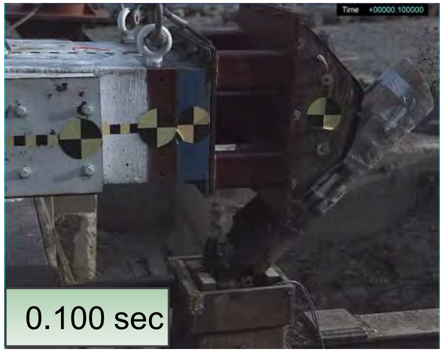





Fractured Post







Test Information

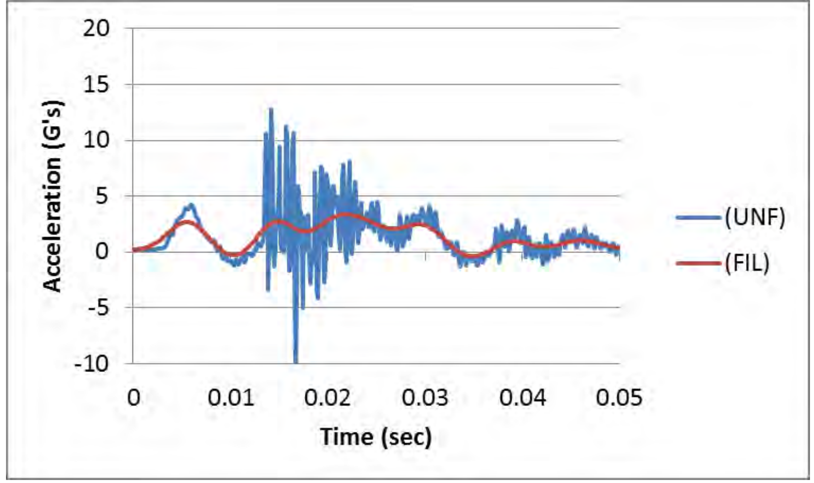
Test Number:	13009Z
Test Date:	01-Oct-2013

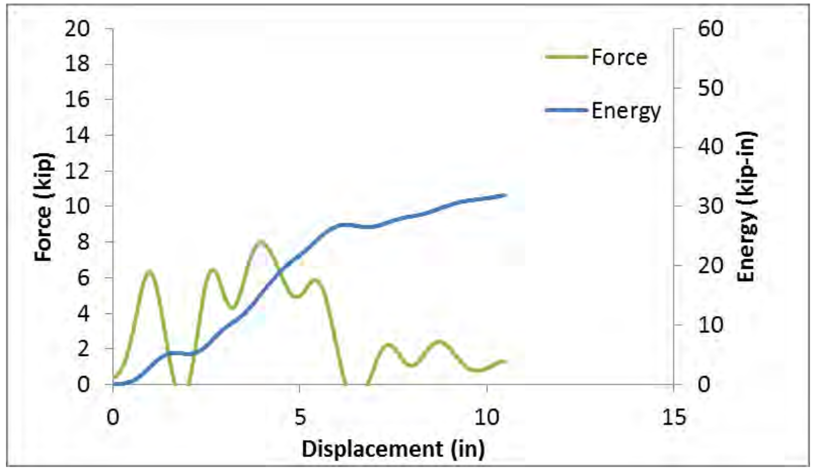
Post Properties

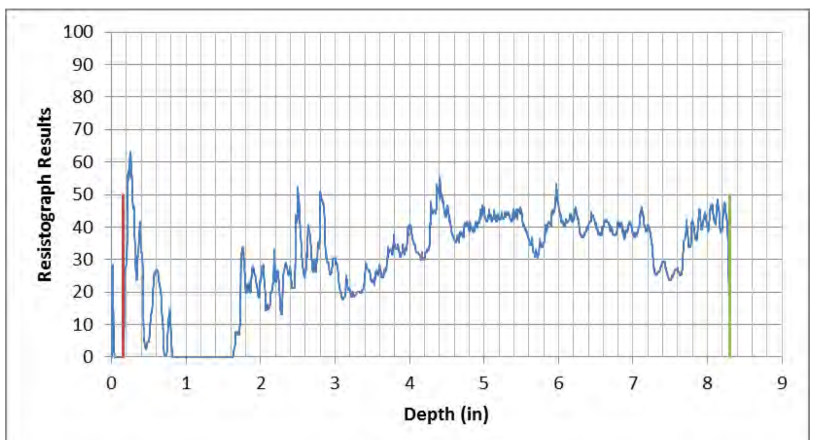
Post Number:	56
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	8.12 inches
Moisture Content:	45.1%
Ring Density (avg.):	7.3 per inch
Resi Score S_{MOR}:	0.67
Resi Score S_{U}:	0.64

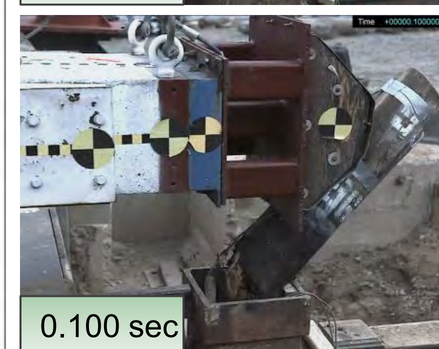
Pendulum Properties

Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches









Fractured Post

Test Information

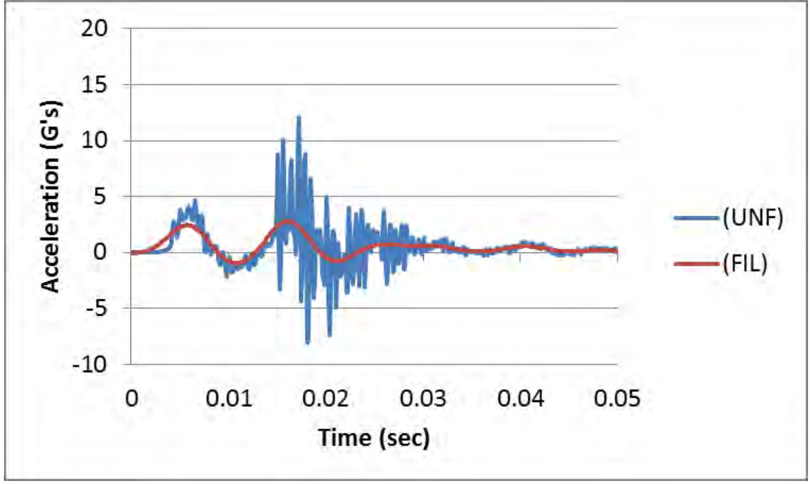
Test Number:	13009A1
Test Date:	01-Oct-2013

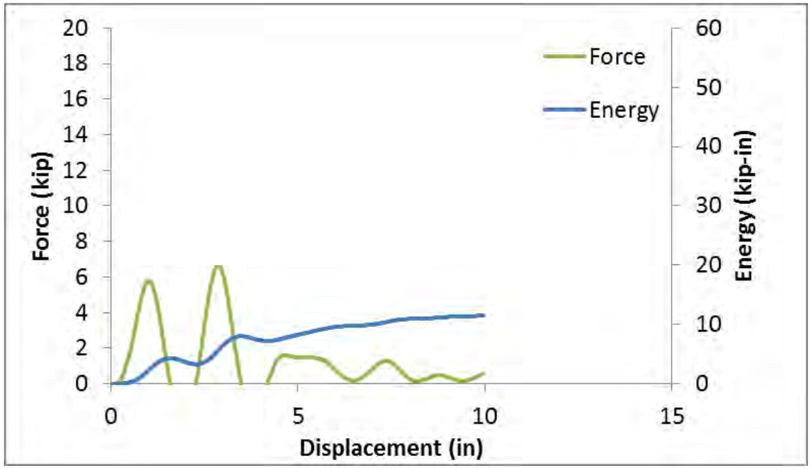
Post Properties

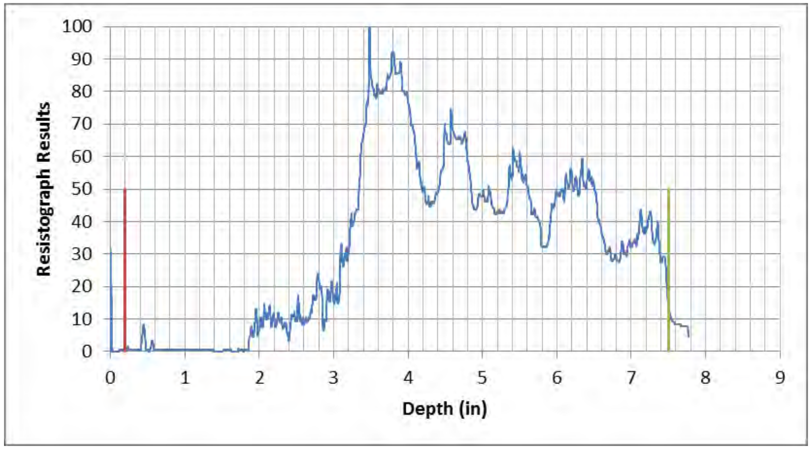
Post Number:	50
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	7.4 inches
Moisture Content:	>50%
Ring Density (avg.):	12.8 per inch
Resi Score S_{MOR}:	0.36
Resi Score S_U:	0.37

Pendulum Properties

Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches





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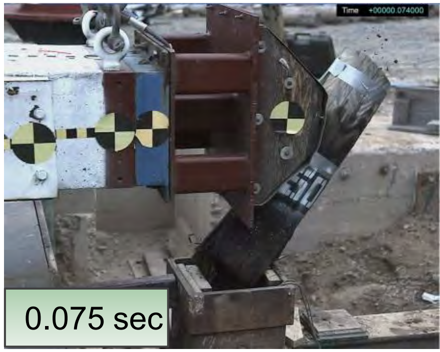
0.050 sec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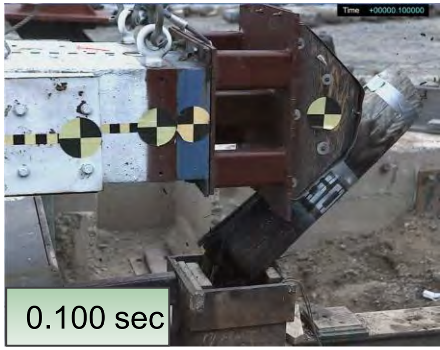
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Fractured Post

Test Information

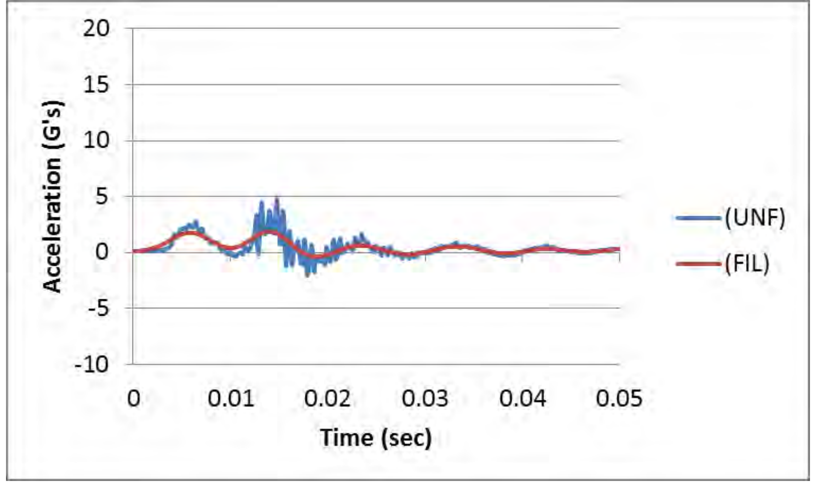
Test Number:	13009B1
Test Date:	01-Oct-2013

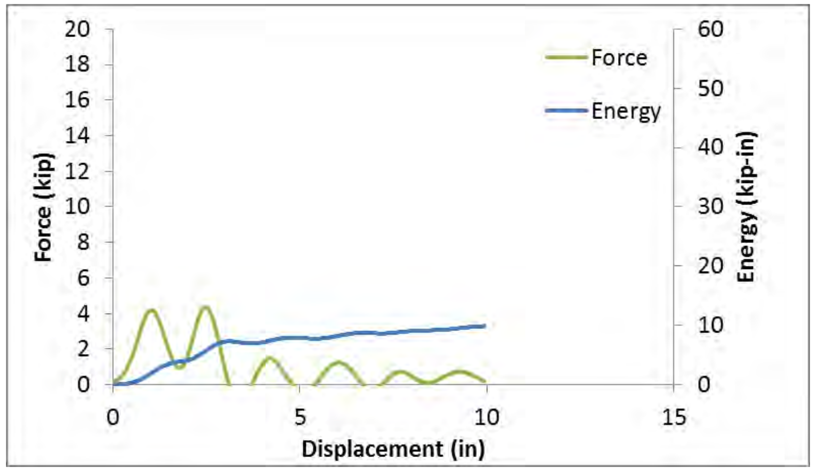
Post Properties

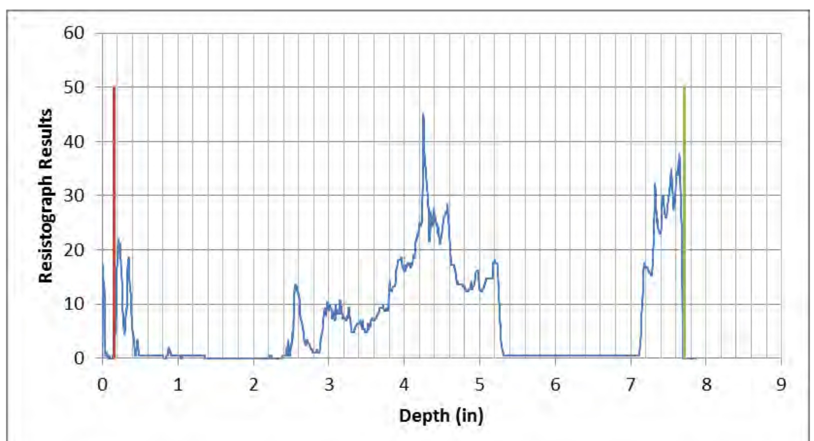
Post Number:	31
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	7.64 inches
Moisture Content:	>50%
Ring Density (avg.):	7.7 per inch
Resi Score S_{MOR}:	0.16
Resi Score S_U:	0.16

Pendulum Properties

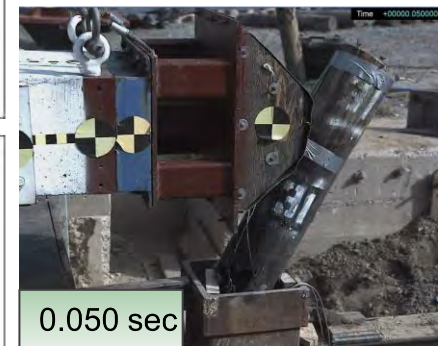
Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches








0.025 sec


0.050 sec


0.075 sec


0.100 sec


Fractured Post

Test Information

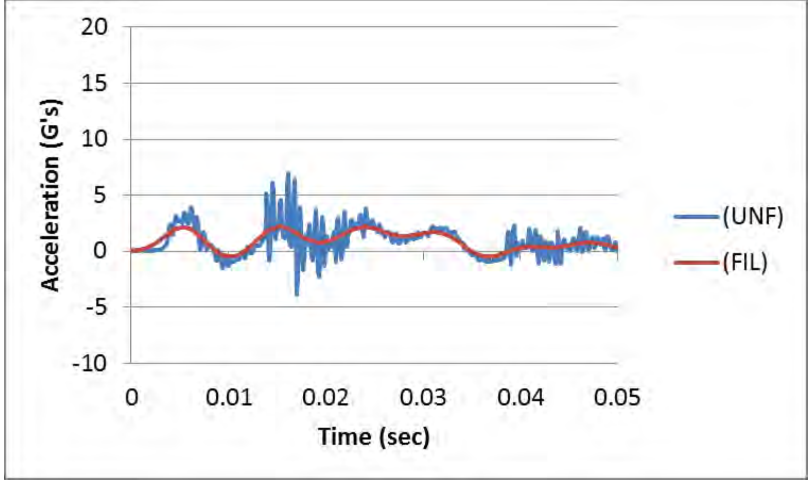
Test Number:	13009C1
Test Date:	01-Oct-2013

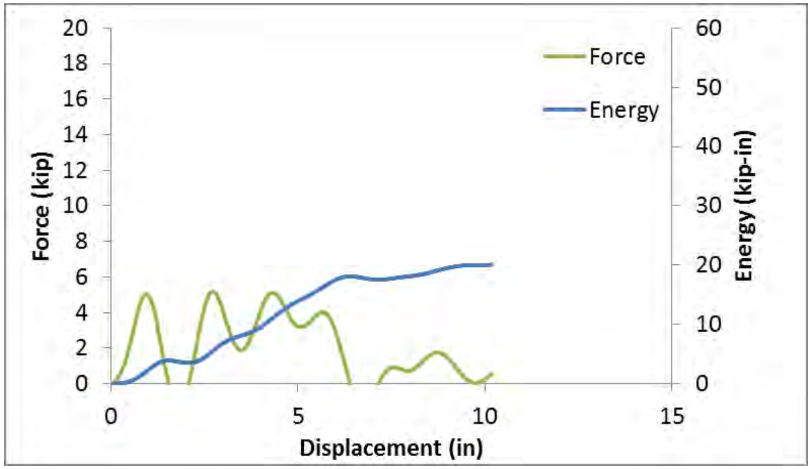
Post Properties

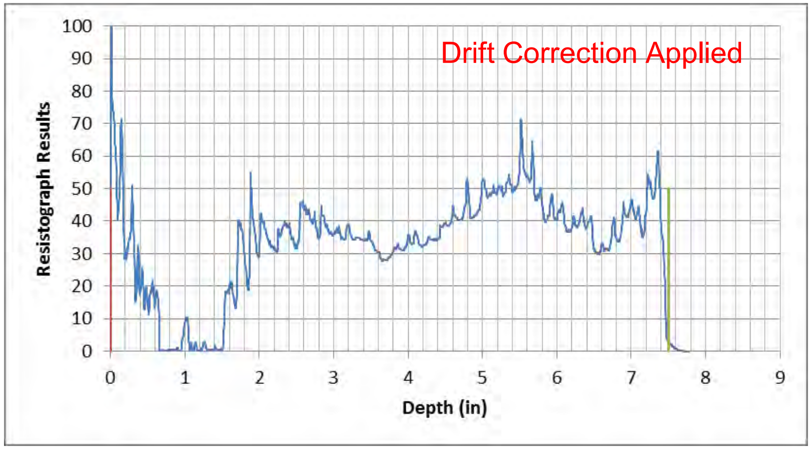
Post Number:	47
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	7.96 inches
Moisture Content:	N/A
Ring Density (avg.):	6.6 per inch
Resi Score S_{MOR}:	0.63
Resi Score S_U:	0.64

Pendulum Properties

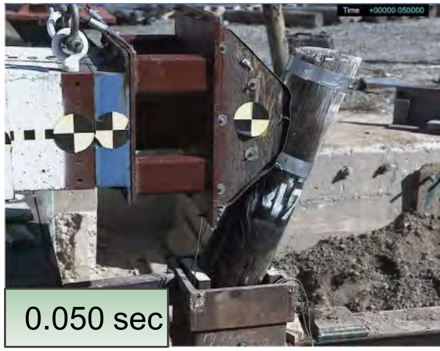
Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches

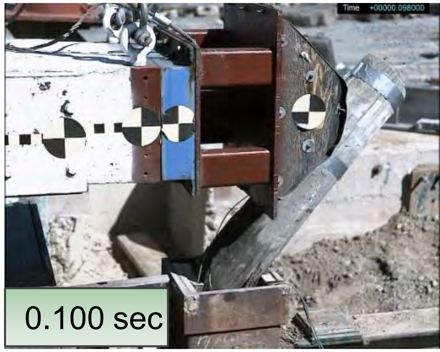






Fractured Post





Test Information

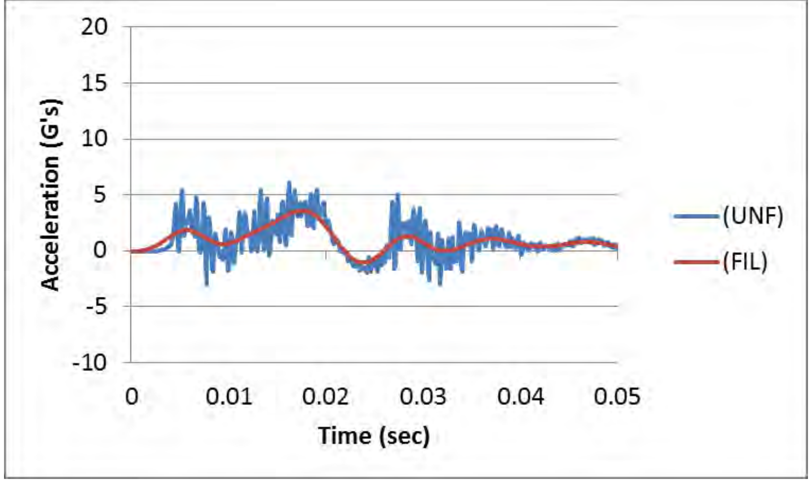
Test Number:	13009D1
Test Date:	01-Oct-2013

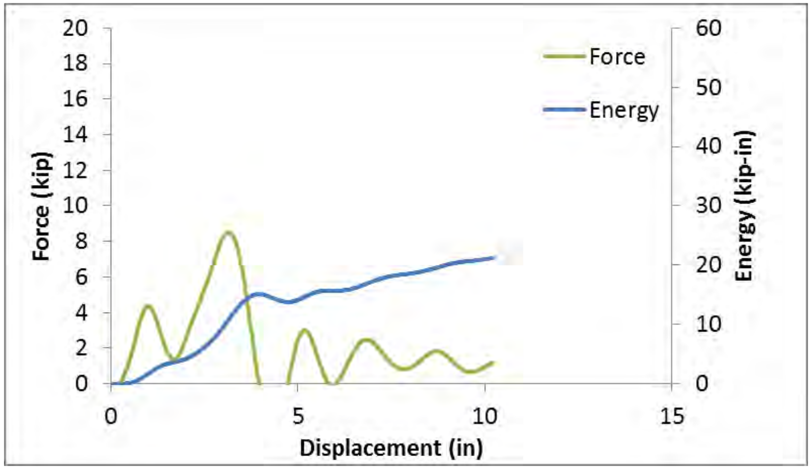
Post Properties

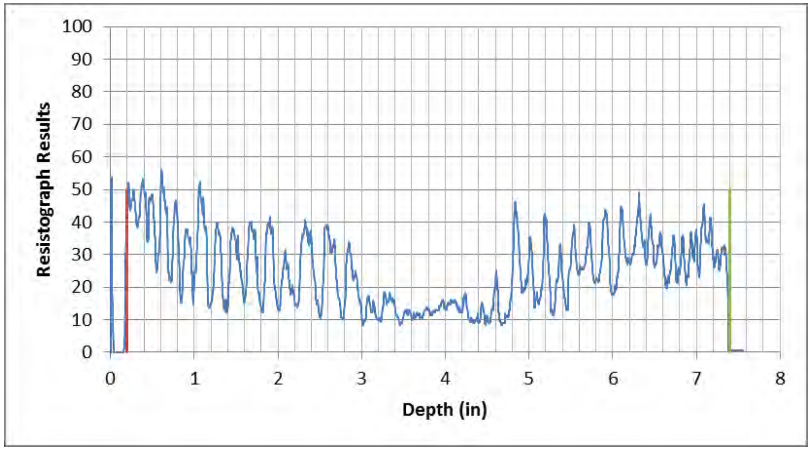
Post Number:	55
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	7.32 inches
Moisture Content:	37.7%
Ring Density (avg.):	7.3 per inch
Resi Score S_{MOR}:	0.57
Resi Score S_U:	0.60

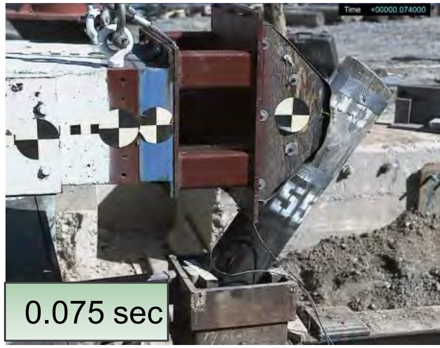
Pendulum Properties

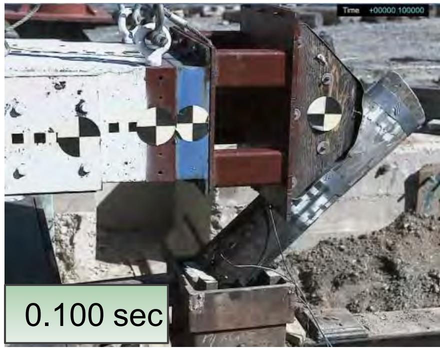
Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches











Fractured Post

Test Information

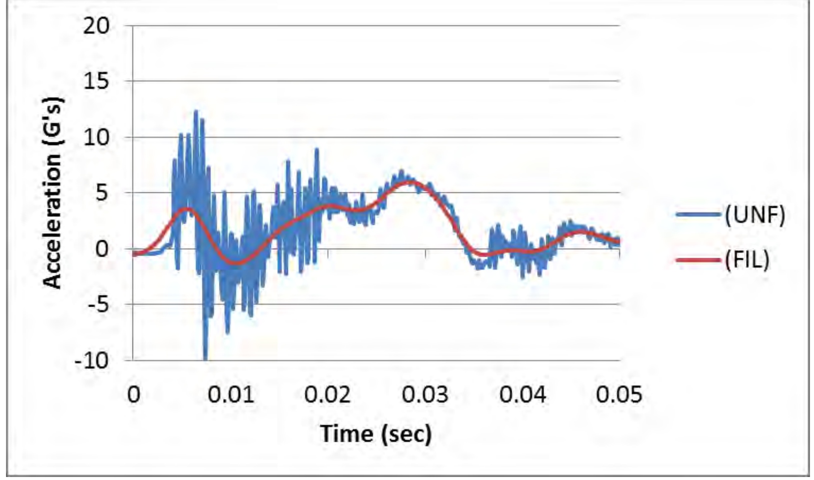
Test Number:	13009E1
Test Date:	01-Oct-2013

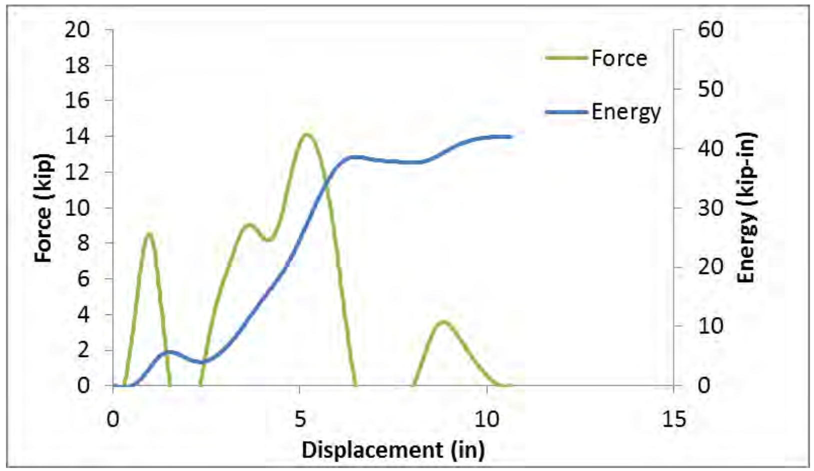
Post Properties

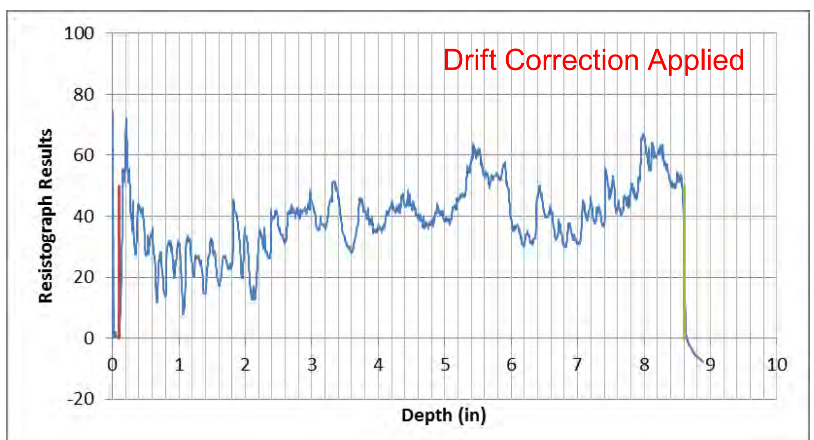
Post Number:	32
Post Type:	Round SYP
Post Length:	60 inches
Post Diameter:	8.76 inches
Moisture Content:	>50%
Ring Density (avg.):	6.1 per inch
Resi Score S_{MOR}:	1.15
Resi Score S_U:	1.04

Pendulum Properties

Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches







Ring density at bottom of post

Fractured Post

Test Information

Test Number:	13009F1
Test Date:	01-Oct-2013

Post Properties

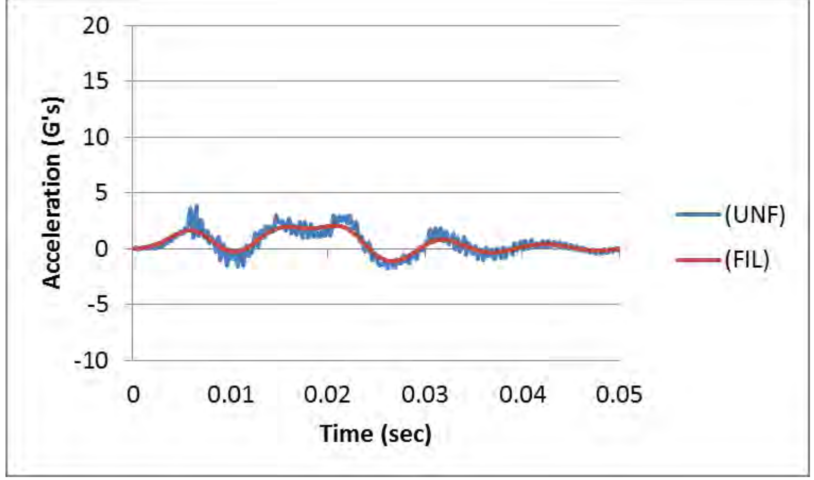
Post Number:	88
Post Type:	Round SYP
Post Length:	60 inches
Post Diameter:	7.56 inches
Moisture Content:	>50%
Ring Density (avg.):	5.3 per inch
Resi Score S_{MOR}:	0.11
Resi Score S_U:	0.12

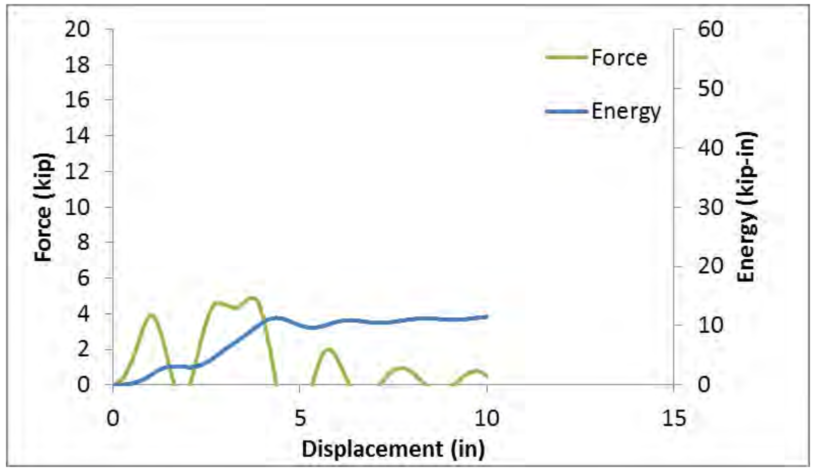
Pendulum Properties

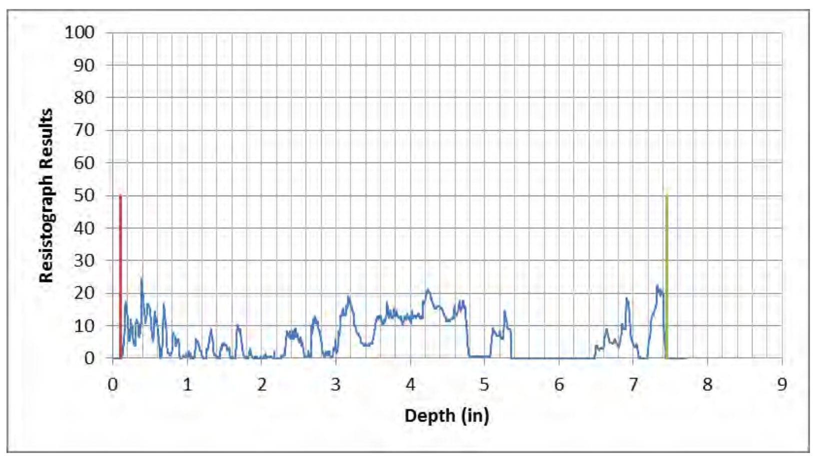
Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches

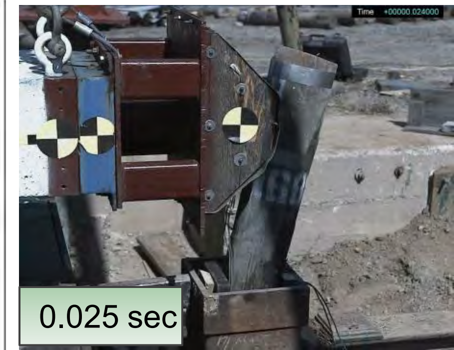
Ring density at bottom of post

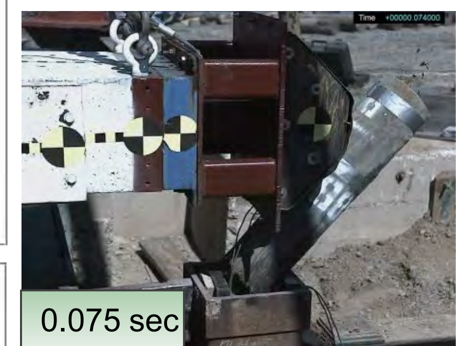
Fractured Post

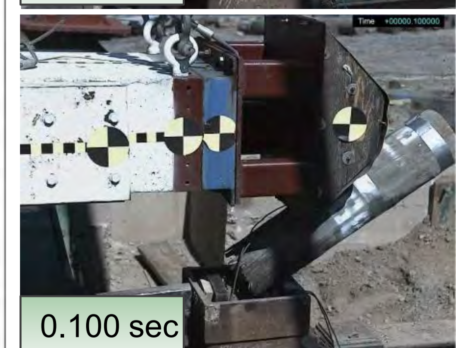












Test Information

Test Number:	13009G1
Test Date:	02-Oct-2013

Post Properties

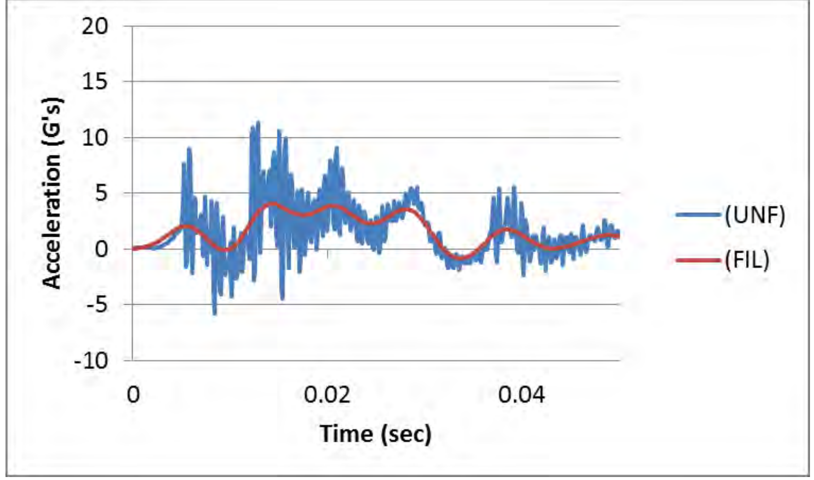
Post Number:	71
Post Type:	Round SYP
Post Length:	60 inches
Post Diameter:	7.64 inches
Moisture Content:	42.2%
Ring Density (avg.):	8.0 per inch
Resi Score S_{MOR}:	0.71
Resi Score S_U:	0.74

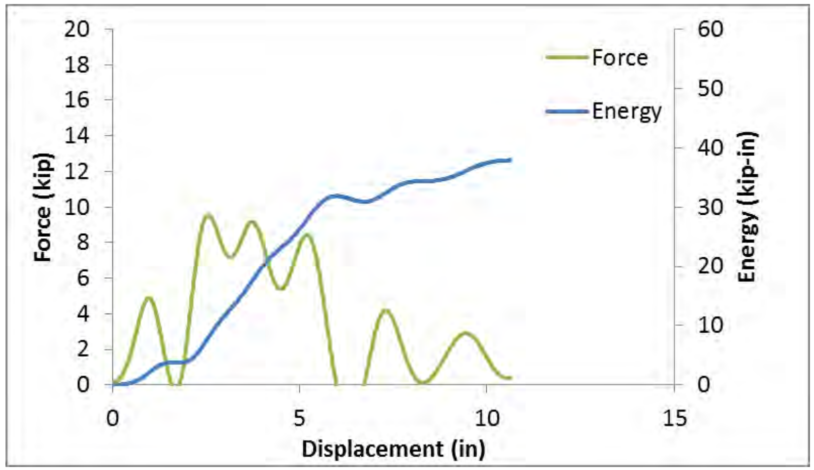
Pendulum Properties

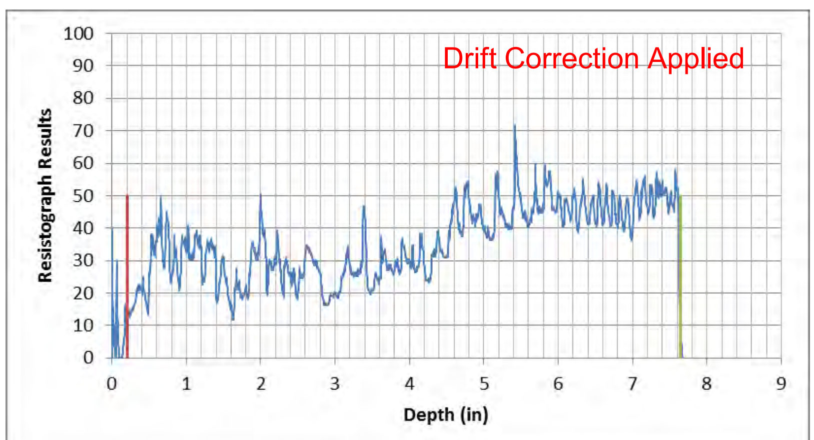
Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches

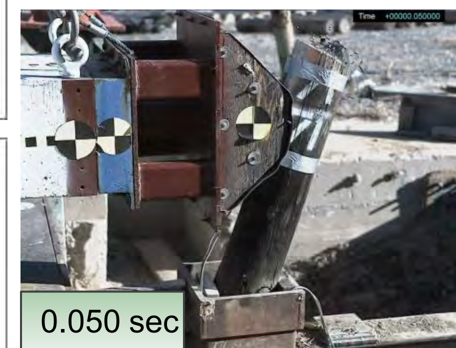
Ring density at bottom of post

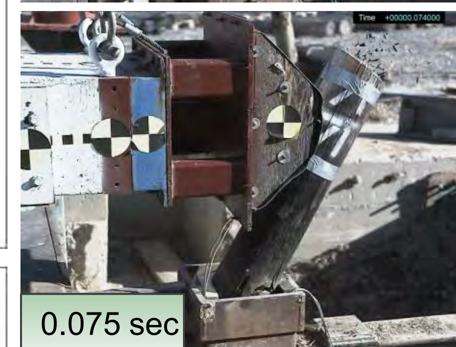
Fractured Post

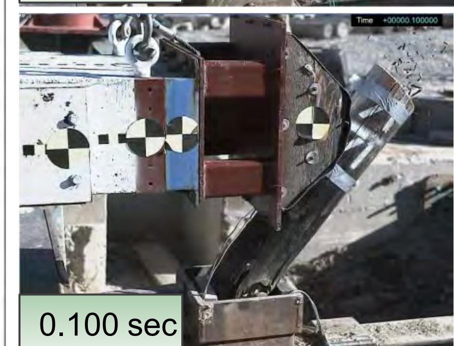












Test Information

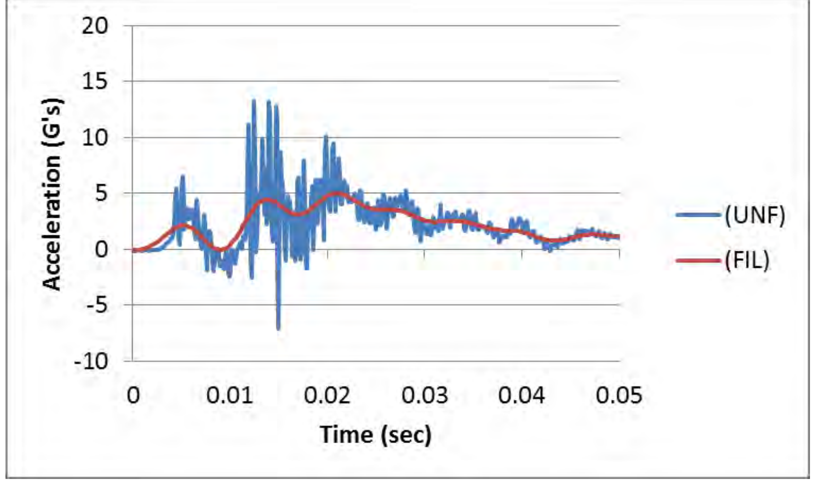
Test Number:	13009H1
Test Date:	02-Oct-2013

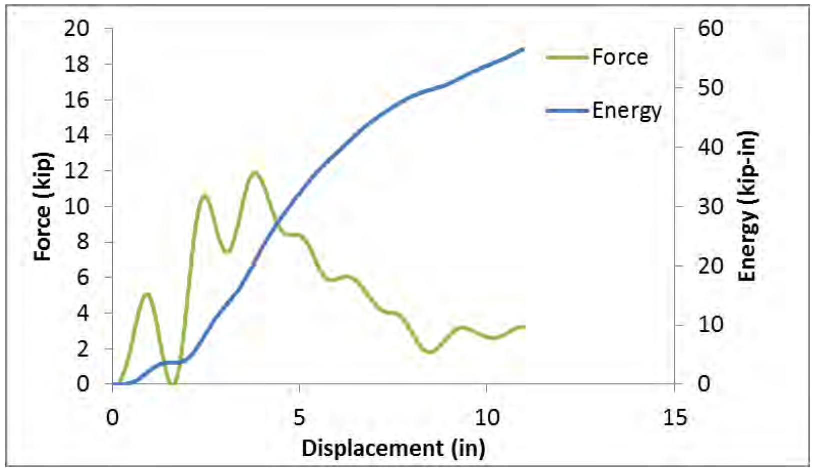
Post Properties

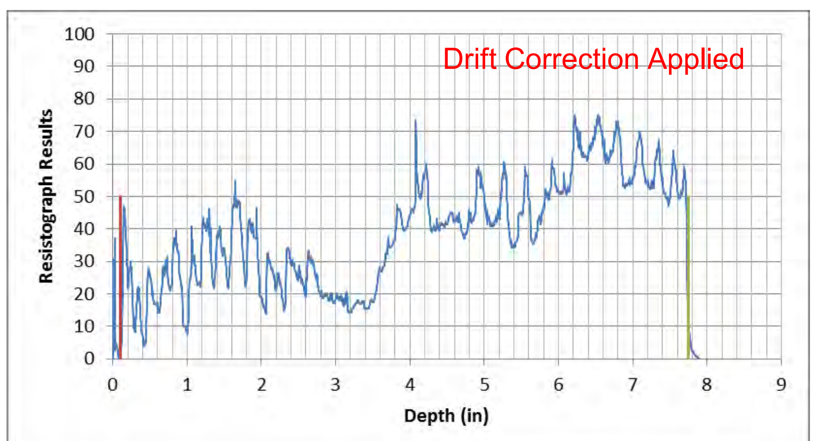
Post Number:	30
Post Type:	Round SYP
Post Length:	60 inches
Post Diameter:	7.96 inches
Moisture Content:	43.6%
Ring Density (avg.):	7.0 per inch
Resi Score S_{MOR}:	0.84
Resi Score S_U:	0.85

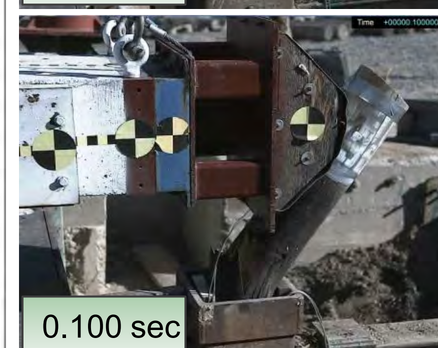
Pendulum Properties

Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches









Fractured Post

Test Information

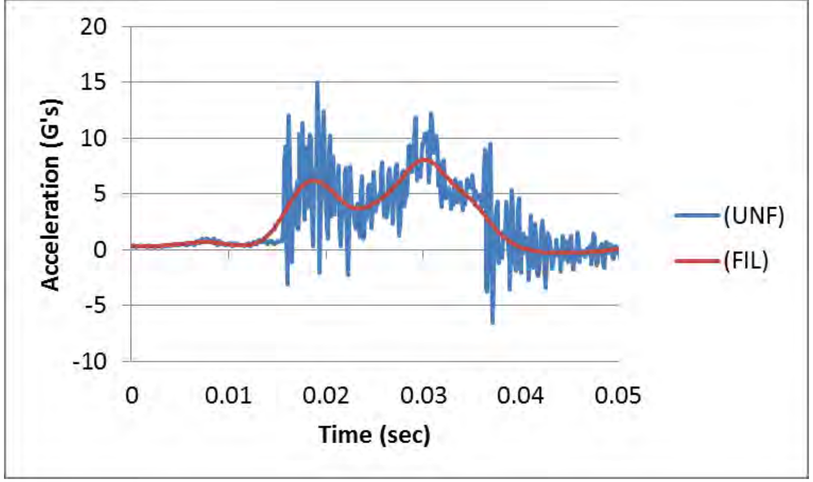
Test Number:	13009I1
Test Date:	02-Oct-2013

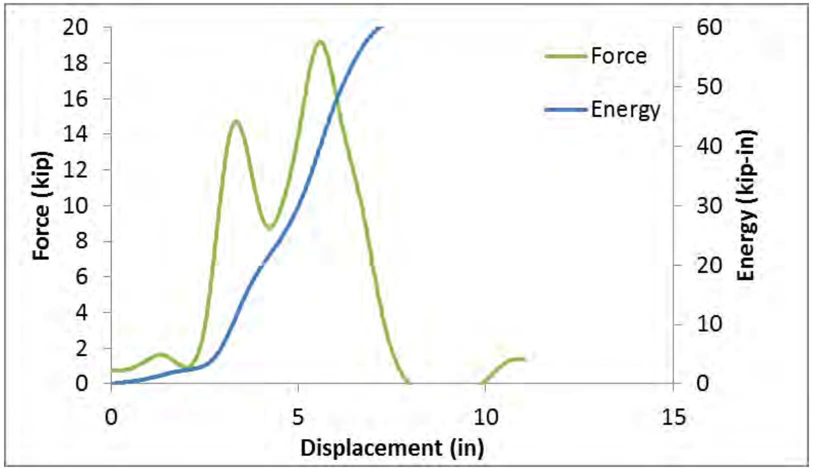
Post Properties

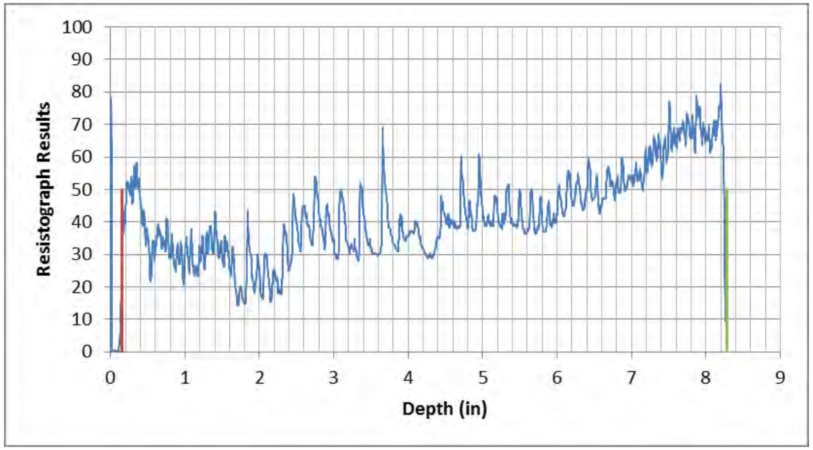
Post Number:	76
Post Type:	Round SYP
Post Length:	60 inches
Post Diameter:	8.36 inches
Moisture Content:	47.6%
Ring Density (avg.):	7.2 per inch
Resi Score S_{MOR}:	1.19
Resi Score S_U:	1.13

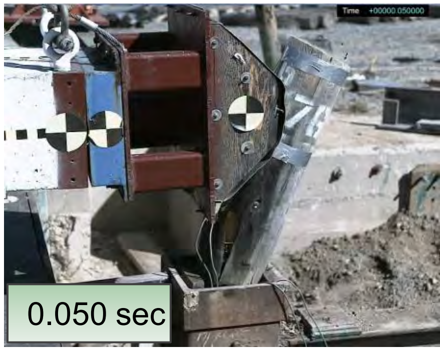
Pendulum Properties

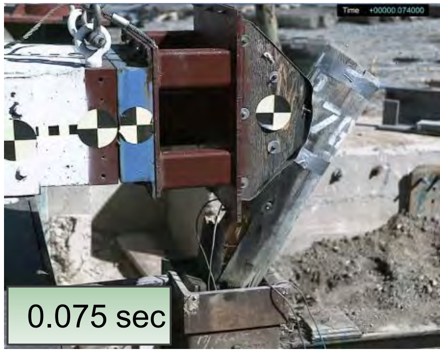
Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches

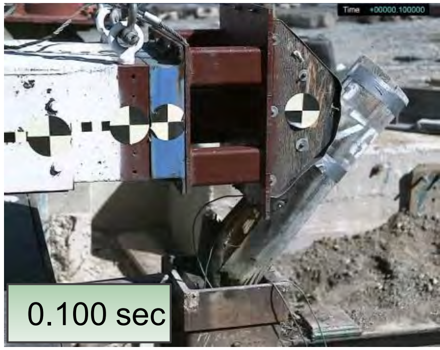












Fractured Post

Test Information

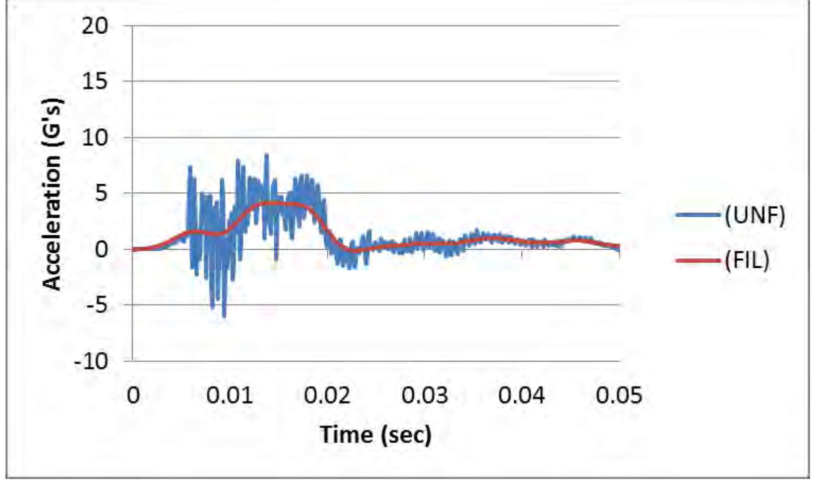
Test Number:	13009J1
Test Date:	02-Oct-2013

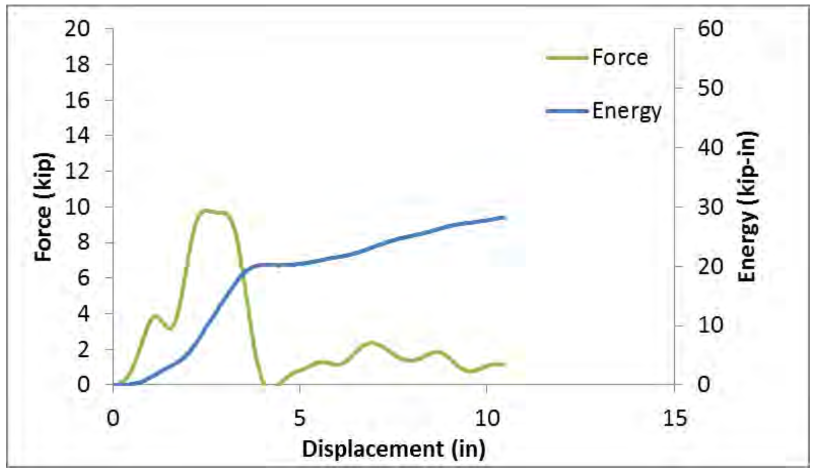
Post Properties

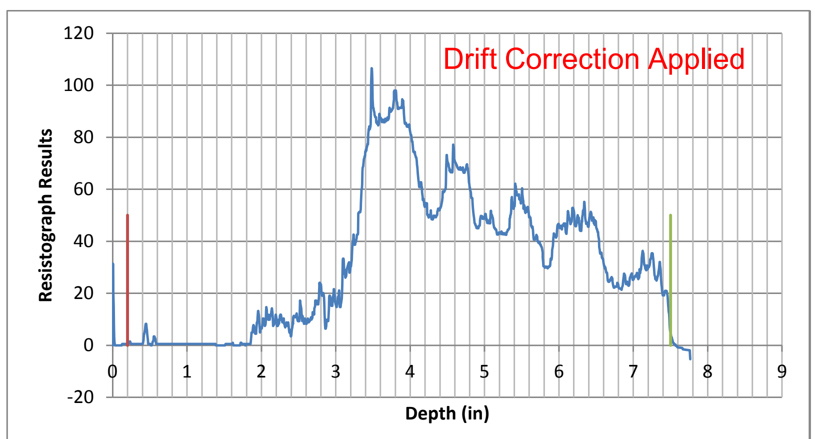
Post Number:	49
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	7.48 inches
Moisture Content:	36.6%
Ring Density (avg.):	7.8 per inch
Resi Score S_{MOR}:	0.30
Resi Score S_U:	0.32

Pendulum Properties

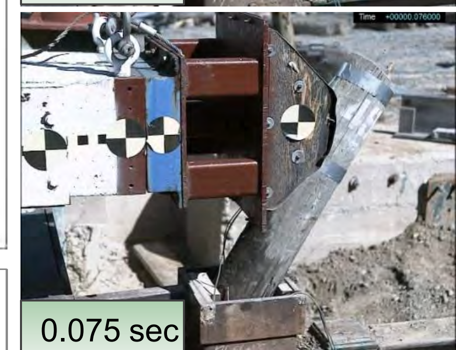
Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches

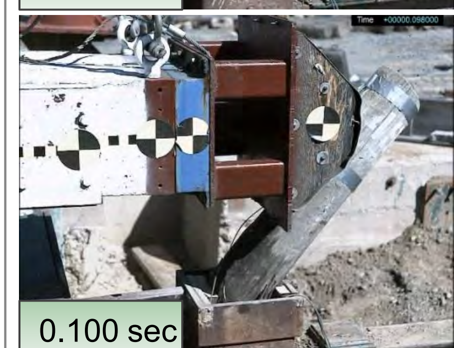






Fractured Post





Test Information

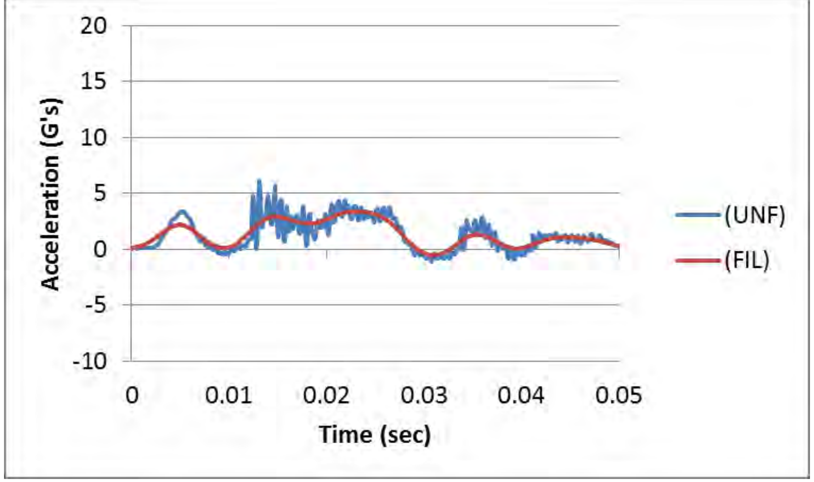
Test Number:	13009K1
Test Date:	02-Oct-2013

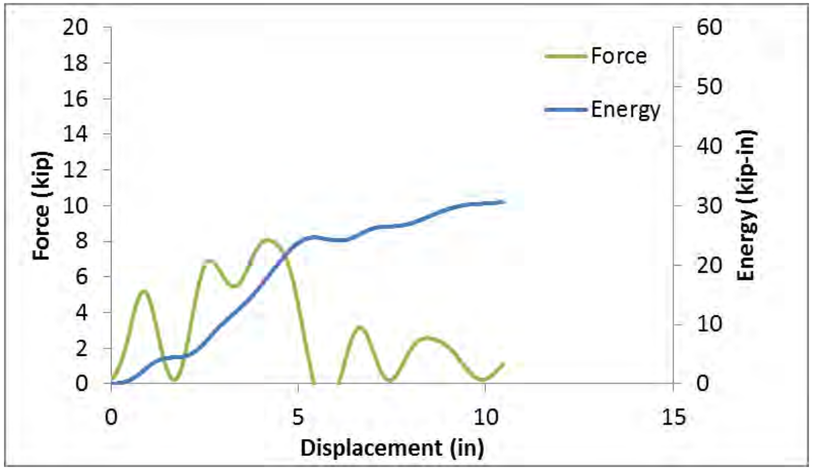
Post Properties

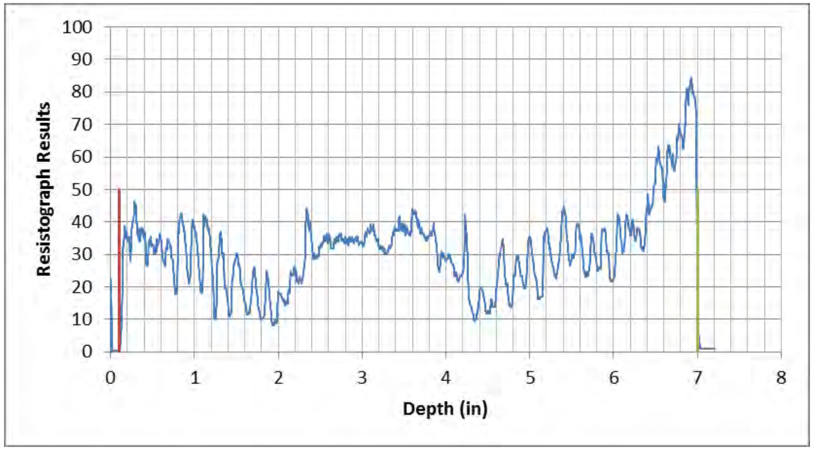
Post Number:	29
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	7.01 inches
Moisture Content:	50%
Ring Density (avg.):	7.1 per inch
Resi Score S_{MOR}:	0.60
Resi Score S_U:	0.67

Pendulum Properties

Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches

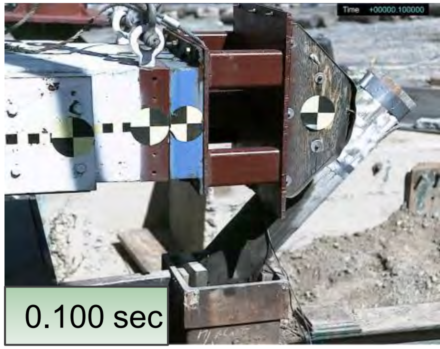






Ring density at bottom of post

Fractured Post



Test Information

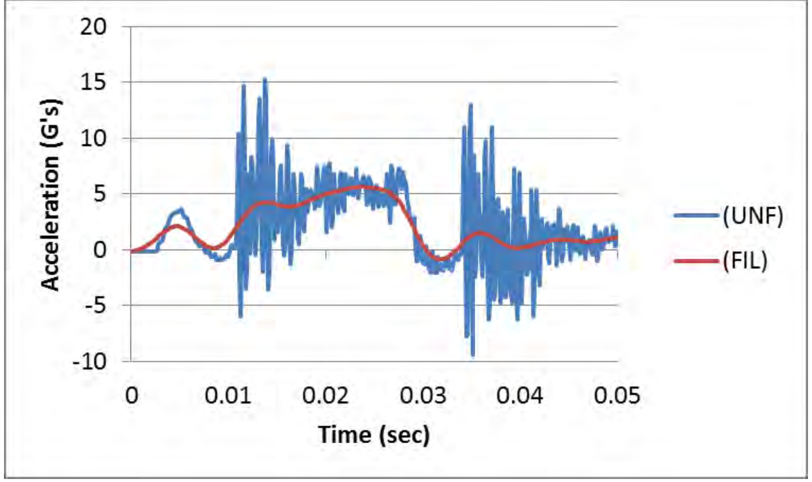
Test Number:	13009L1
Test Date:	02-Oct-2013

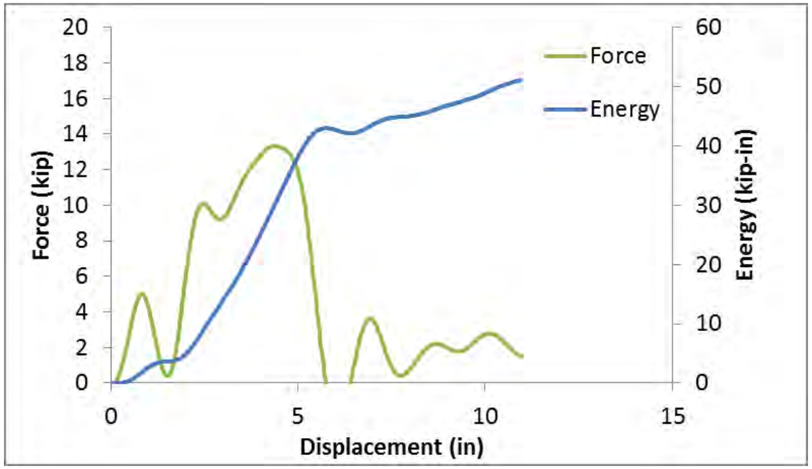
Post Properties

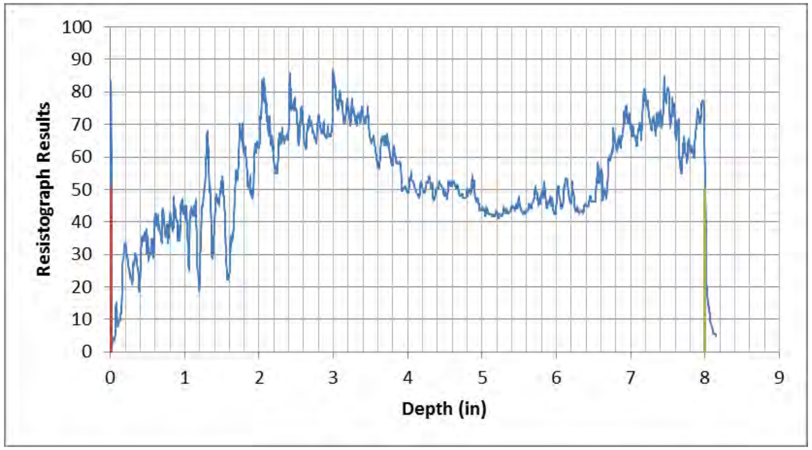
Post Number:	92
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	8.04 inches
Moisture Content:	44.5%
Ring Density (avg.):	8.0 per inch
Resi Score S_{MOR}:	1.18
Resi Score S_U:	1.14

Pendulum Properties

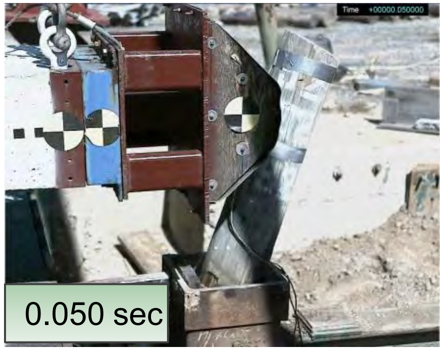
Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches

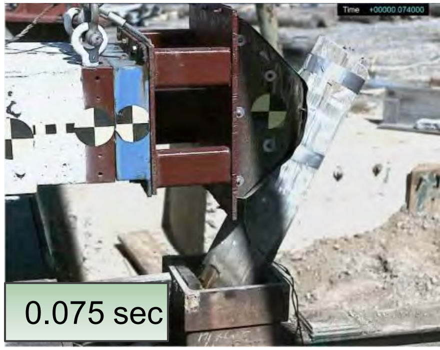


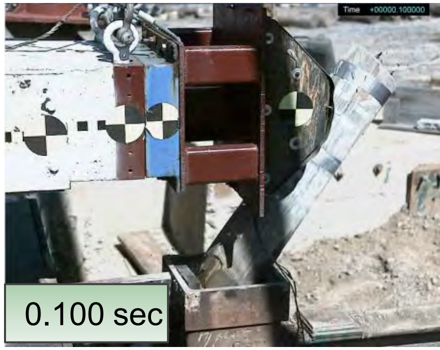




Fractured Post







Test Information

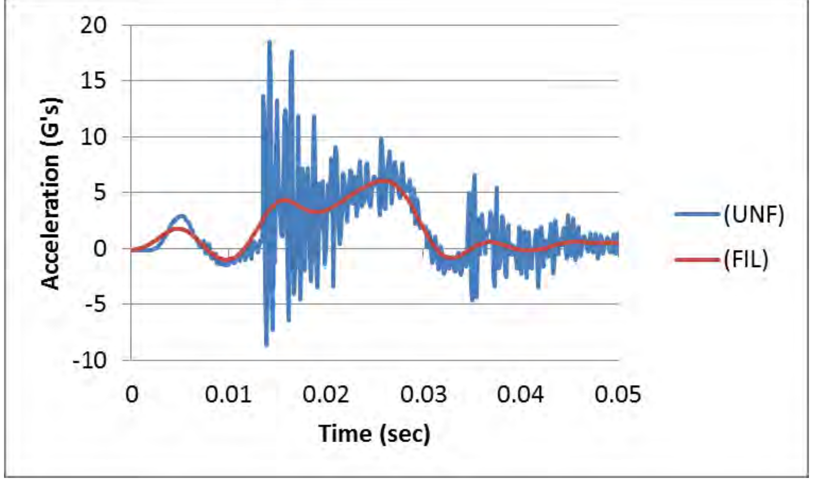
Test Number:	13009M1
Test Date:	02-Oct-2013

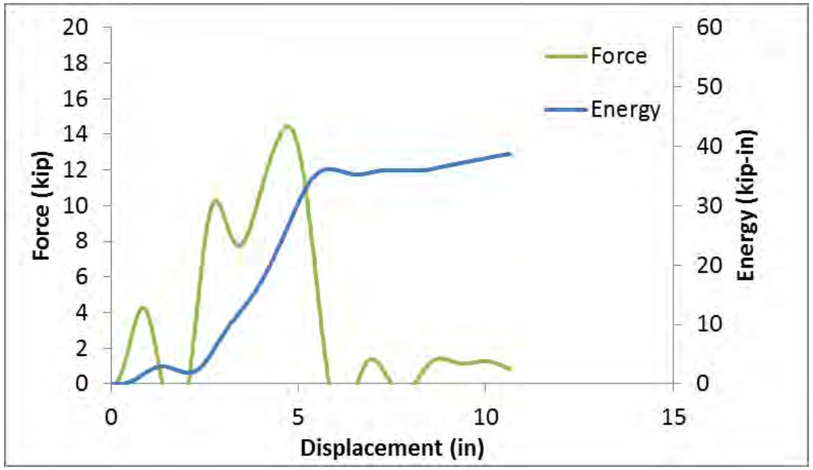
Post Properties

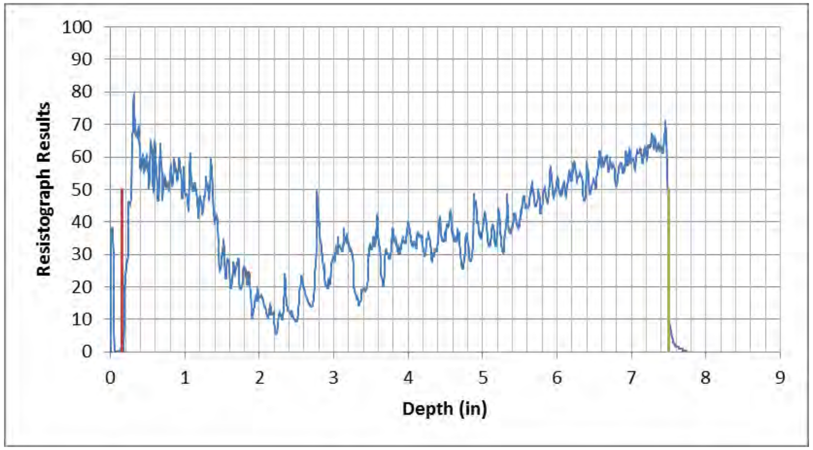
Post Number:	68
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	7.4 inches
Moisture Content:	47.2%
Ring Density (avg.):	9.5 per inch
Resi Score S_{MOR}:	0.95
Resi Score S_U:	0.99

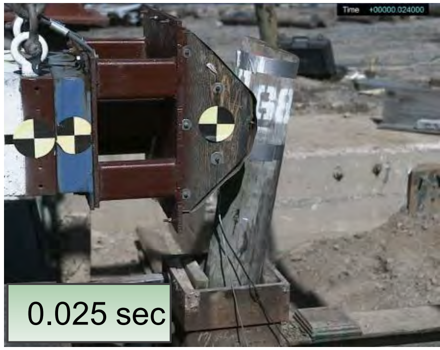
Pendulum Properties

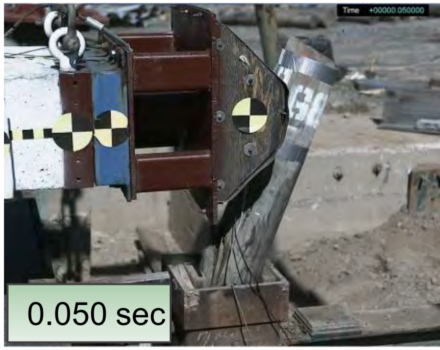
Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches

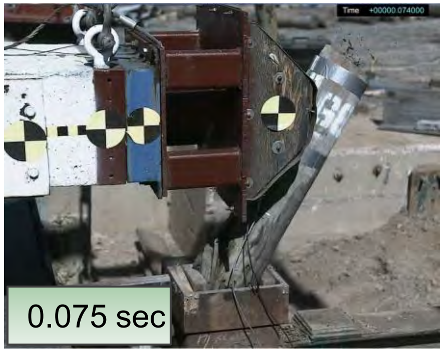


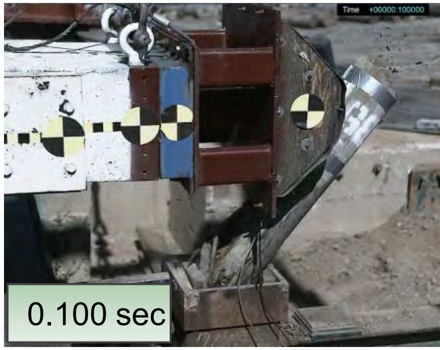












Fractured Post

Test Information

Test Number:	13009N1
Test Date:	03-Oct-2013

Post Properties

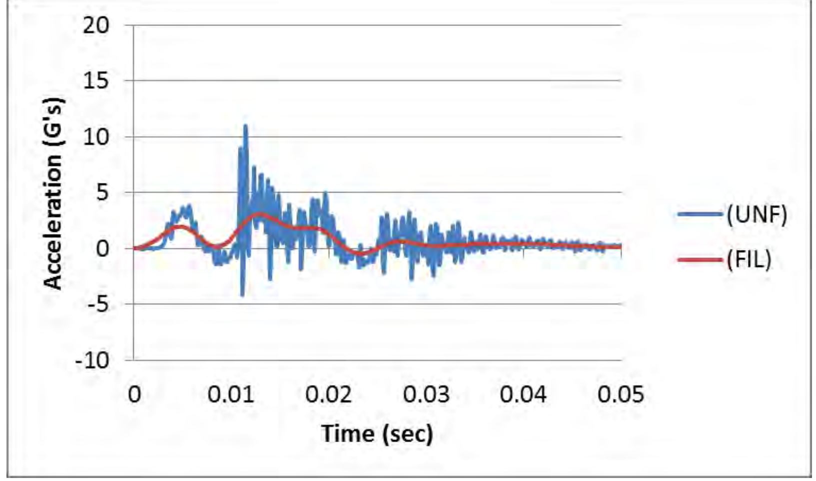
Post Number:	17
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	8.0 inches
Moisture Content:	48%
Ring Density (avg.):	7.4 per inch
Resi Score S_{MOR}:	0.40
Resi Score S_U:	0.38

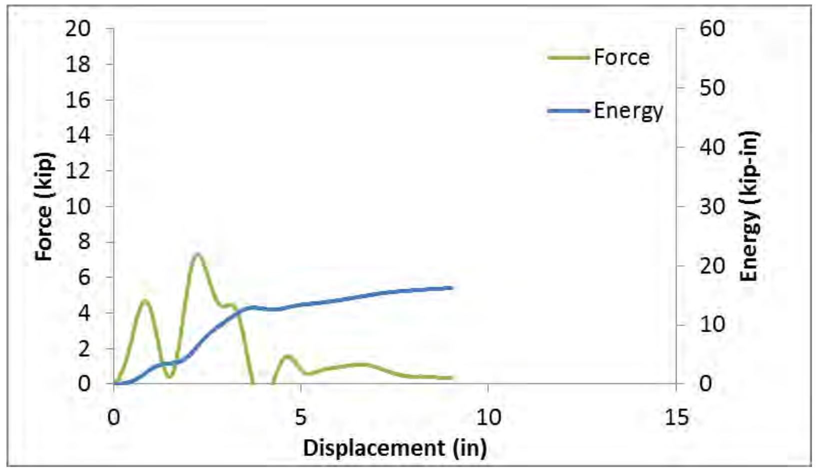
Pendulum Properties

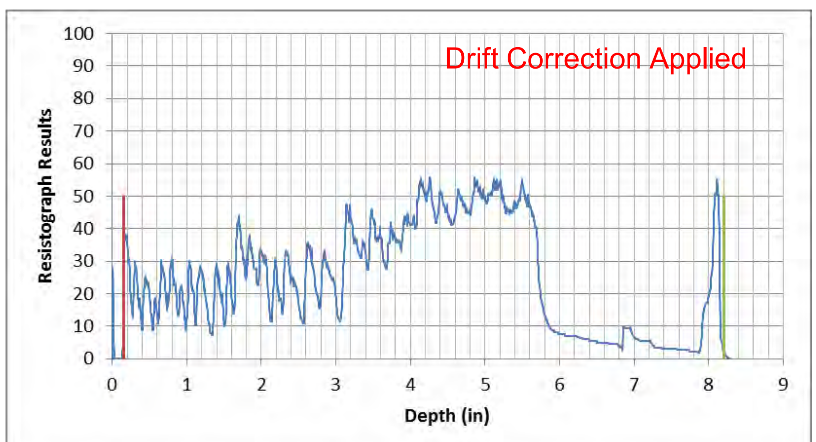
Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches

Ring density at bottom of post

Fractured Post

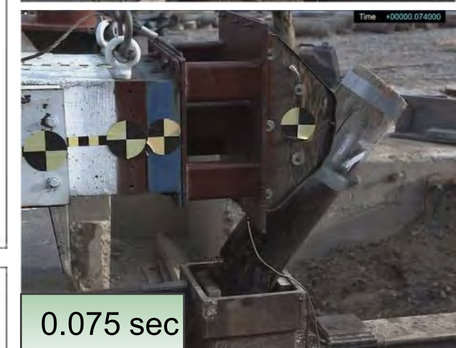




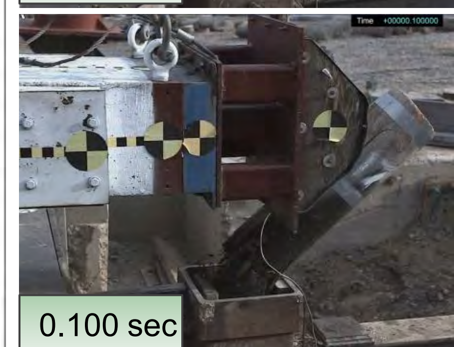


0.025 sec

0.050 sec



0.075 sec



0.100 sec

Test Information

Test Number:	13009O1
Test Date:	03-Oct-2013

Post Properties

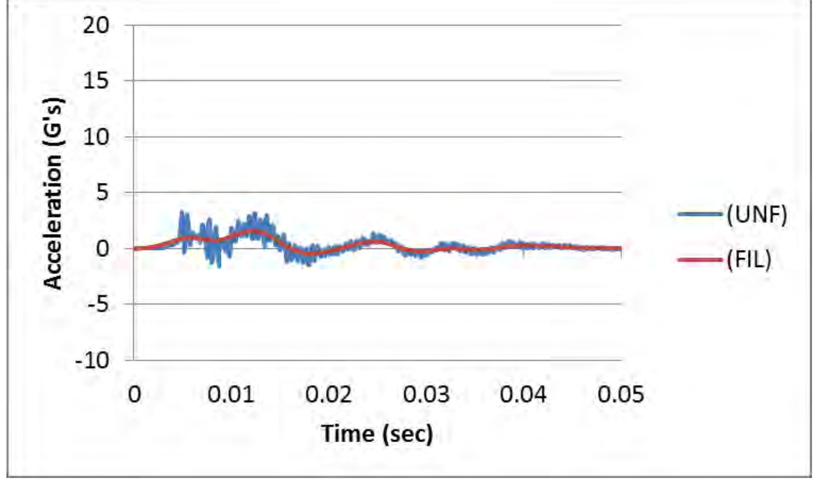
Post Number:	94
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	6.61 inches
Moisture Content:	< 50%
Ring Density (avg.):	6.1 per inch
Resi Score S_{MOR}:	0.24
Resi Score S_U:	0.29

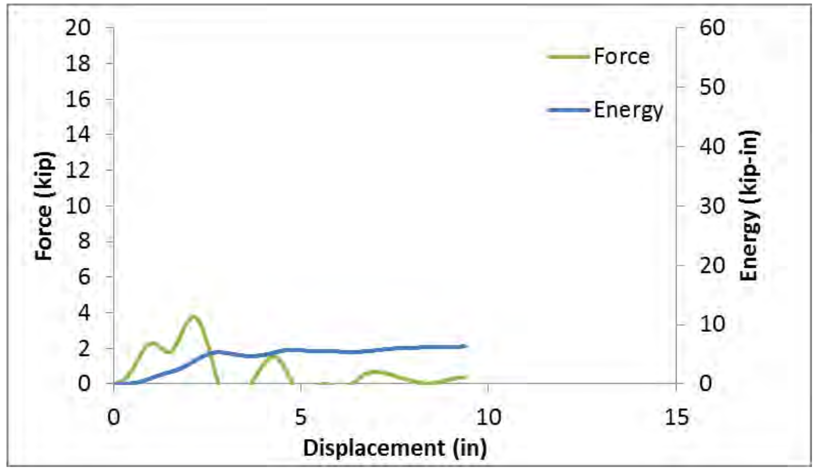
Pendulum Properties

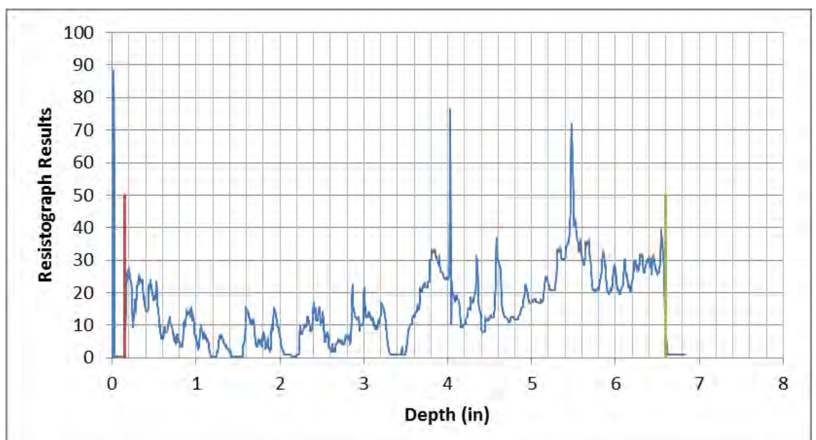
Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches

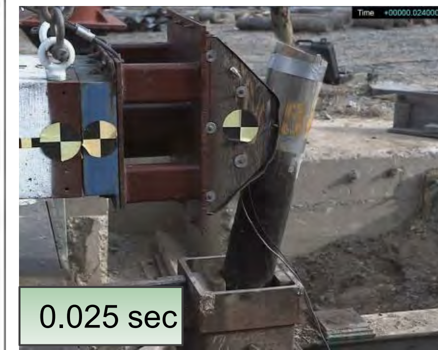
Ring density at bottom of post

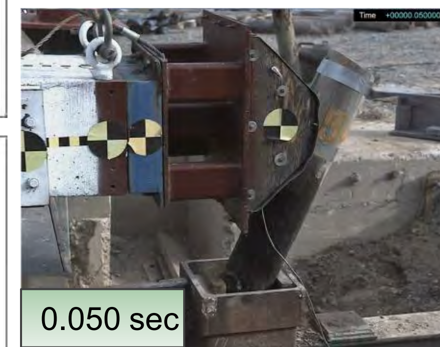
Fractured Post

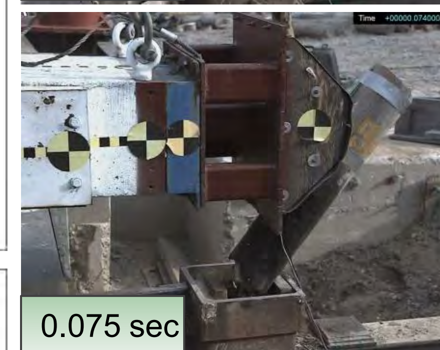


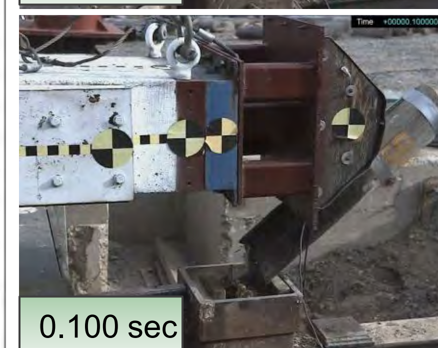












Test Information

Test Number:	13009P1
Test Date:	03-Oct-2013

Post Properties

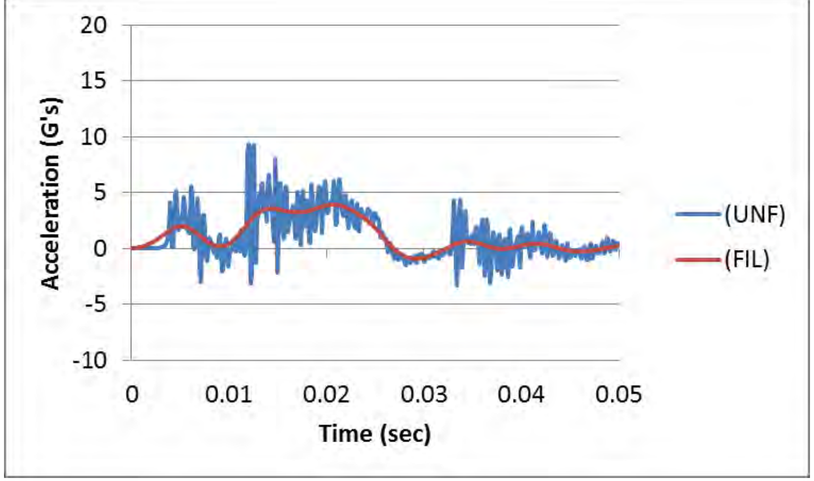
Post Number:	44
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	7.56 inches
Moisture Content:	< 50%
Ring Density (avg.):	8.1 per inch
Resi Score S_{MOR}:	0.40
Resi Score S_U:	0.43

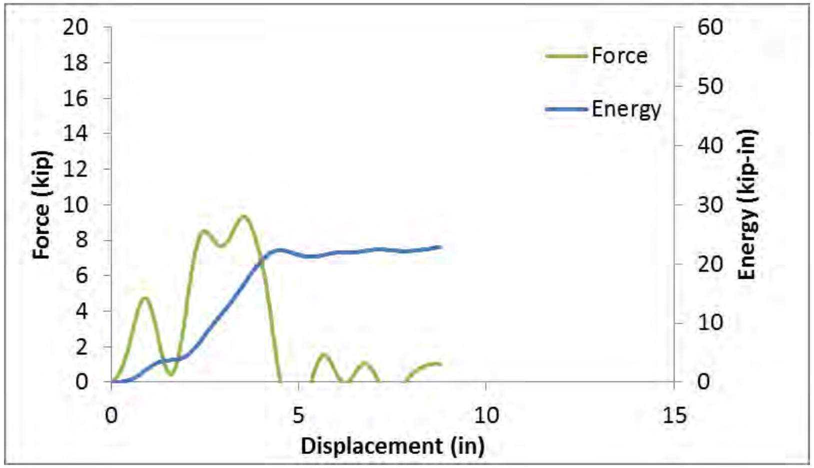
Pendulum Properties

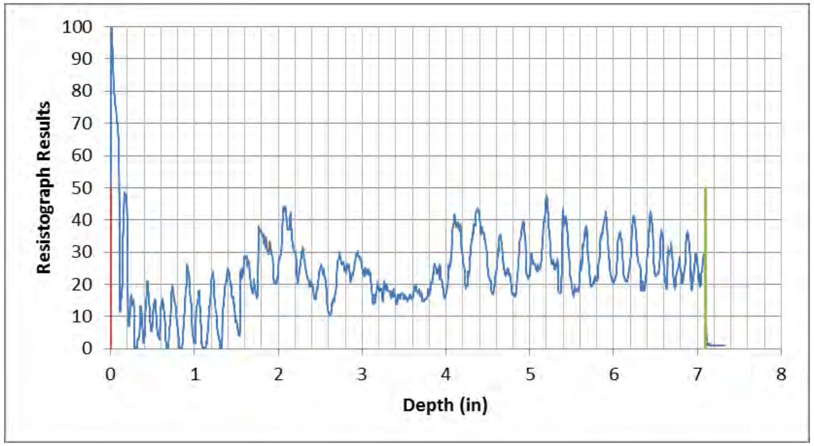
Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches

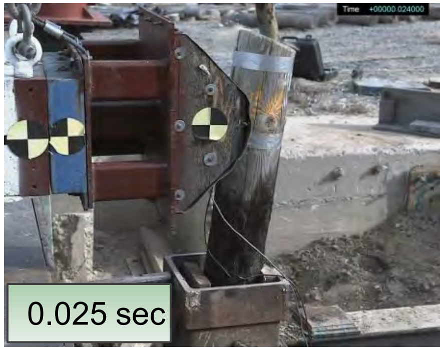
Ring density at bottom of post

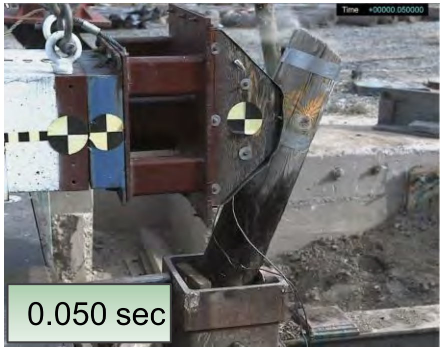
Fractured Post

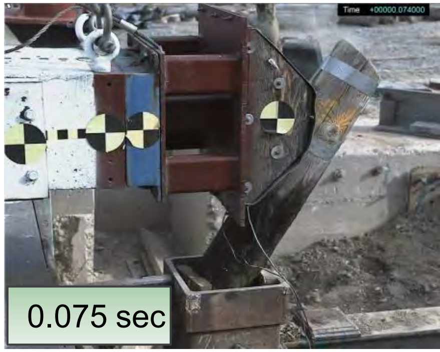


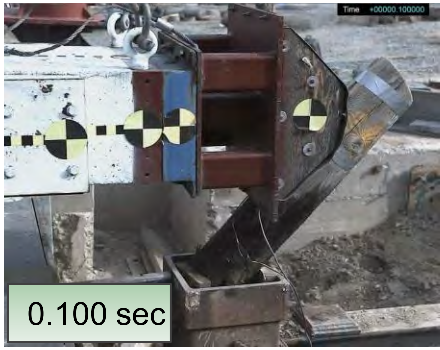












Test Information

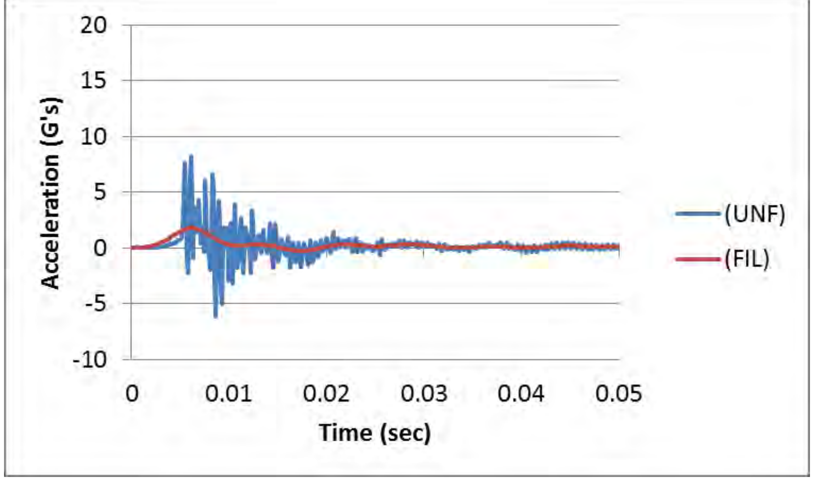
Test Number:	13009Q1
Test Date:	03-Oct-2013

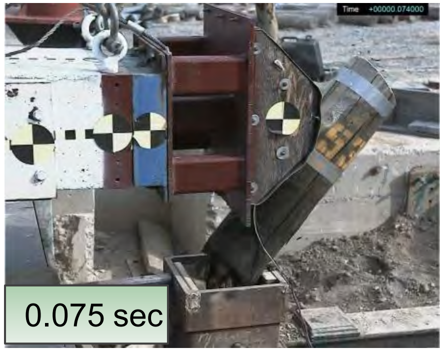
Post Properties

Post Number:	53
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	7.64 inches
Moisture Content:	47.62%
Ring Density (avg.):	6.2 per inch
Resi Score S_{MOR}:	0.68
Resi Score S_U:	0.67

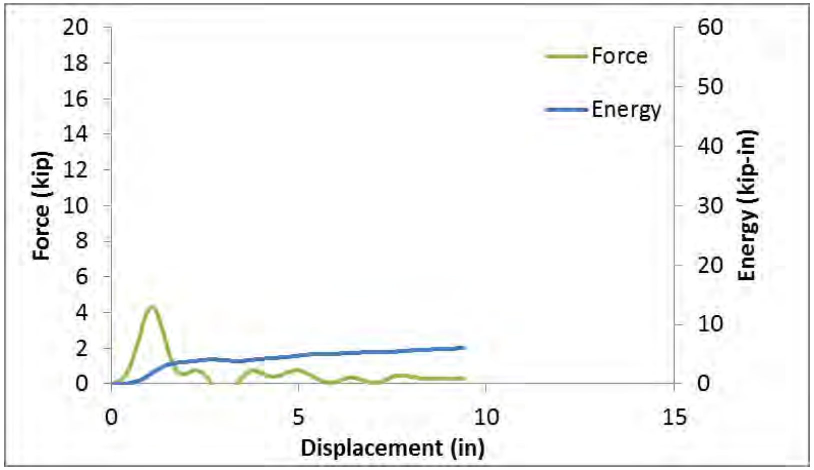
Pendulum Properties

Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches

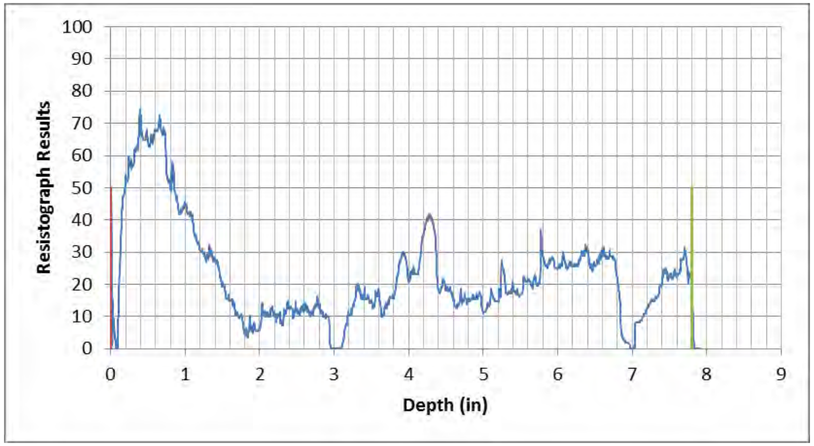




Ring density at bottom of post



Fractured Post



Test Information

Test Number:	13009R1
Test Date:	03-Oct-2013

Post Properties

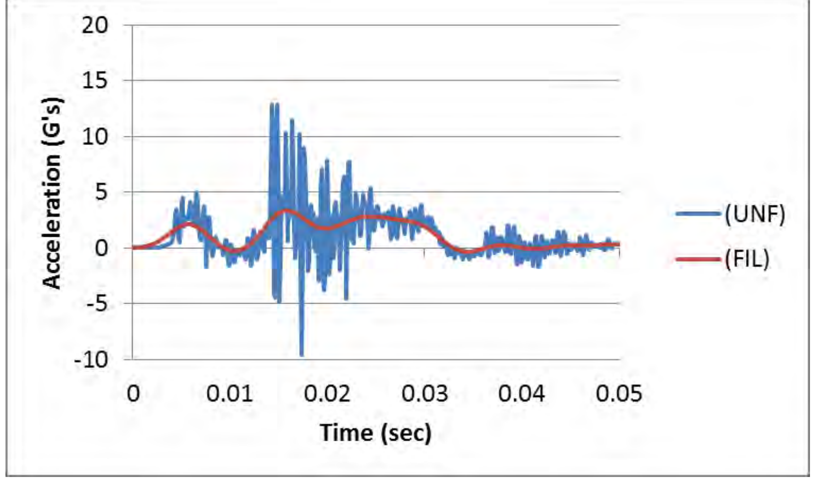
Post Number:	84
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	6.61 inches
Moisture Content:	49.72%
Ring Density (avg.):	8.5 per inch
Resi Score S_{MOR}:	0.43
Resi Score S_U:	0.47

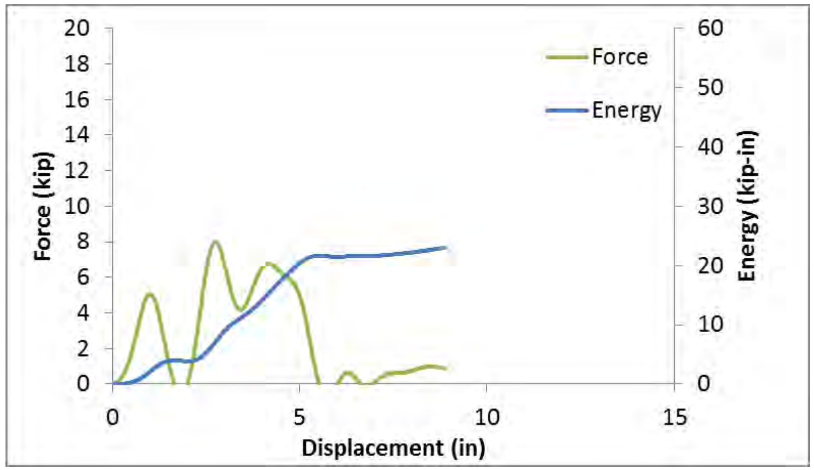
Pendulum Properties

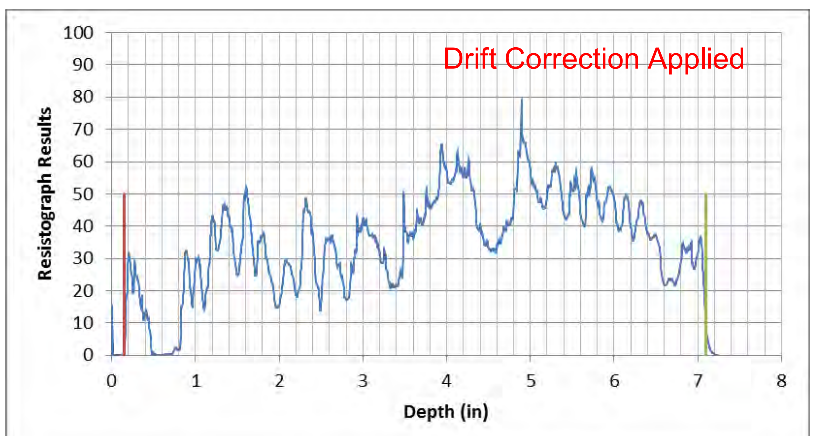
Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches

Ring density at bottom of post


Fractured Post







Test Information

Test Number:	13009S1
Test Date:	03-Oct-2013

Post Properties

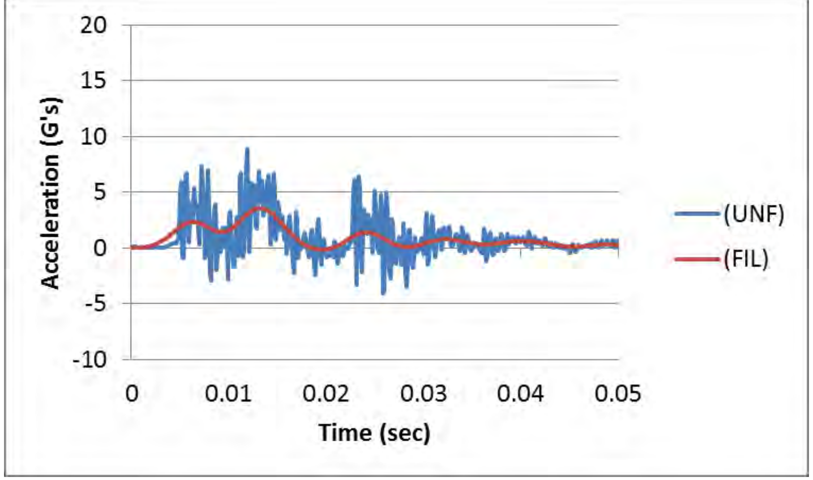
Post Number:	21
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	7.96 inches
Moisture Content:	< 50%
Ring Density (avg.):	12.2 per inch
Resi Score S_{MOR}:	0.82
Resi Score S_U:	0.77

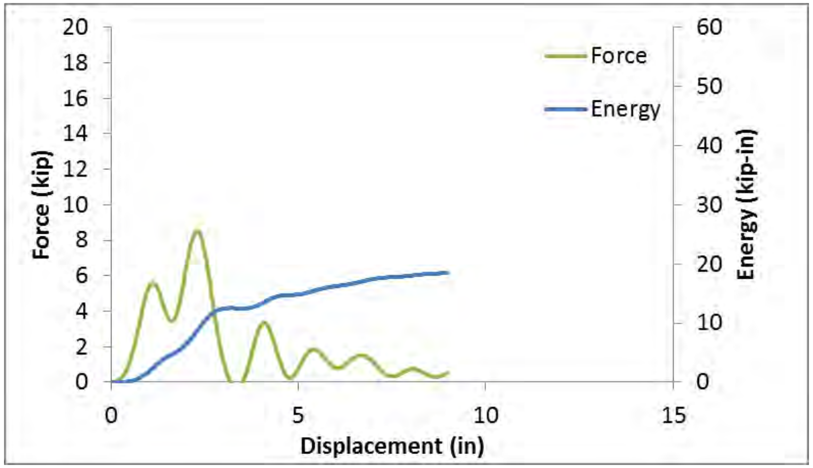
Pendulum Properties

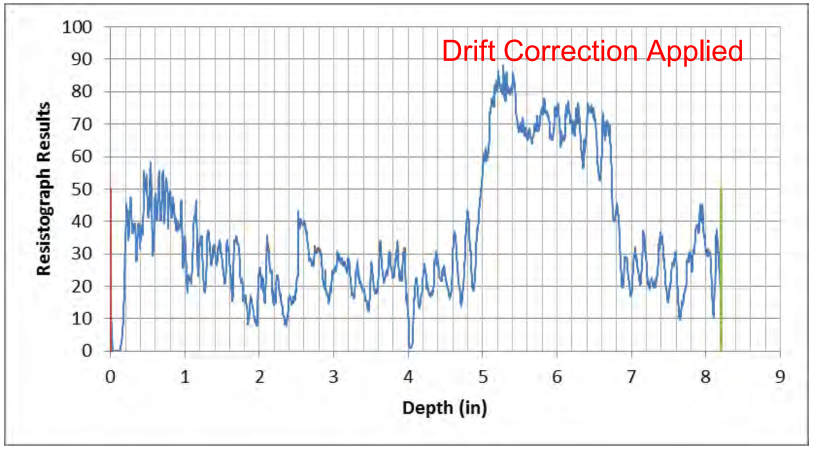
Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches

Ring density at bottom of post

Fractured Post







Test Information

Test Number:	13009T1
Test Date:	03-Oct-2013

Post Properties

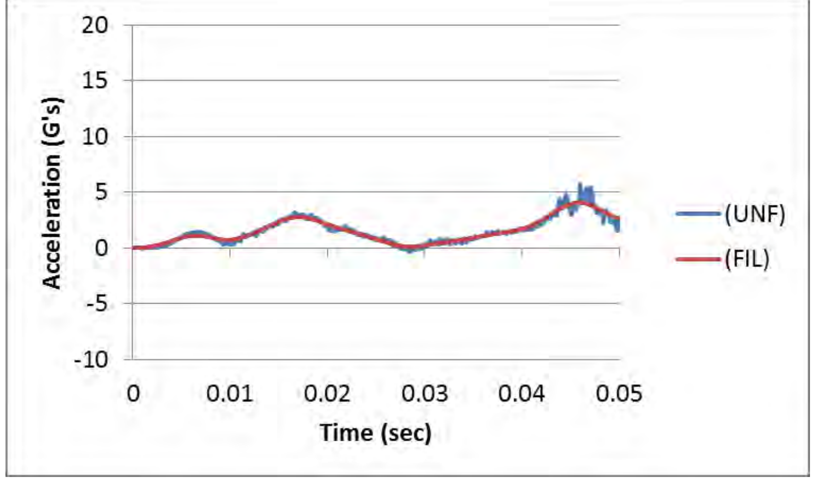
Post Number:	63
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	7.48 inches
Moisture Content:	37.26%
Ring Density (avg.):	8.0 per inch
Resi Score S_{MOR}:	0.69
Resi Score S_U:	0.75

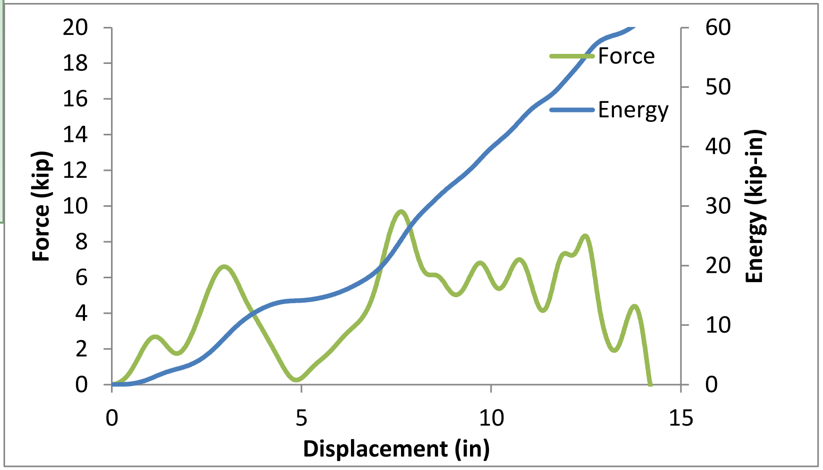
Pendulum Properties

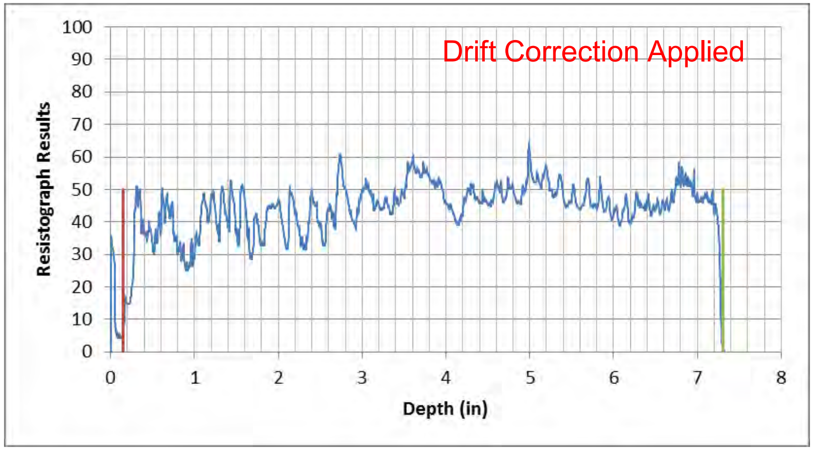
Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches

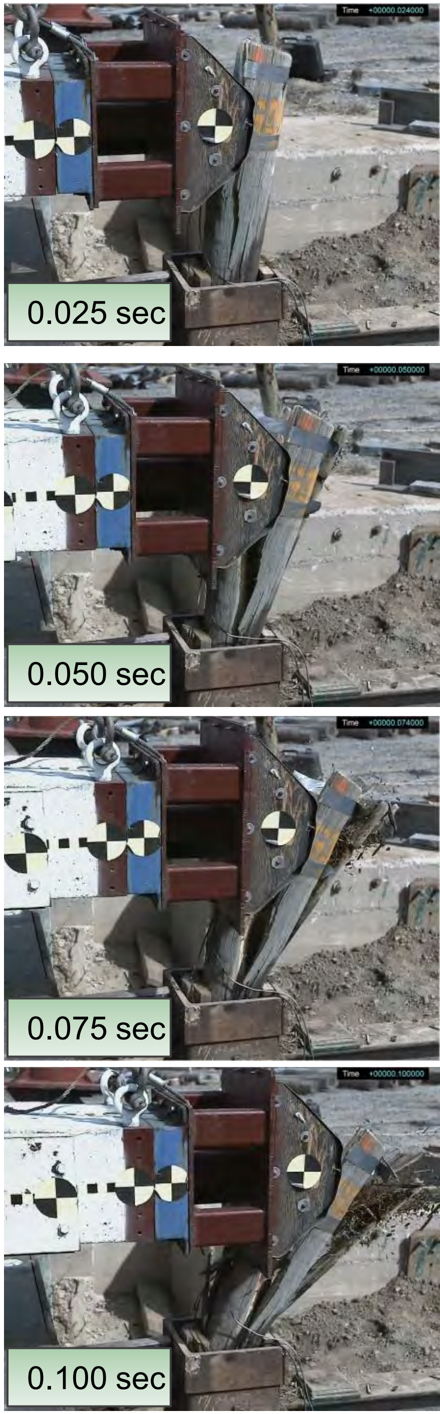
Ring density at bottom of post

Fractured Post









Test Information

Test Number:	13009U1
Test Date:	03-Oct-2013

Post Properties

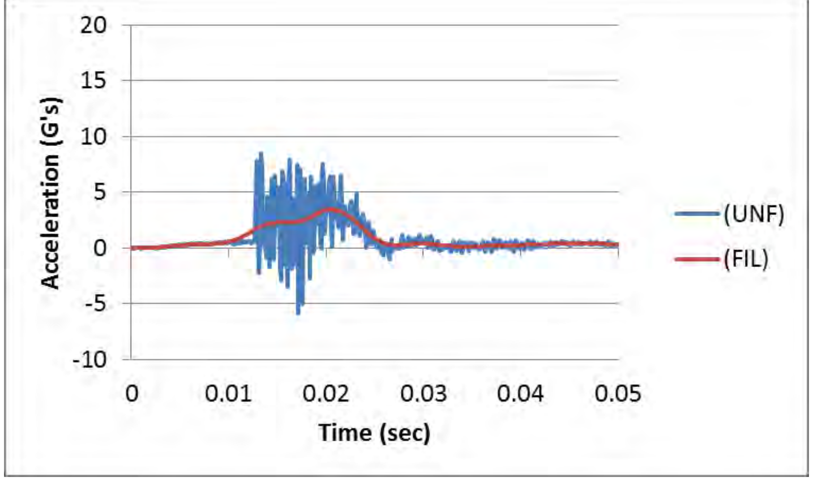
Post Number:	65
Post Type:	Round SYP
Post Length:	60 inches
Post Diameter:	7.64 inches
Moisture Content:	< 50%
Ring Density (avg.):	8.3 per inch
Resi Score S_{MOR}:	0.34
Resi Score S_U:	0.34

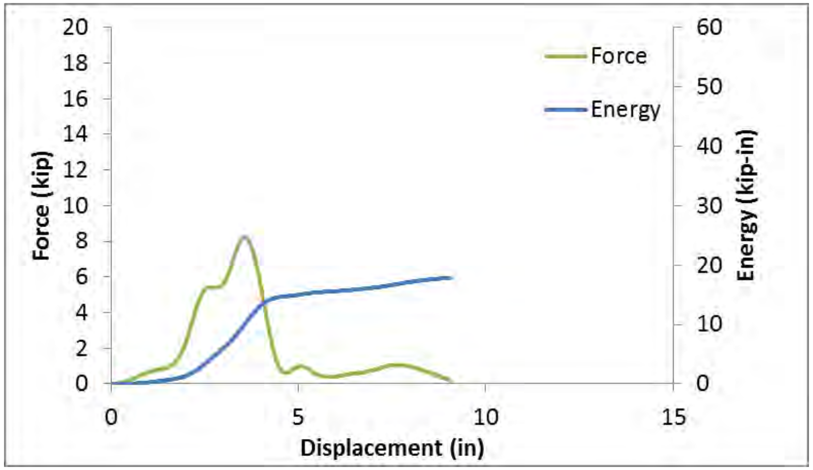
Pendulum Properties

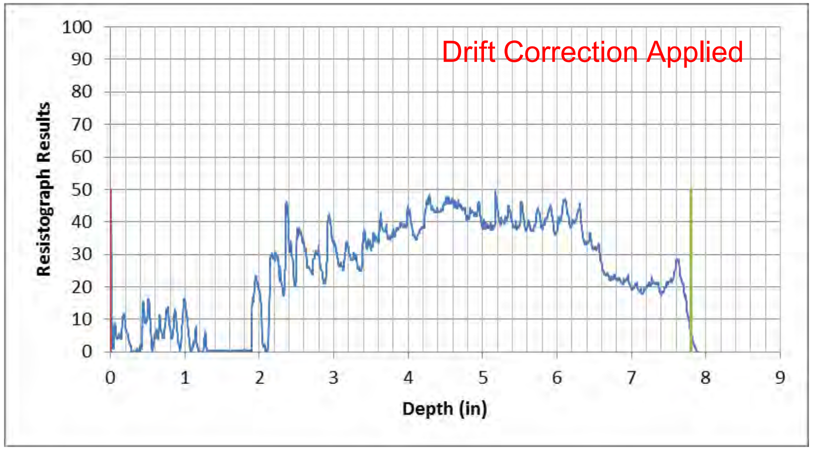
Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches

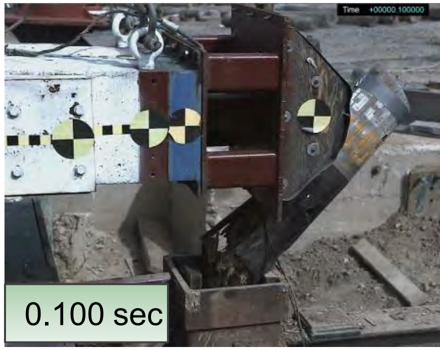
Ring density at bottom of post

Fractured Post









Test Information

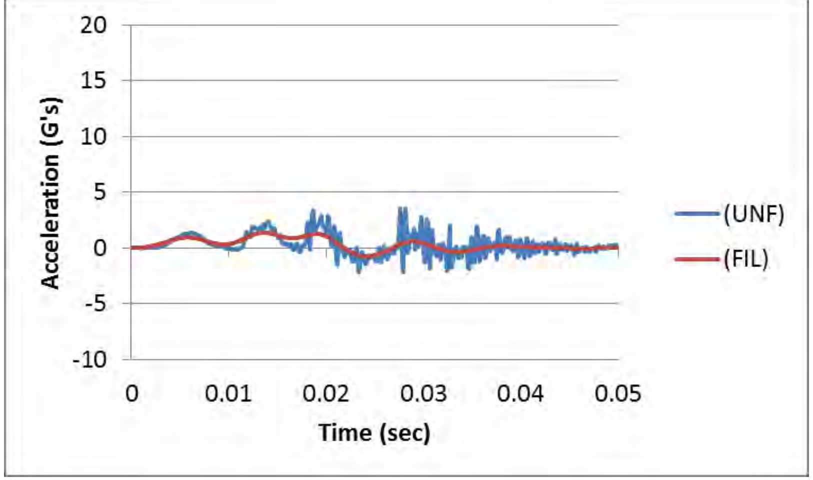
Test Number:	13009V1
Test Date:	08-Oct-2013

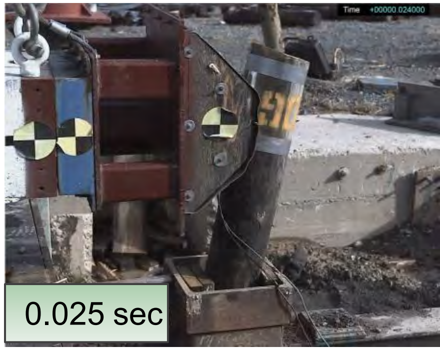
Post Properties

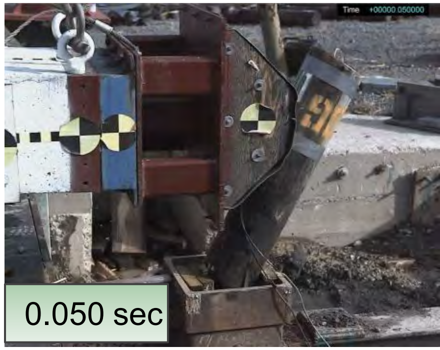
Post Number:	90
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	7.01 inches
Moisture Content:	< 50%
Ring Density (avg.):	4.5 per inch
Resi Score S_{MOR}:	0.12
Resi Score S_U:	0.13

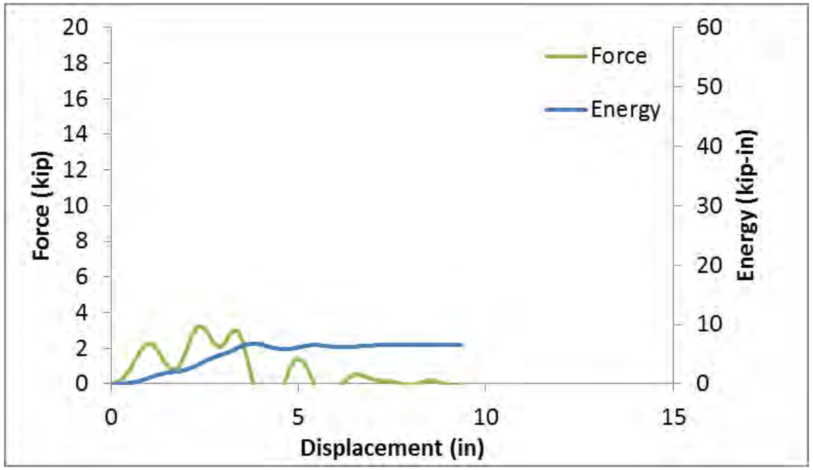
Pendulum Properties

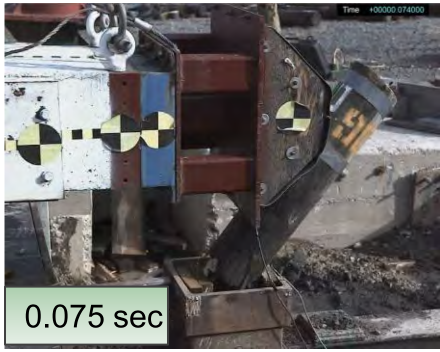
Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches



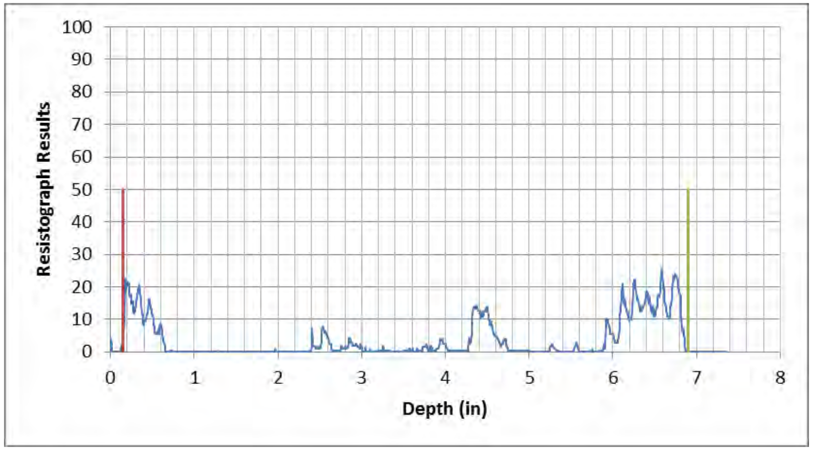


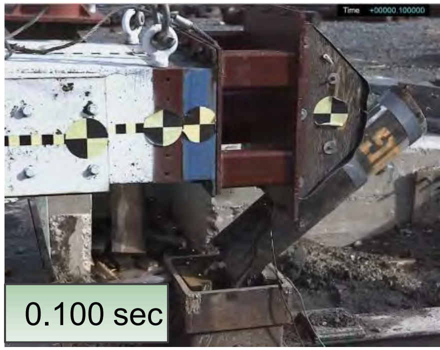






Ring density at bottom of post





Fractured Post

Test Information

Test Number:	13009W1
Test Date:	08-Oct-2013

Post Properties

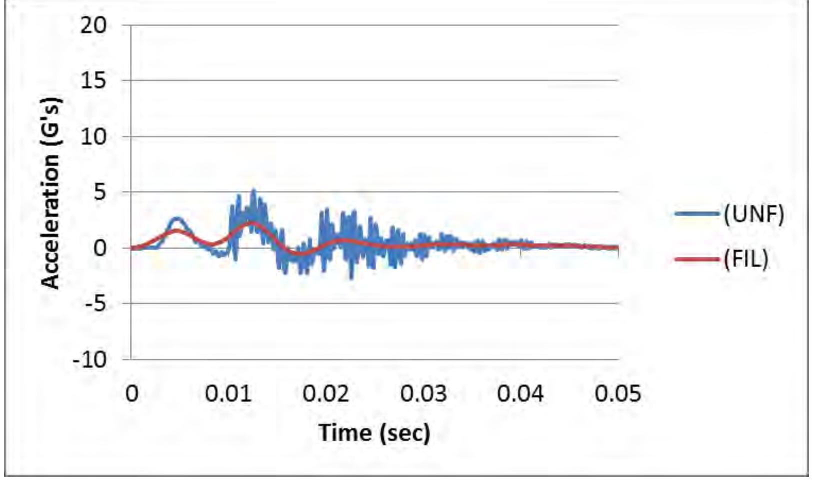
Post Number:	118
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	7.72 inches
Moisture Content:	< 50%
Ring Density (avg.):	6.9 per inch
Resi Score S_{MOR}:	0.34
Resi Score S_U:	0.34

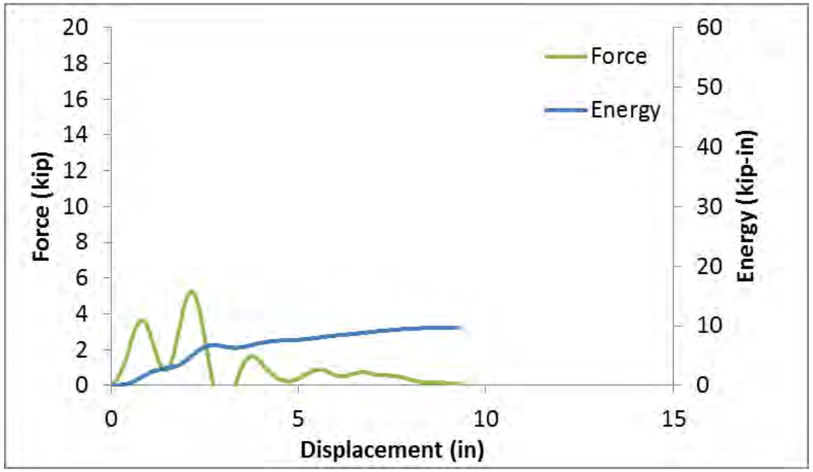
Pendulum Properties

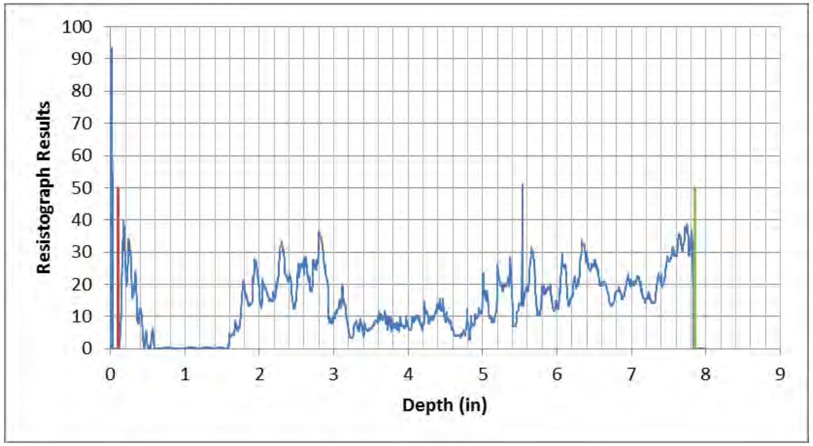
Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches

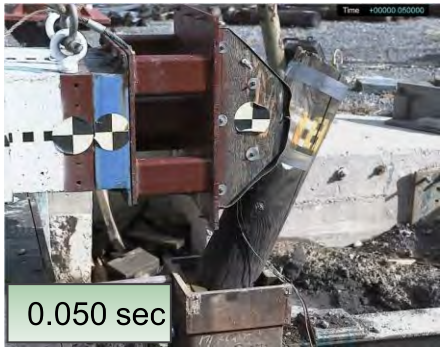
Ring density at bottom of post

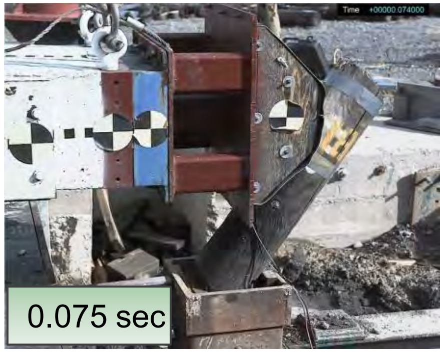
Fractured Post

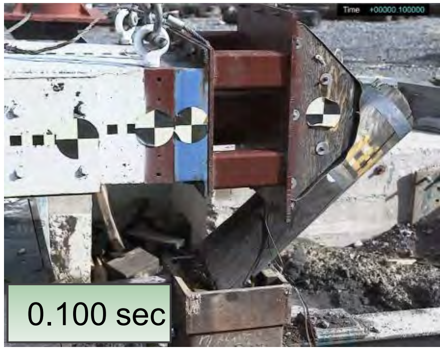












Test Information

Test Number:	13009X1
Test Date:	08-Oct-2013

Post Properties

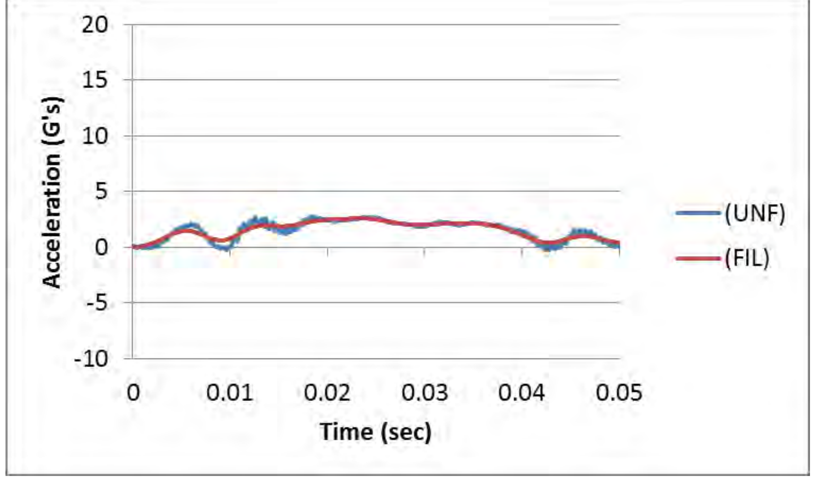
Post Number:	81
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	6.69 inches
Moisture Content:	< 50%
Ring Density (avg.):	6.1 per inch
Resi Score S_{MOR}:	0.33
Resi Score S_U:	0.38

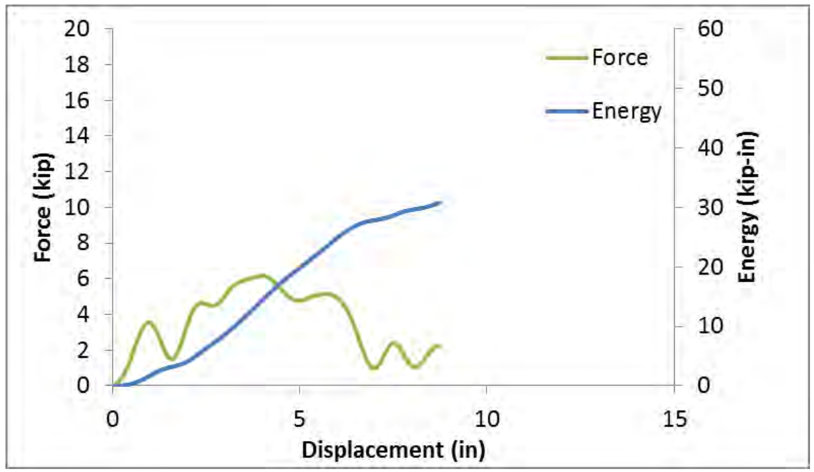
Pendulum Properties

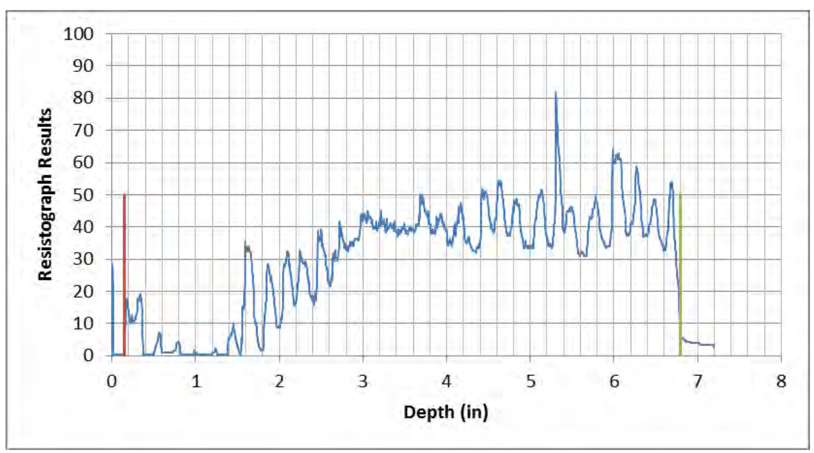
Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches

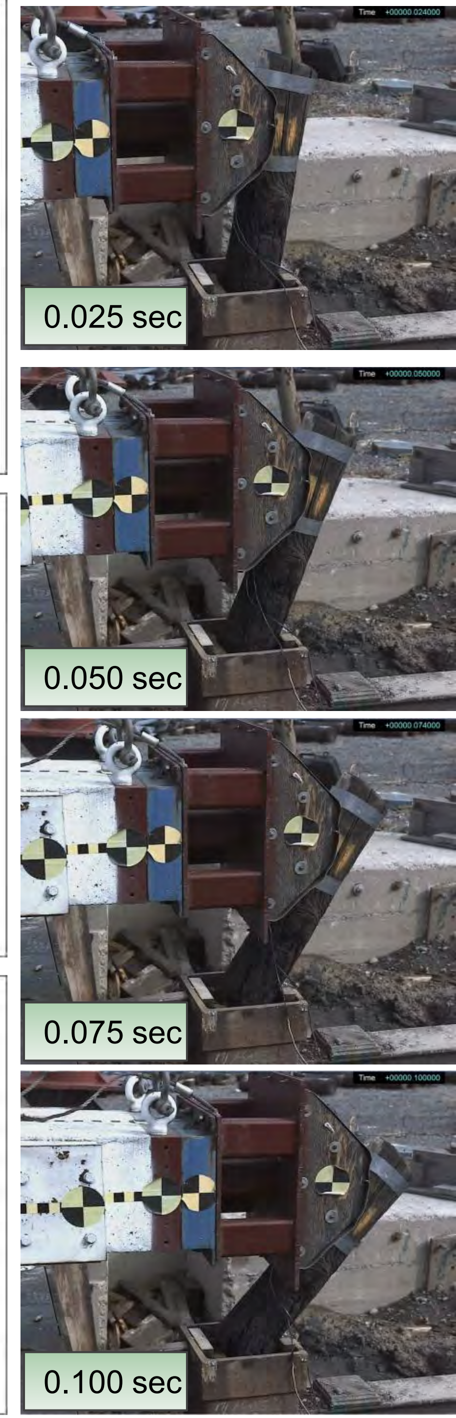
Ring density at bottom of post

Fractured Post









Test Information

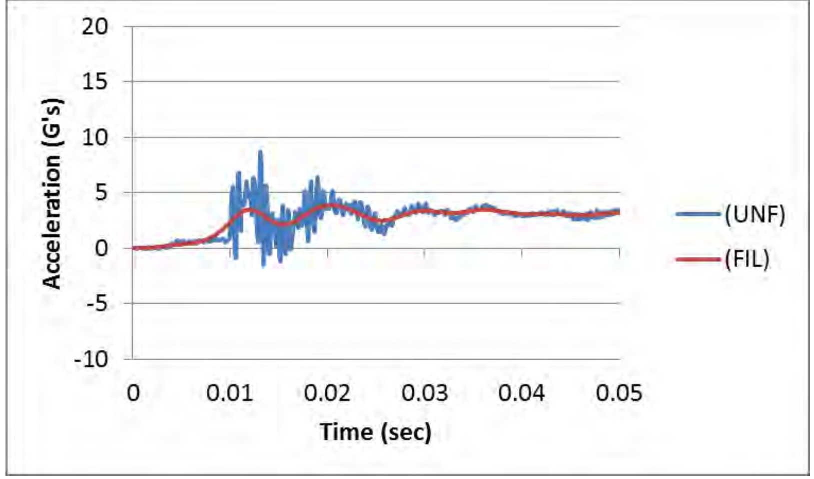
Test Number:	13009Y1
Test Date:	08-Oct-2013

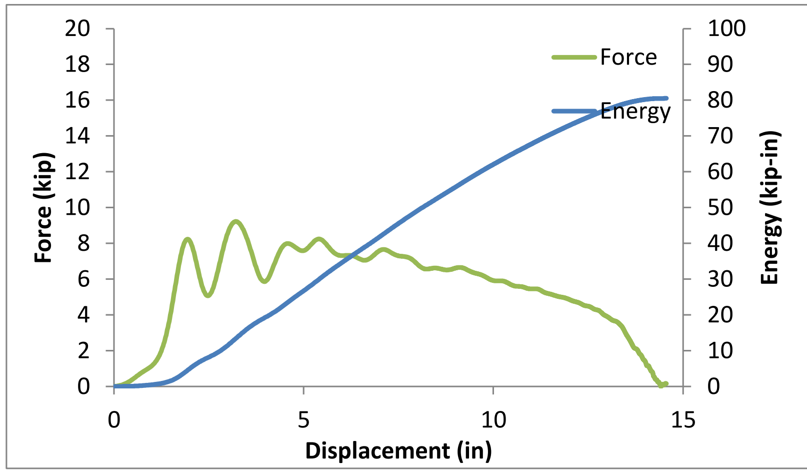
Post Properties

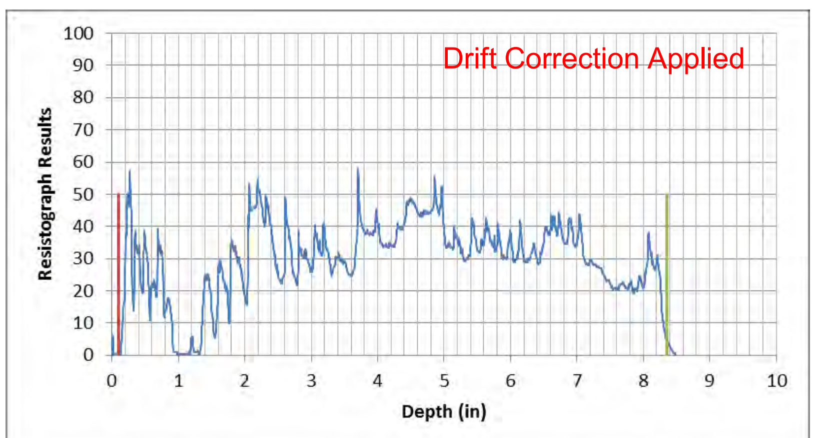
Post Number:	123
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	8.28 inches
Moisture Content:	< 50%
Ring Density (avg.):	4.6 per inch
Resi Score S_{MOR}:	0.66
Resi Score S_U:	0.61

Pendulum Properties

Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches








Ring density at bottom of post


Fractured Post

Test Information

Test Number:	13009Z1
Test Date:	08-Oct-2013

Post Properties

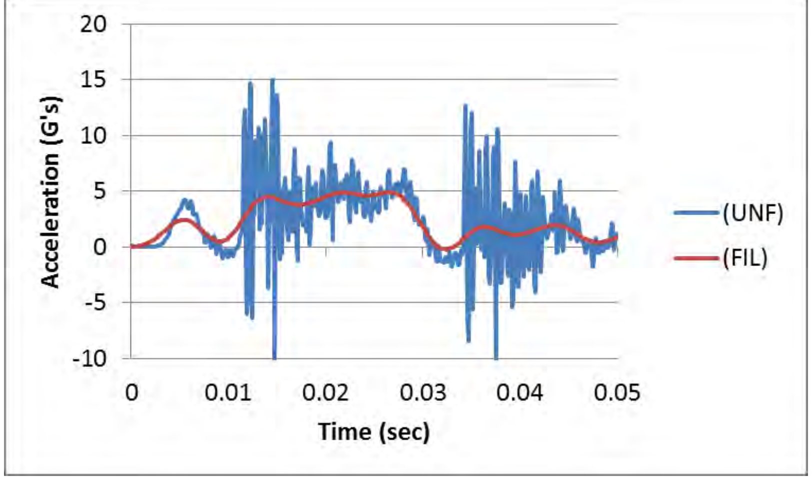
Post Number:	61
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	8.2 inches
Moisture Content:	45.5%
Ring Density (avg.):	6.0 per inch
Resi Score S_{MOR}:	0.71
Resi Score S_U:	0.68

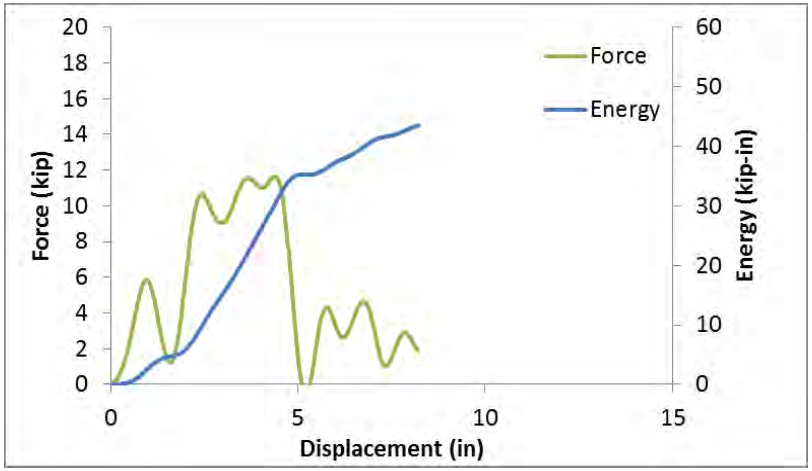
Pendulum Properties

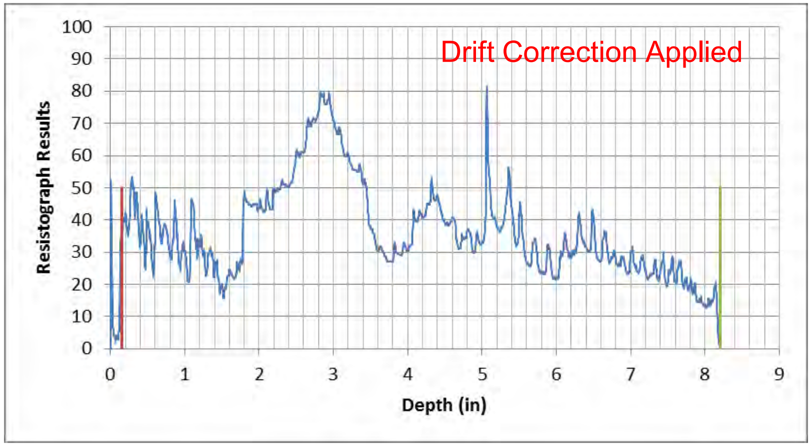
Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches

Ring density at bottom of post

Fractured Post







Test Information

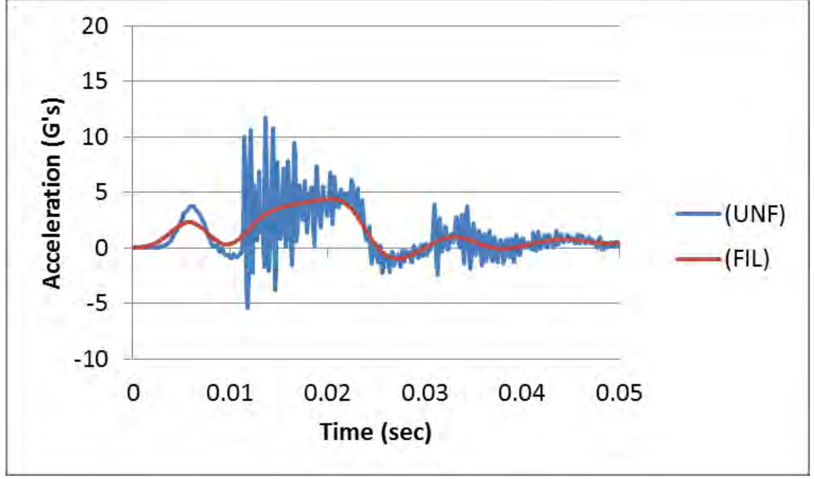
Test Number:	13009A2
Test Date:	08-Oct-2013

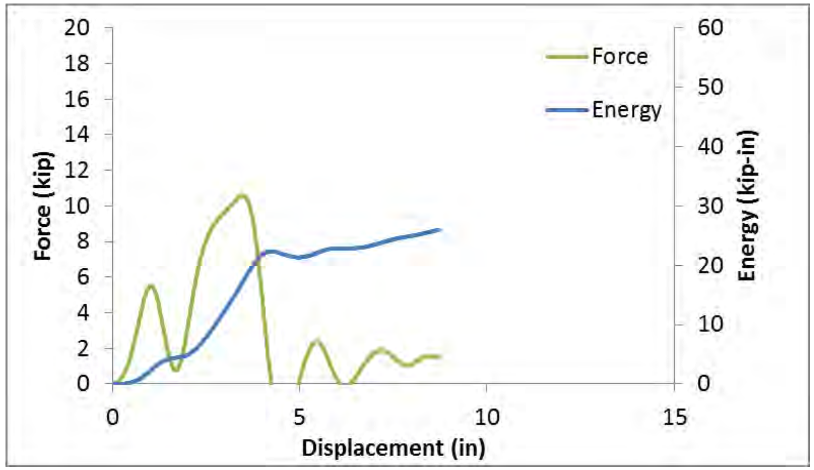
Post Properties

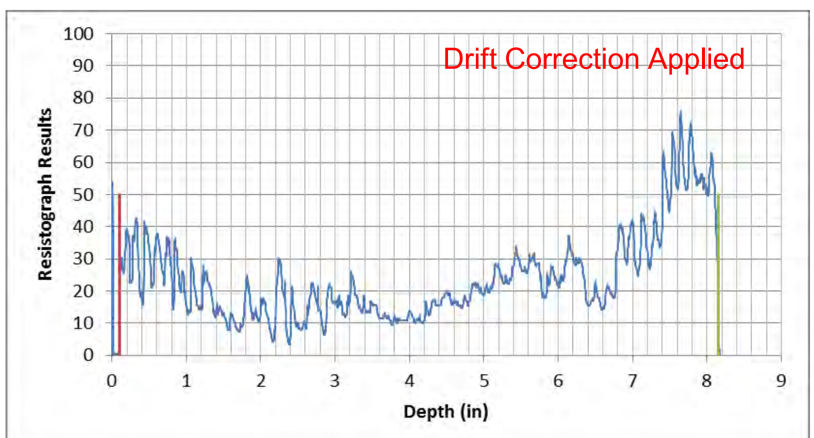
Post Number:	67
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	8.2 inches
Moisture Content:	< 50%
Ring Density (avg.):	5.2 per inch
Resi Score S_{MOR}:	0.83
Resi Score S_U:	0.80

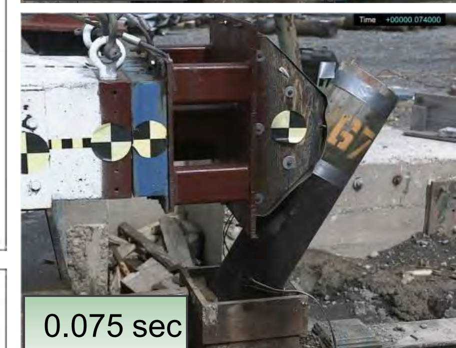
Pendulum Properties

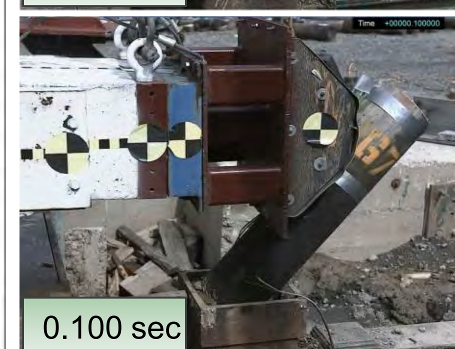
Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches











Ring density at bottom of post

Fractured Post

Test Information

Test Number:	13009B2
Test Date:	08-Oct-2013

Post Properties

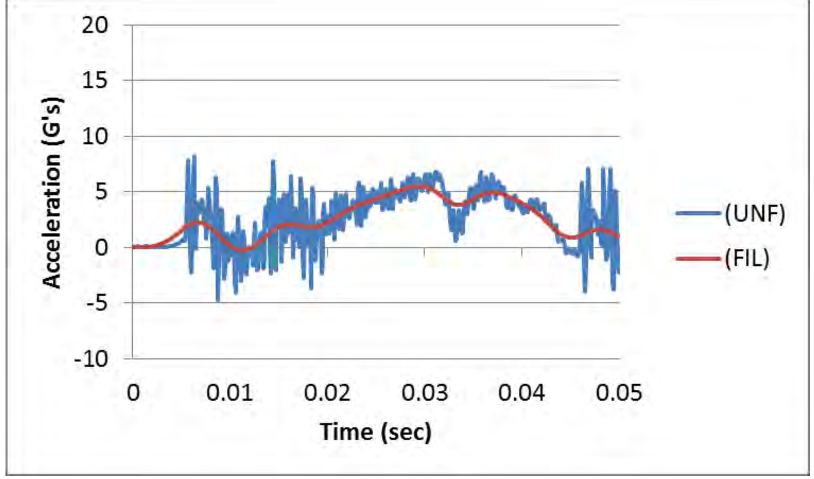
Post Number:	126
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	8.28 inches
Moisture Content:	< 50%
Ring Density (avg.):	6.9 per inch
Resi Score S_{MOR}:	0.98
Resi Score S_U:	0.91

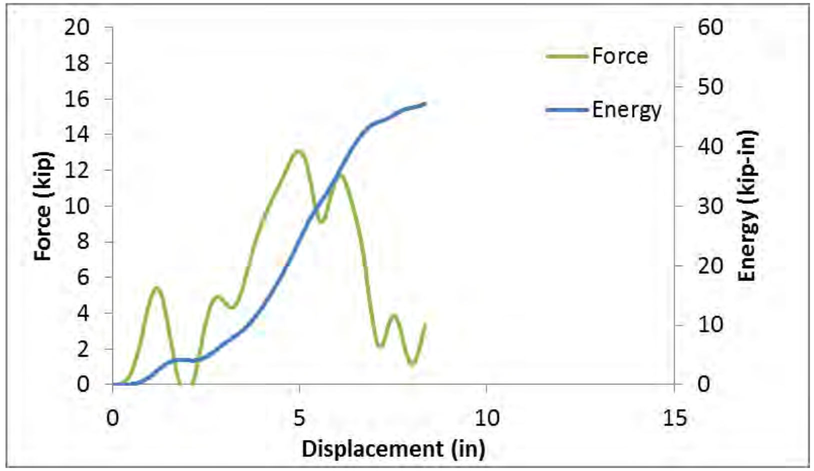
Pendulum Properties

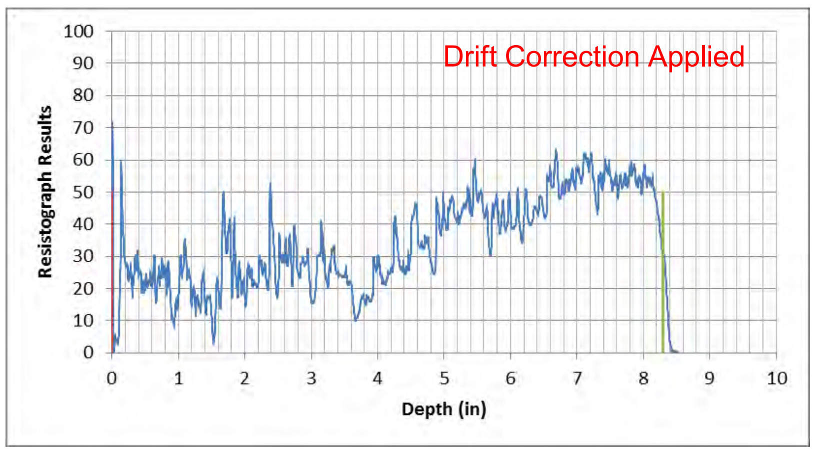
Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches

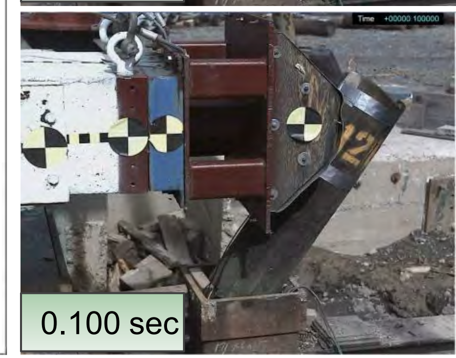
Ring density at bottom of post

Fractured Post









Test Information

Test Number:	13009C2
Test Date:	08-Oct-2013

Post Properties

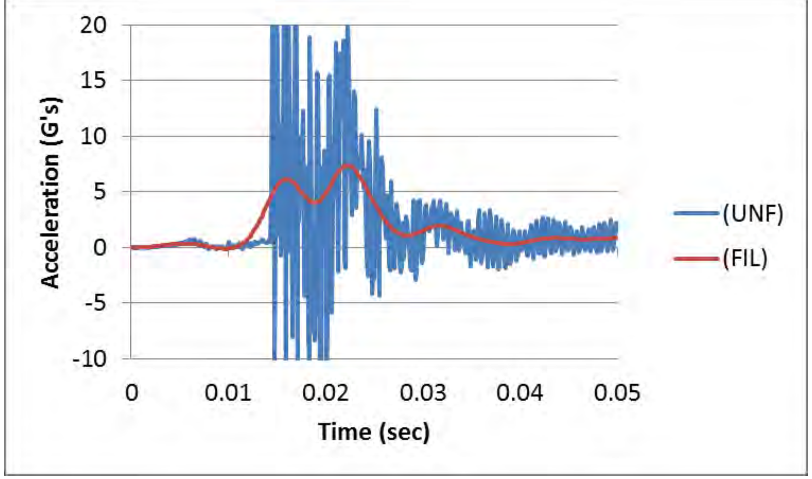
Post Number:	91
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	8.6 inches
Moisture Content:	46.16%
Ring Density (avg.):	8.6 per inch
Resi Score S_{MOR}:	1.14
Resi Score S_U:	1.01

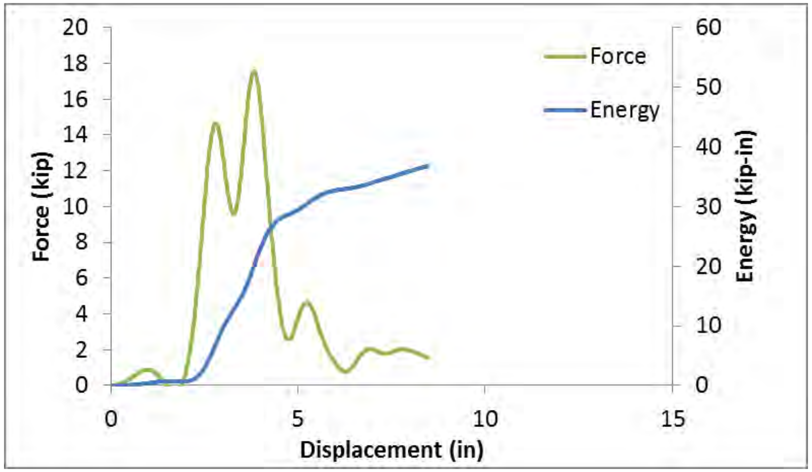
Pendulum Properties

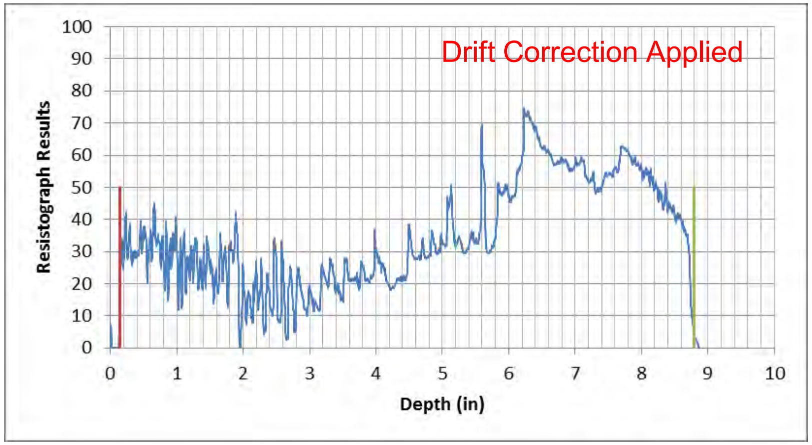
Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches

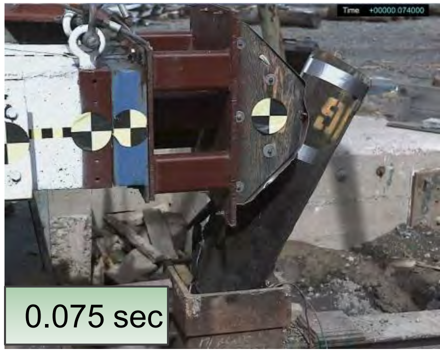
Ring density at bottom of post

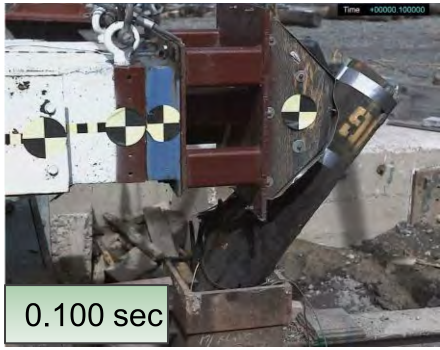
Fractured Post











Test Information

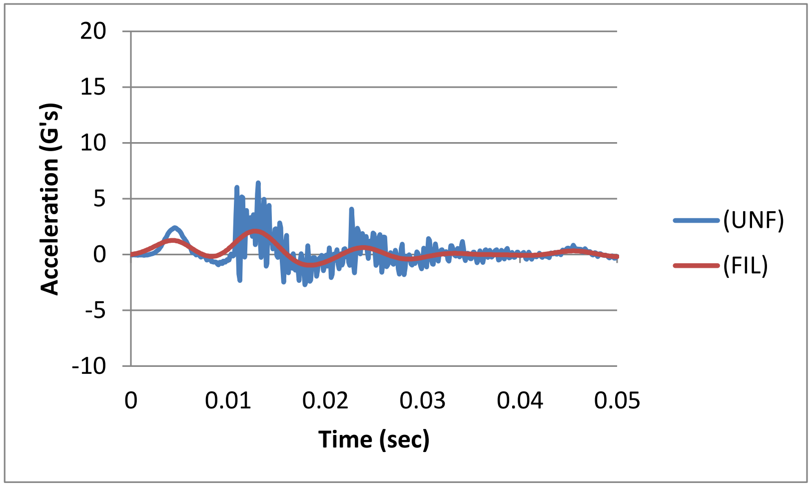
Test Number:	13009D2
Test Date:	9-Oct-2013

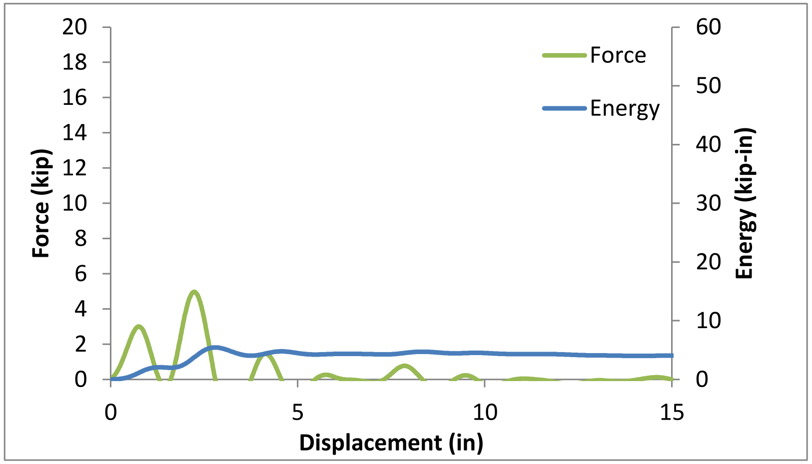
Post Properties

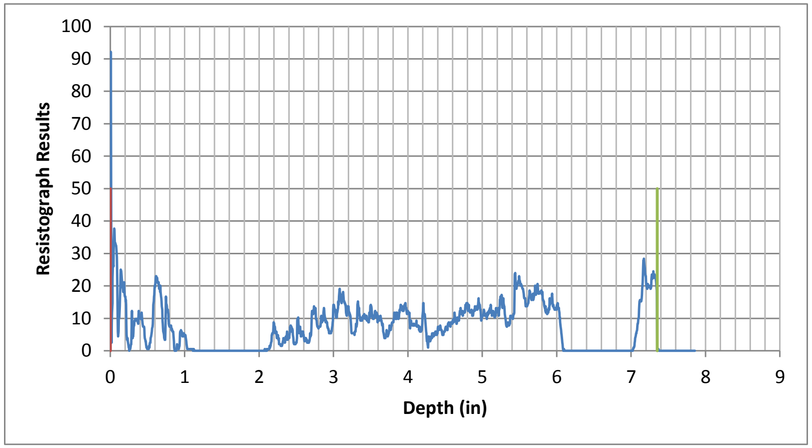
Post Number:	105
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	7.4 inches
Moisture Content:	>50%
Ring Density (avg.):	4.9 per inch
Resi Score S_{MOR}:	0.16
Resi Score S_U:	0.16

Pendulum Properties

Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches

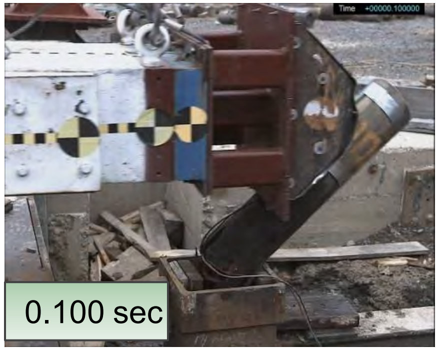






Ring density at bottom of post

Fractured Post



Test Information

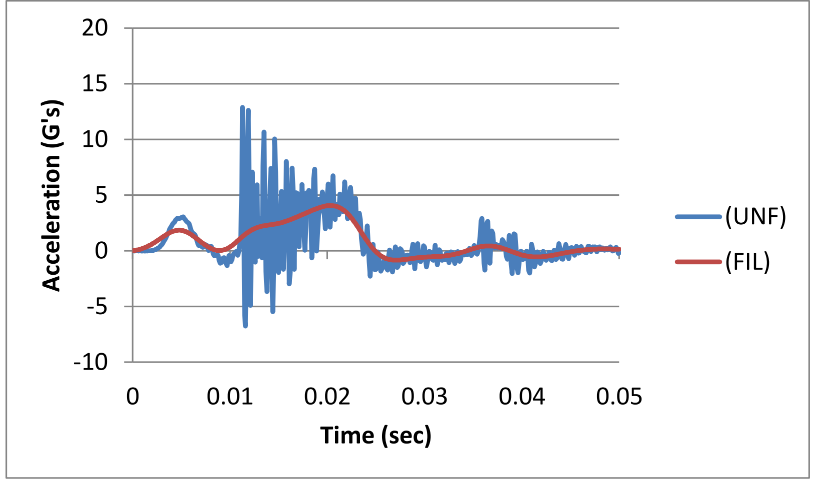
Test Number:	13009E2
Test Date:	9-Oct-2013

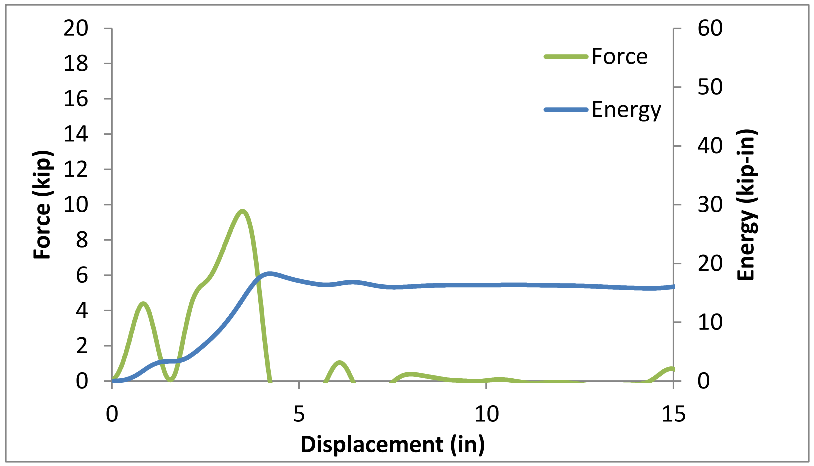
Post Properties

Post Number:	117
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	8.6 inches
Moisture Content:	46.2%
Ring Density (avg.):	5.8 per inch
Resi Score S_{MOR}:	0.40
Resi Score S_U:	0.37

Pendulum Properties

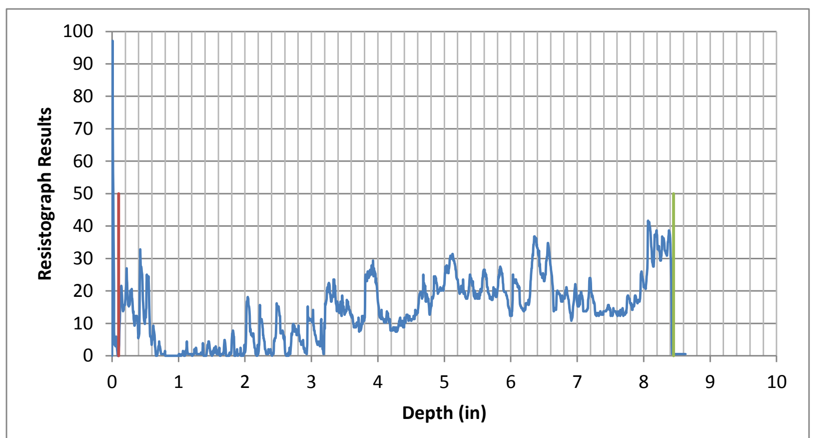
Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches





Ring density at bottom of post

Fractured Post



Test Information

Test Number:	13009F2
Test Date:	9-Oct-2013

Post Properties

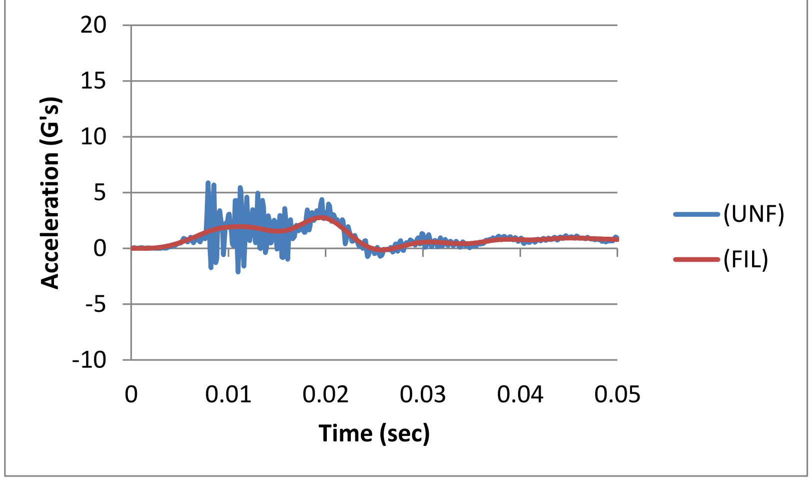
Post Number:	129
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	8.6 inches
Moisture Content:	>50%
Ring Density (avg.):	7.7 per inch
Resi Score S_{MOR}:	0.38
Resi Score S_U:	0.41

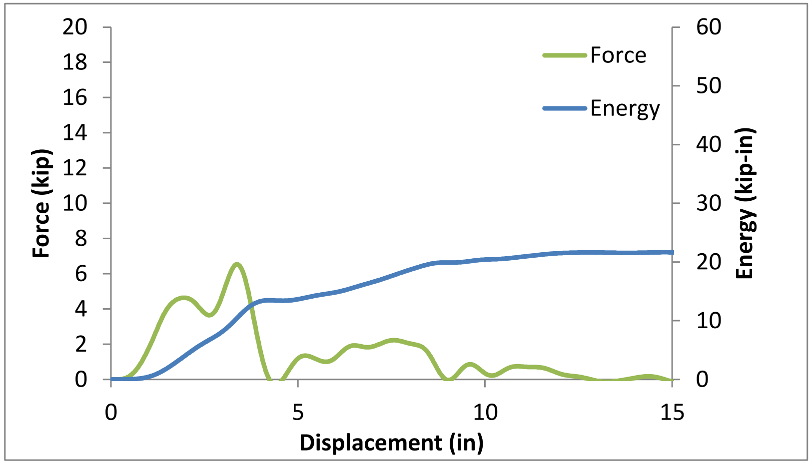
Pendulum Properties

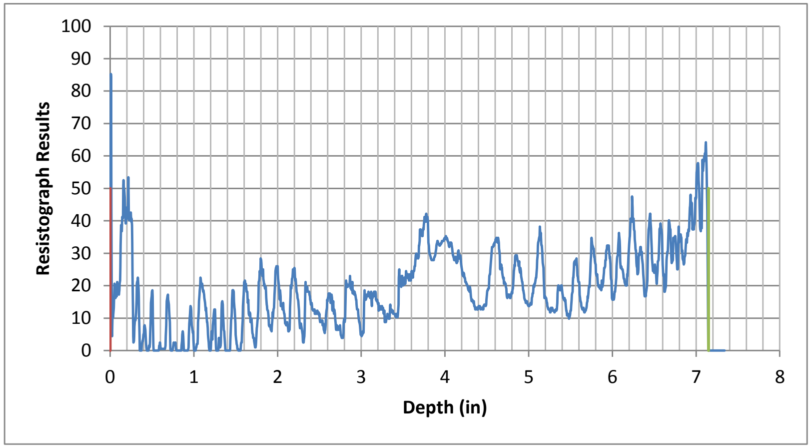
Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches

Ring density at bottom of post

Fractured Post







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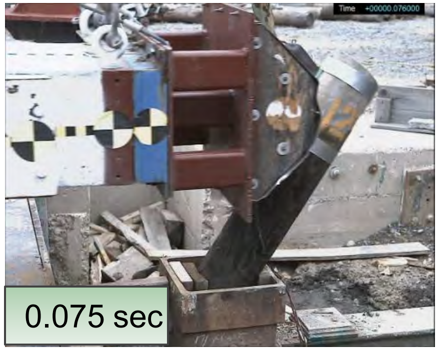
0.050 sec



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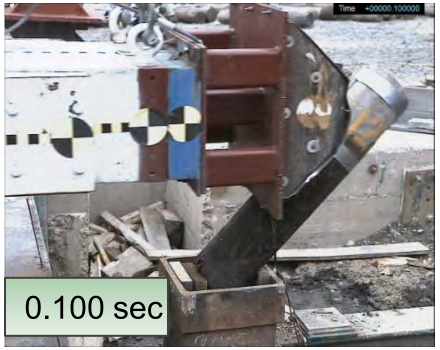


0.100 sec

Test Information

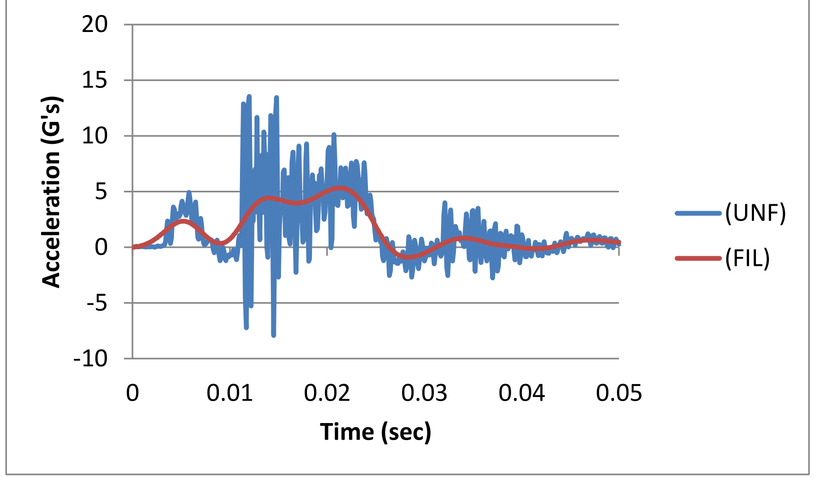
Test Number:	13009G2
Test Date:	9-Oct-2013

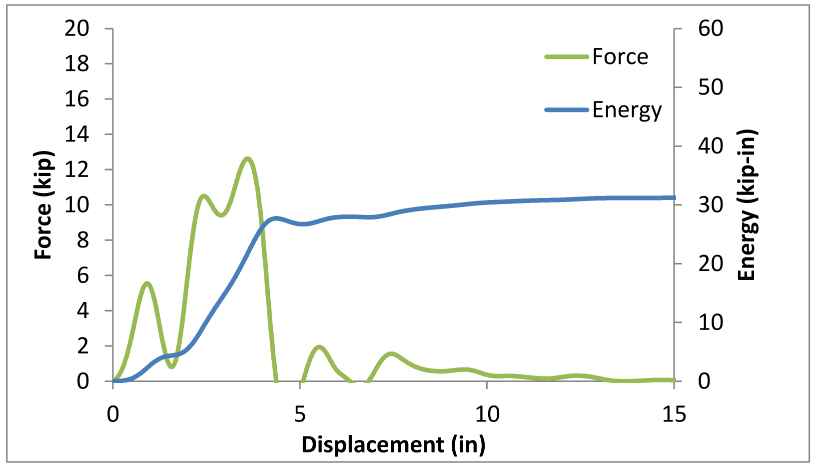
Post Properties

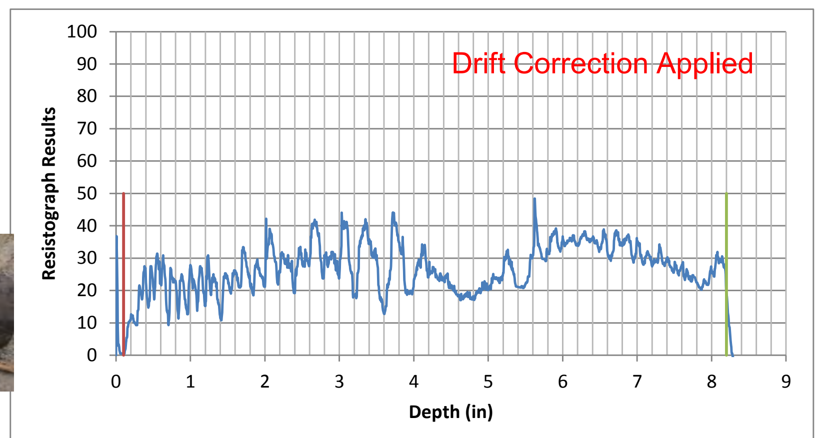
Post Number:	24
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	8.4 inches
Moisture Content:	>50%
Ring Density (avg.):	7.1 per inch
Resi Score S_{MOR}:	0.60
Resi Score S_U:	0.57

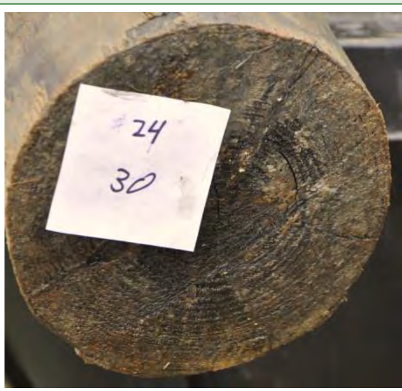
Pendulum Properties

Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches









Ring density at bottom of post

Fractured Post

Test Information

Test Number:	13009H2
Test Date:	9-Oct-2013

Post Properties

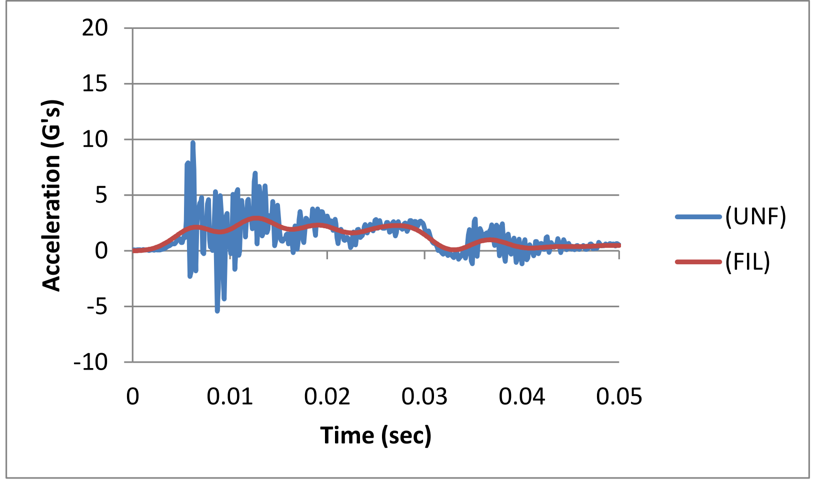
Post Number:	35
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	8.1 inches
Moisture Content:	36.3%
Ring Density (avg.):	5.4 per inch
Resi Score S_{MOR}:	0.66
Resi Score S_U:	0.65

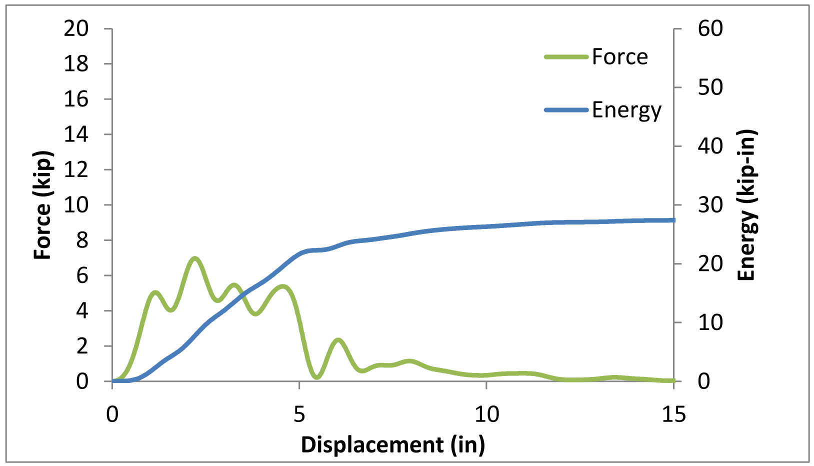
Pendulum Properties

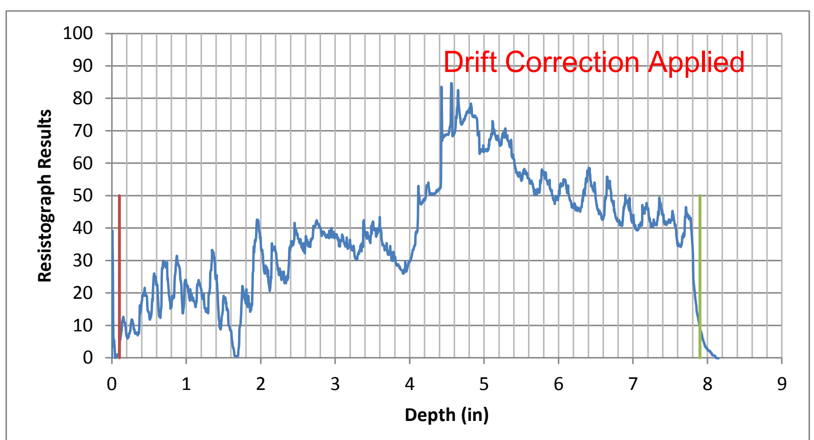
Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches

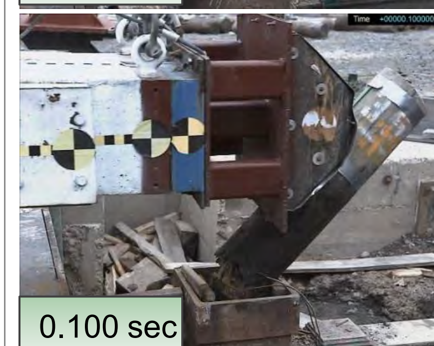
Ring density at bottom of post

Fractured Post









Test Information

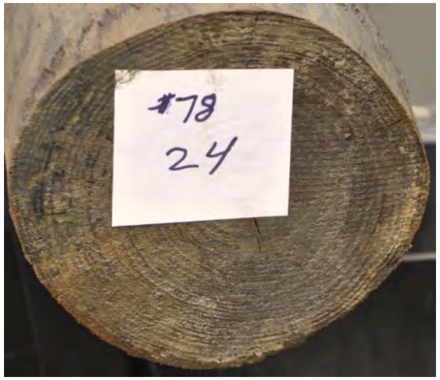
Test Number:	13009I2
Test Date:	9-Oct-2013

Post Properties

Post Number:	78
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	7.6 inches
Moisture Content:	>50%
Ring Density (avg.):	6.3 per inch
Resi Score S_{MOR}:	0.92
Resi Score S_U:	0.91

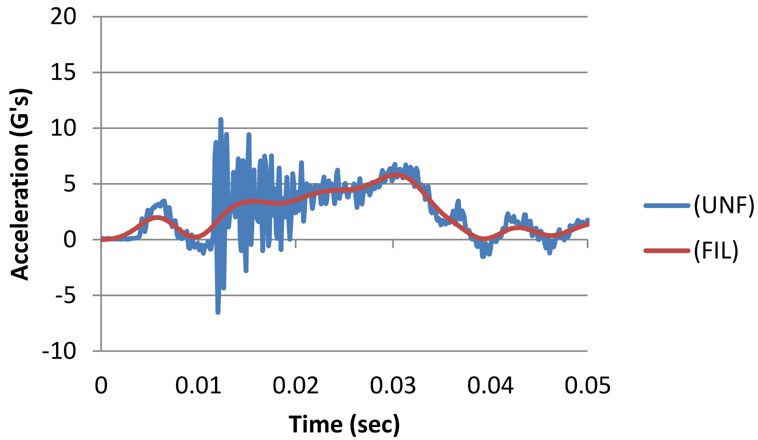
Pendulum Properties

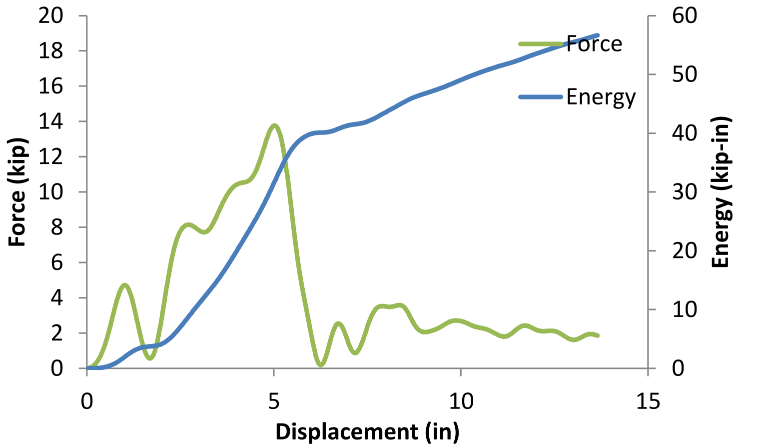
Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches

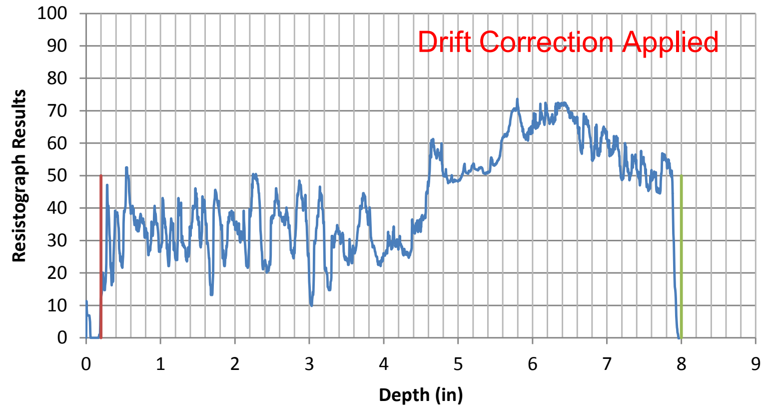


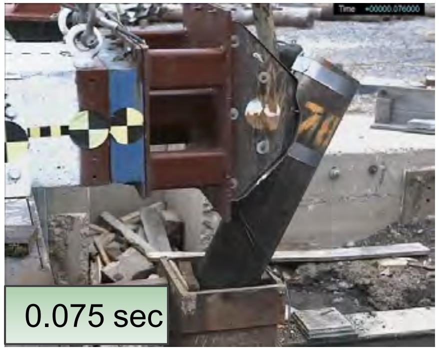
Ring density at bottom of post

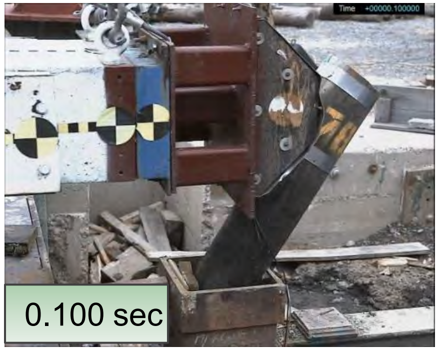
Fractured Post











Test Information

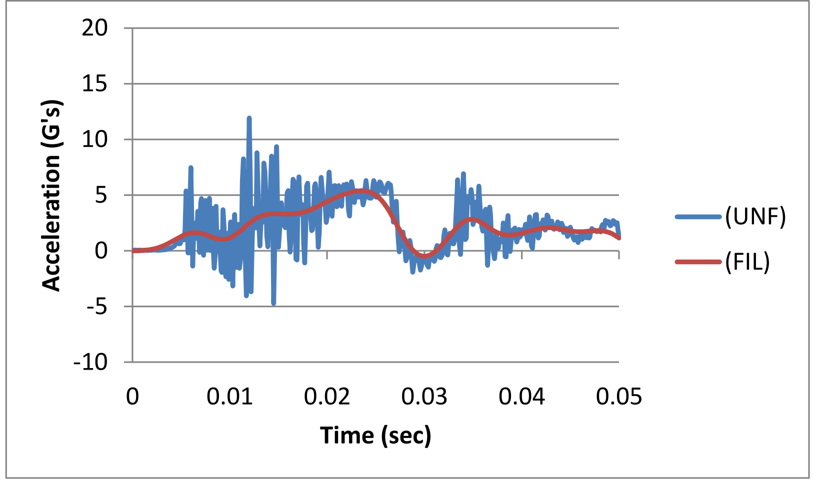
Test Number:	13009J2
Test Date:	9-Oct-2013

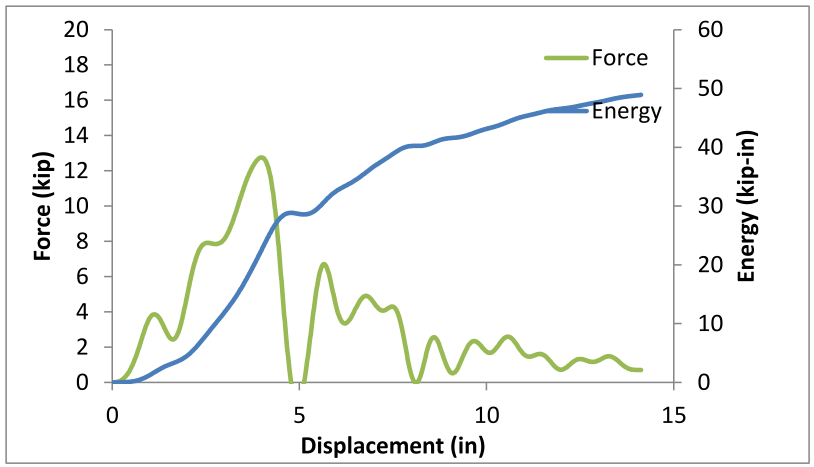
Post Properties

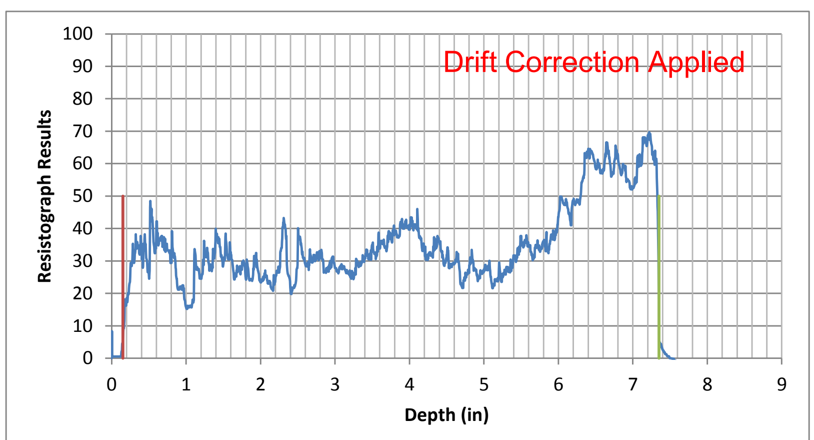
Post Number:	111
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	7.6 inches
Moisture Content:	>50%
Ring Density (avg.):	7.4 per inch
Resi Score S_{MOR}:	0.72
Resi Score S_{U}:	0.77

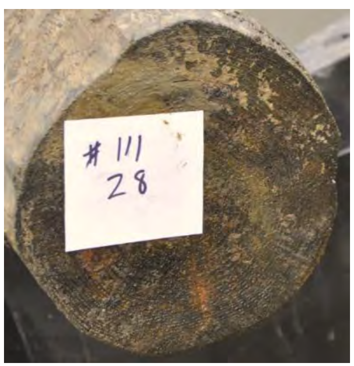
Pendulum Properties

Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches









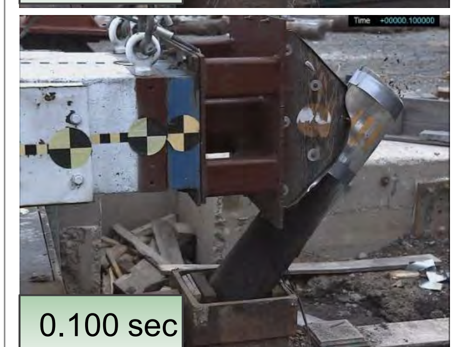
Ring density at bottom of post


Fractured Post


0.025 sec


0.050 sec


0.075 sec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Test Information

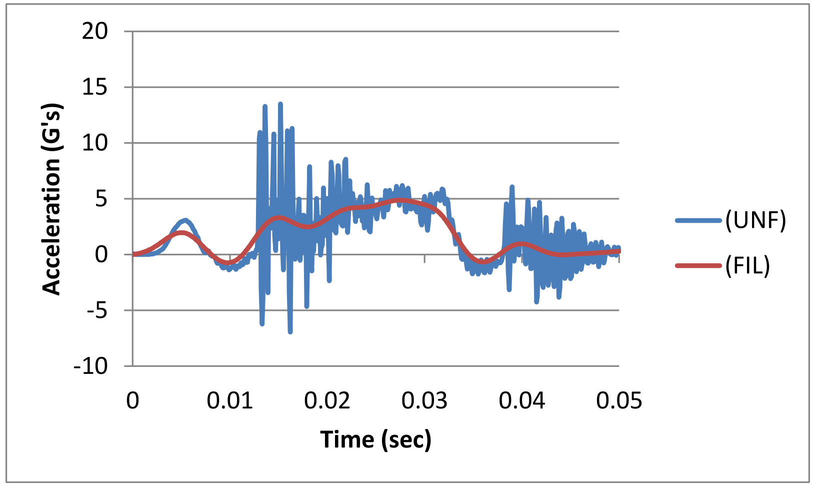
Test Number:	13009K2
Test Date:	9-Oct-2013

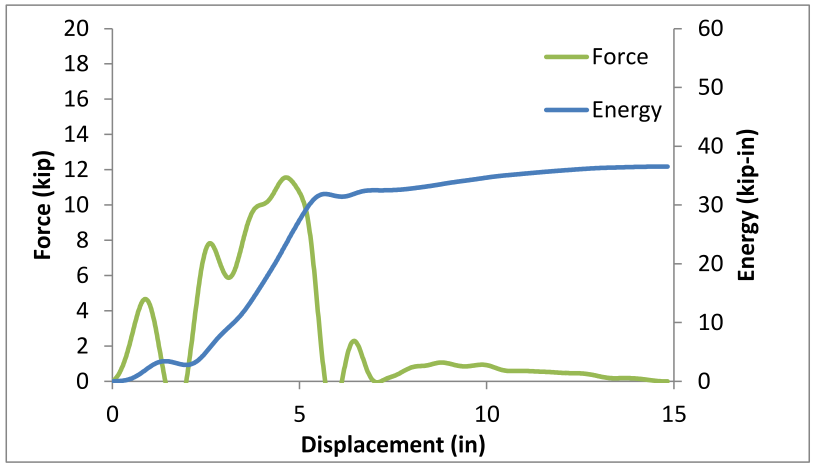
Post Properties

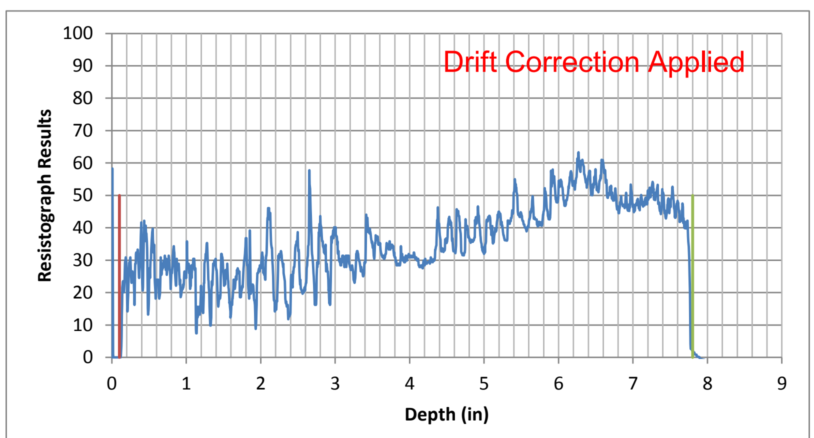
Post Number:	114
Post Type:	Round SYP
Post Length:	66 inches
Post Diameter:	8.0 inches
Moisture Content:	48%
Ring Density (avg.):	8.8 per inch
Resi Score S_{MOR}:	0.76
Resi Score S_U:	0.76

Pendulum Properties

Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	21.5 inches

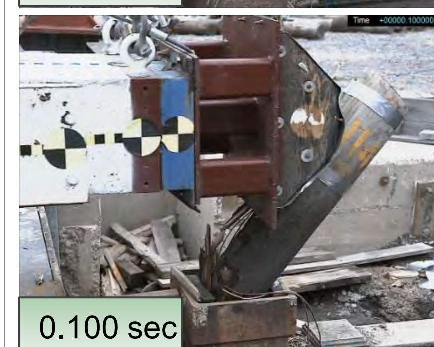






Ring density at bottom of post

Fractured Post



APPENDIX F

Task 4A-3
Assess Effects of Guardrail Post Deterioration on Performance of G4(2W)

FOIL Tests 13010 Summary Sheets
Posts in Soil

Chuck A. Plaxico, Ph.D.
Archie Ray
Roadsafe LLC

December 27, 2013

Test Information

Test Number:	13010A
Test Date:	23-Oct-2013

Post Properties

Post Number:	102
Post Type:	Round SYP
Post Length:	68 inches
Post Diameter:	7.6 inches
Embedment Depth:	40 inches
Moisture Content:	>50%
Ring Density (avg.):	8.4 per inch
Resi Score S_M:	0.63
Resi Score S_U:	0.69

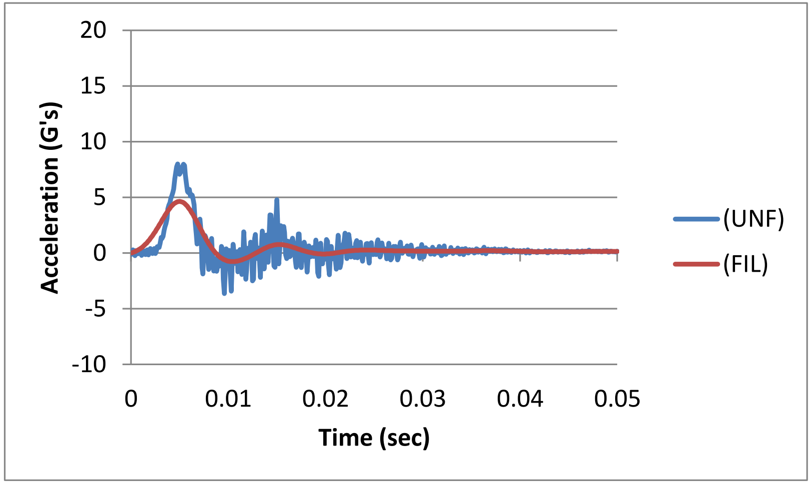
Soil Properties

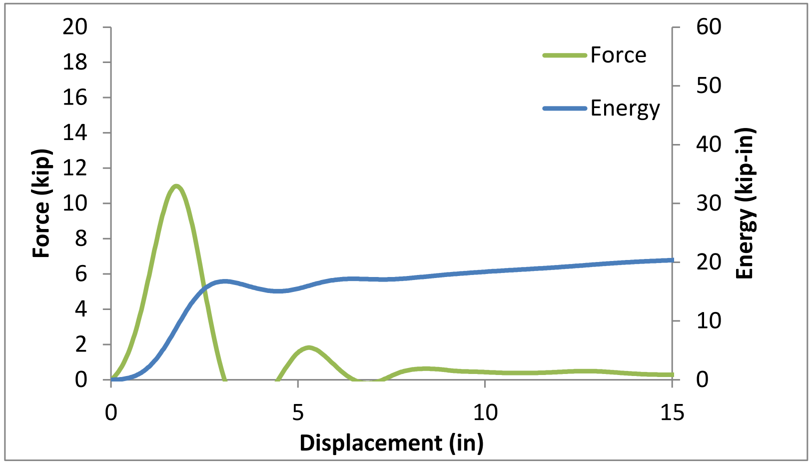
Dry Density:	148.3 pcf
Moisture Content:	4.0 percent
Compaction:	98.7 percent

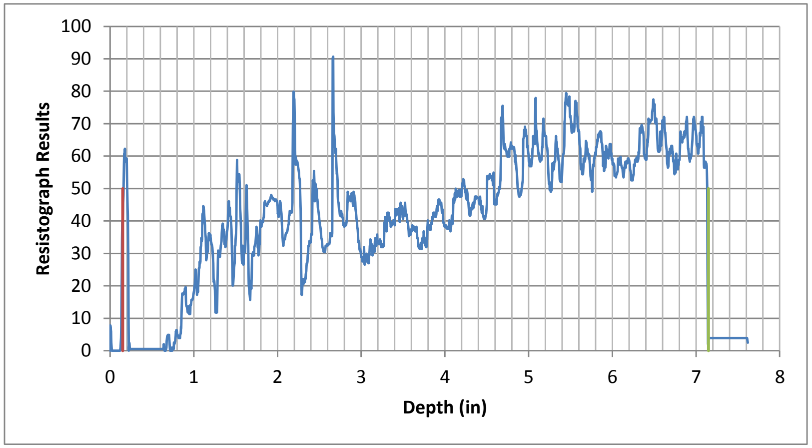
Pendulum Properties

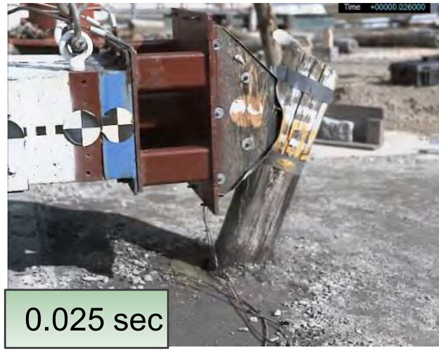
Weight:	2,372 lb
Impact Speed:	20 mph
Impact Height:	21.5 inches

Fractured Post









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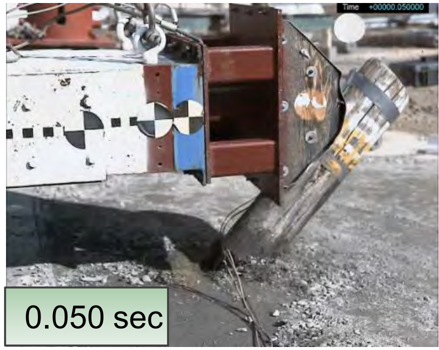

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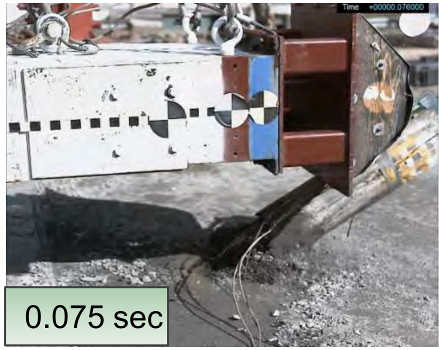

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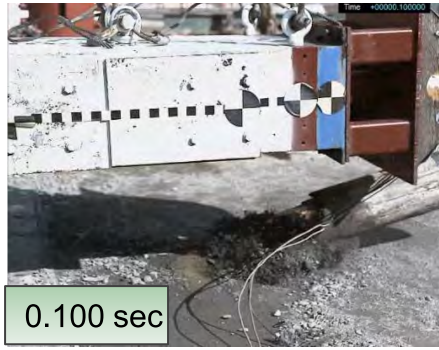

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Test Information

Test Number:	13010B
Test Date:	24-Oct-2013

Post Properties

Post Number:	54
Post Type:	Round SYP
Post Length:	68 inches
Post Diameter:	8.4 inches
Embedment Depth:	40 inches
Moisture Content:	38 percent
Ring Density (avg.):	12.0 per inch
Resi Score S_{MOR}:	1.04
Resi Score S_{U}:	0.95

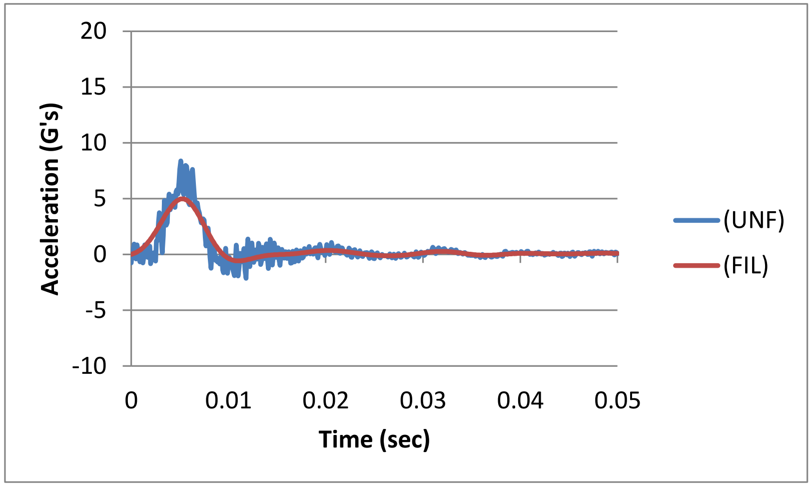
Soil Properties

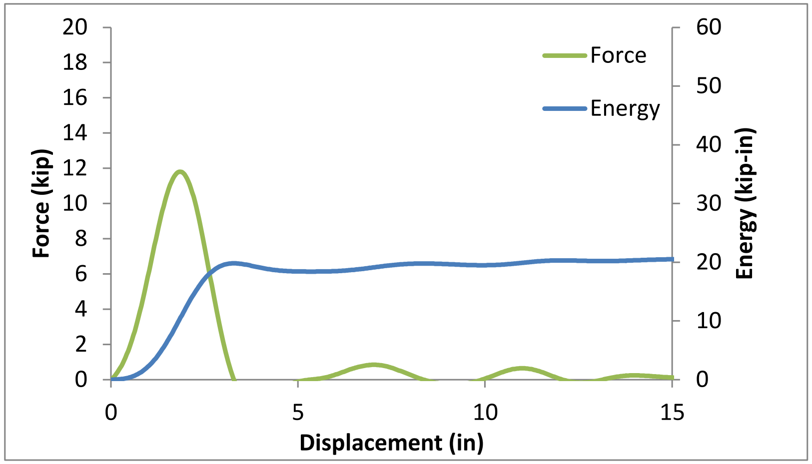
Dry Density:	pcf
Moisture Content:	percent
Compaction:	percent

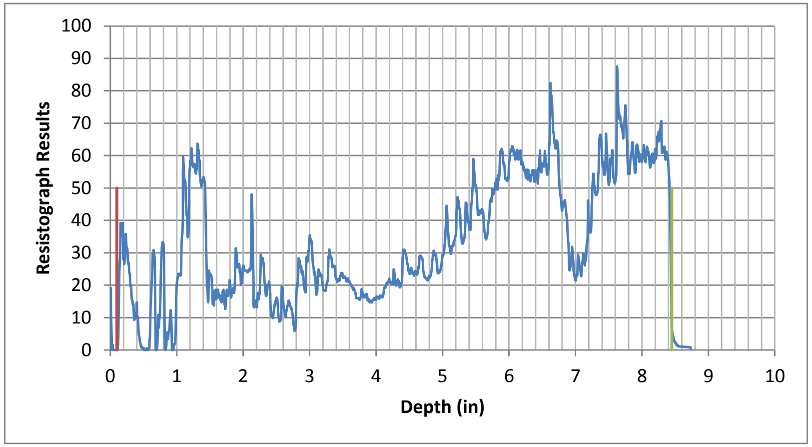
Pendulum Properties

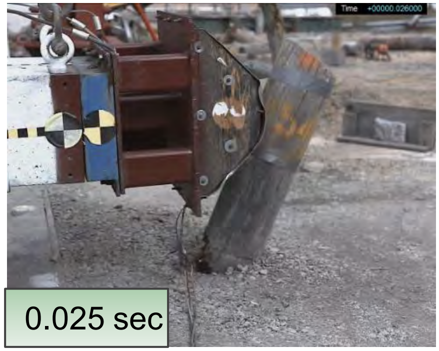
Weight:	2,372 lb
Impact Speed:	20 mph
Impact Height:	21.5 inches

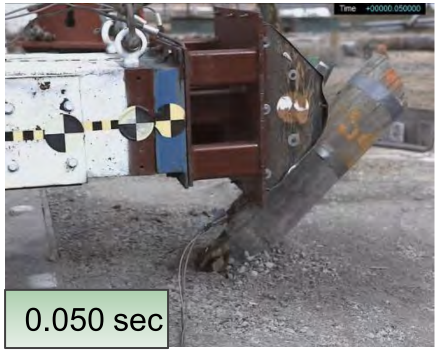
Fractured Post

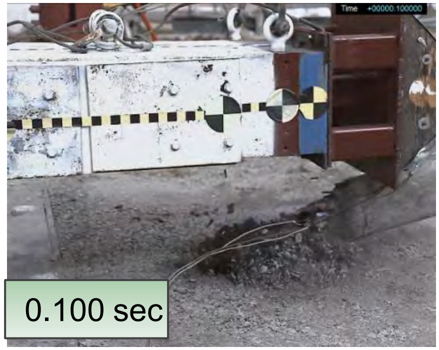












Test Information

Test Number:	13010C
Test Date:	29-Oct-2013

Post Properties

Post Number:	C
Post Type:	Round SYP
Post Length:	68 inches
Post Diameter:	7.3 inches
Embedment Depth:	40 inches
Moisture Content:	25 percent
Ring Density (avg.):	8.2 per inch
Resi Score S_{MOR}:	0.51
Resi Score S_{U}:	0.54

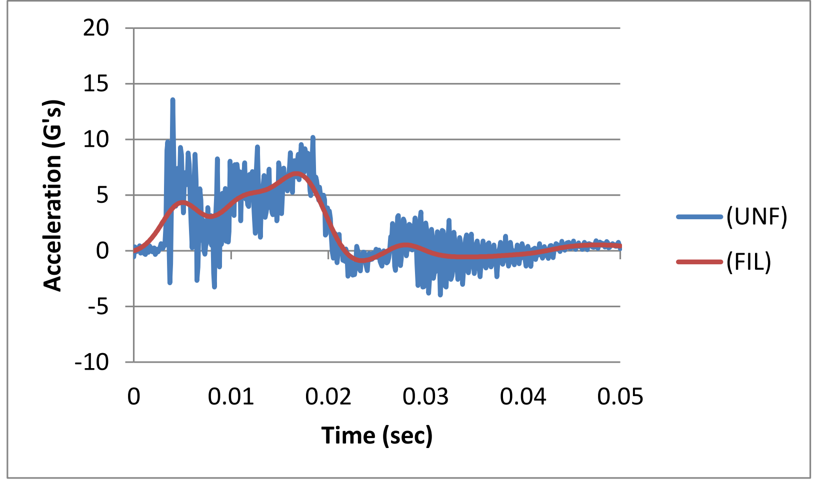
Soil Properties

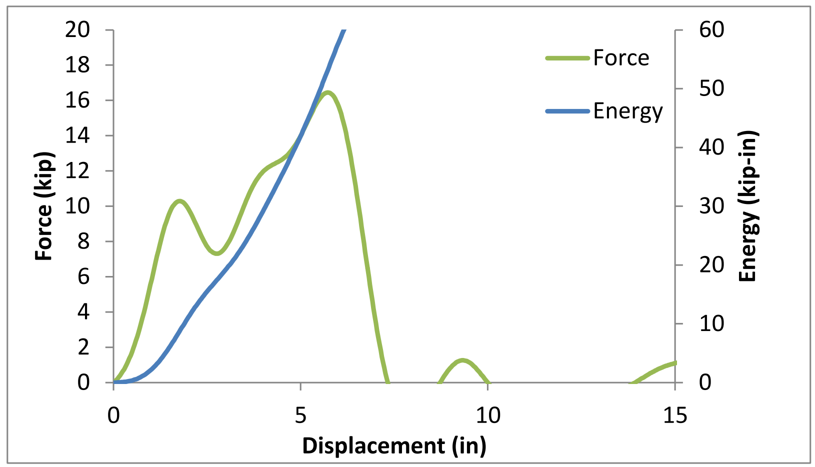
Dry Density:	142.1 pcf
Moisture Content:	3.6 percent
Compaction:	94.7 percent

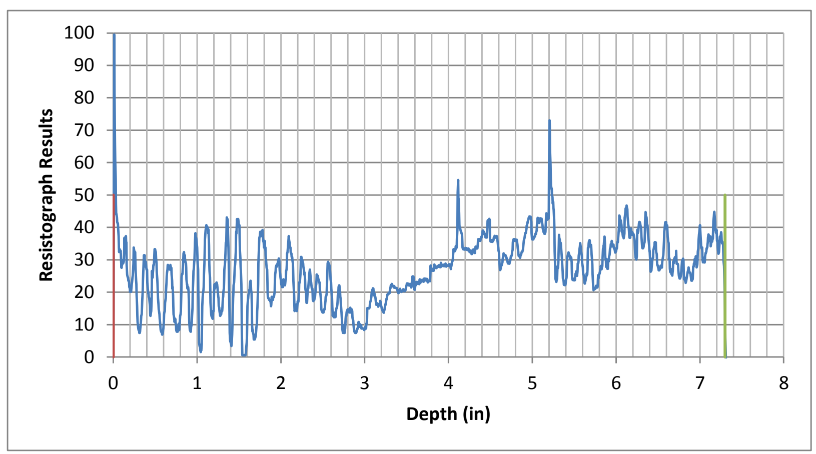
Pendulum Properties

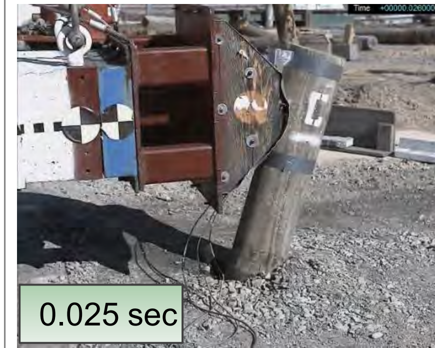
Weight:	2,372 lb
Impact Speed:	20 mph
Impact Height:	21.5 inches

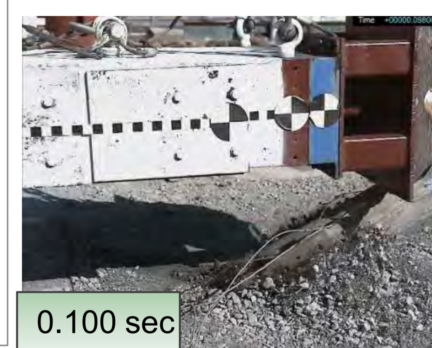
Fractured Post











Test Information

Test Number:	13010D
Test Date:	29-Oct-2013

Post Properties

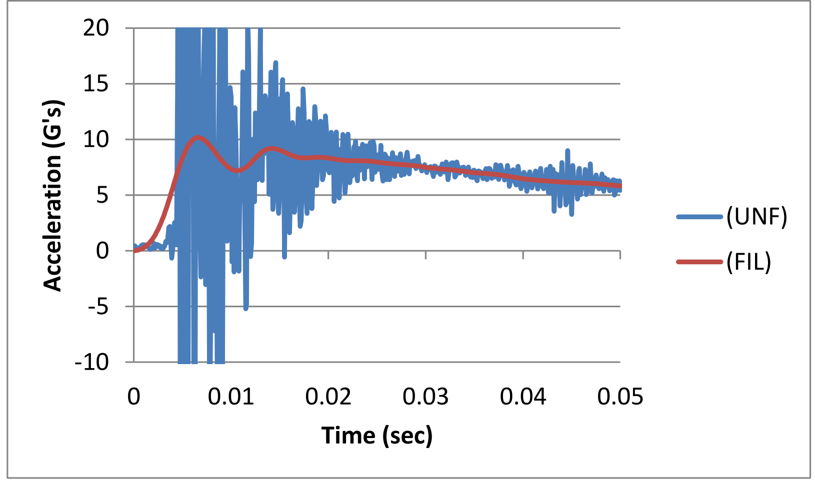
Post Number:	
Post Type:	W6x16
Post Length:	72 inches
Post Diameter:	N/A
Embedment Depth:	40 inches
Moisture Content:	N/A
Ring Density (avg.):	N/A
Resi Score S_{MOR}:	N/A
Resi Score S_U:	N/A

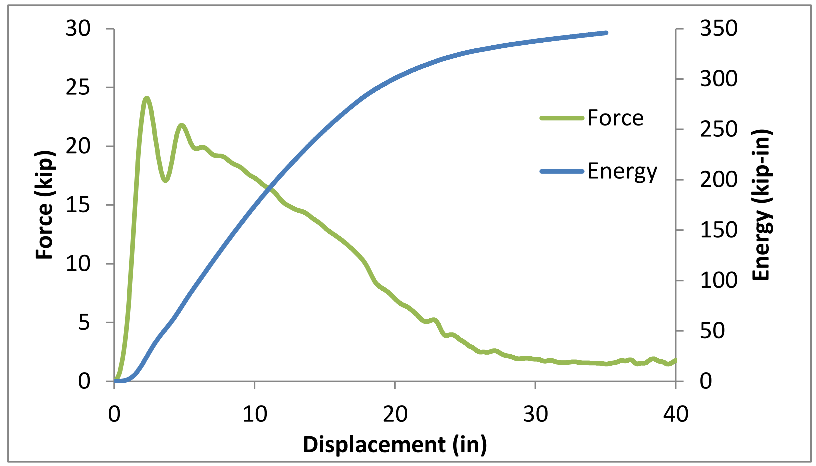
Soil Properties

Dry Density:	143.5 pcf
Moisture Content:	3.8 percent
Compaction:	95.6 percent

Pendulum Properties

Weight:	2,372 lb
Impact Speed:	20 mph
Impact Height:	24.9 inches



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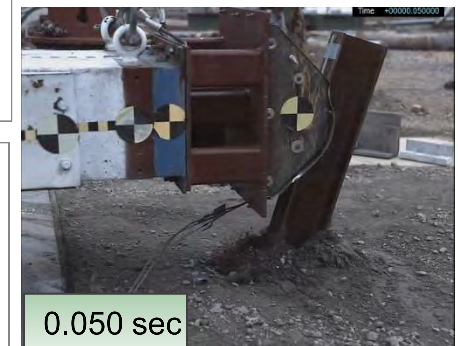
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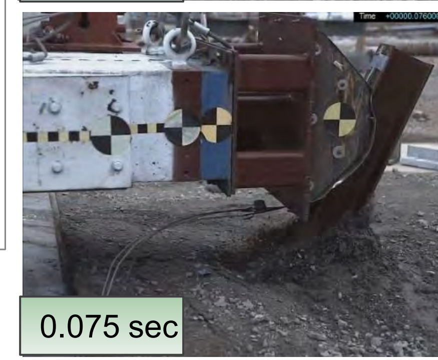

0.075 sec


0.100 sec

Test Information

Test Number:	13010E
Test Date:	4-Nov-2013

Post Properties

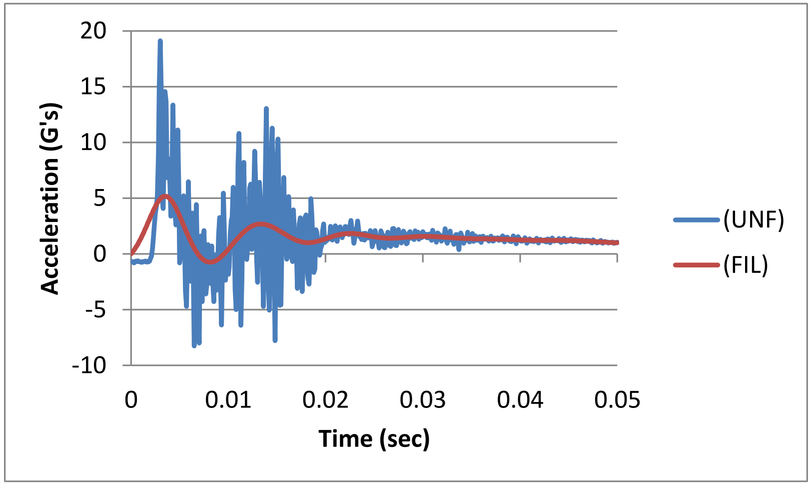
Post Number:	
Post Type:	W6x16
Post Length:	72 inches
Post Diameter:	N/A
Embedment Depth:	40 inches
Moisture Content:	N/A
Ring Density (avg.):	N/A
Resi Score S_{MOR}:	N/A
Resi Score S_U:	N/A

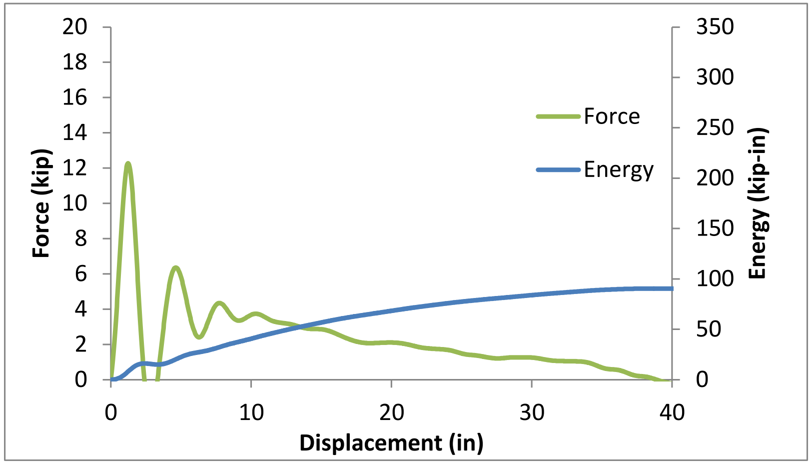
Soil Properties

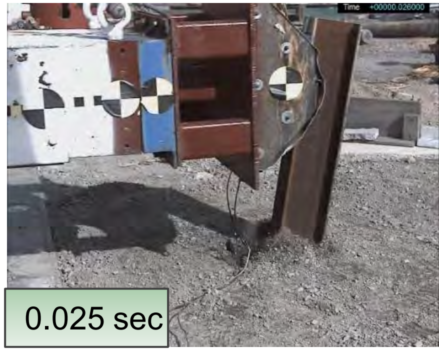
Dry Density:	132.4 pcf
Moisture Content:	3.1 percent
Compaction:	88.1 percent

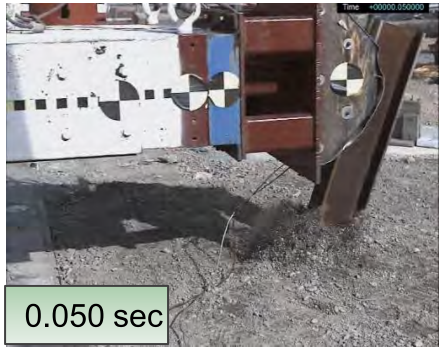
Pendulum Properties

Weight:	2,372 lb
Impact Speed:	20 mph
Impact Height:	24.9 inches









Test Information

Test Number:	13010F
Test Date:	6-Nov-2013

Post Properties

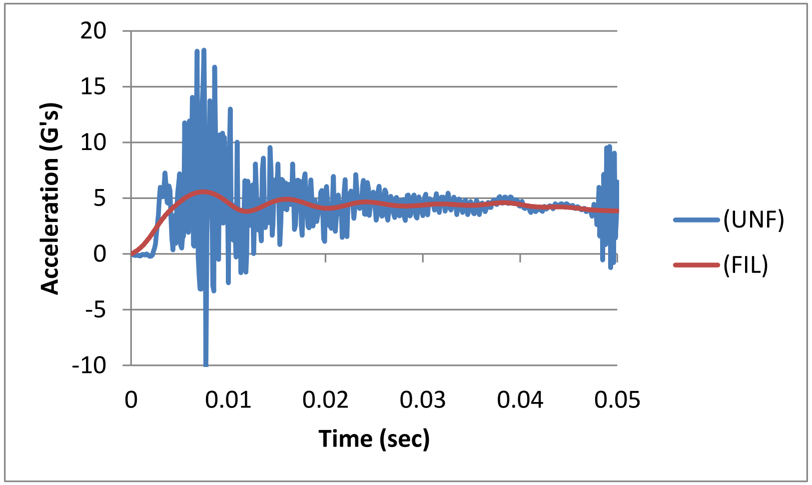
Post Number:	
Post Type:	W6x16
Post Length:	72 inches
Post Diameter:	N/A
Embedment Depth:	40 inches
Moisture Content:	N/A
Ring Density (avg.):	N/A
Resi Score S_{MOR}:	N/A
Resi Score S_{U}:	N/A

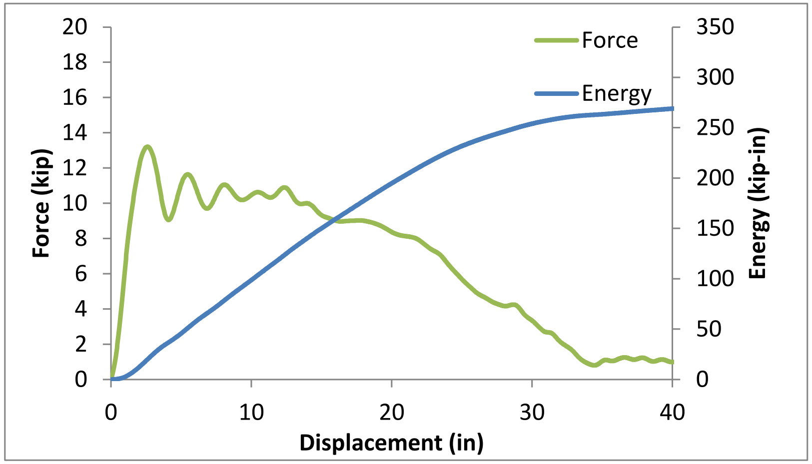
Soil Properties

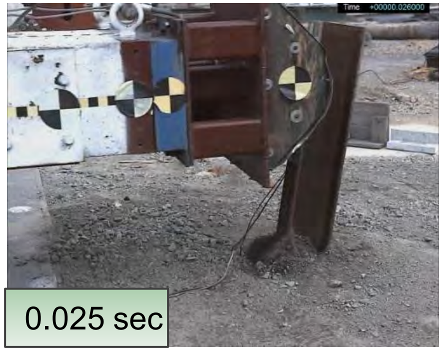
Dry Density:	138.4 pcf
Moisture Content:	3.3 percent
Compaction:	92.1 percent

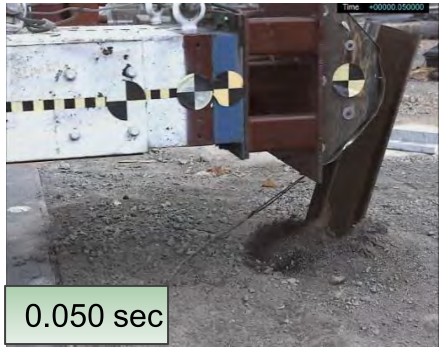
Pendulum Properties

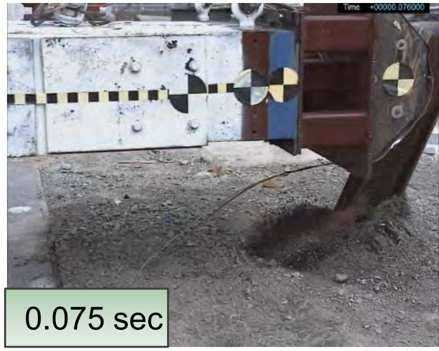
Weight:	2,372 lb
Impact Speed:	20 mph
Impact Height:	24.9 inches











Test Information

Test Number:	13010G
Test Date:	8-Nov-2013

Post Properties

Post Number:	57
Post Type:	Round SYP
Post Length:	68 inches
Post Diameter:	7.2 inches
Embedment Depth:	40 inches
Moisture Content:	39 percent
Ring Density (avg.):	9.2 per inch
Resi Score S_M:	0.86
Resi Score S_U:	0.97

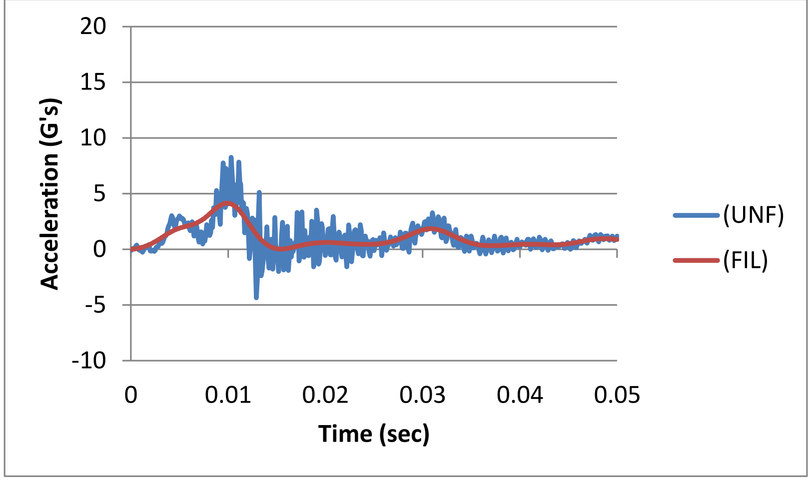
Soil Properties

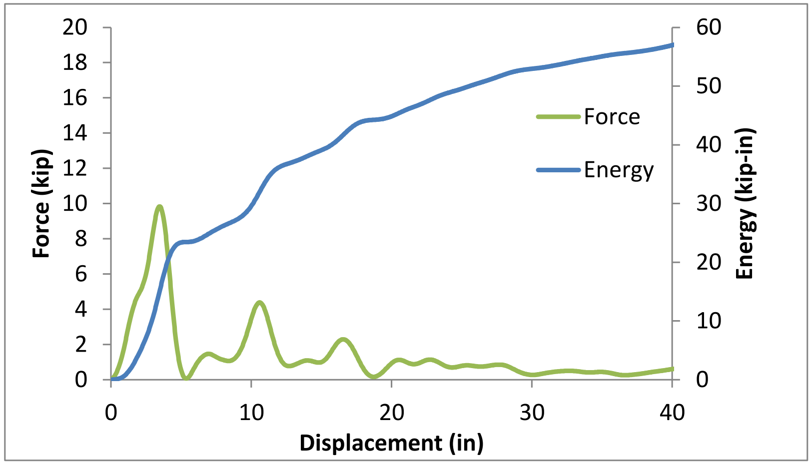
Dry Density:	138.6 pcf
Moisture Content:	3.4 percent
Compaction:	92.3 percent

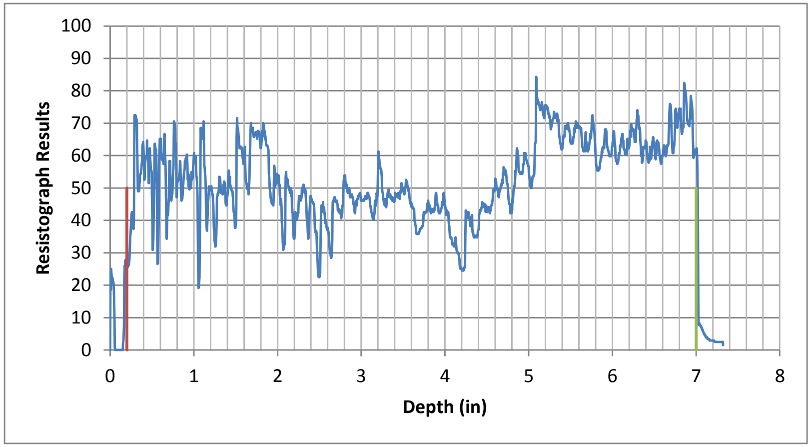
Pendulum Properties

Weight:	2,372 lb
Impact Speed:	20 mph
Impact Height:	24.8 inches

Fractured Post







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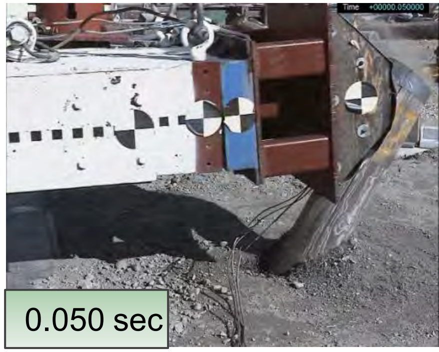

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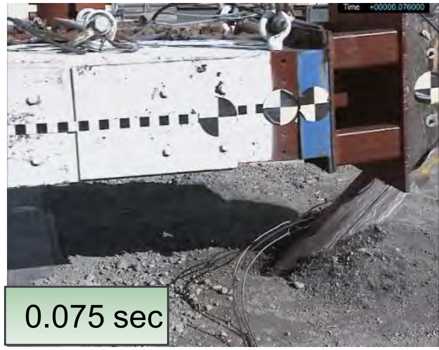

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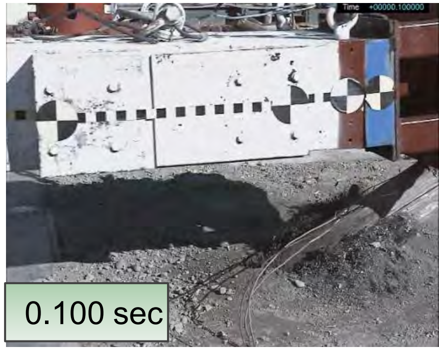


0.100 sec

Test Information

Test Number:	13010H
Test Date:	16-Dec-2013

Post Properties

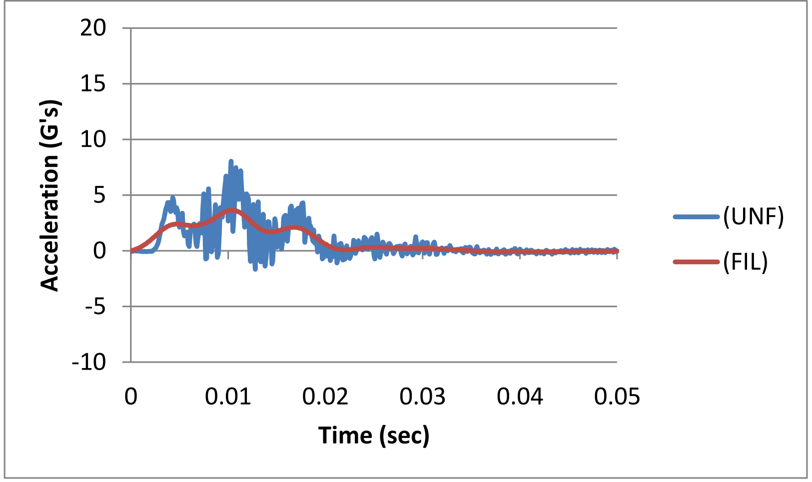
Post Number:	D
Post Type:	Round SYP
Post Length:	72 inches
Post Diameter:	7.5 inches
Embedment Depth:	40 inches
Moisture Content:	35 percent
Ring Density (avg.):	6.4 per inch
Resi Score S_M:	
Resi Score S_U:	

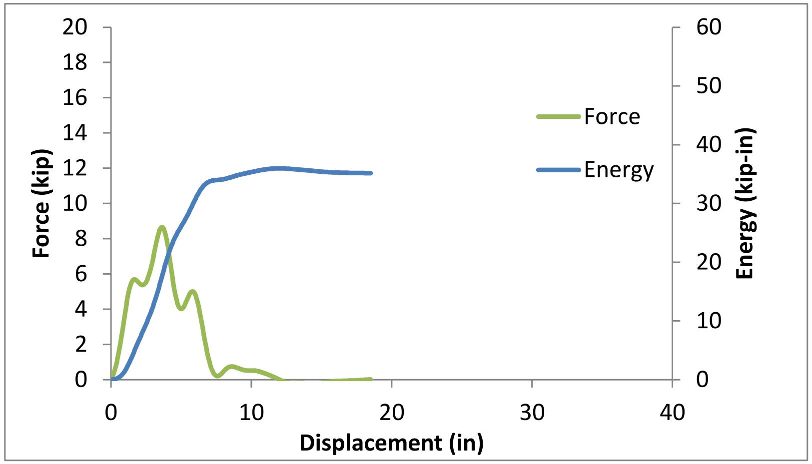
Soil Properties

Dry Density:	142.4 pcf
Moisture Content:	6.2 percent
Compaction:	94.8 percent

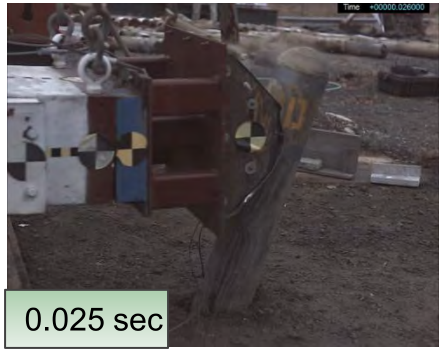
Pendulum Properties

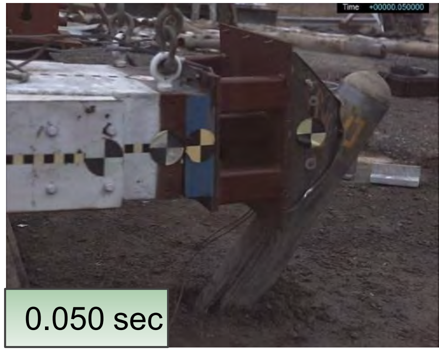
Weight:	2,372 lb
Impact Speed:	20 mph
Impact Height:	24.8 inches

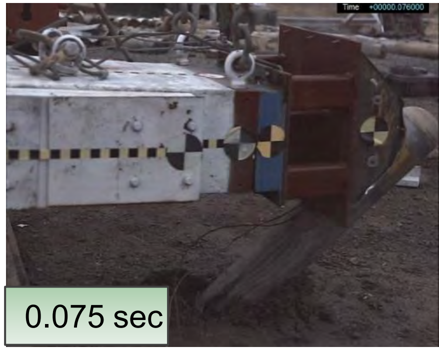




Fractured Post







Test Information

Test Number:	13010I
Test Date:	18-Dec-2013

Post Properties

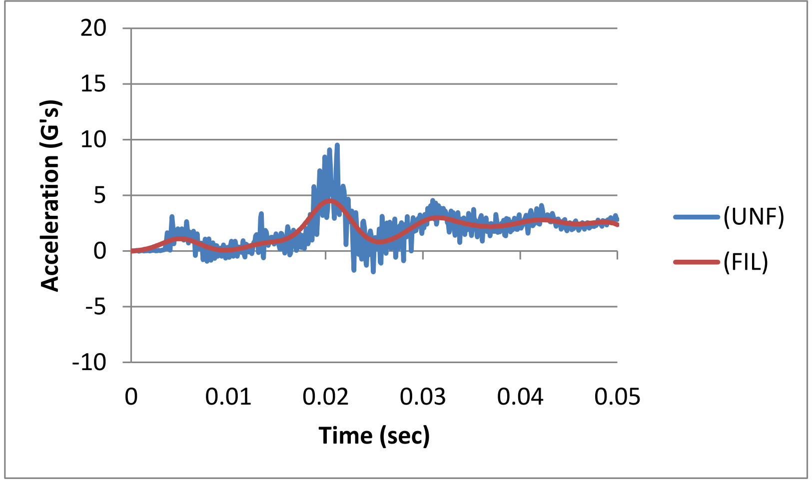
Post Number:	E
Post Type:	Round SYP
Post Length:	72 inches
Post Diameter:	7.4 inches
Embedment Depth:	40 inches
Moisture Content:	19 percent
Ring Density (avg.):	4.1 per inch
Resi Score S_M:	
Resi Score S_U:	

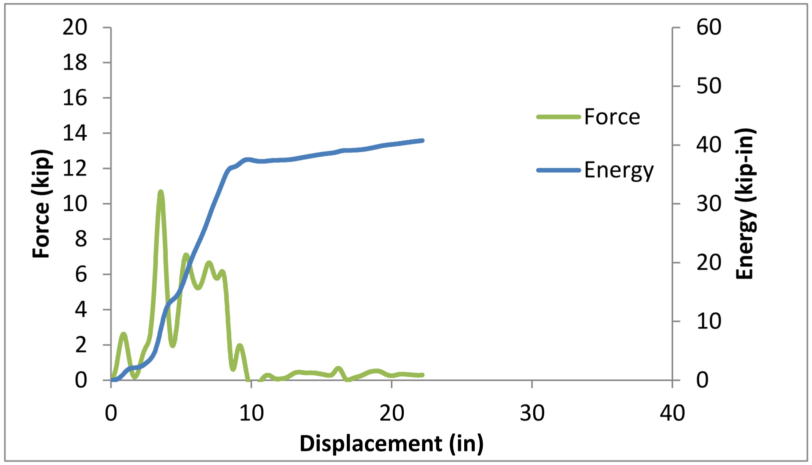
Soil Properties

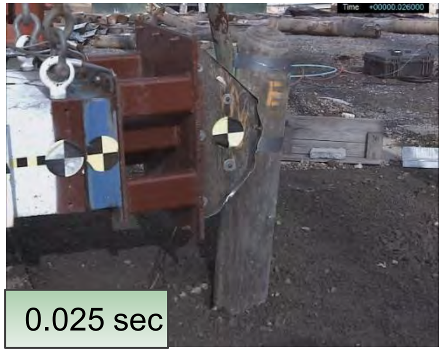
Dry Density:	- pcf
Moisture Content:	- percent
Compaction:	- percent

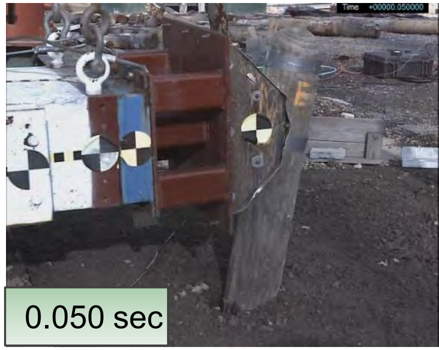
Pendulum Properties

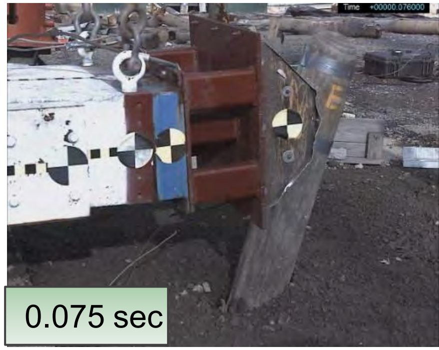
Weight:	2,372 lb
Impact Speed:	10 mph
Impact Height:	24.8 inches

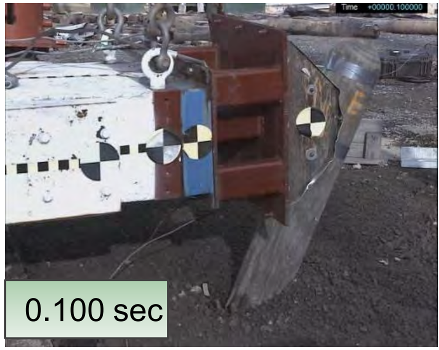












Fractured Post

APPENDIX G

Sequential Views from FEA Evaluation of Uniform Post Deterioration in Impact Region

Task 4A-3: Assess Effects of Guardrail Post Deterioration on Performance of G4(2W)

By: Chuck A. Plaxico

January 2014

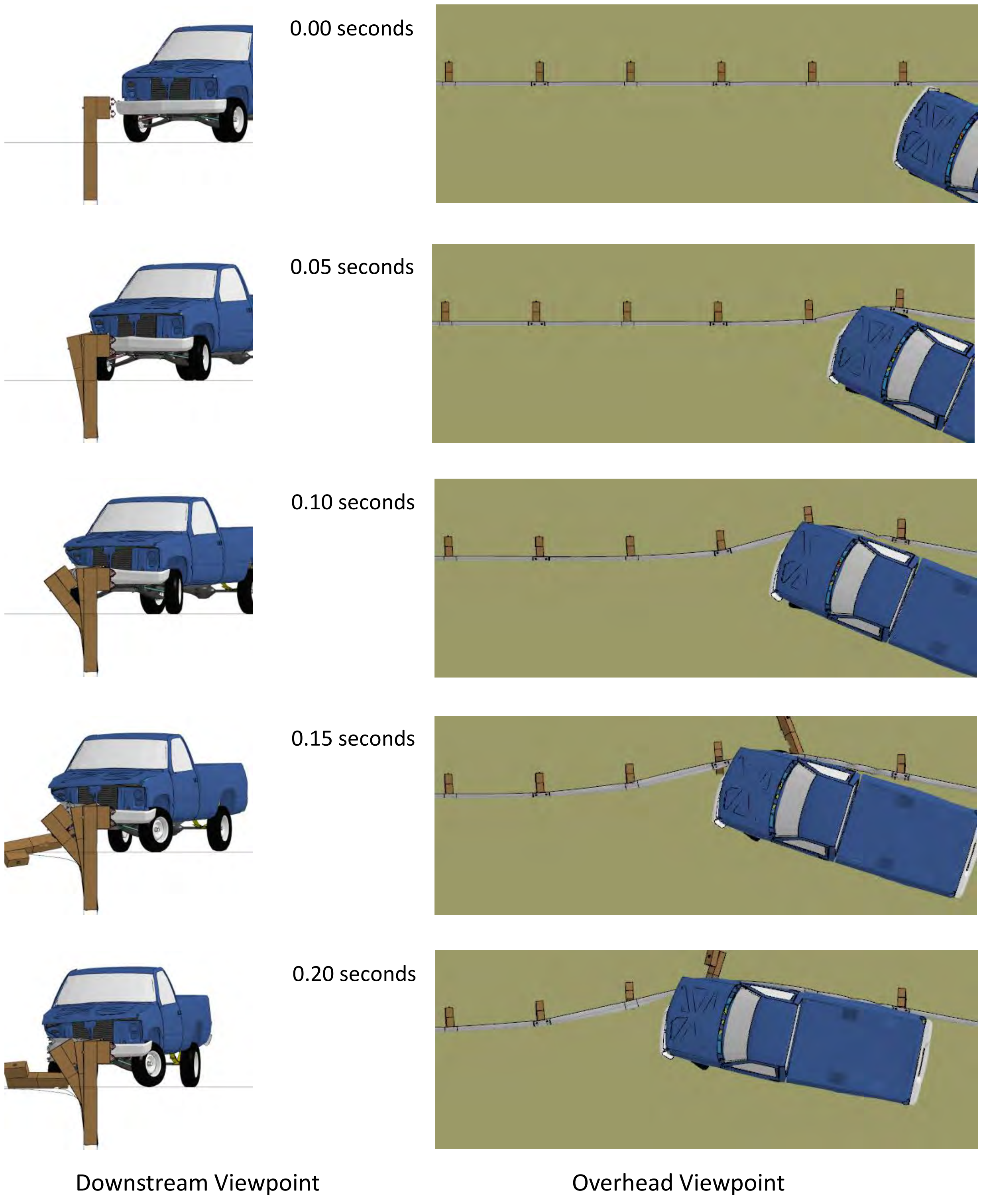


Figure F-1: Sequential views from Analysis Case DL1 from a downstream and overhead viewpoint.

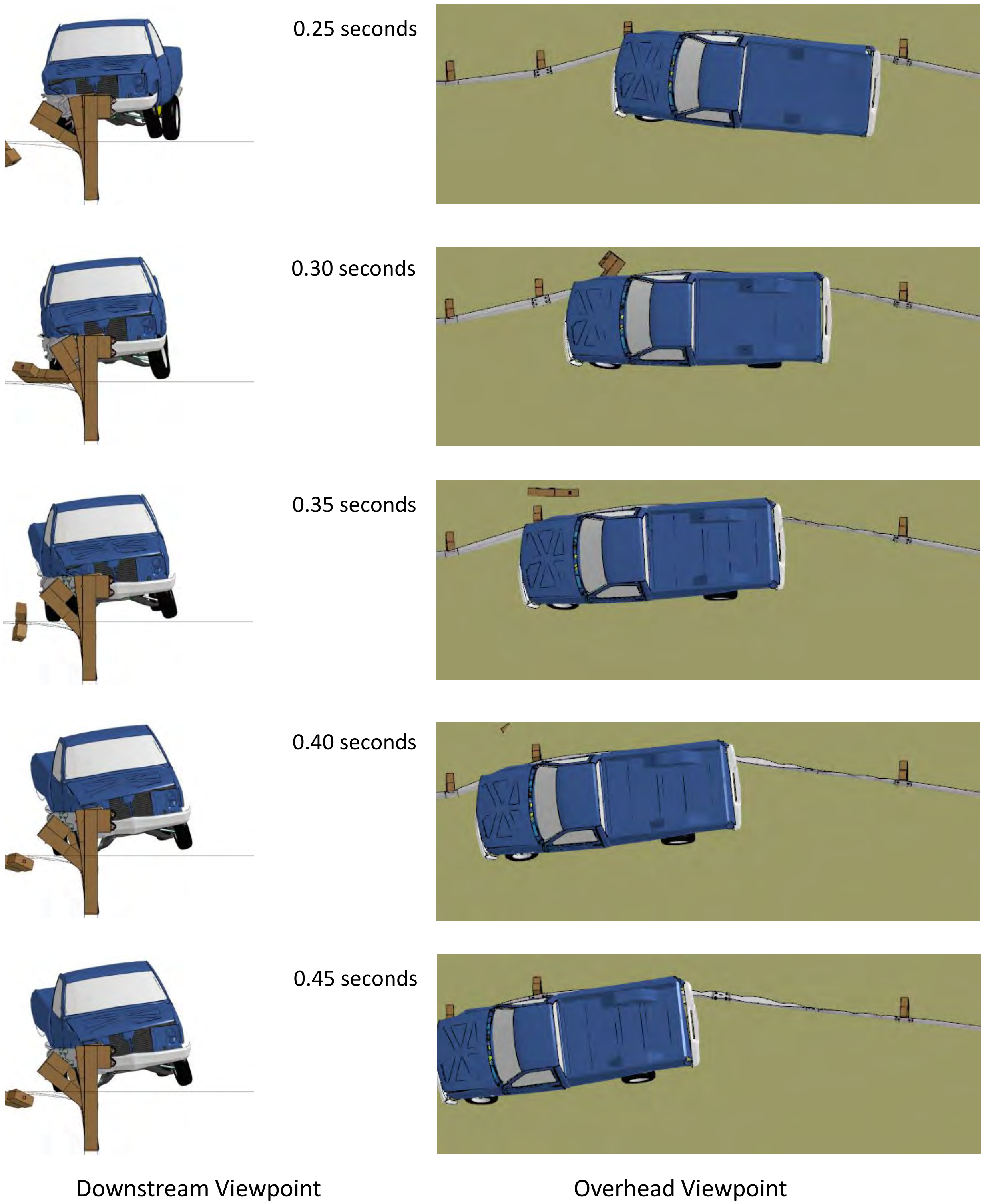
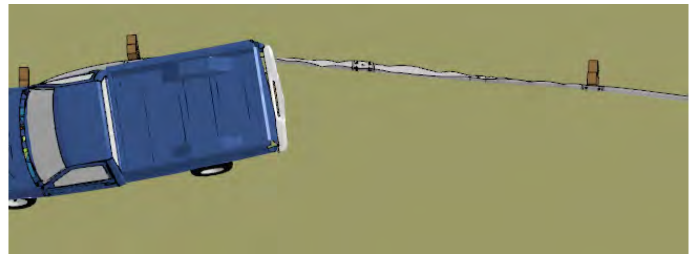


Figure F-1: [CONTINUED] Sequential views from Analysis Case DL1 from a downstream and overhead viewpoint.

0.50 seconds



Premature Termination

Downstream Viewpoint Overhead Viewpoint

Figure F-1: [CONTINUED] Sequential views from Analysis Case DL1 from a downstream and overhead viewpoint.

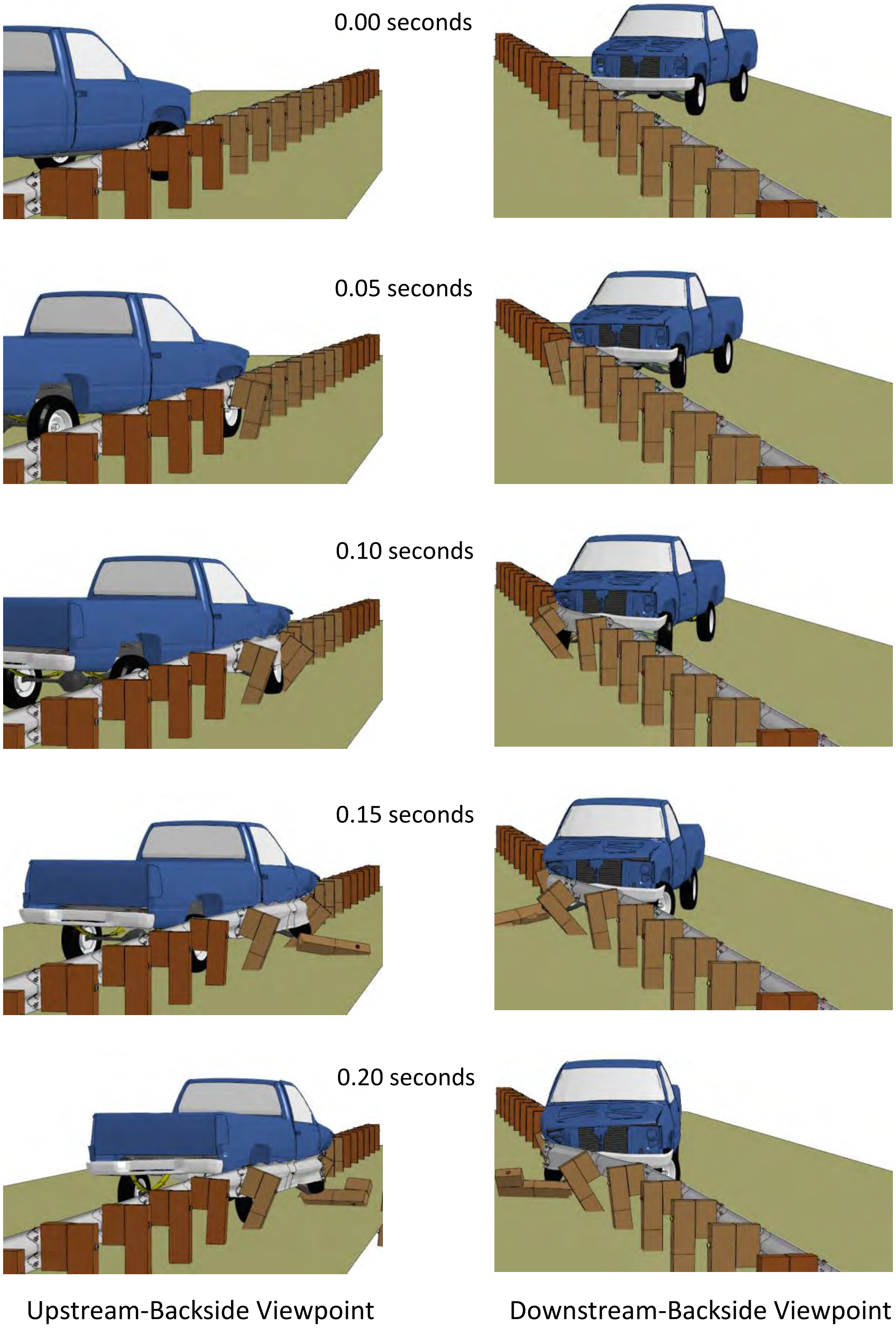


Figure F-2: Sequential views from Analysis Case DL1 from an upstream-backside and downstream-backside viewpoint.

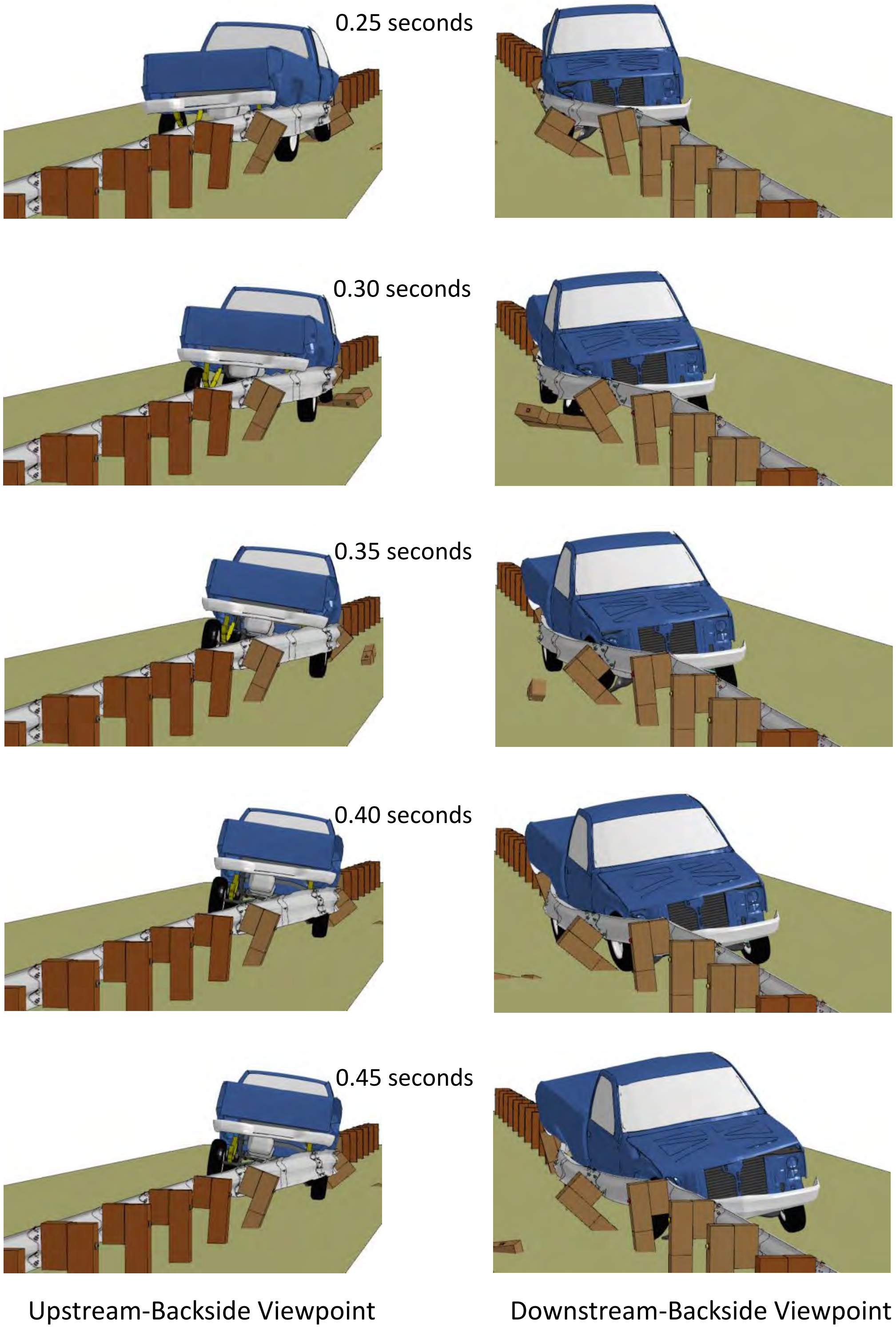
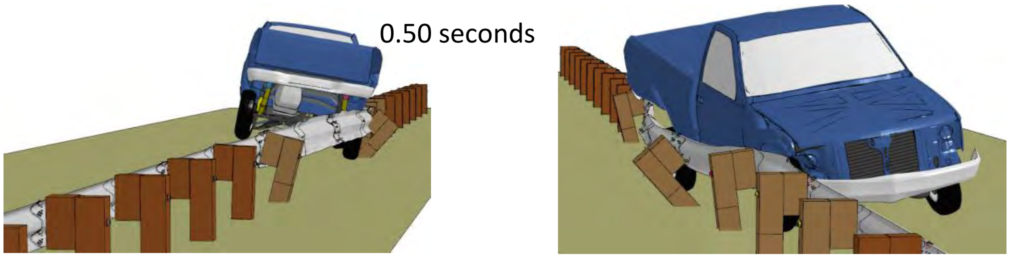


Figure F-2: [CONTINUED] Sequential views from Analysis Case DL1 from an upstream-backside and downstream-backside viewpoint.



Premature Termination

Upstream-Backside Viewpoint   Downstream-Backside Viewpoint

Figure F-2: [CONTINUED] Sequential views from Analysis Case DL1 from an upstream-backside and downstream-backside viewpoint.

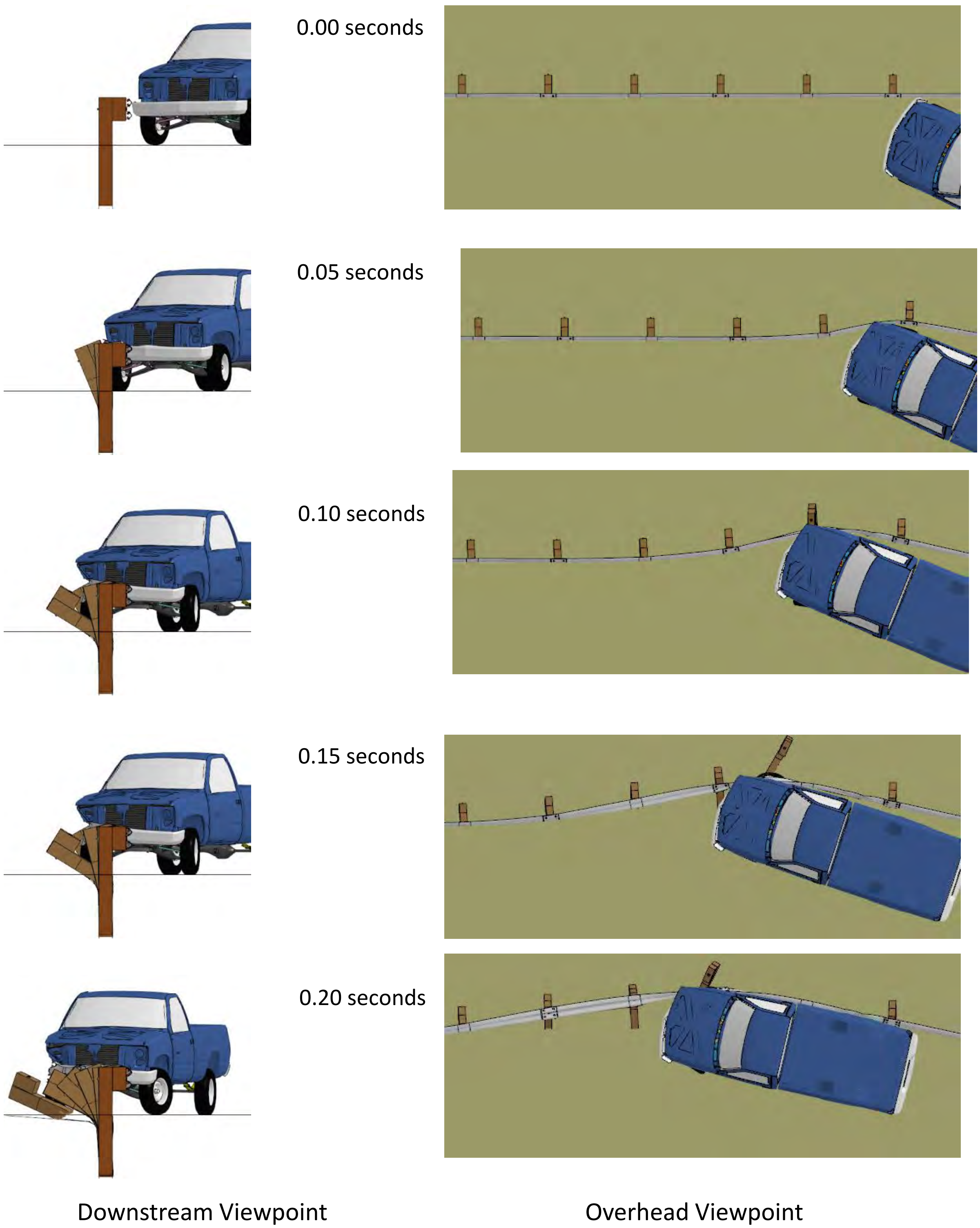


Figure F-3: Sequential views from Analysis Case DL2 from a downstream and overhead viewpoint.

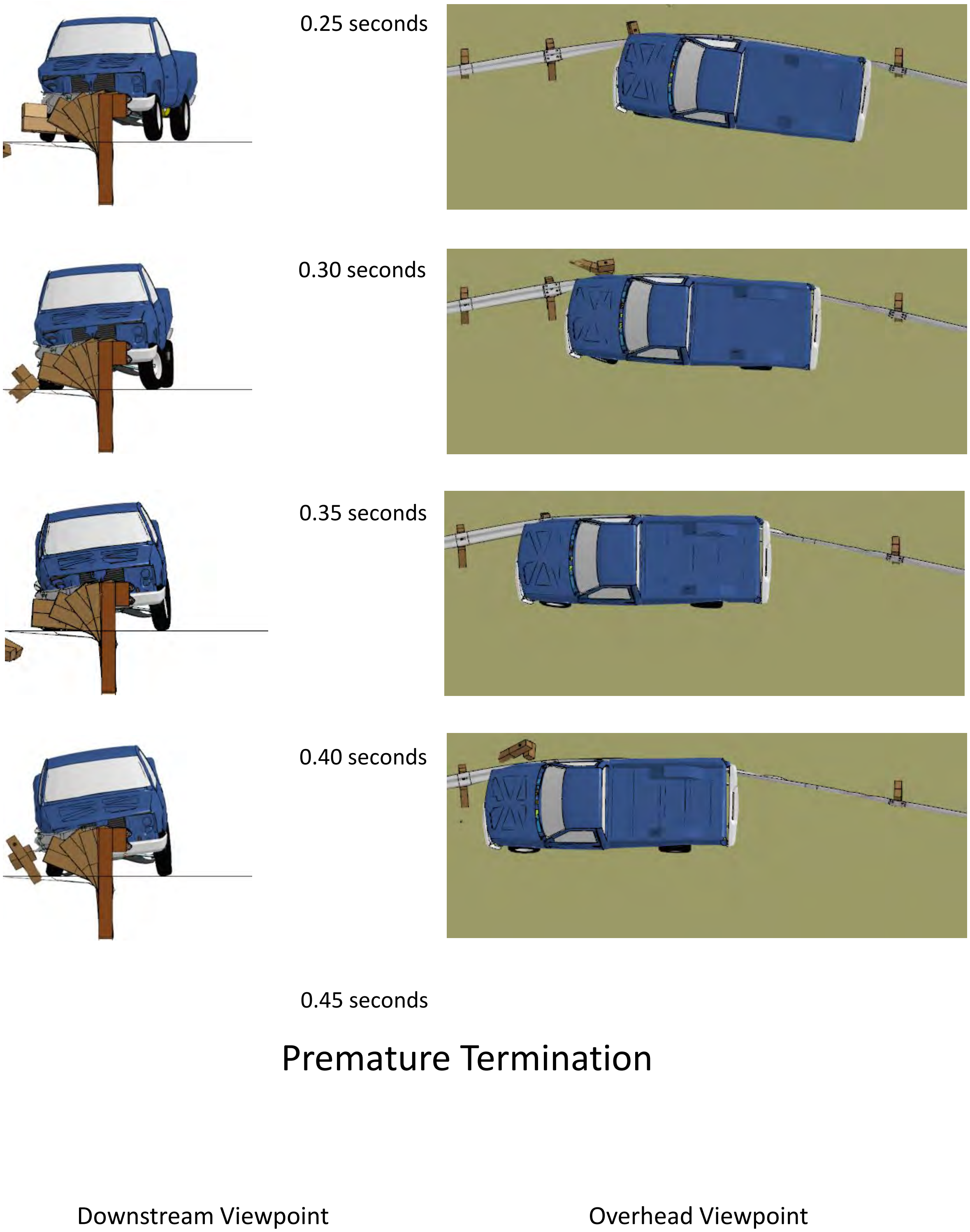
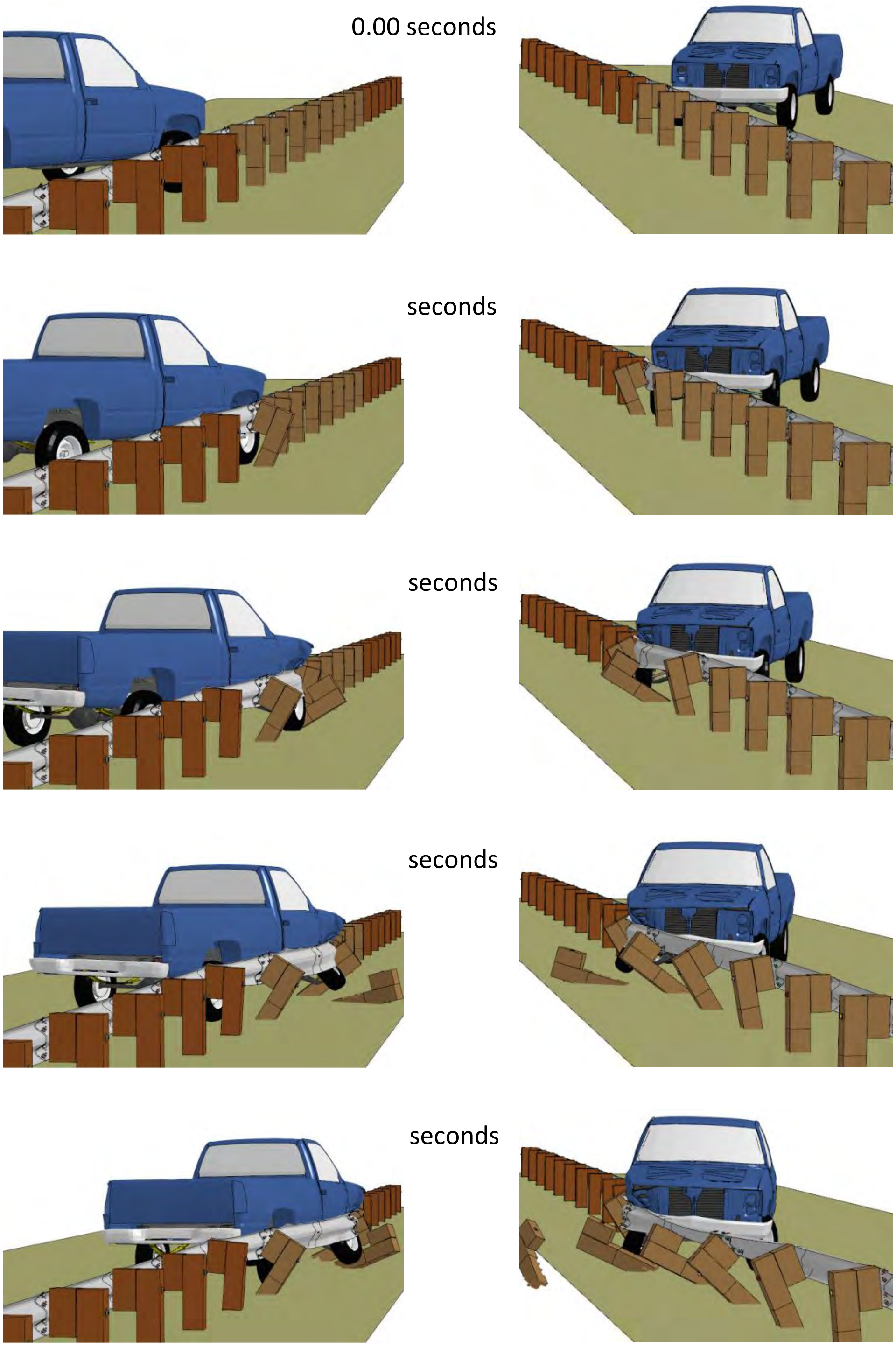


Figure F-3: [CONTINUED] Sequential views from Analysis Case DL2 from a downstream and overhead viewpoint.



Upstream-Backside Viewpoint Downstream-Backside Viewpoint

Figure F-4: Sequential views from Analysis Case DL2 from an upstream-backside and downstream-backside viewpoint.

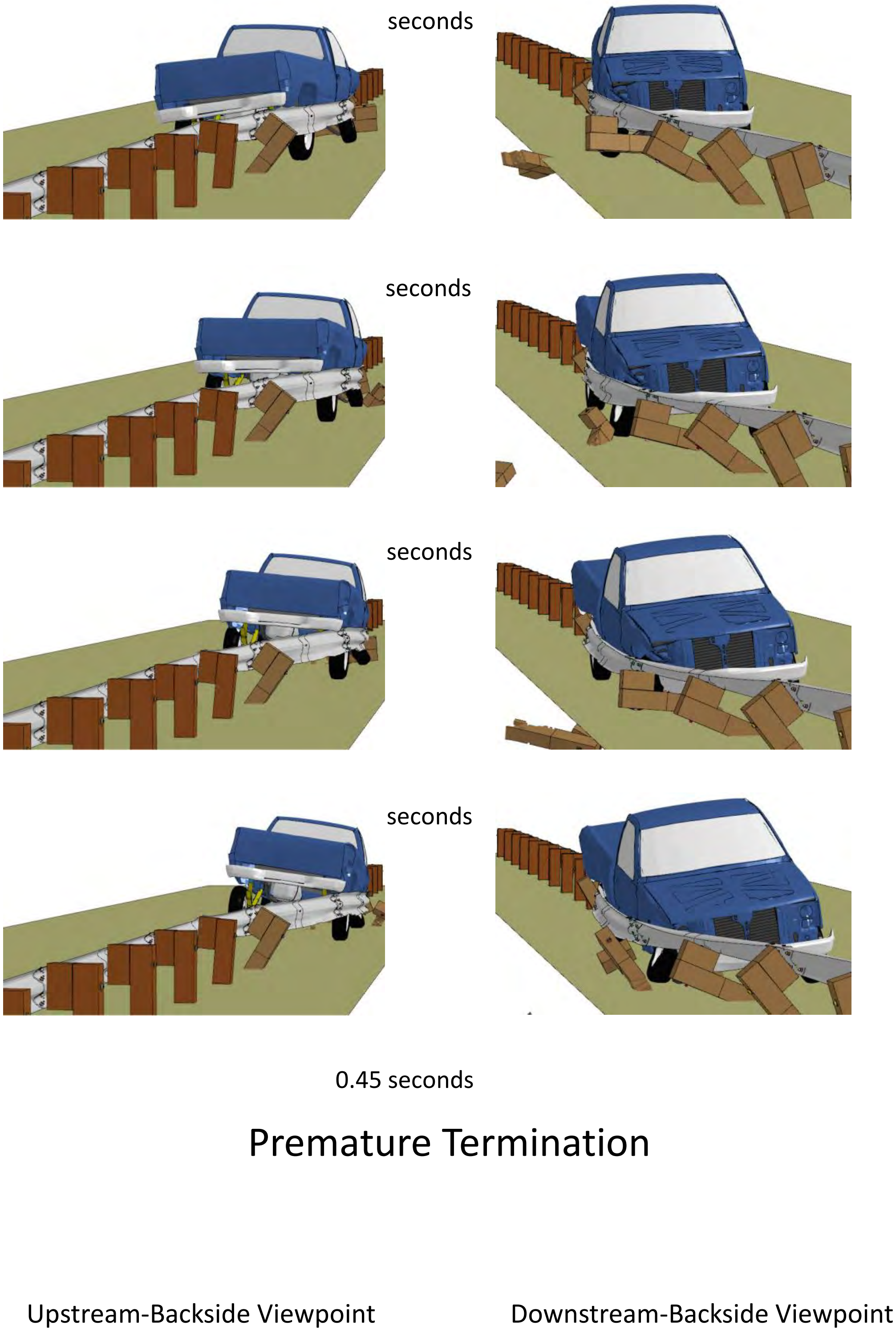


Figure F-4: [CONTINUED] Sequential views from Analysis Case DL2 from an upstream-backside and downstream-backside viewpoint.

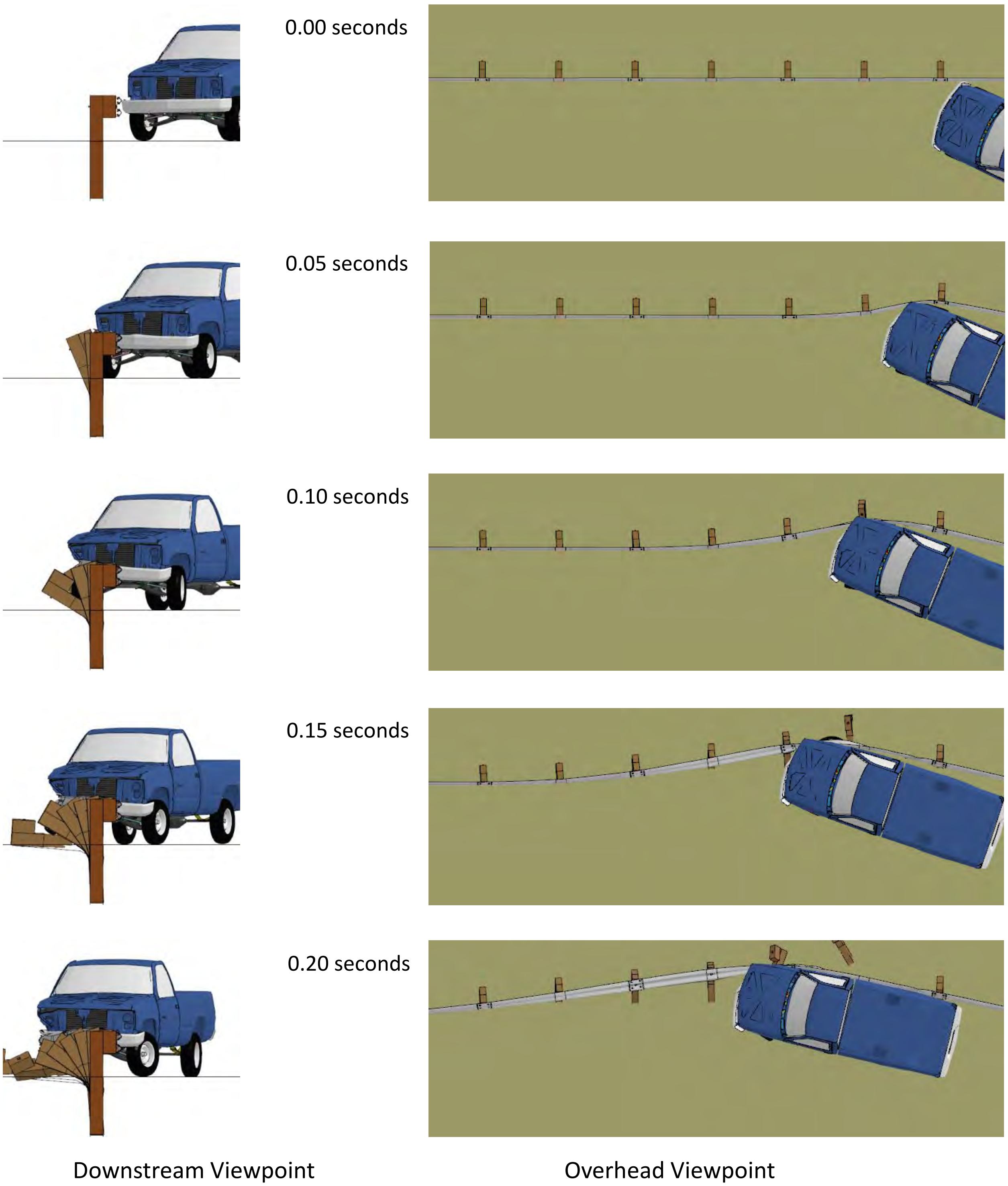


Figure F-5: Sequential views from Analysis Case DL3 from a downstream and overhead viewpoint.

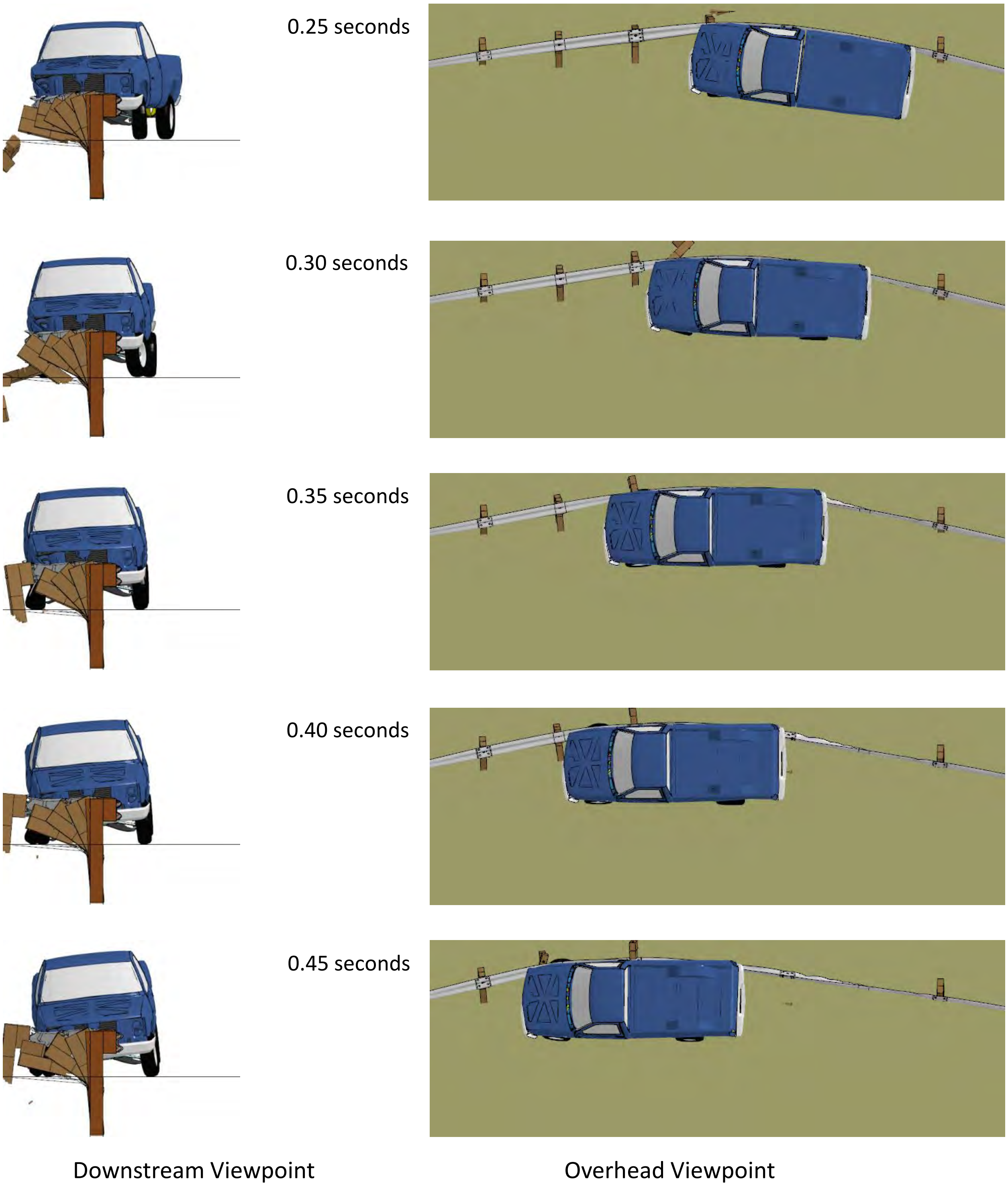


Figure F-5: [CONTINUED] Sequential views from Analysis Case DL3 from a downstream and overhead viewpoint.

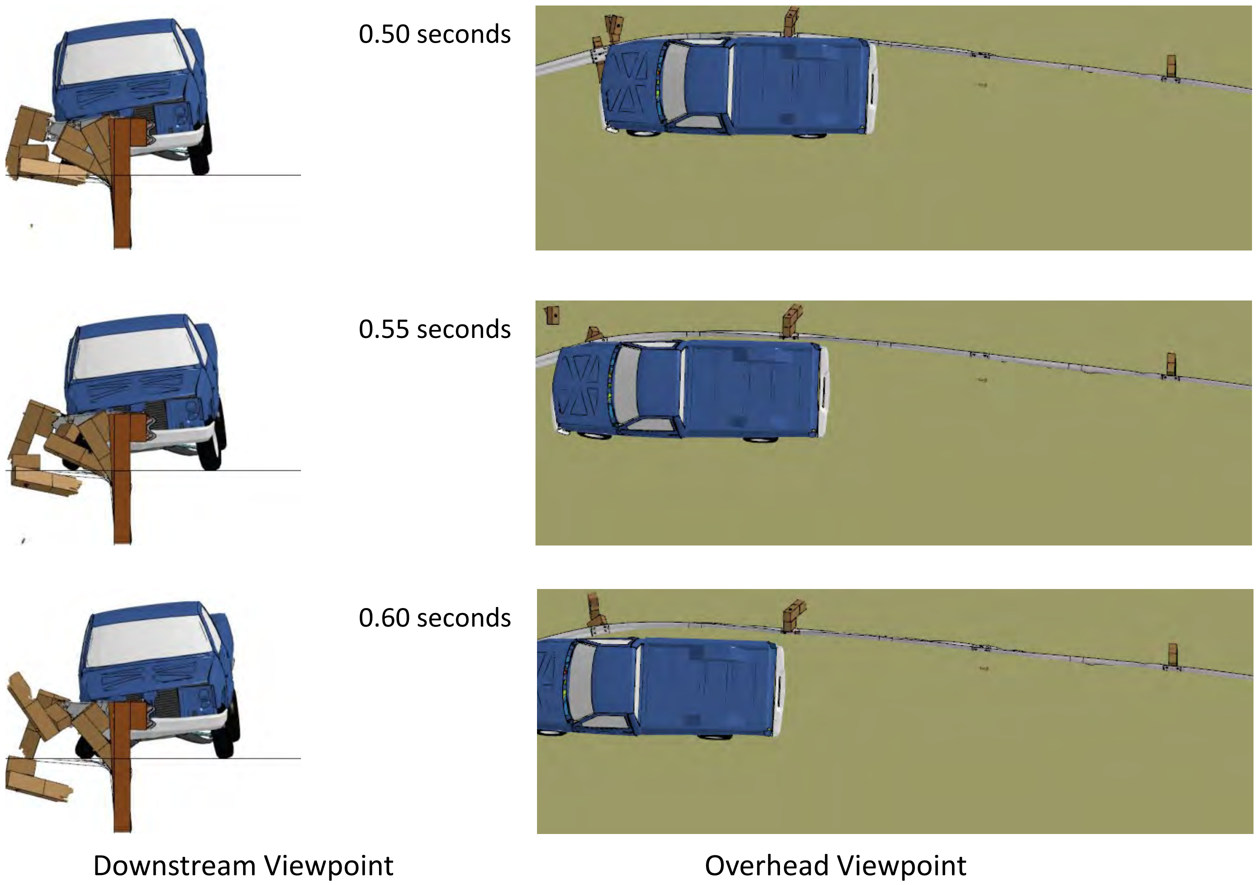


Figure F-5: [CONTINUED] Sequential views from Analysis Case DL3 from a downstream and overhead viewpoint.

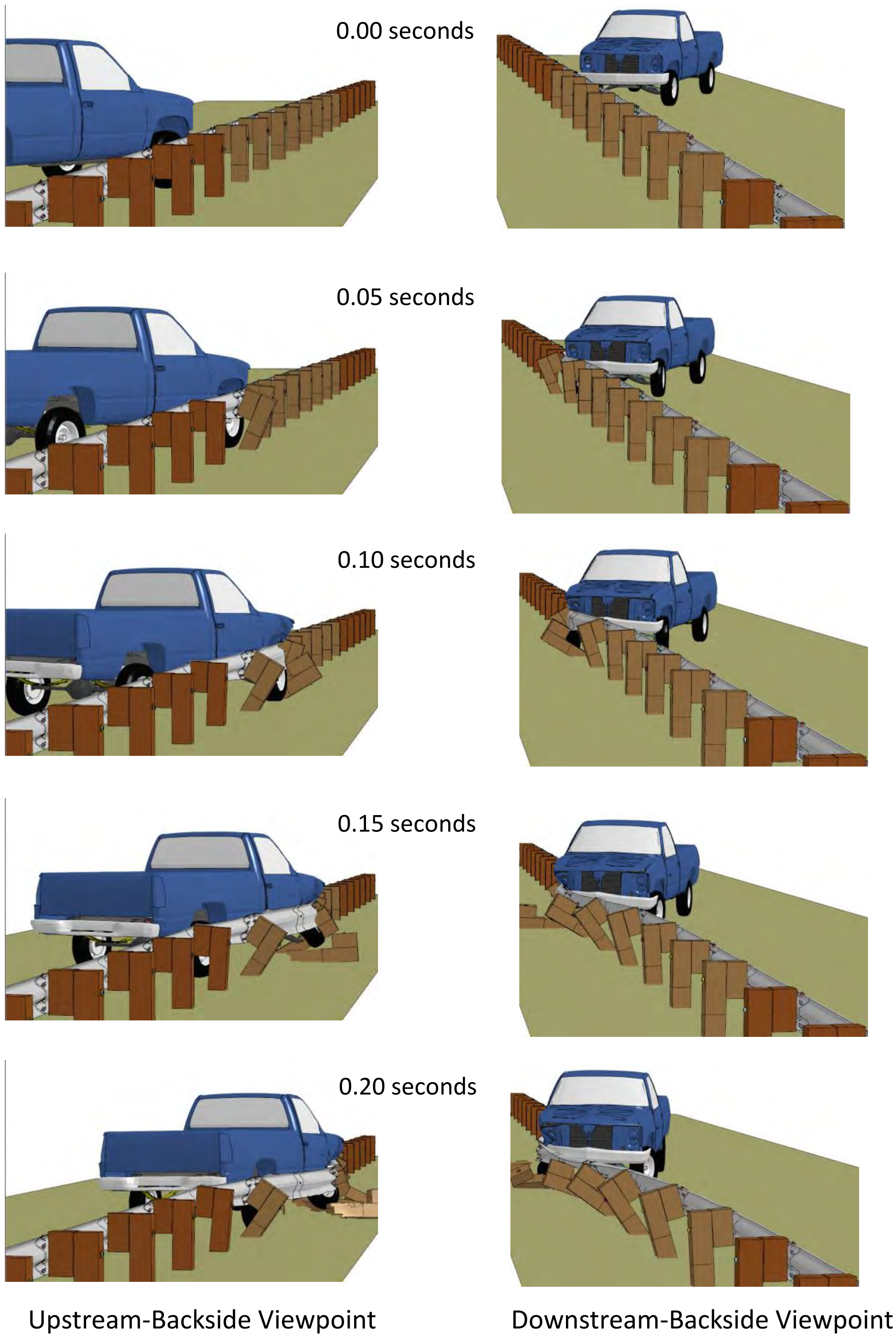


Figure F-6: Sequential views from Analysis Case DL3 from an upstream-backside and downstream-backside viewpoint.

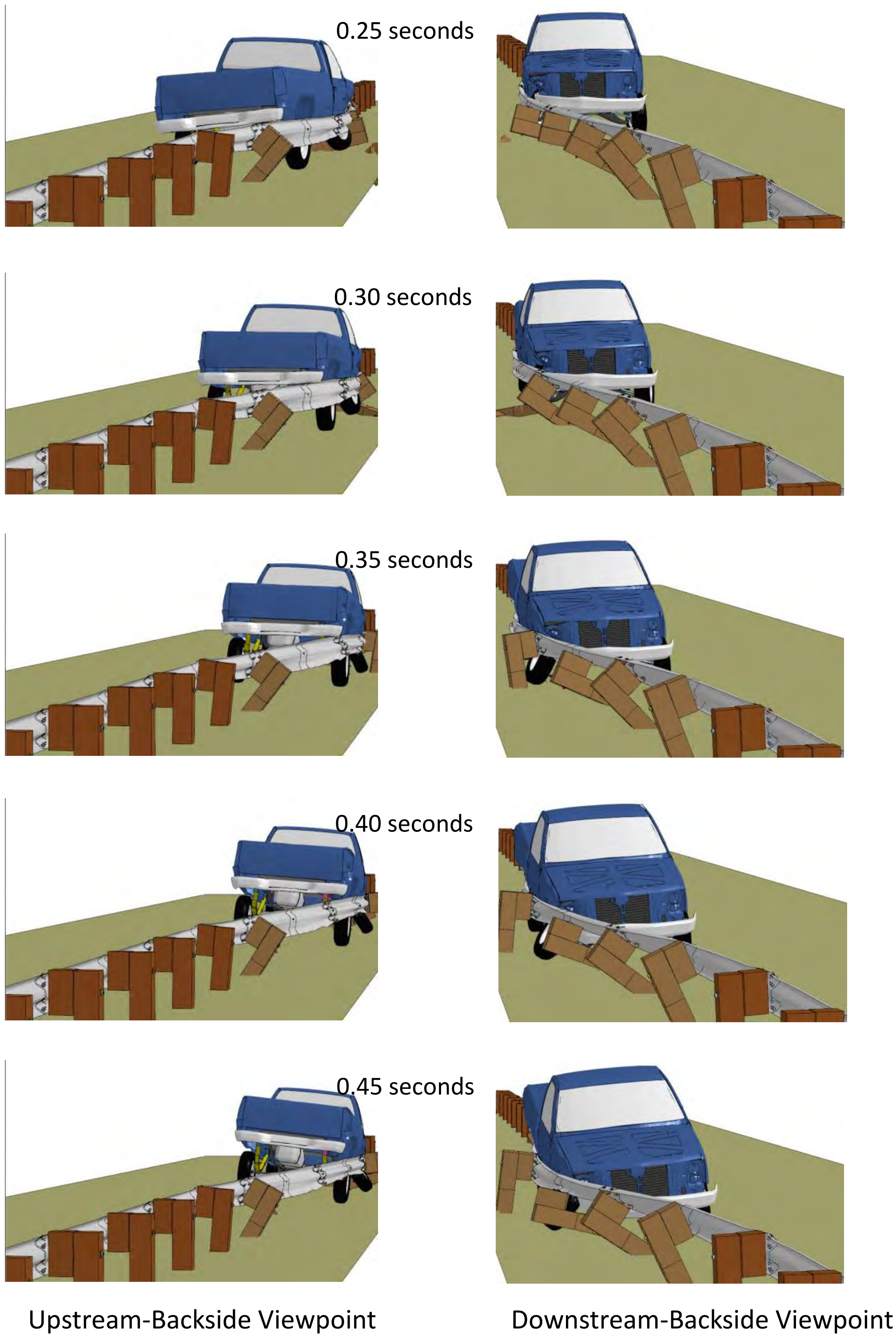


Figure F-6: [CONTINUED] Sequential views from Analysis Case DL3 from an upstream-backside and downstream-backside viewpoint.

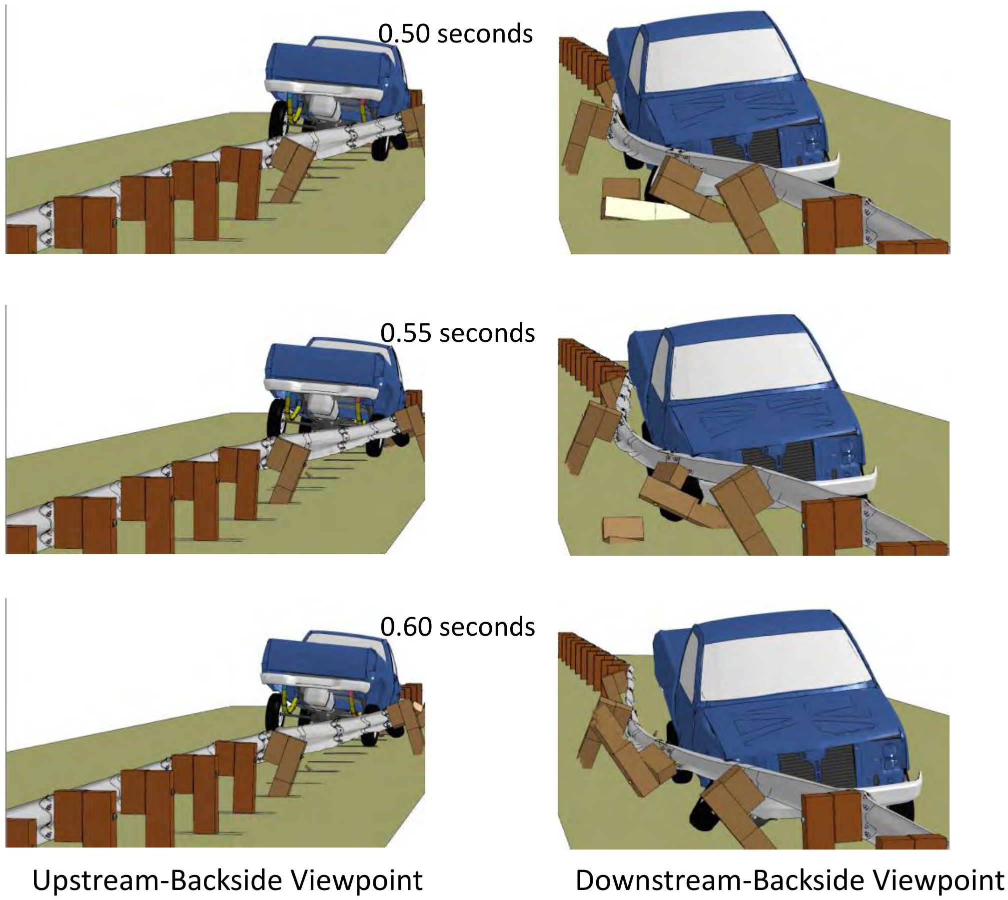


Figure F-6: [CONTINUED] Sequential views from Analysis Case DL3 from an upstream-backside and downstream-backside viewpoint.

APPENDIX H

Sequential Views from FEA Evaluation of Deteriorated Posts Located Upstream of Undamaged Posts

Task 4A-3: Assess Effects of Guardrail Post Deterioration on Performance of G4(2W)

By: Chuck A. Plaxico

January 2014

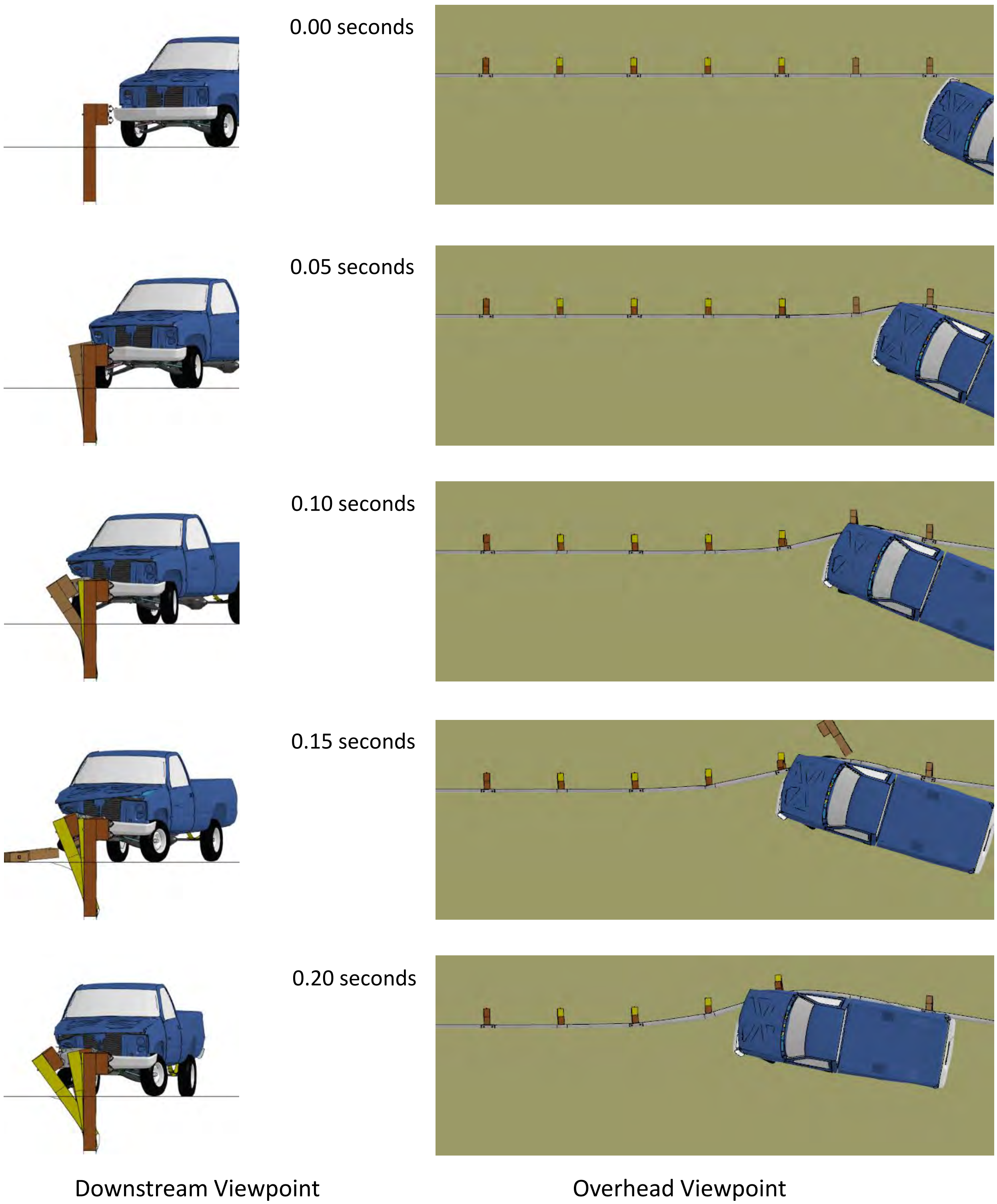


Figure G-1: Sequential views from Analysis Case DL1-DL0 from a downstream and overhead viewpoint.

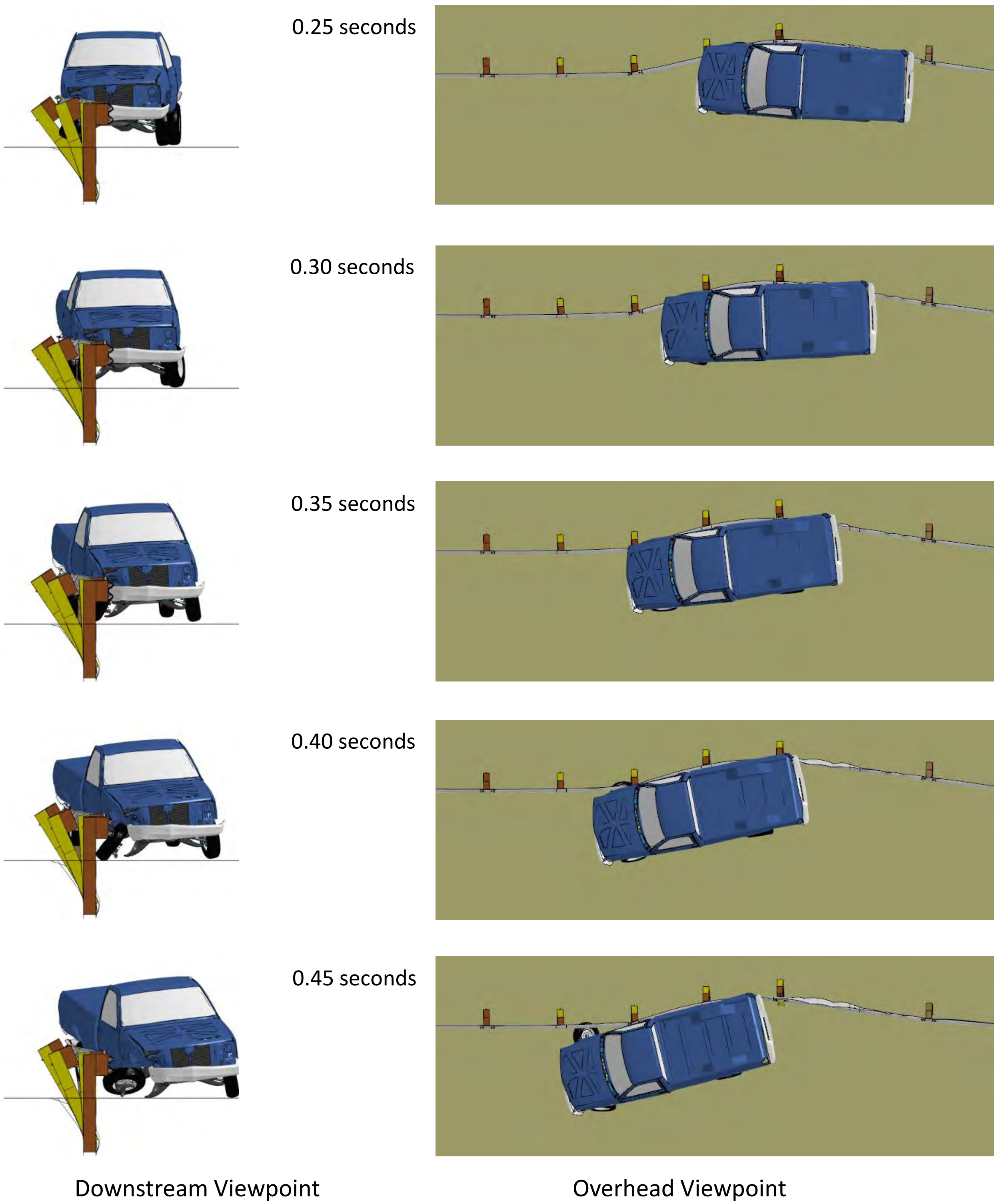


Figure G-1: [CONTINUED] Sequential views from Analysis Case DL1-DL0 from a downstream and overhead viewpoint.

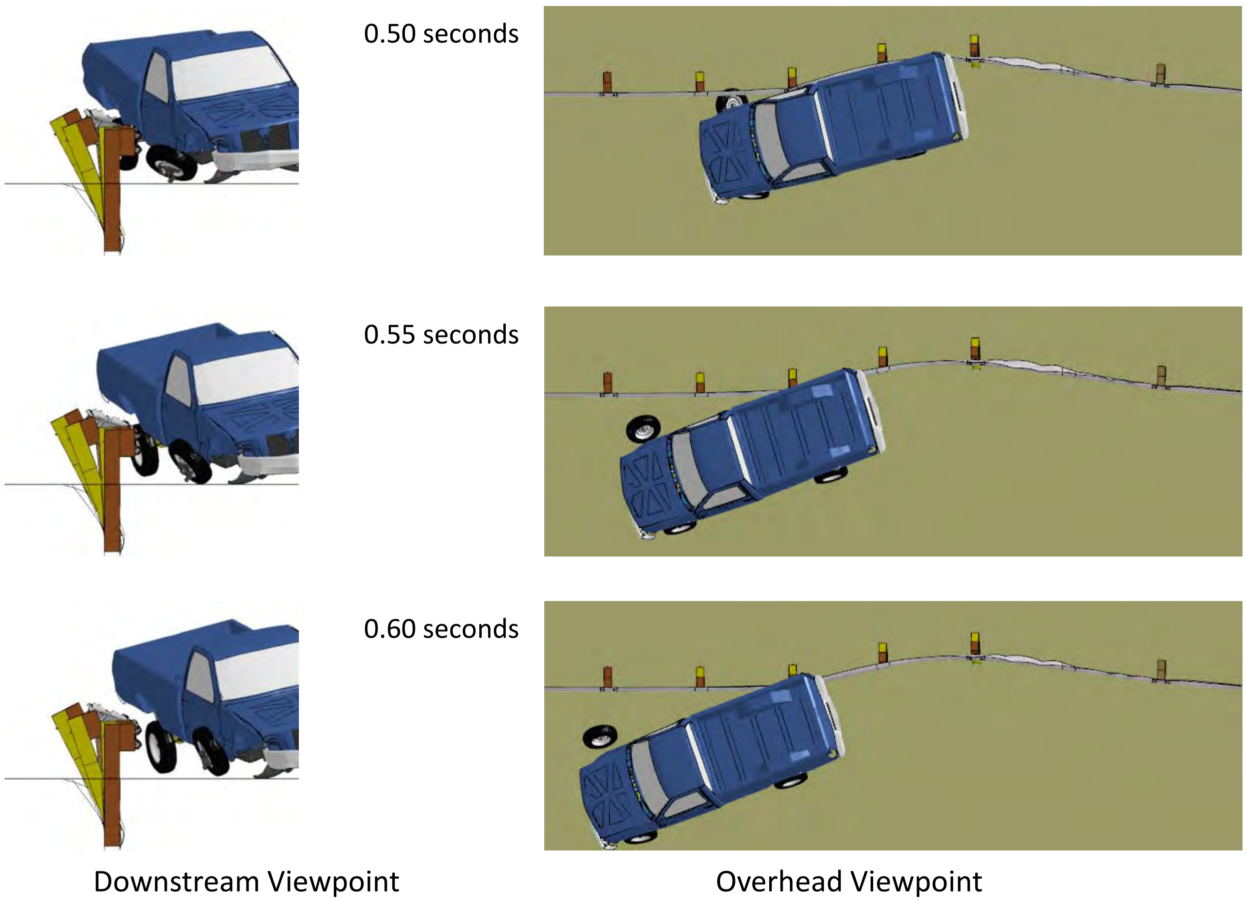


Figure G-1: [CONTINUED] Sequential views from Analysis Case DL1-DL0 from a downstream and overhead viewpoint.

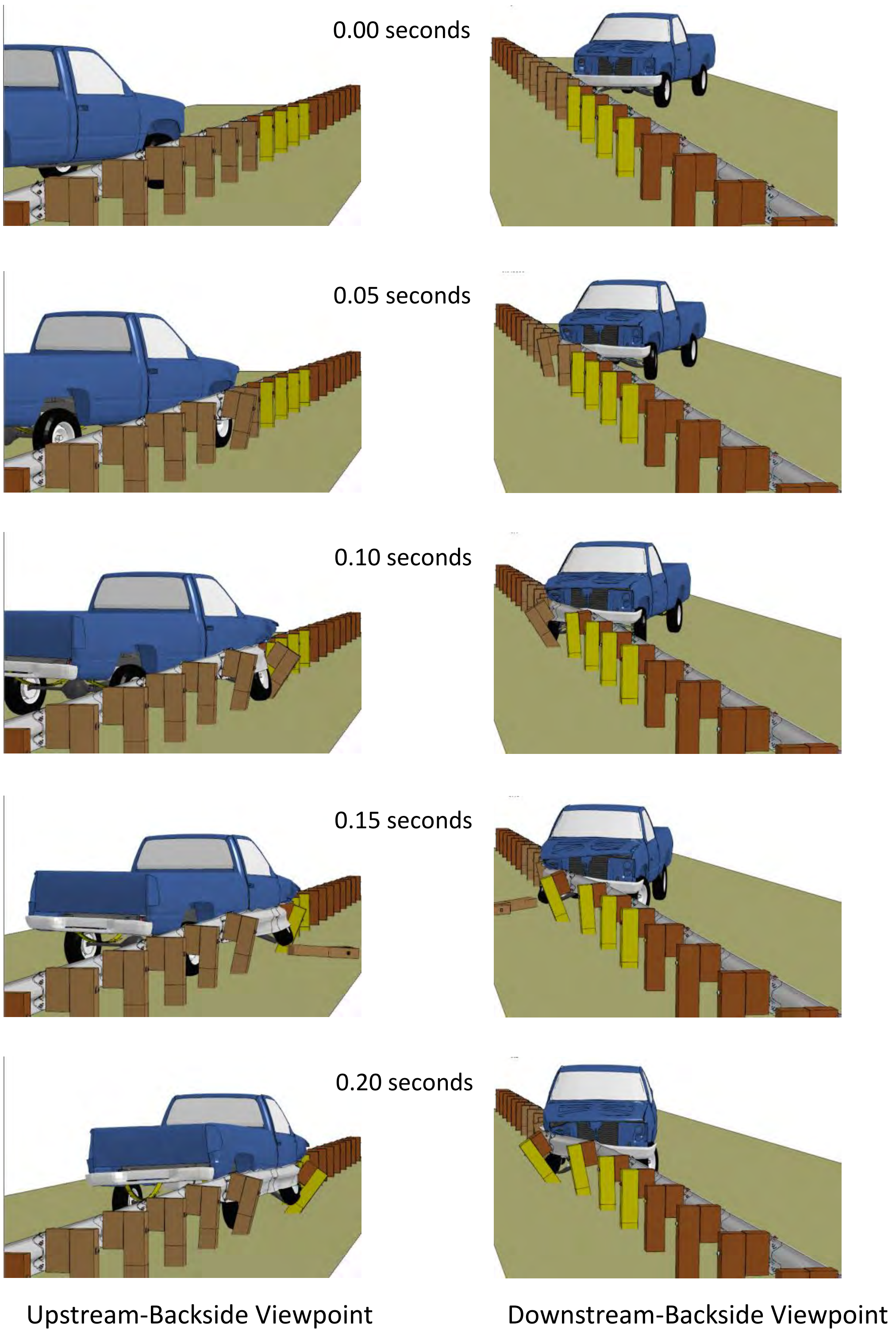


Figure G-2: Sequential views from Analysis Case DL1-DL0 from an upstream-backside and downstream-backside viewpoint.

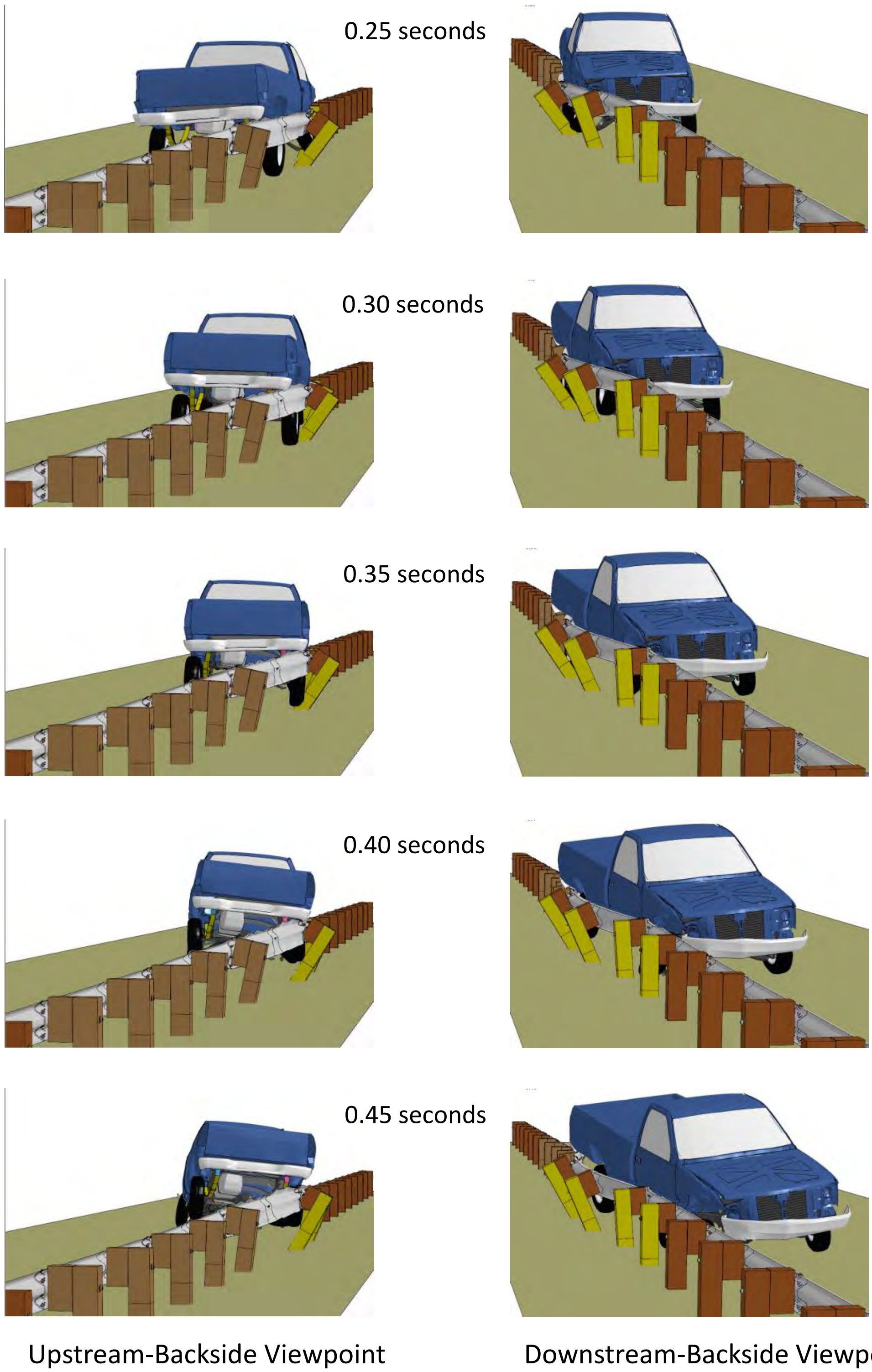


Figure G-2: [CONTINUED] Sequential views from Analysis Case DL1-DL0 from an upstream-backside and downstream-backside viewpoint.

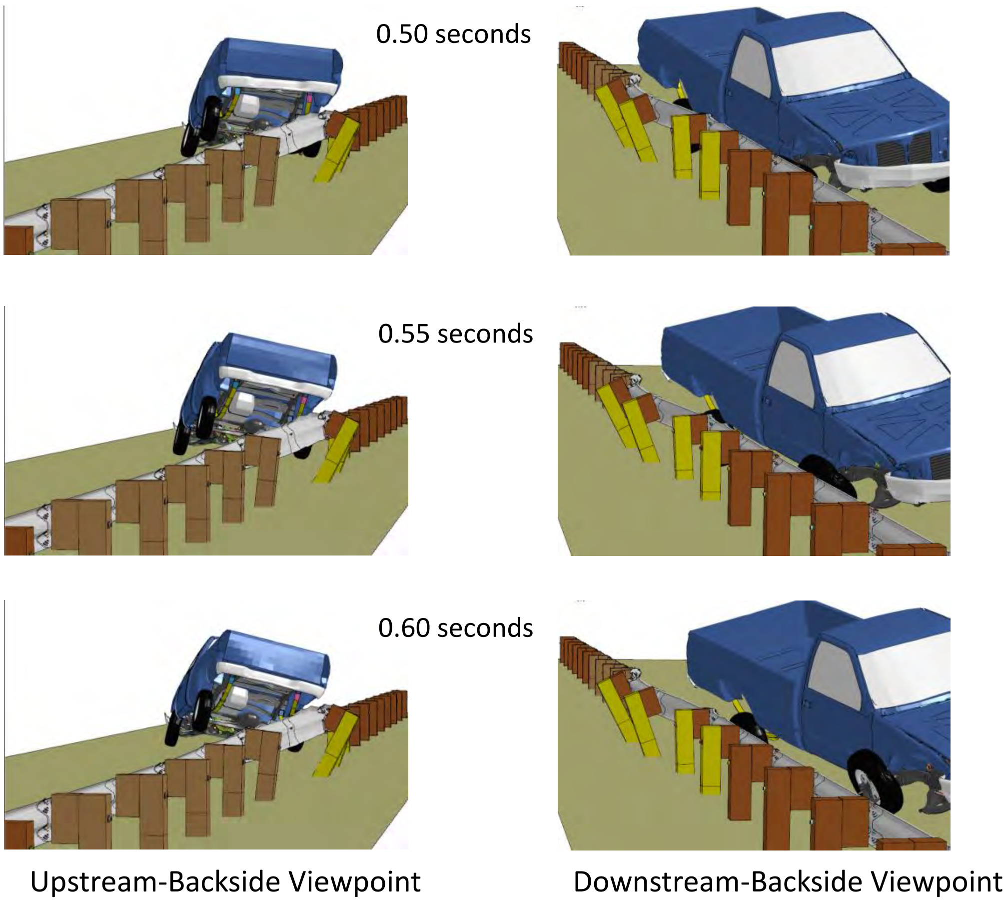


Figure G-2: [CONTINUED] Sequential views from Analysis Case DL1-DL0 from an upstream-backside and downstream-backside viewpoint.

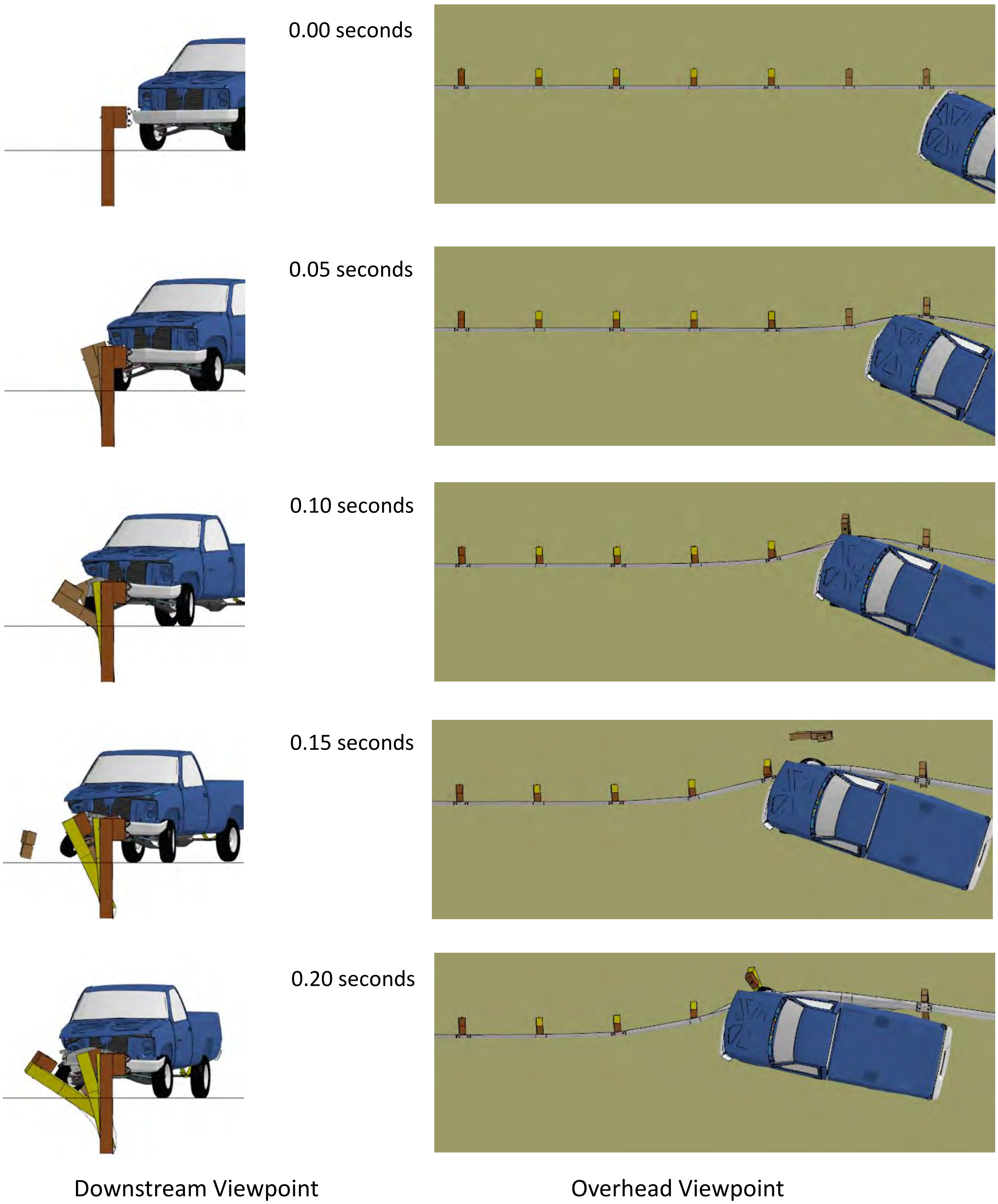


Figure G-3: Sequential views from Analysis Case DL2-DL0 from a downstream and overhead viewpoint.

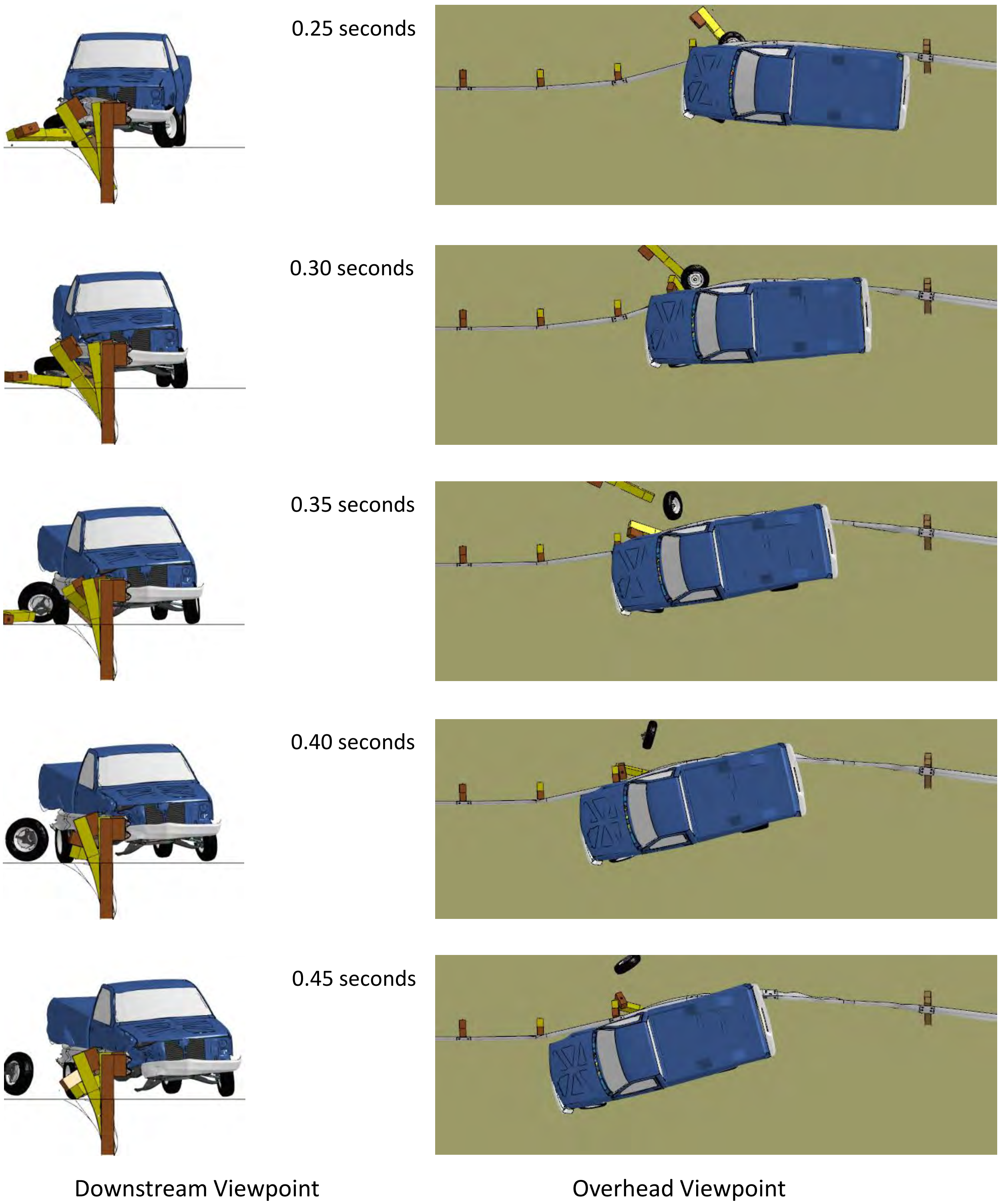


Figure G-3: [CONTINUED] Sequential views from Analysis Case DL2-DL0 from a downstream and overhead viewpoint.

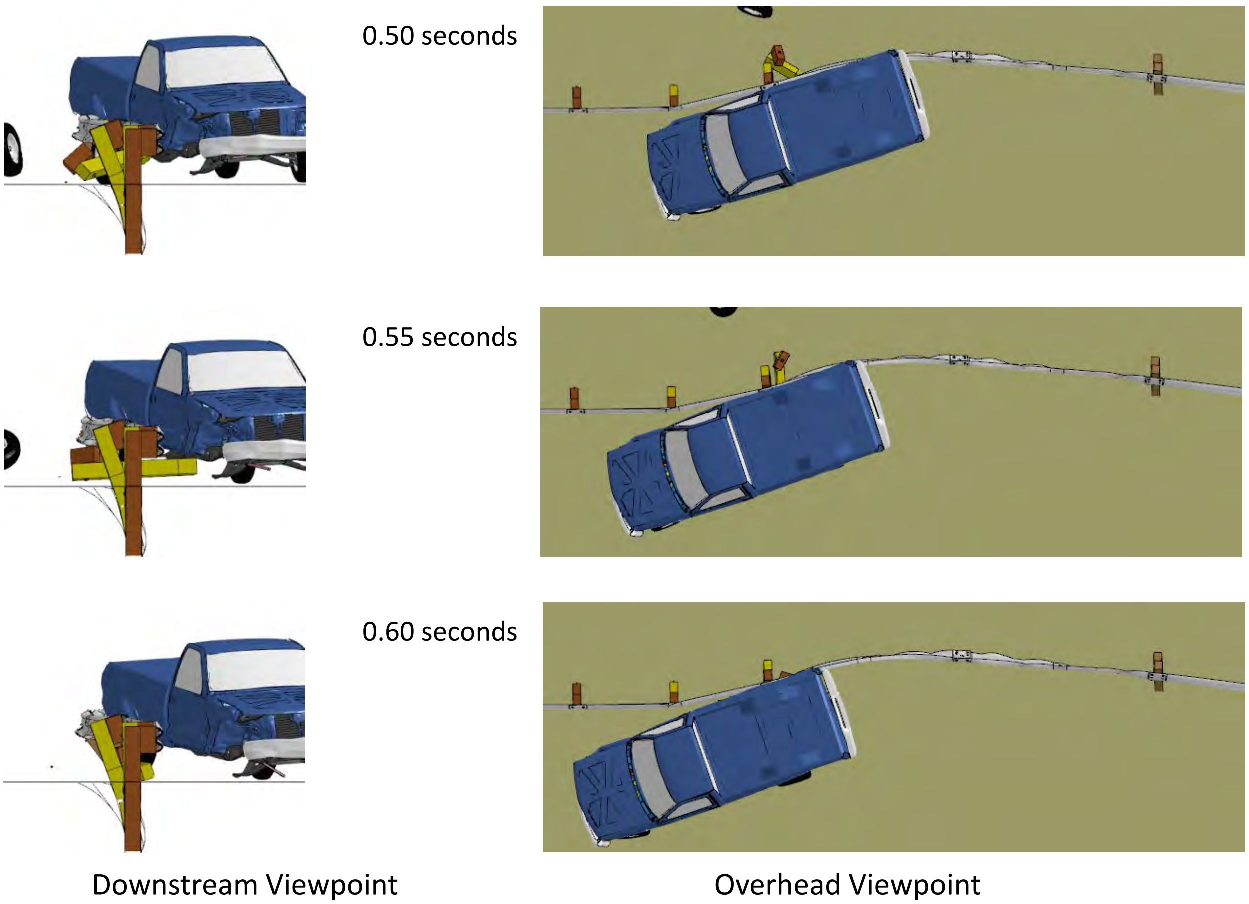


Figure G-3: [CONTINUED] Sequential views from Analysis Case DL2-DL0 from a downstream and overhead viewpoint.

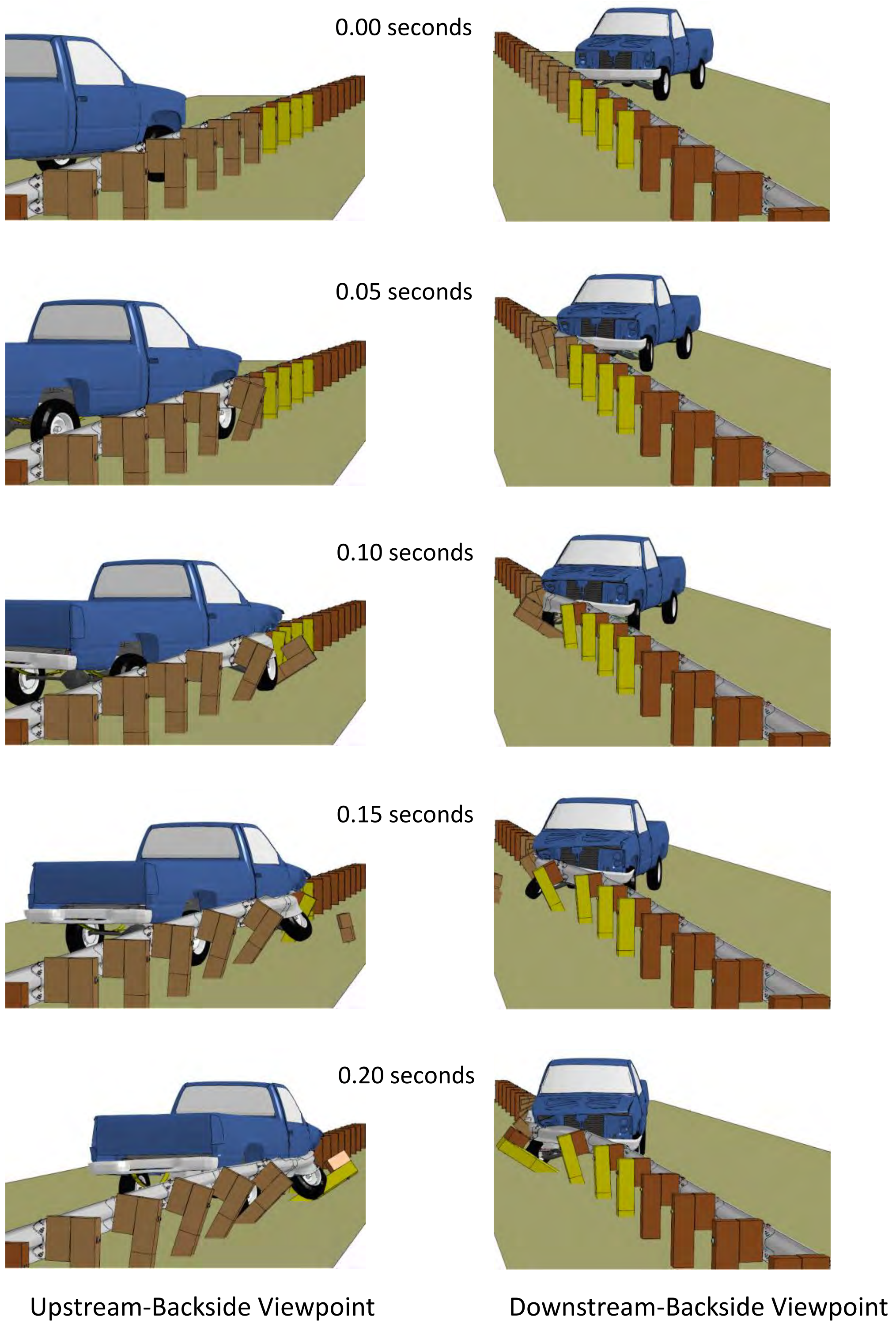


Figure G-4: Sequential views from Analysis Case DL2-DL0 from an upstream-backside and downstream-backside viewpoint.

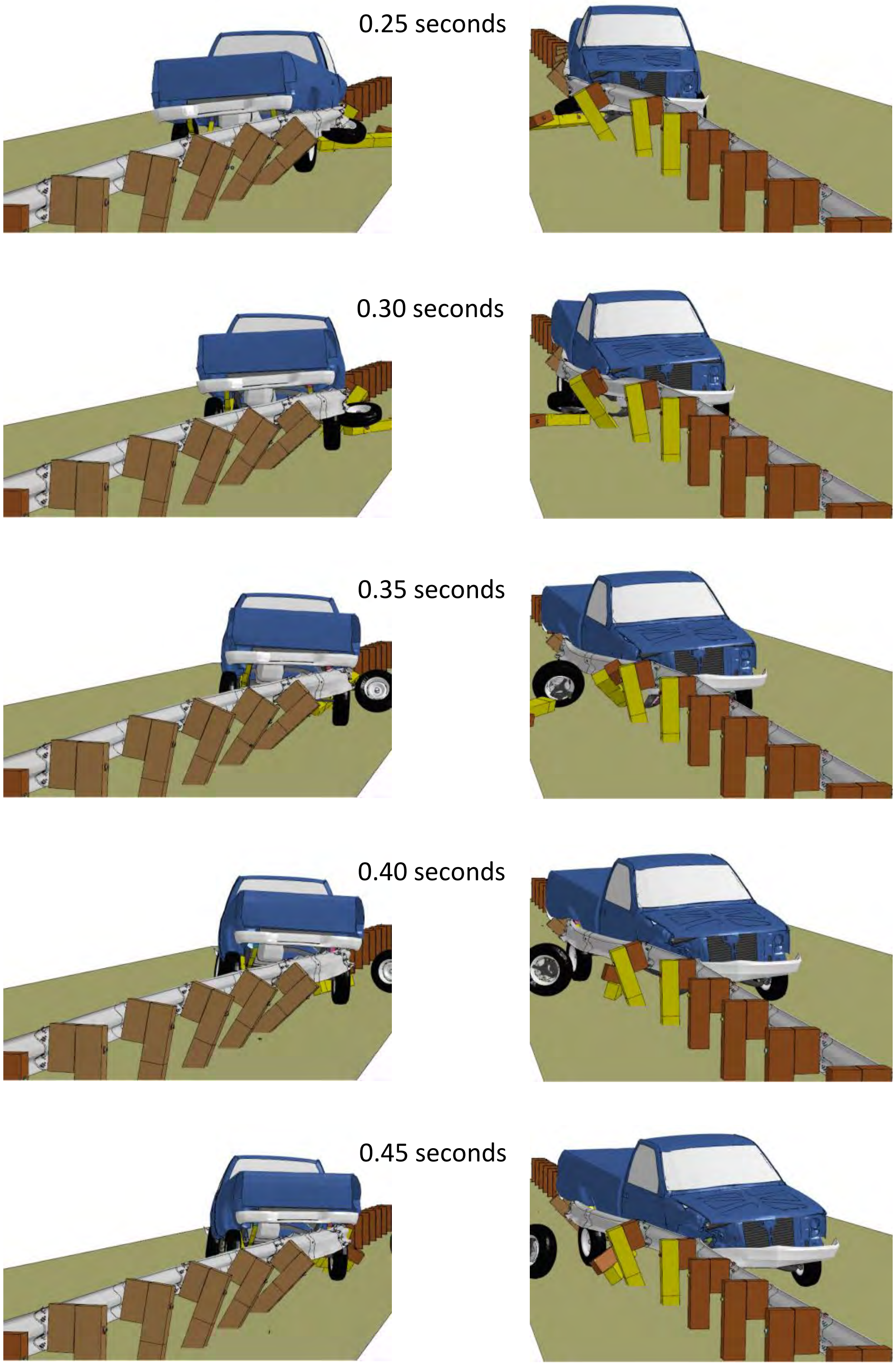


Figure G-4: [CONTINUED] Sequential views from Analysis Case DL2-DL0 from an upstream-backside and downstream-backside viewpoint.

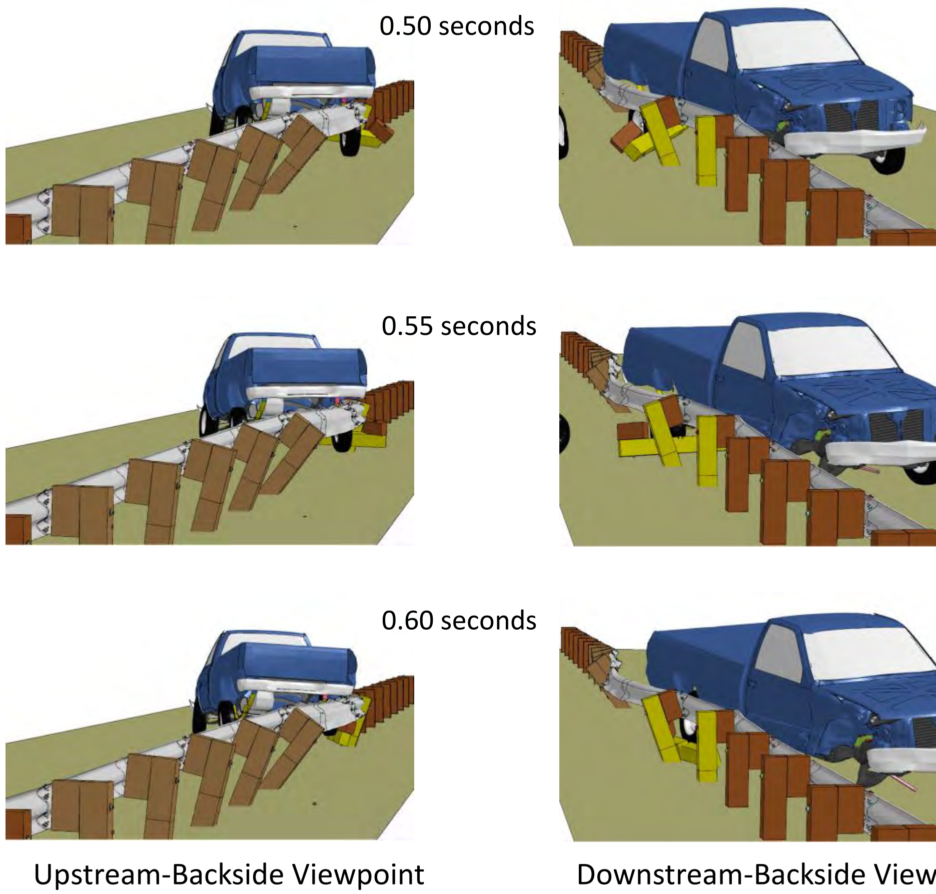


Figure G-4: [CONTINUED]Sequential views from Analysis Case DL2-DL0 from an upstream-backside and downstream-backside viewpoint.

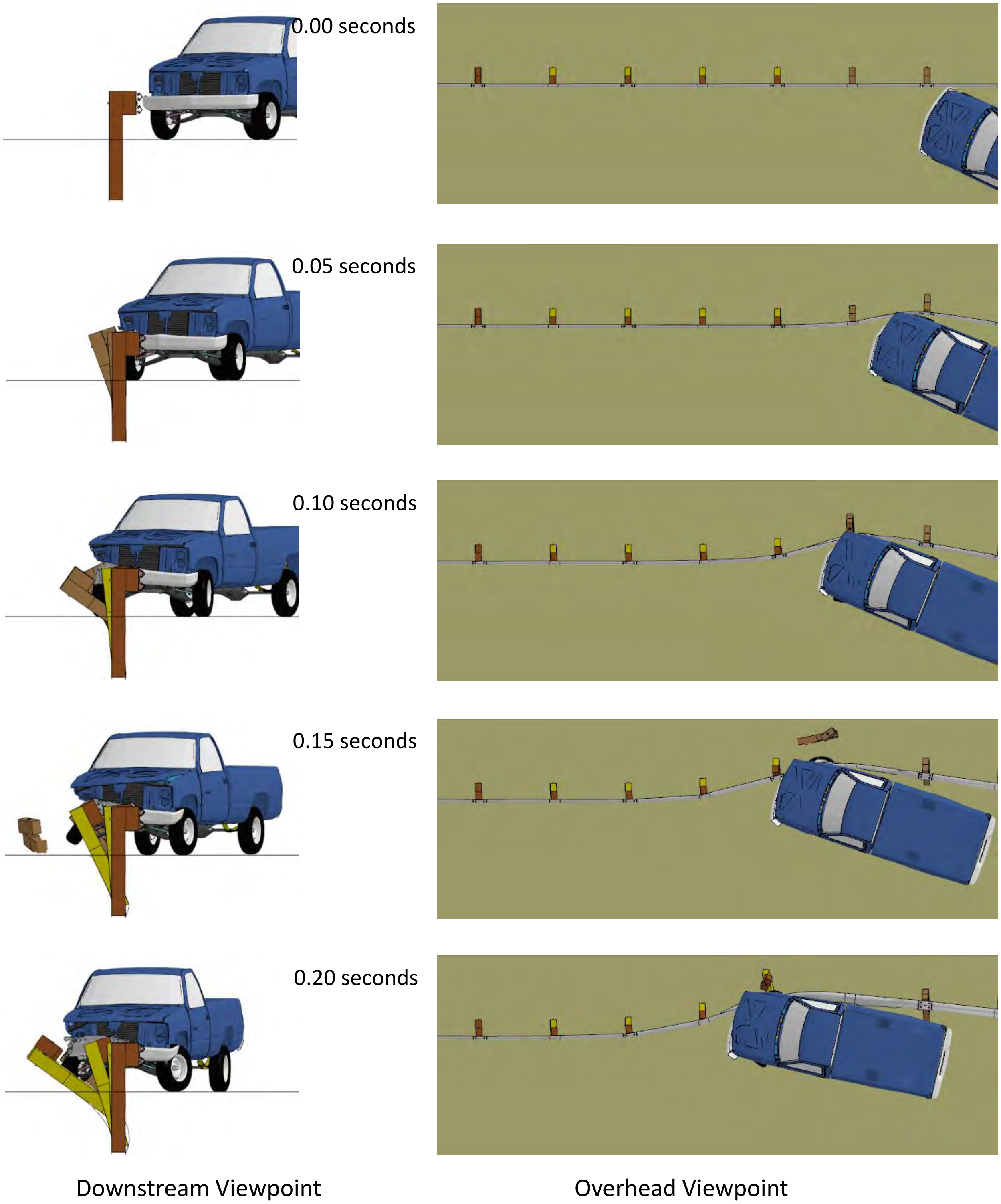


Figure G-5: Sequential views from Analysis Case DL3-DL0 from a downstream and overhead viewpoint.

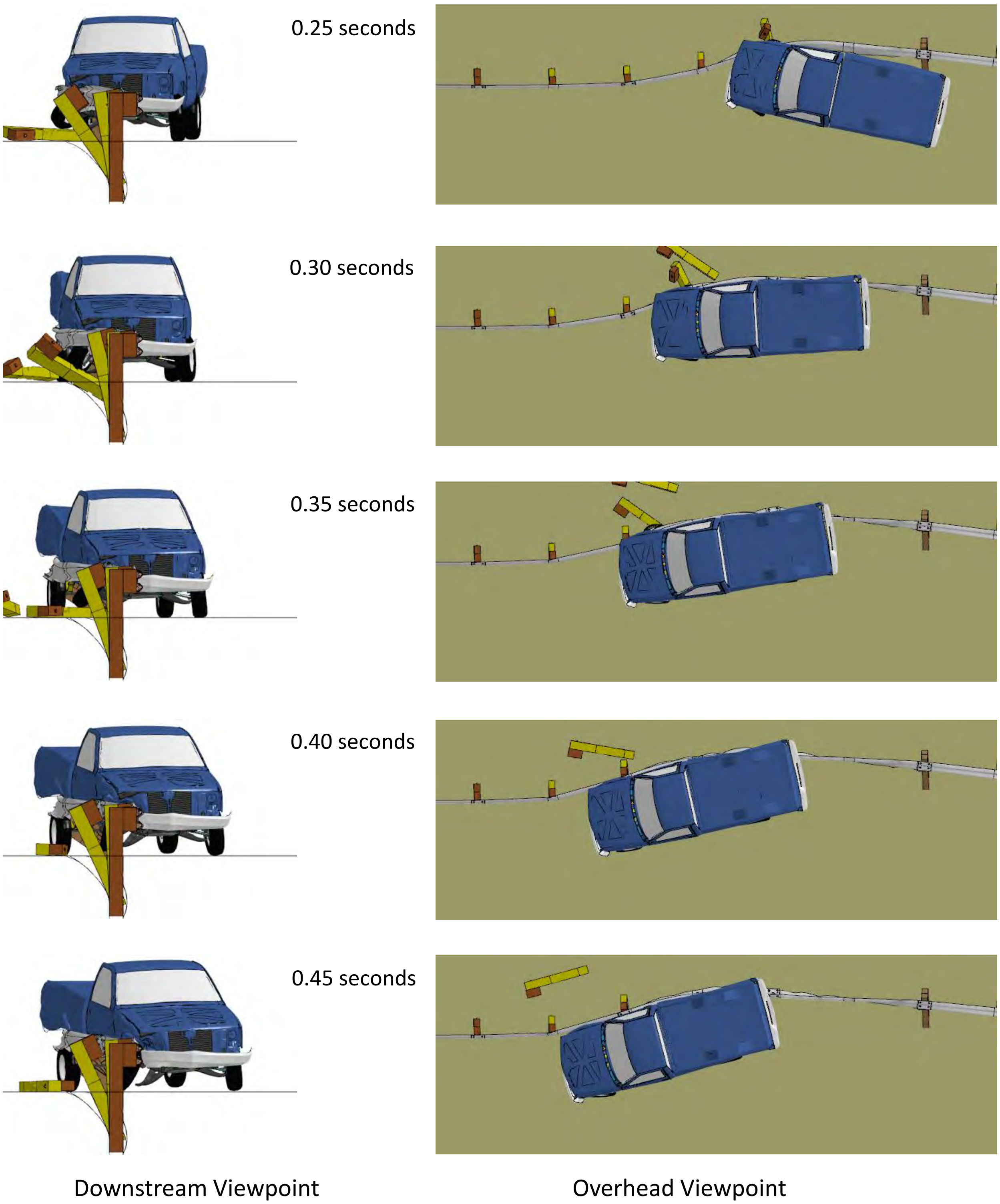


Figure G-5: [CONTINUED] Sequential views from Analysis Case DL3-DL0 from a downstream and overhead viewpoint.

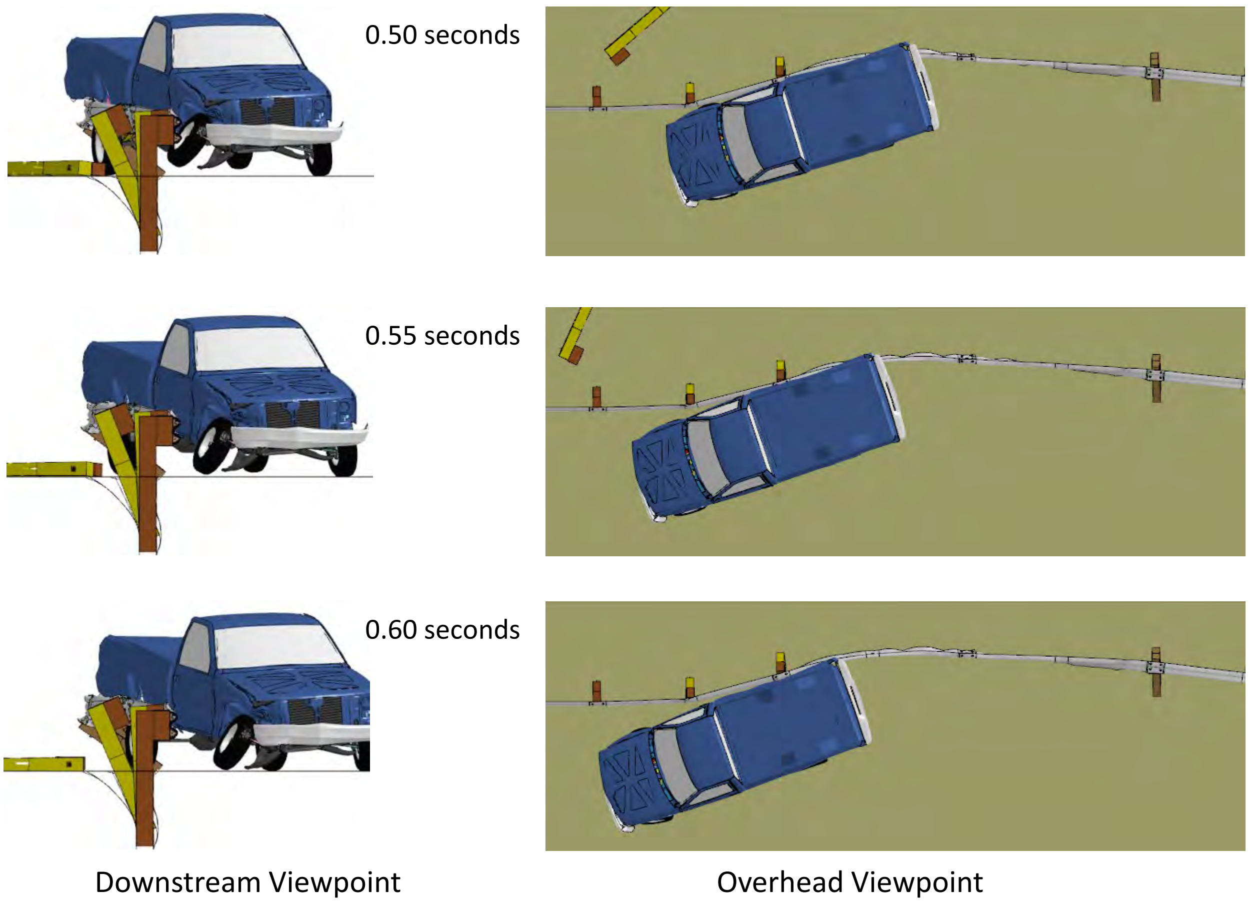


Figure G-5: [CONTINUED] Sequential views from Analysis Case DL3-DL0 from a downstream and overhead viewpoint.

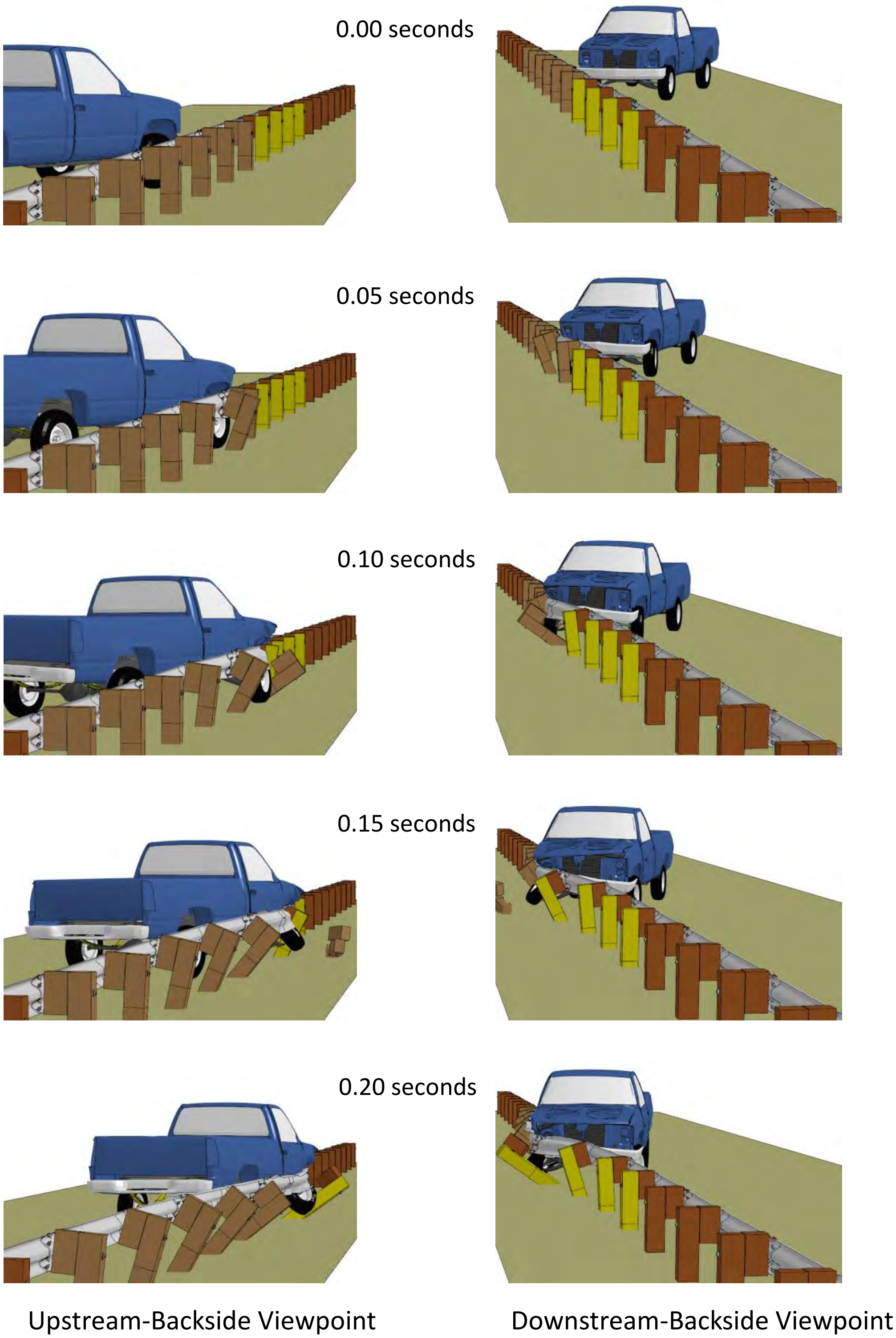


Figure G-6: Sequential views from Analysis Case DL3-DL0 from an upstream-backside and downstream-backside viewpoint.

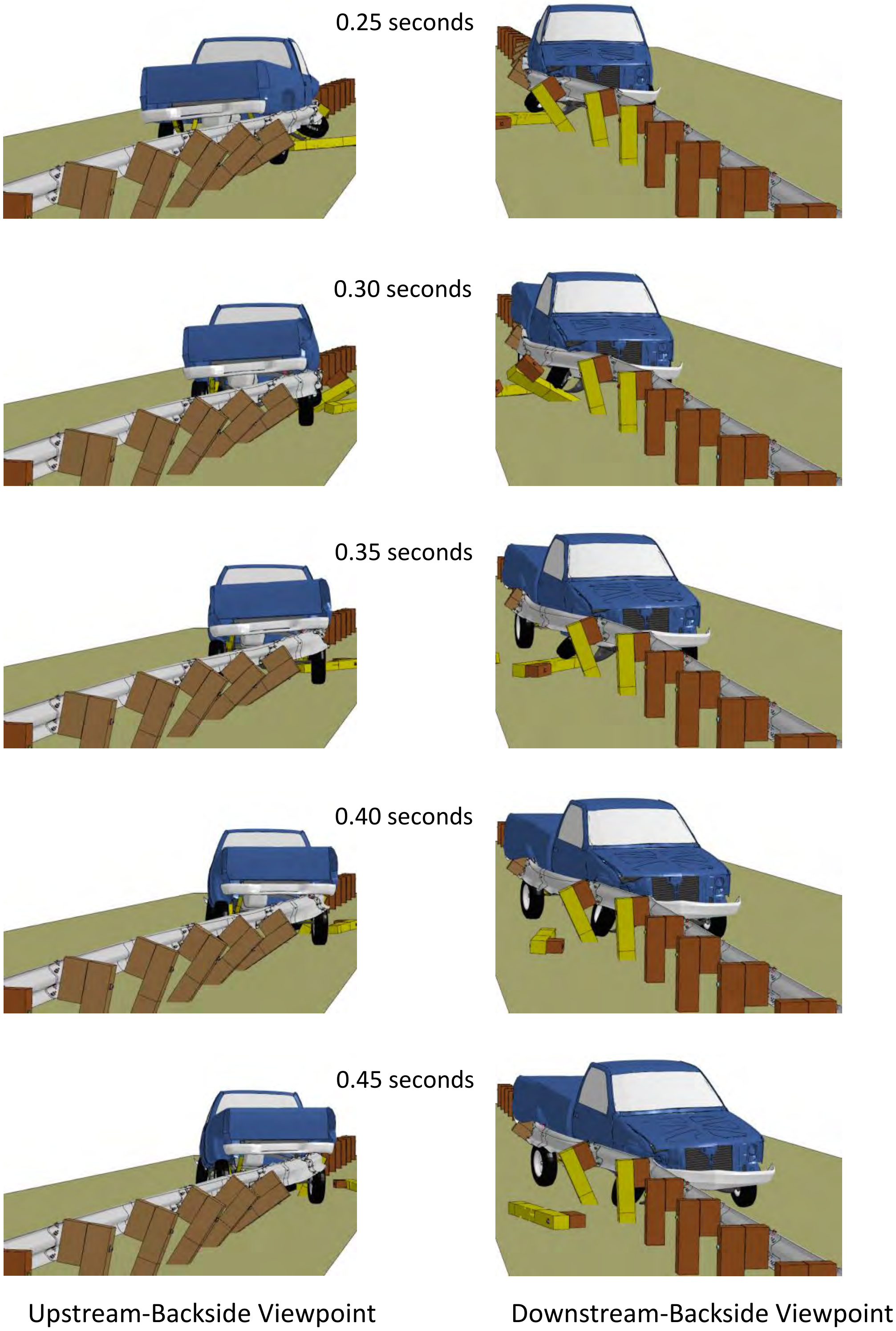


Figure G-6: [CONTINUED] Sequential views from Analysis Case DL3-DL0 from an upstream-backside and downstream-backside viewpoint.

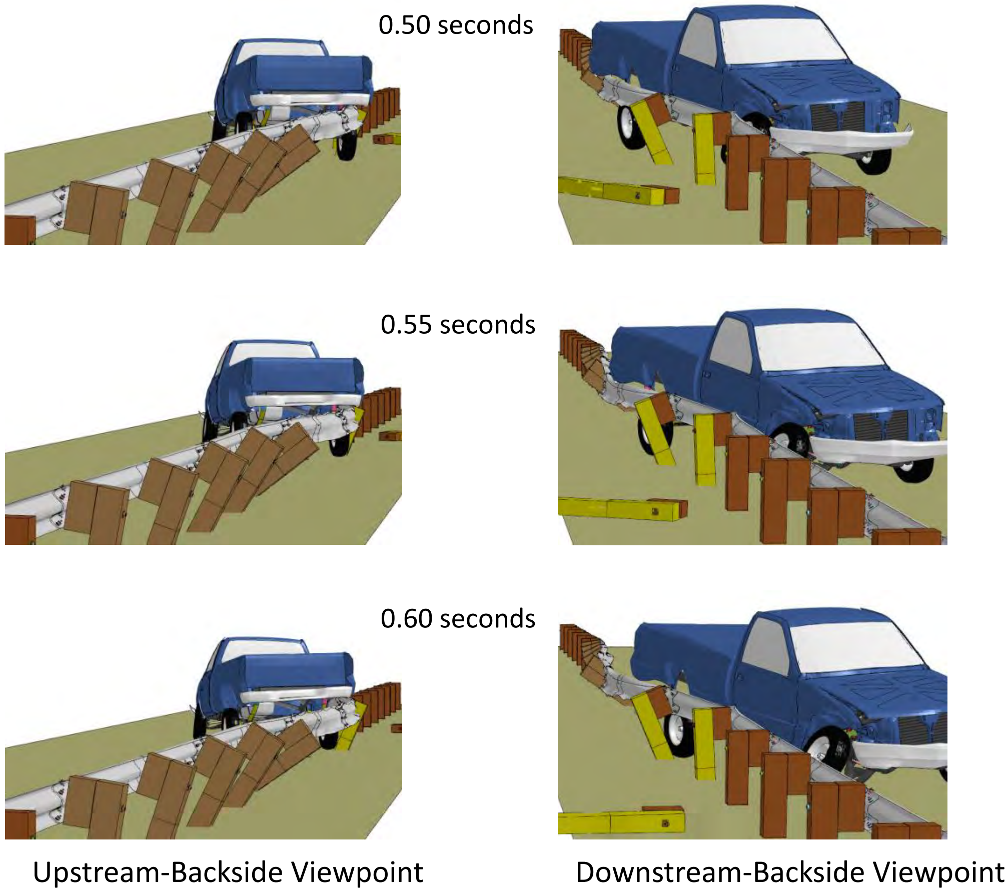


Figure G-6: [CONTINUED] Sequential views from Analysis Case DL3-DL0 from an upstream-backside and downstream-backside viewpoint.

APPENDIX I

Sequential Views from FEA Evaluation of G4(2W) with Various Anchor Strengths

Task 4A-2: Assess Effects of Anchor Strength on Performance of G4(2W)

By: Chuck A. Plaxico

January 2014

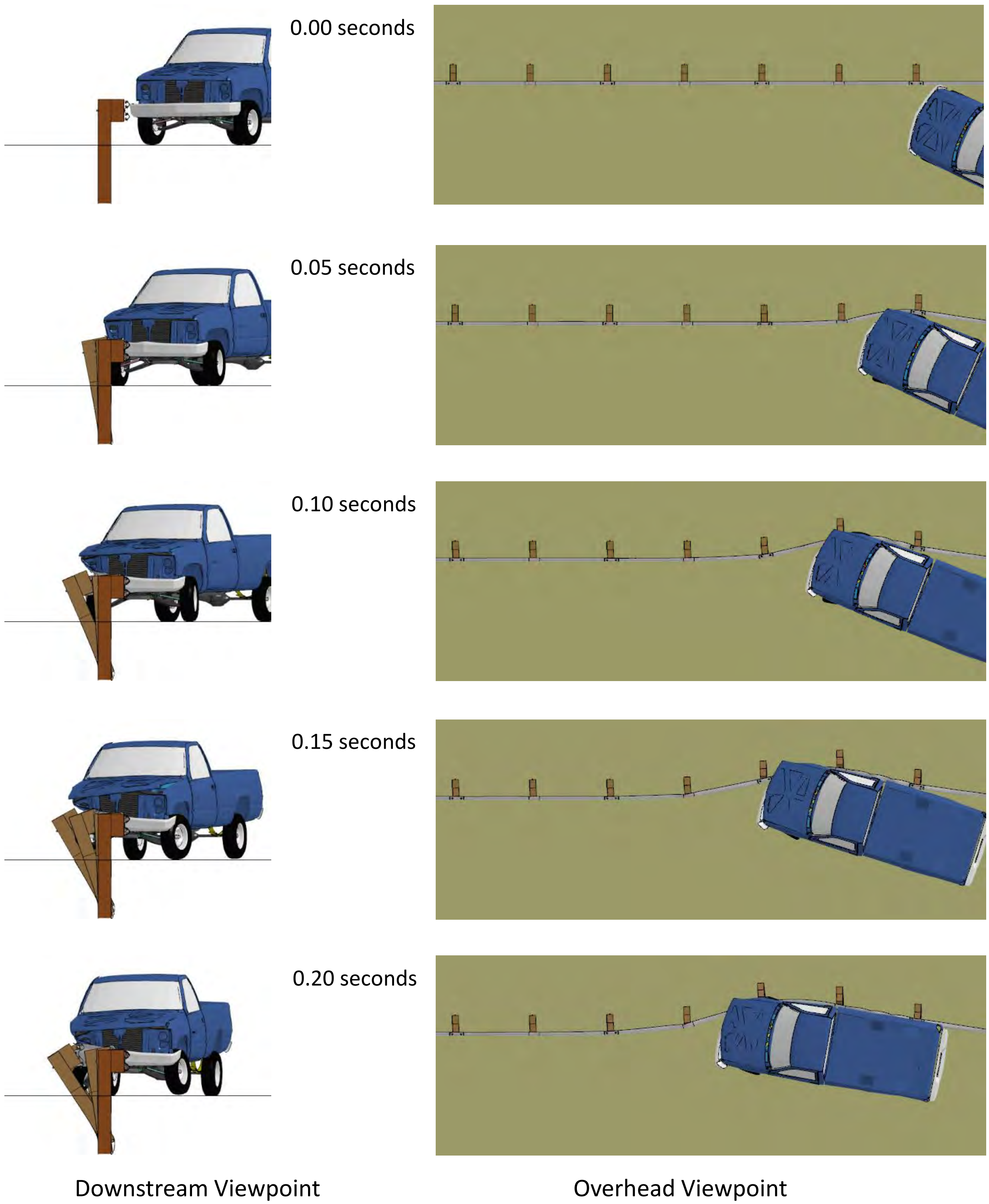


Figure C-1. Sequential views from a downstream and overhead viewpoint for analysis case: 167% baseline anchor strength.

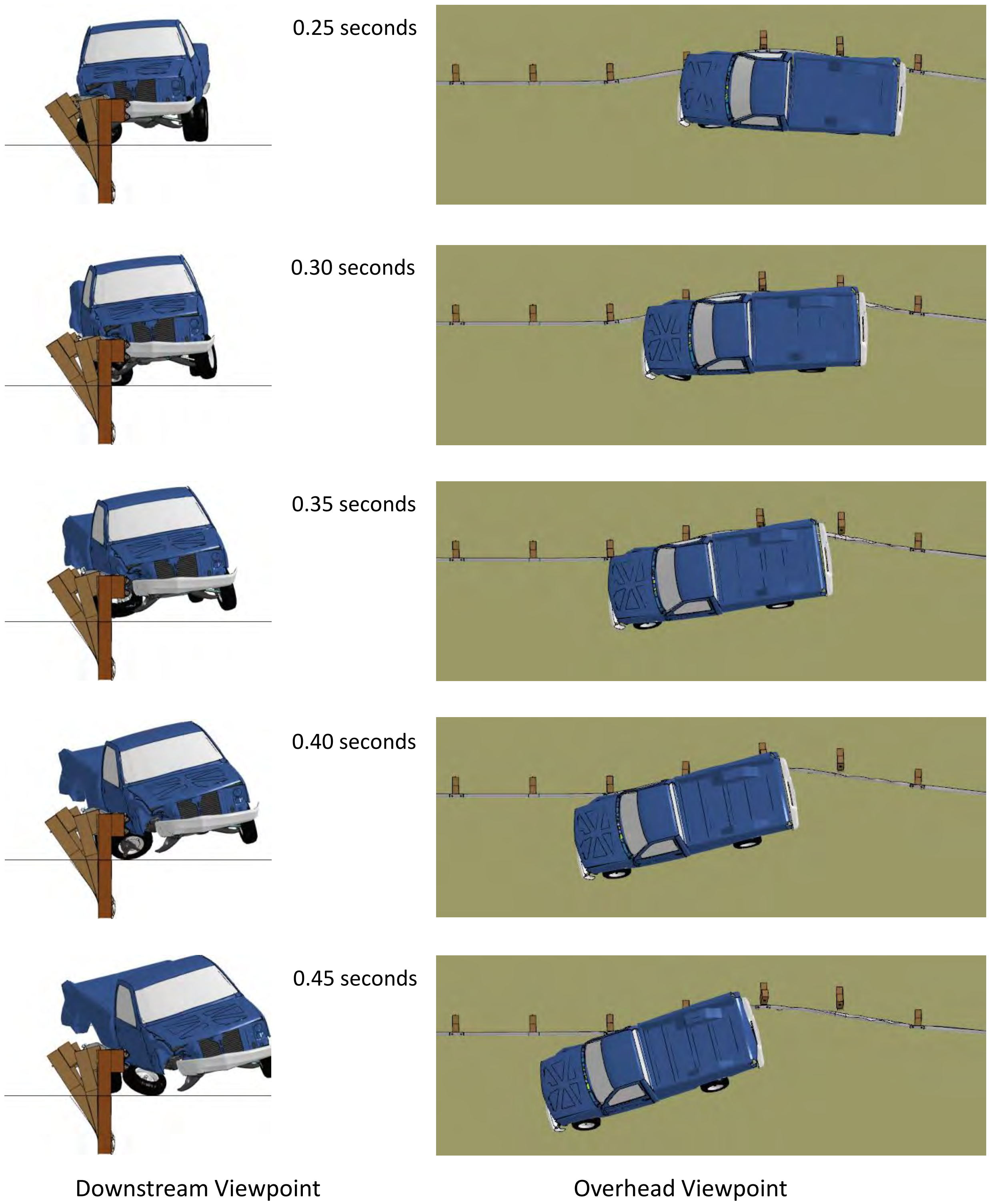


Figure C-1. [CONTINUED] Sequential views from a downstream and overhead viewpoint for analysis case: 167% baseline anchor strength.

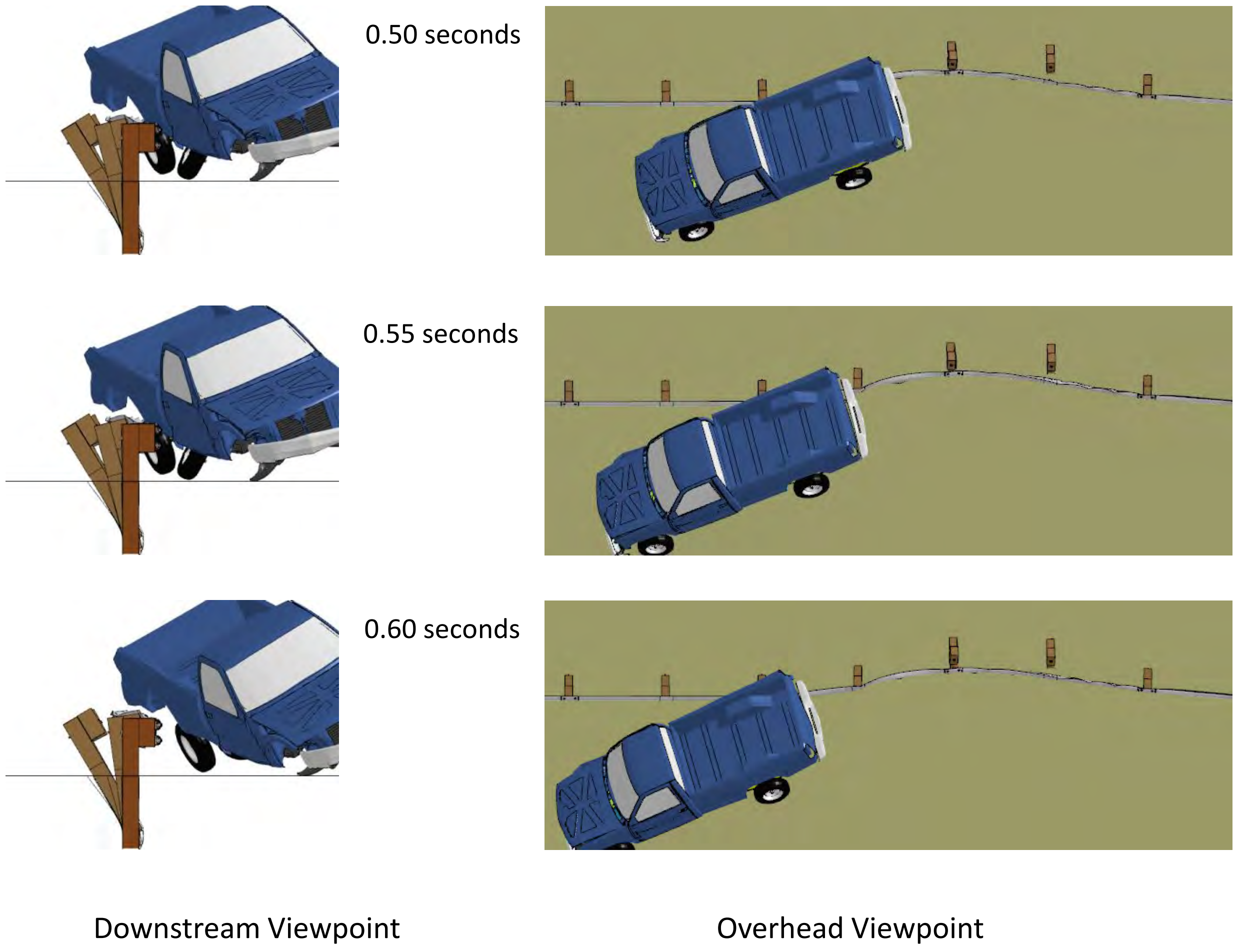


Figure C-1. [CONTINUED] Sequential views from a downstream and overhead viewpoint for analysis case: 167% baseline anchor strength.

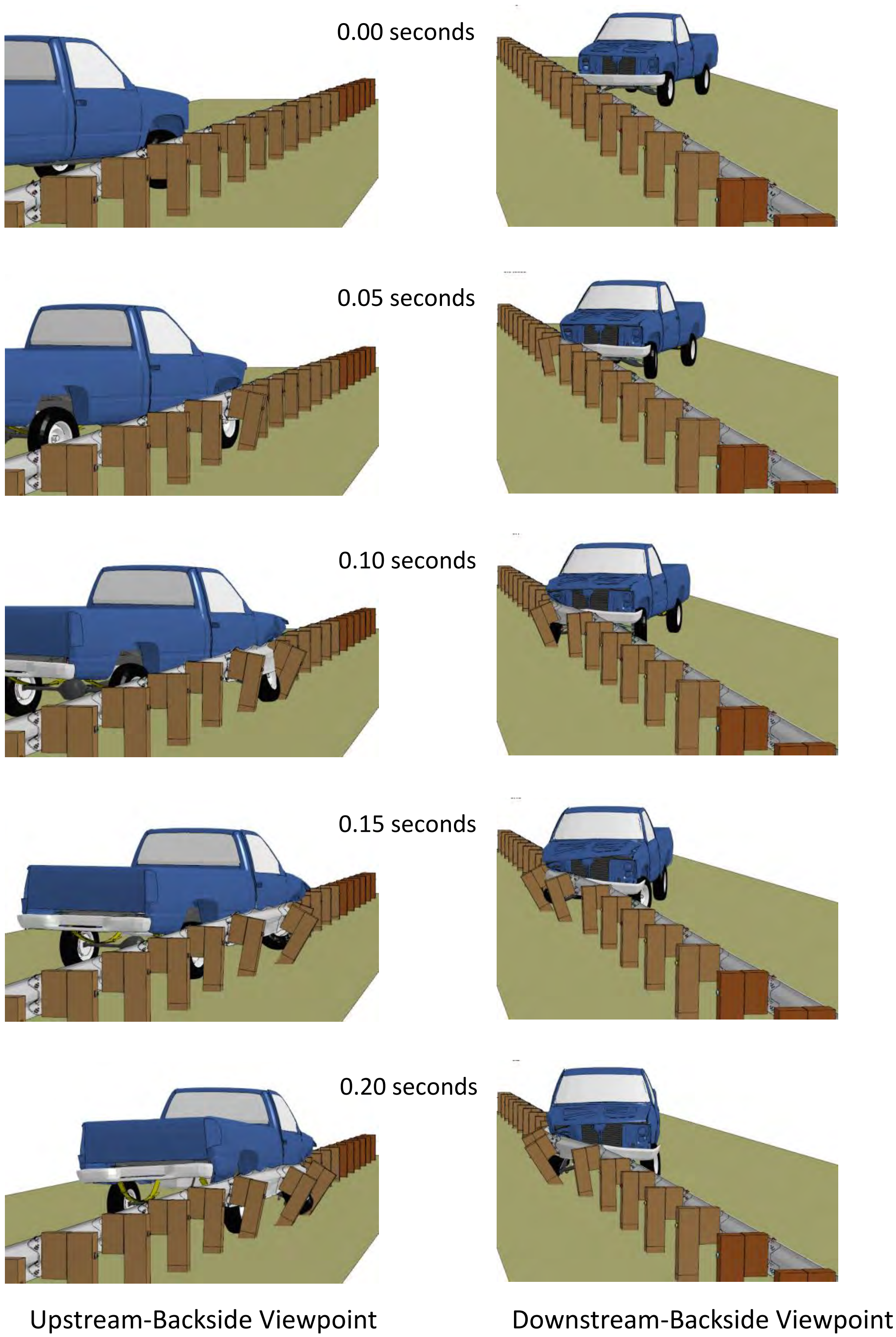


Figure C-2. Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: 167% baseline anchor strength.

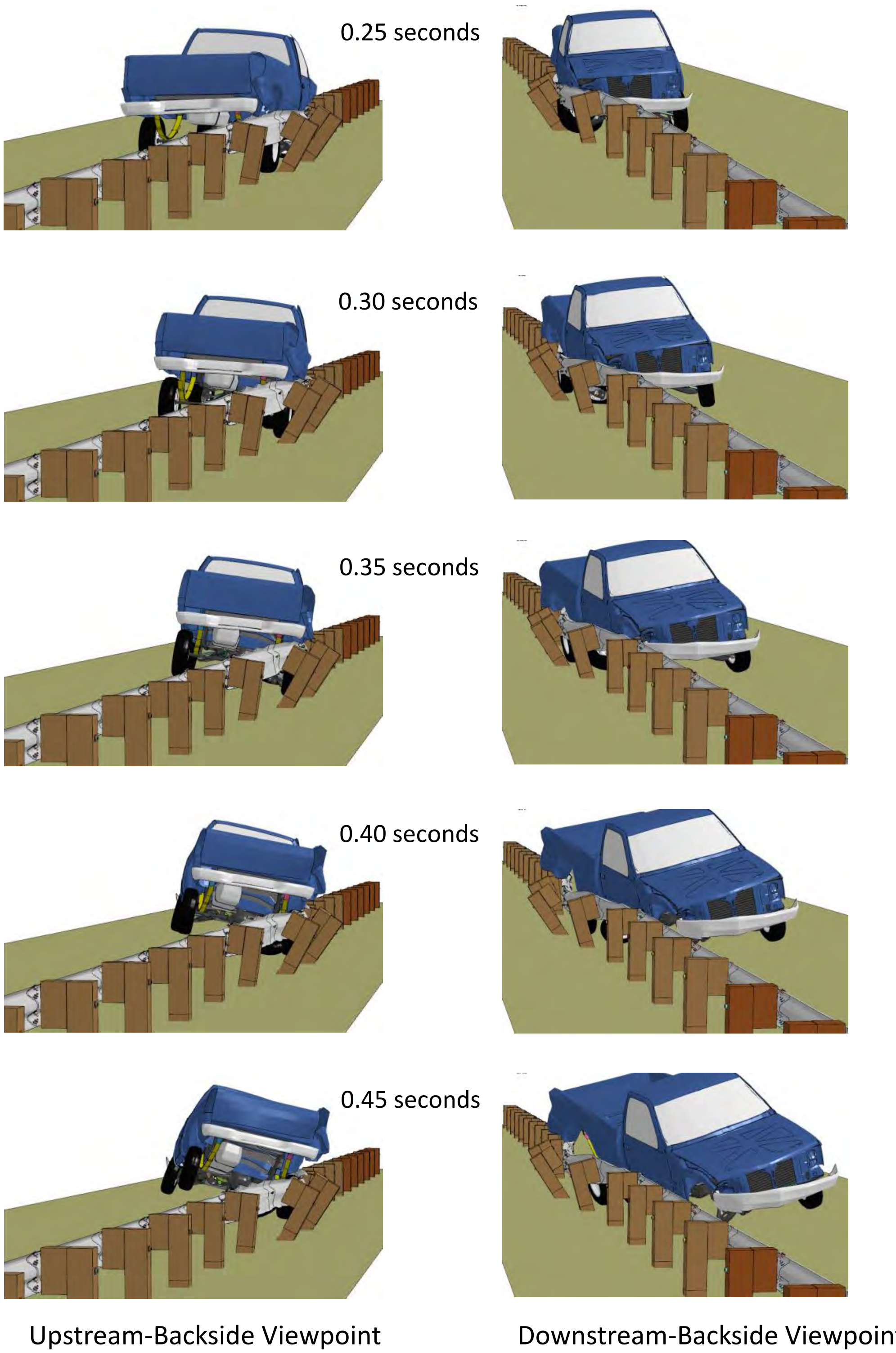


Figure C-2. [CONTINUED] **Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: 167% baseline anchor strength.**

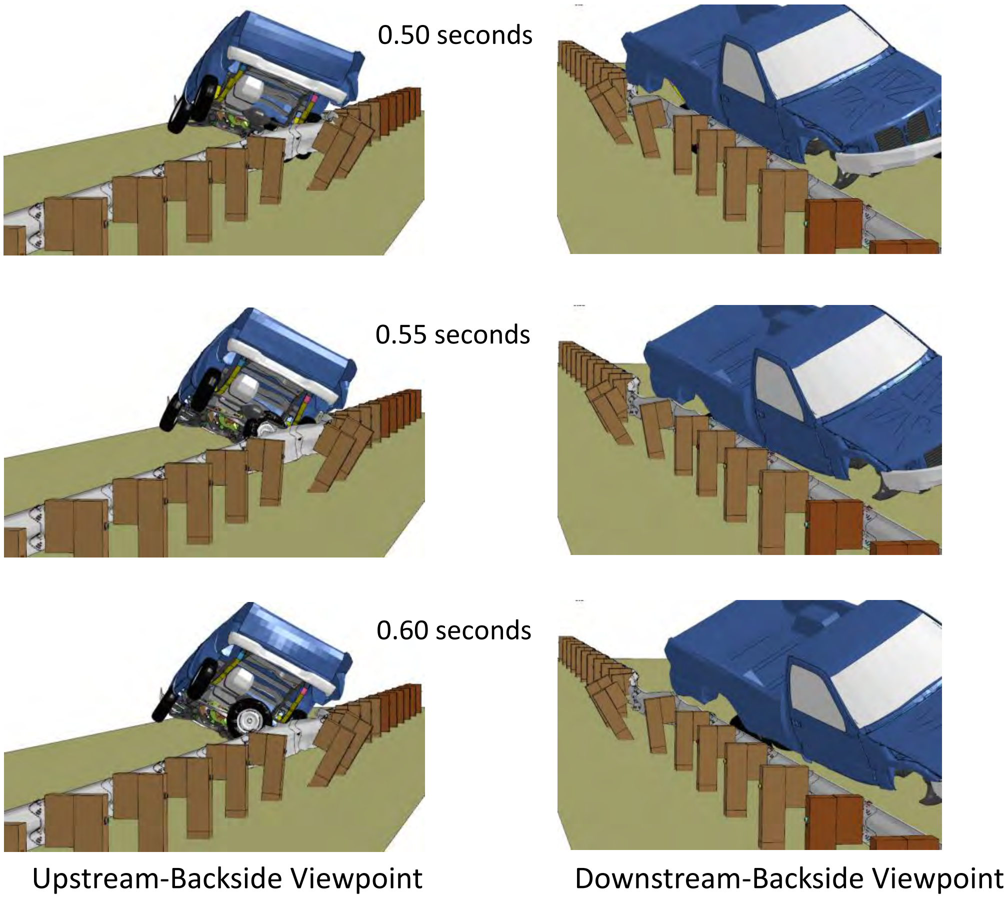


Figure C-2. [CONTINUED] Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: 167% baseline anchor strength.

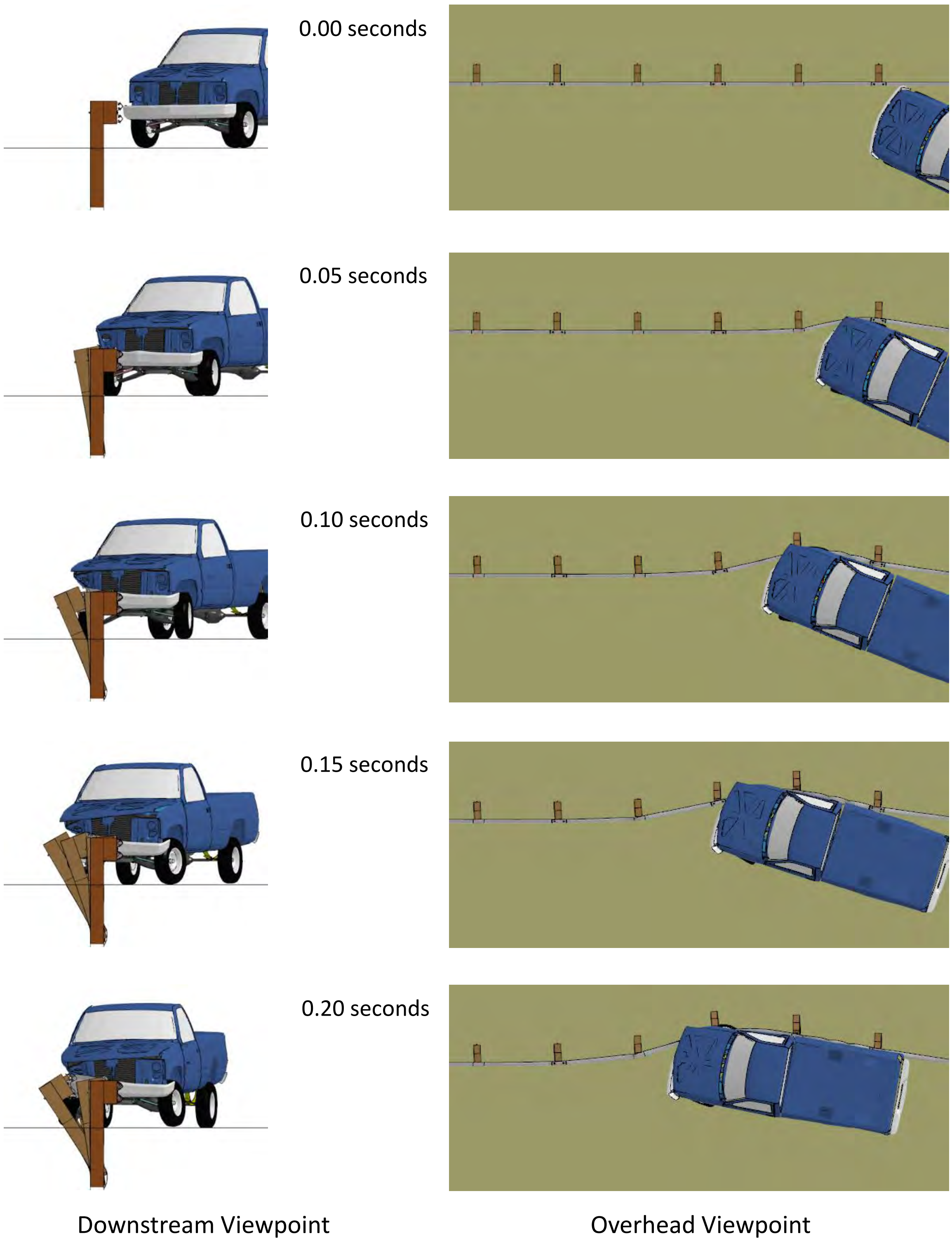


Figure C-3. Sequential views from a downstream and overhead viewpoint for analysis case: 133% baseline anchor strength.

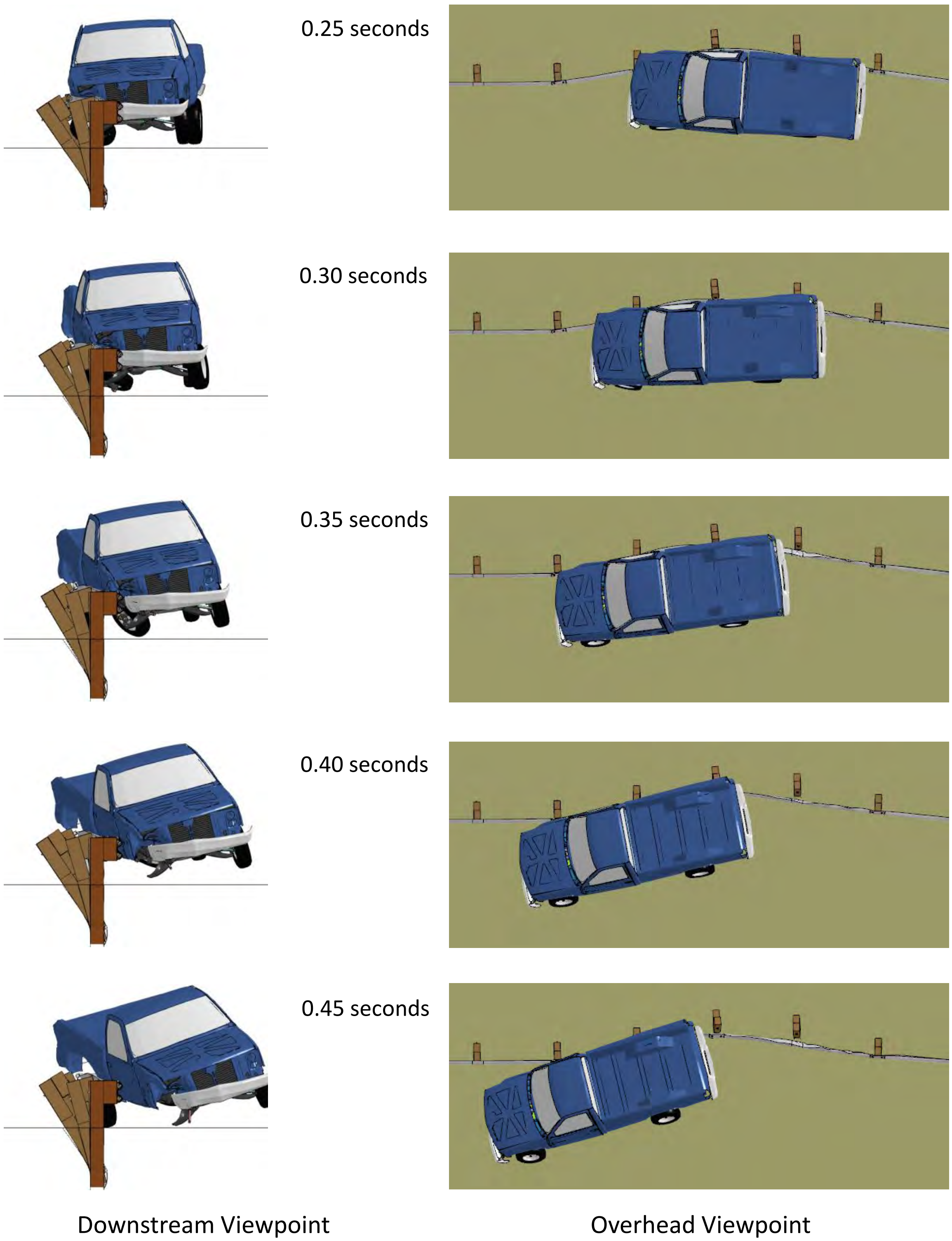


Figure C-3. [CONTINUED] Sequential views from a downstream and overhead viewpoint for analysis case: 133% baseline anchor strength.

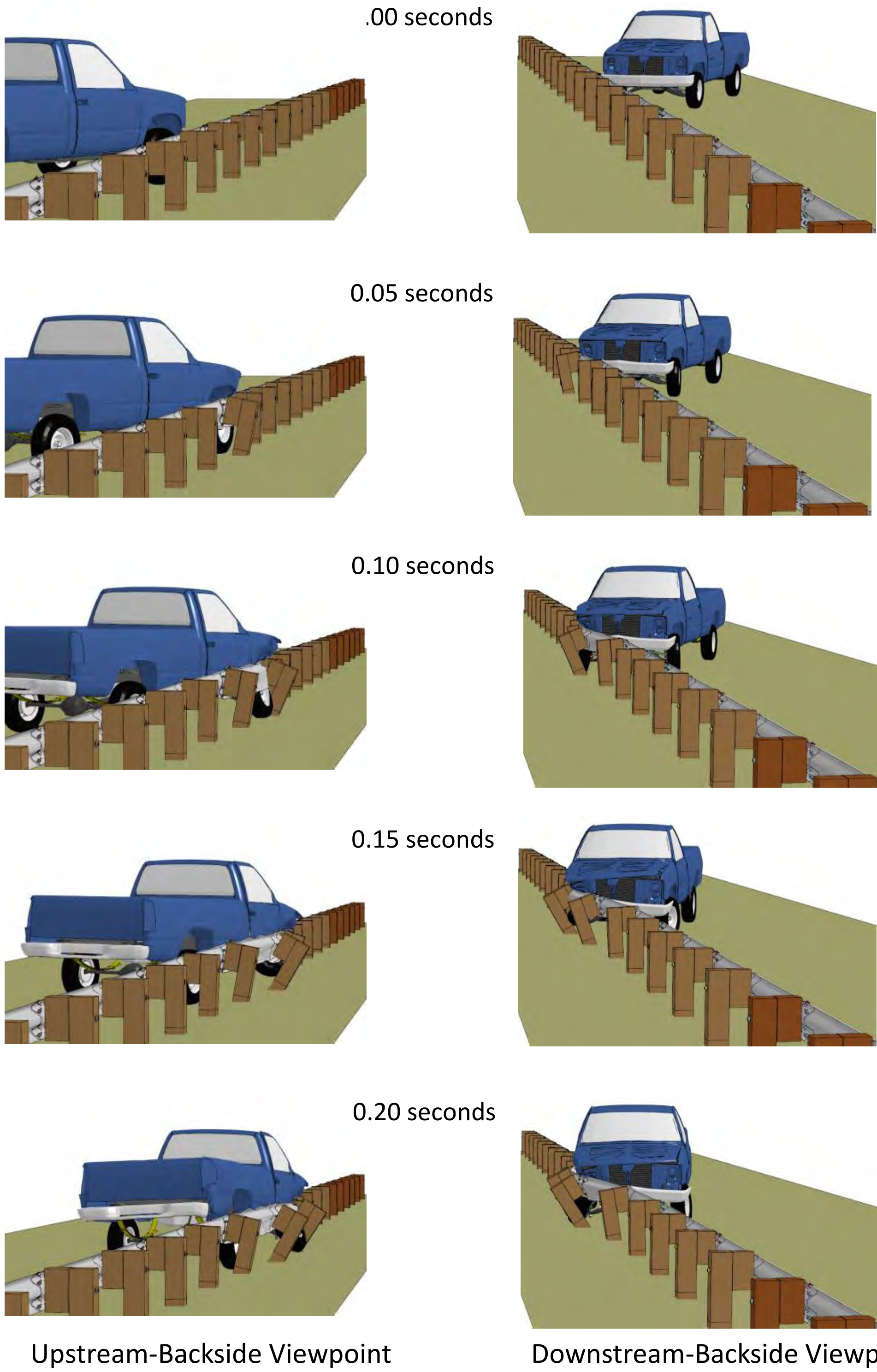


Figure C-4. Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: 133% baseline anchor strength.

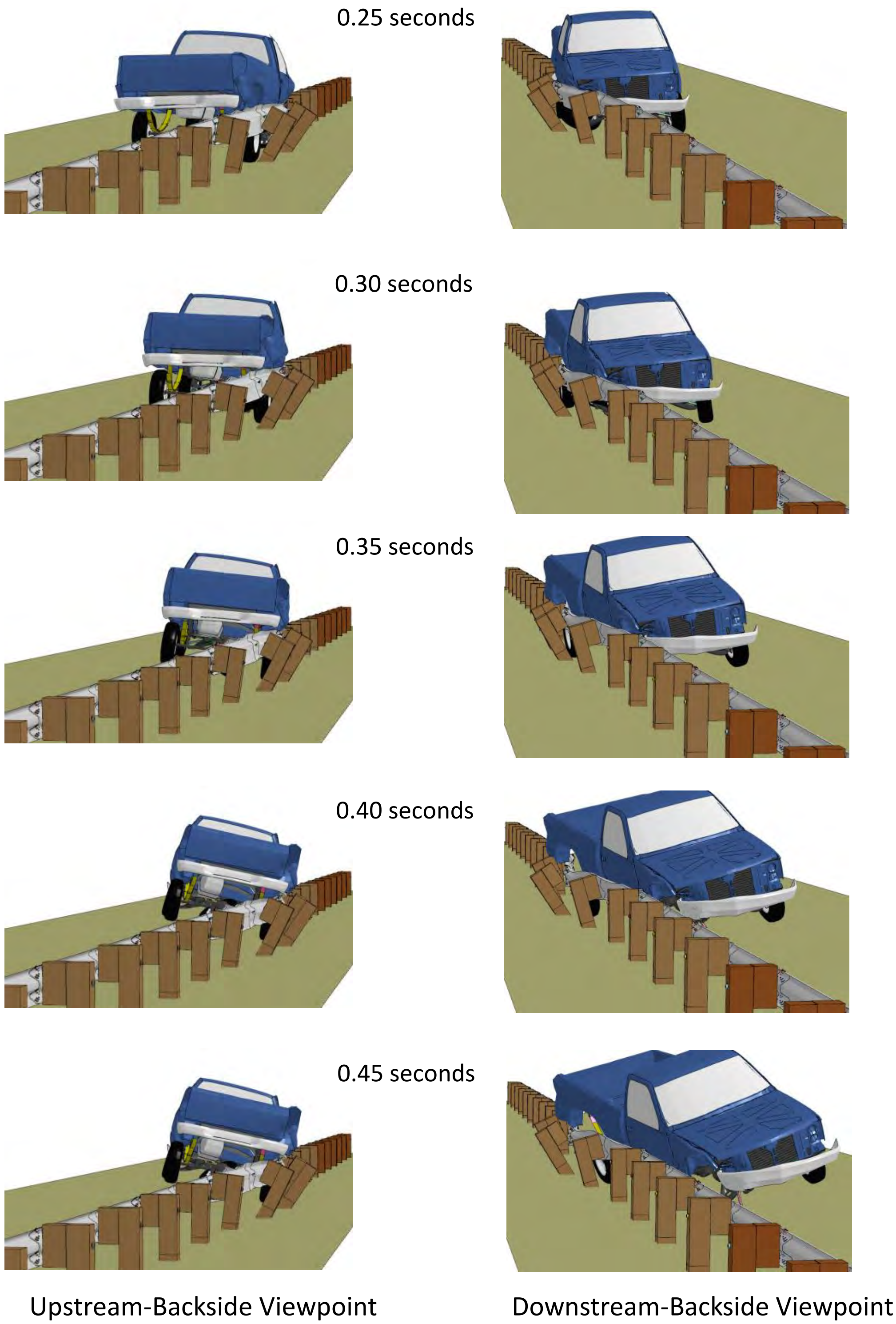


Figure C-4. [CONTINUED] Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: 133% baseline anchor strength.

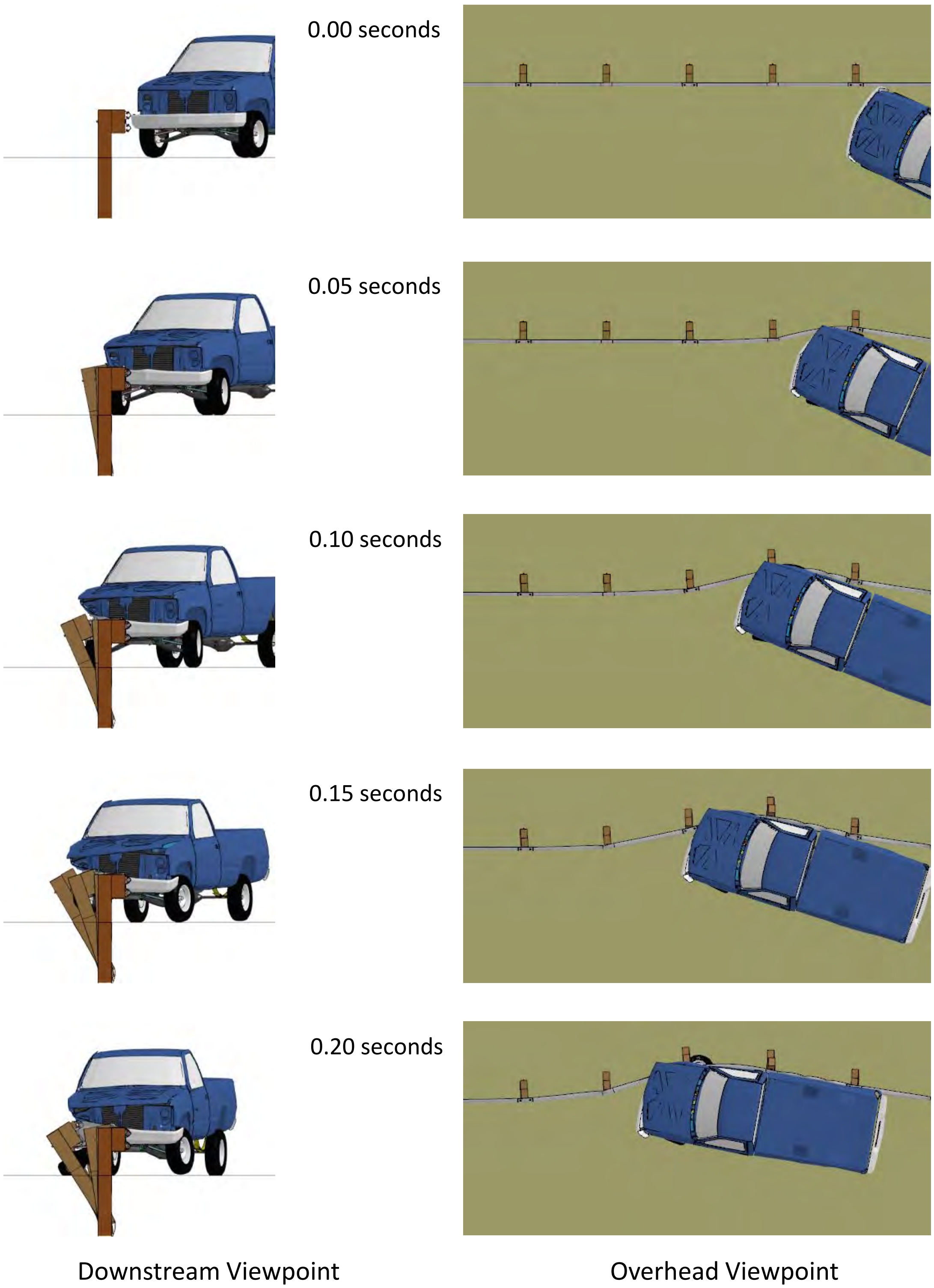
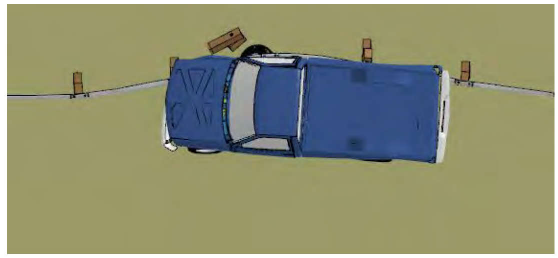
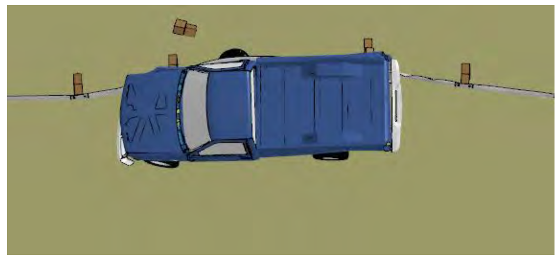


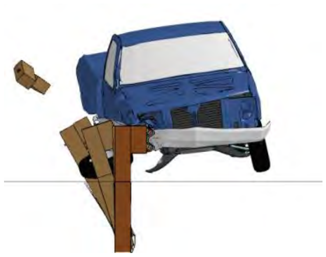
Figure C-5. Sequential views from a downstream and overhead viewpoint for analysis case: 67% baseline anchor strength.

0.25 seconds

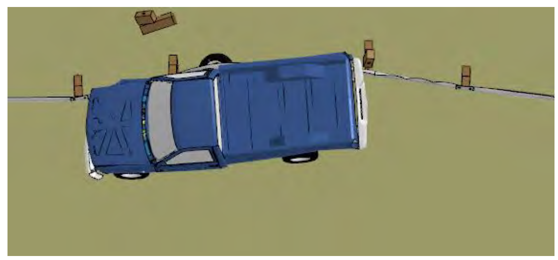


0.30 seconds





0.35 seconds



0.40 seconds

0.45 seconds

Downstream Viewpoint Overhead Viewpoint

Figure C-5. [CONTINUED] Sequential views from a downstream and overhead viewpoint for analysis case: 67% baseline anchor strength.

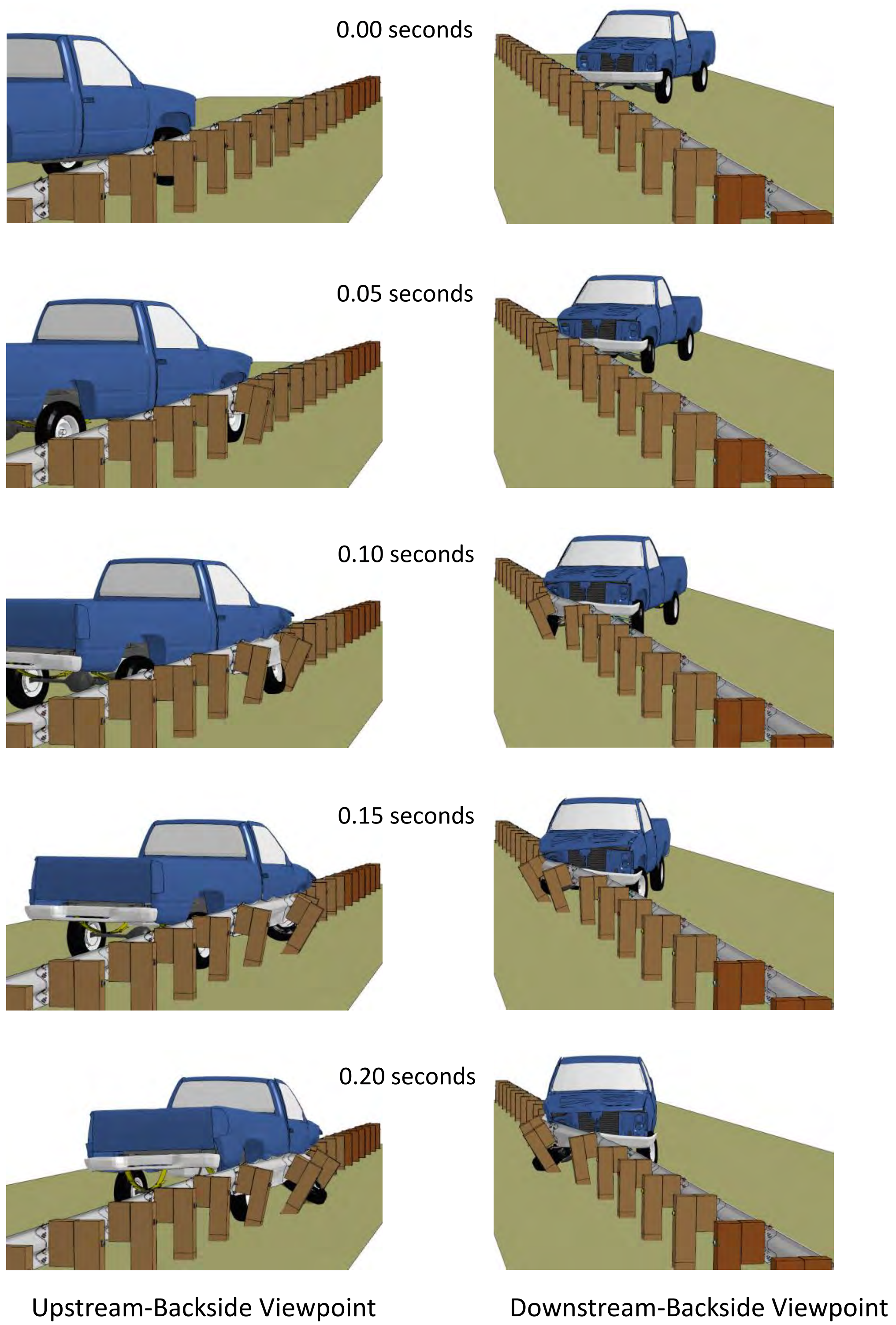


Figure C-6. Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: 67% baseline anchor strength.

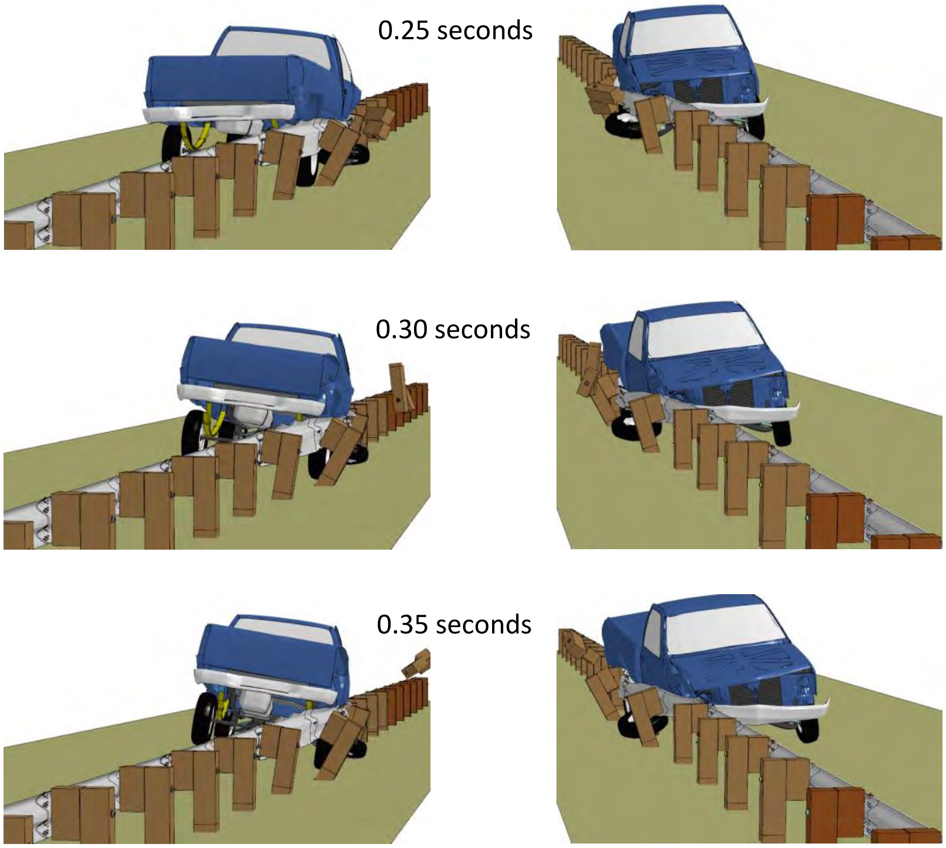


Figure C-6. [CONTINUED] Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: 67% baseline anchor strength.

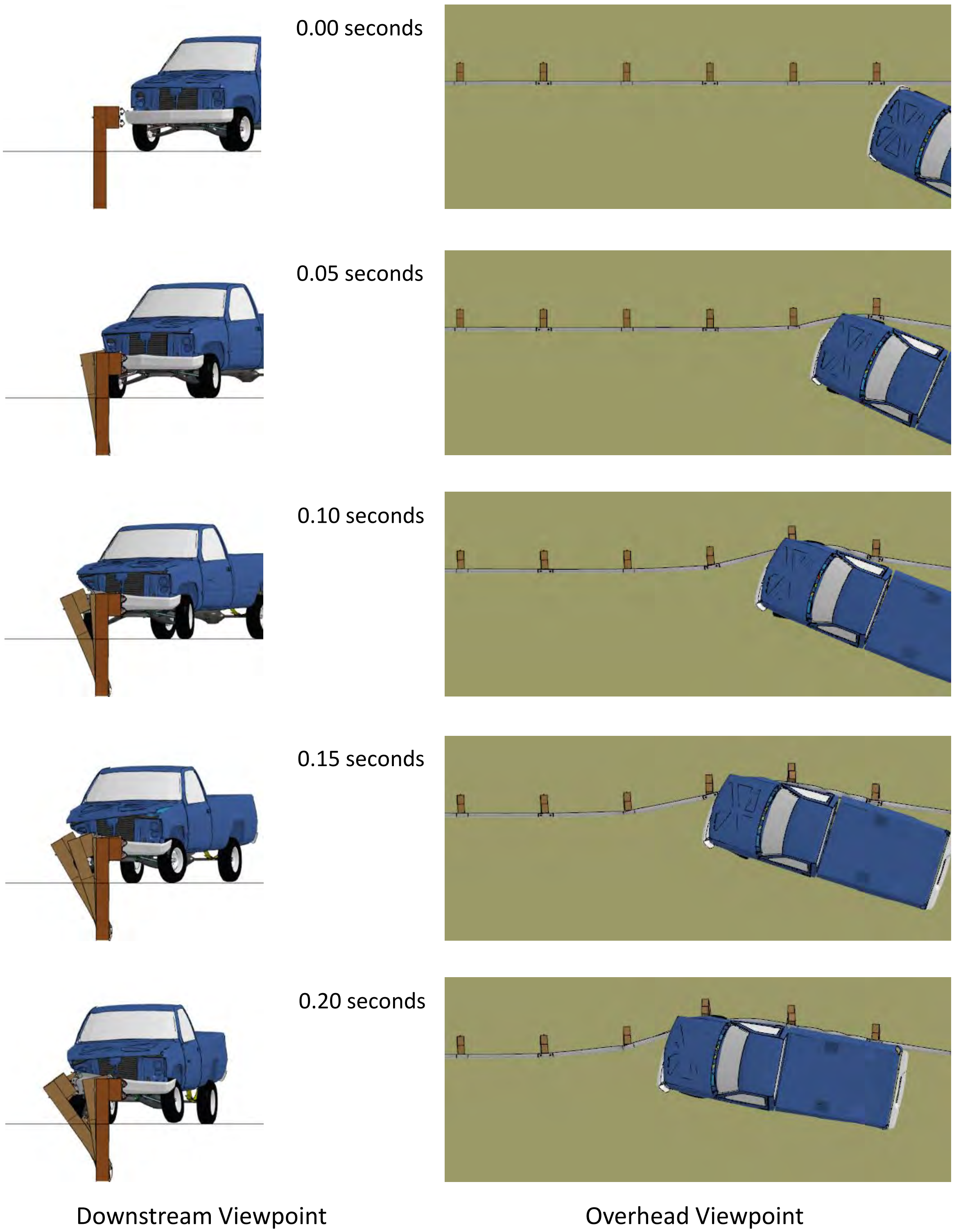


Figure C-7. Sequential views from a downstream and overhead viewpoint for analysis case: 47% baseline anchor strength.

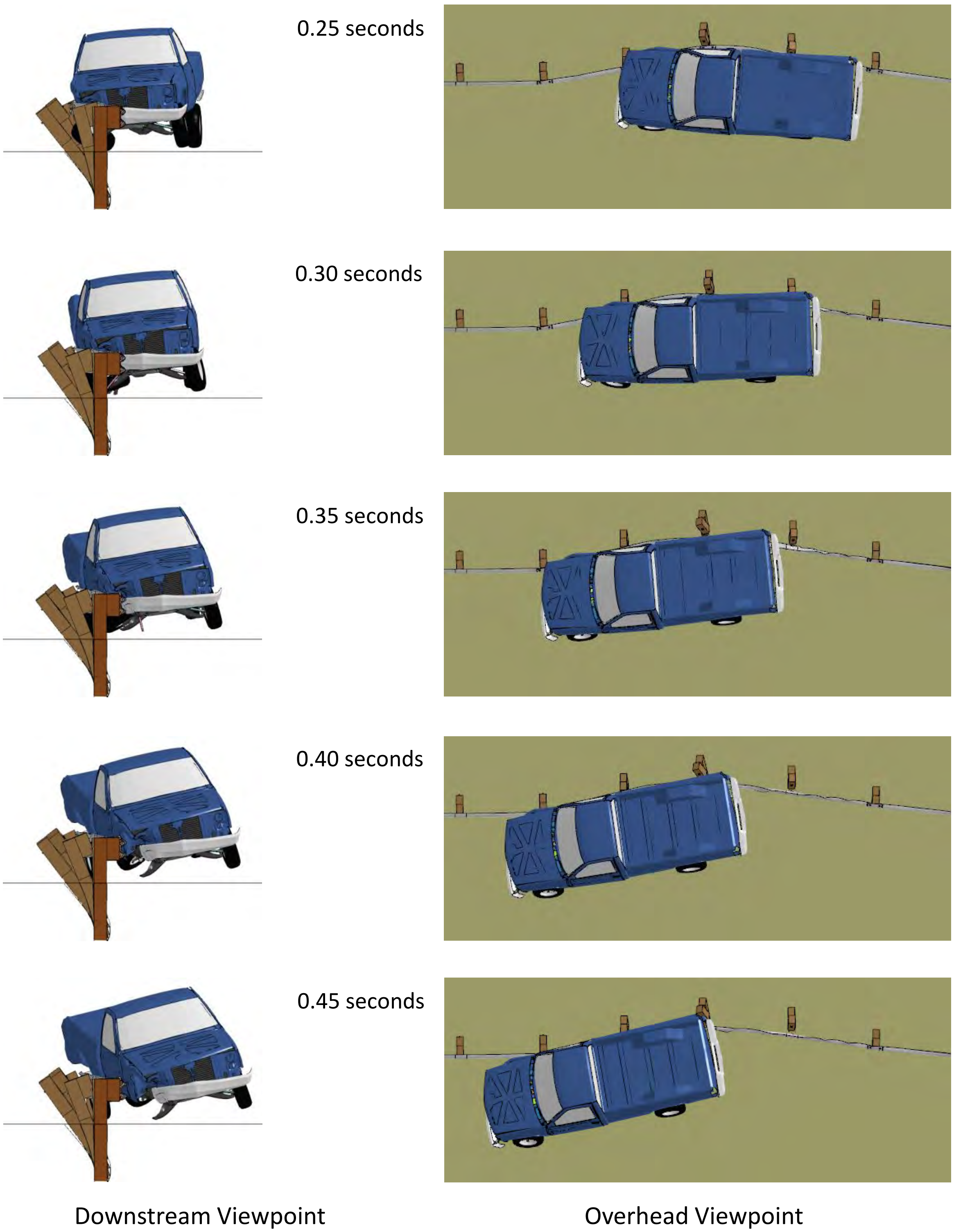


Figure C-7. [CONTINUED] Sequential views from a downstream and overhead viewpoint for analysis case: 47% baseline anchor strength.

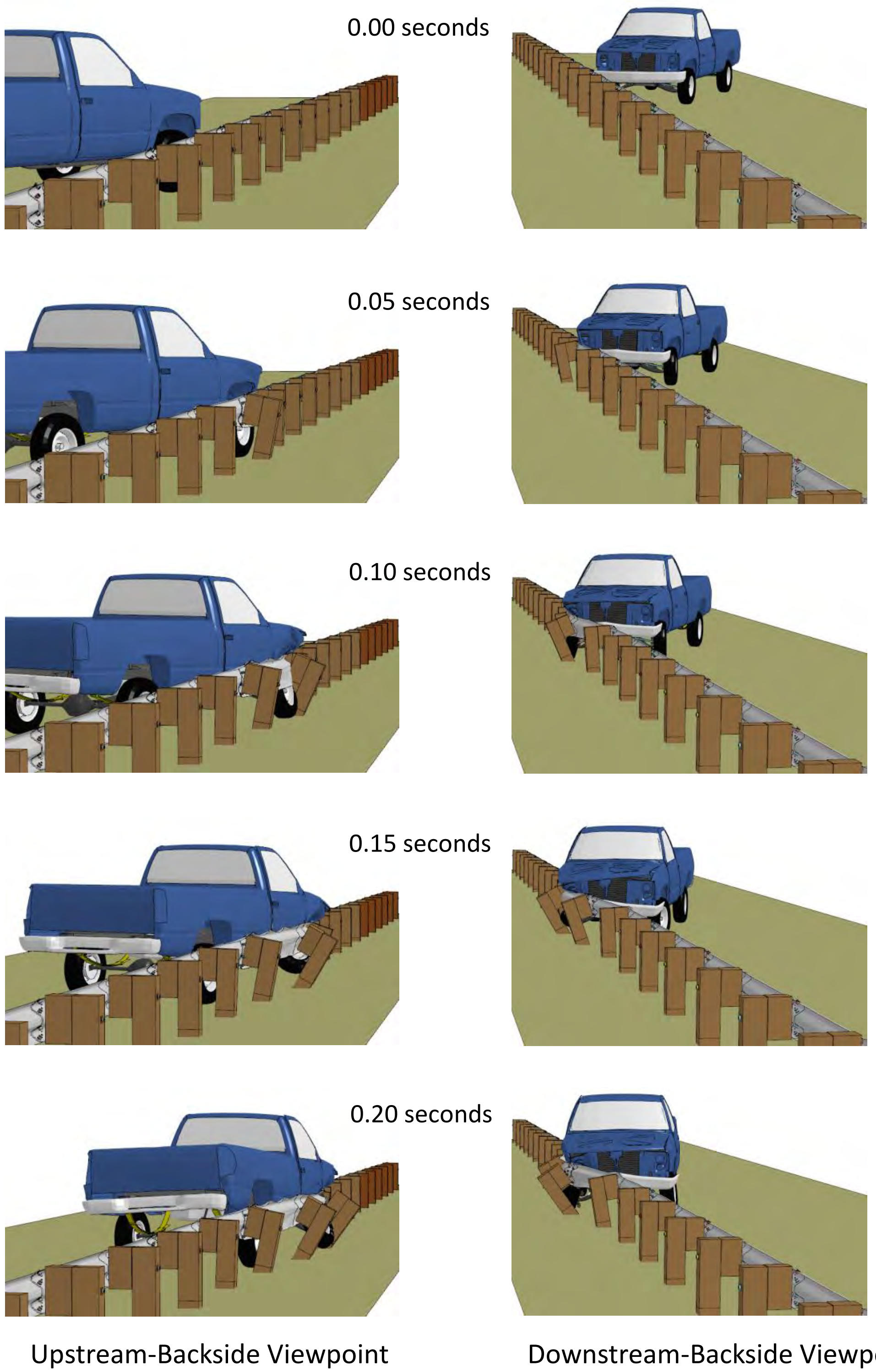


Figure C-8. Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: 47% baseline anchor strength.

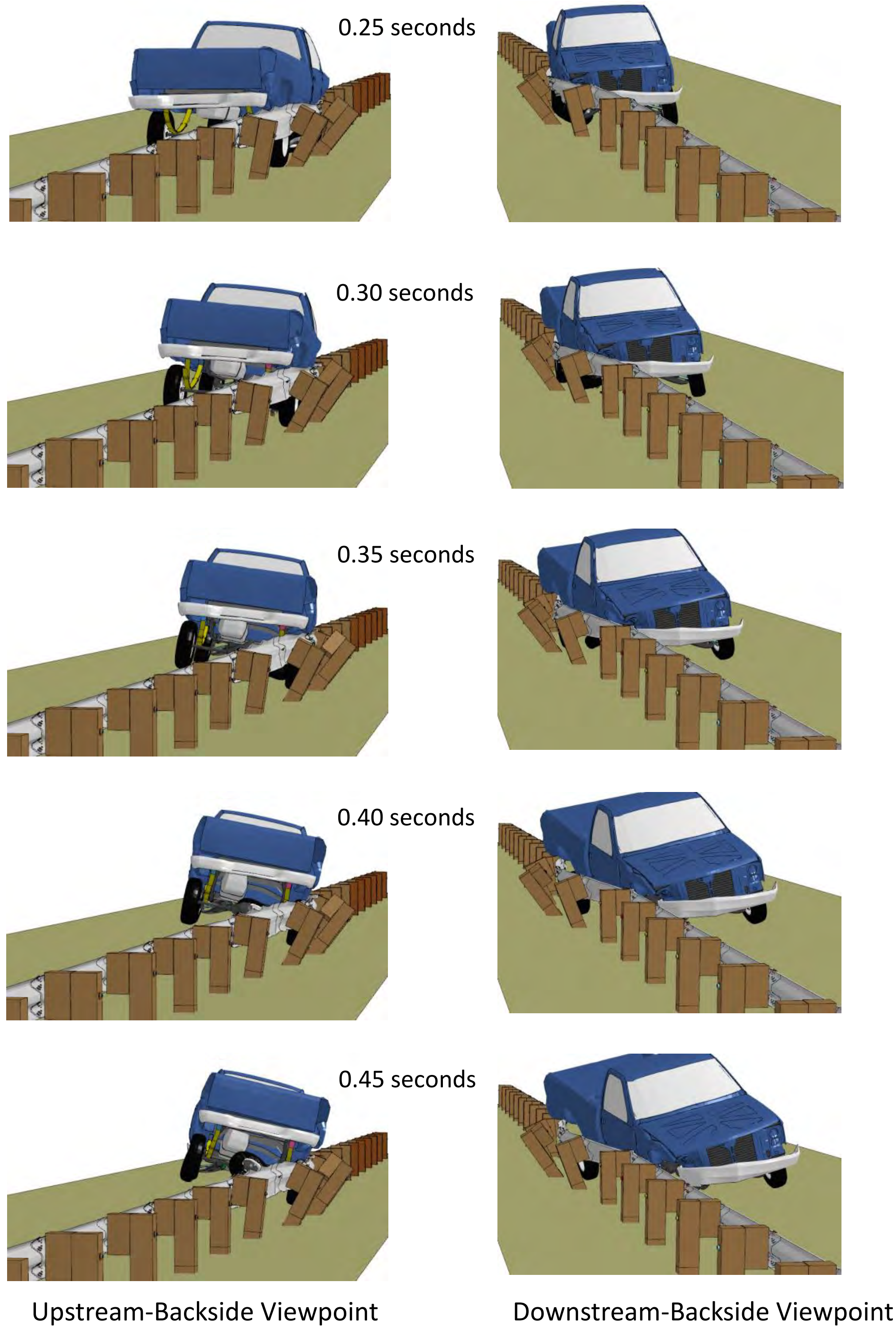


Figure C-8. [CONTINUED] Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: 47% baseline anchor strength.

APPENDIX J

Sequential Views from FEA Evaluation of G4(2W) with Combination of Weak Anchor and Deteriorated Posts

Task 4A-2: Assess Effects of Anchor Strength on Performance of G4(2W)

By: Chuck A. Plaxico

January 2014

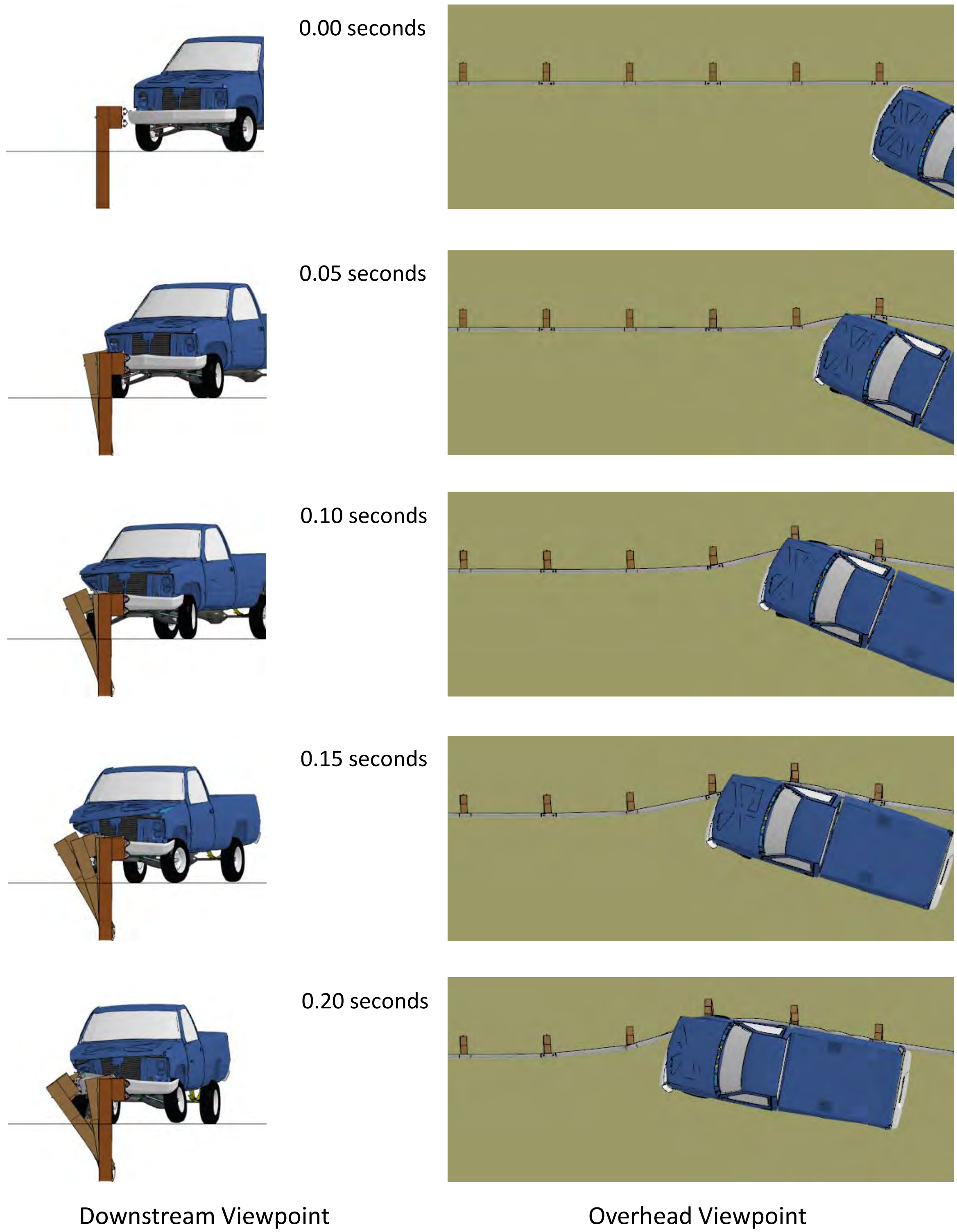


Figure D-1. Sequential views from a downstream and overhead viewpoint for analysis case: 47% baseline anchor strength and DL0 posts.

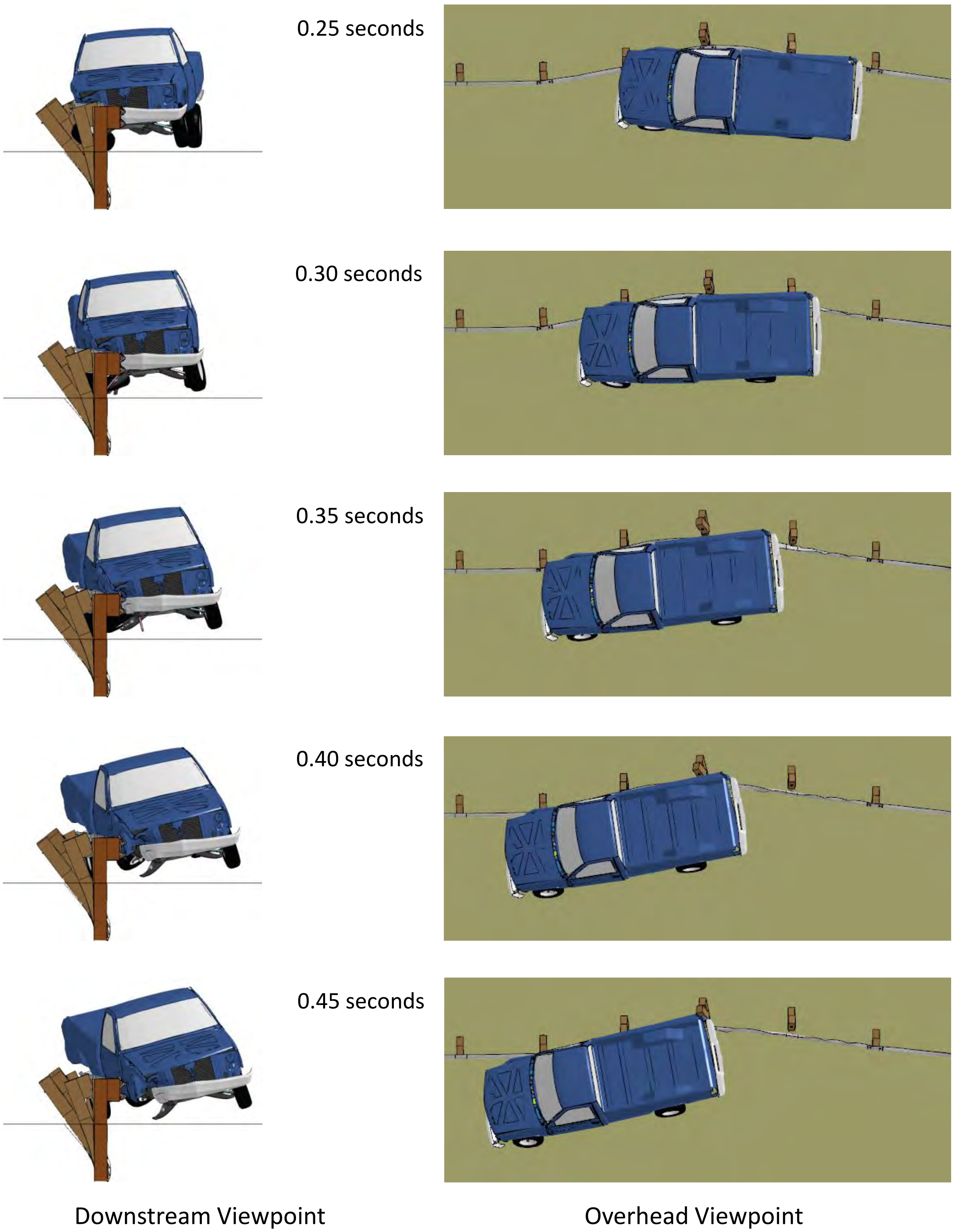


Figure D-1. [CONTINUED] **Sequential views from a downstream and overhead viewpoint for analysis case: 47% baseline anchor strength and DL0 posts.**

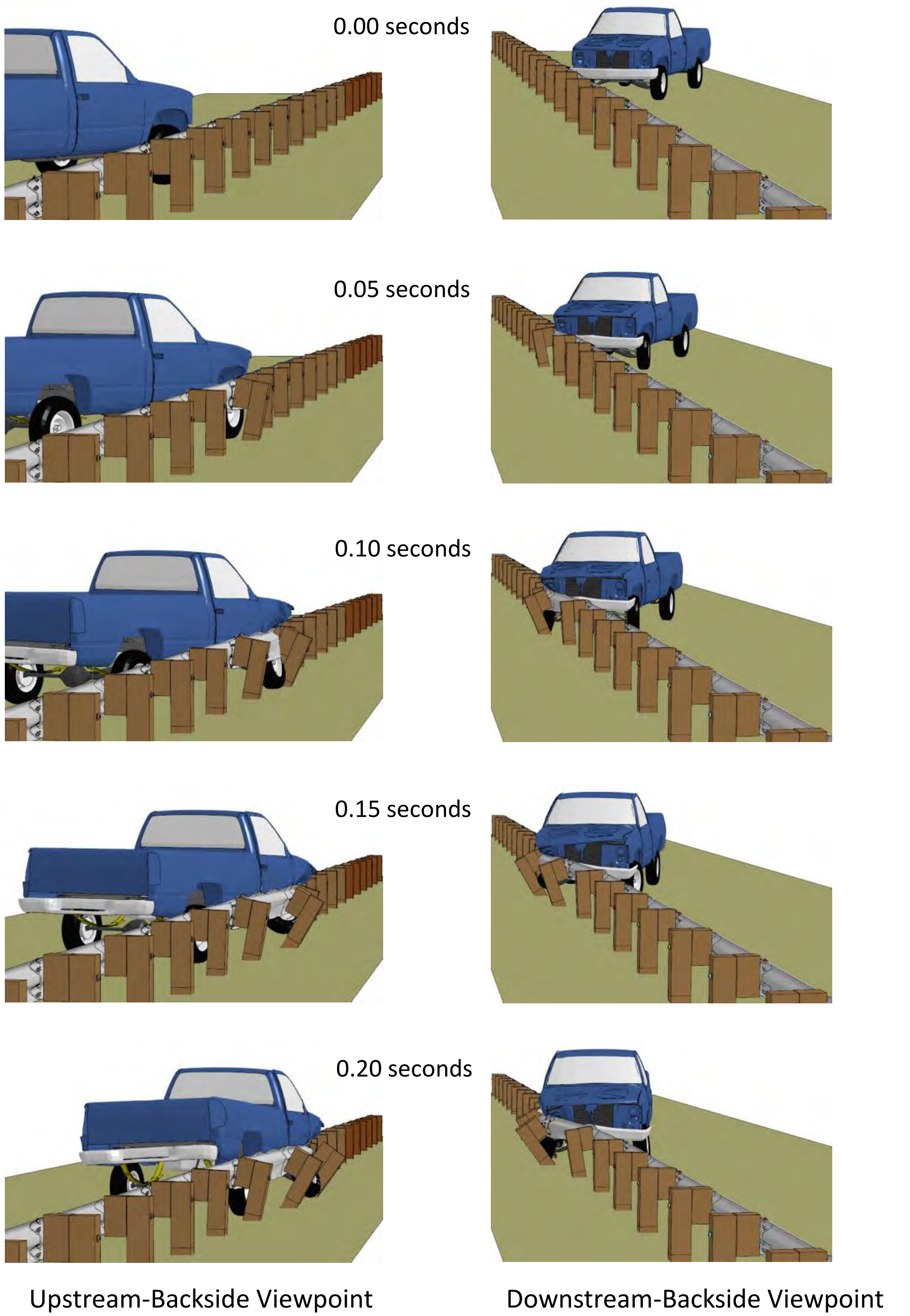


Figure D-2. Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: 47% baseline anchor strength and DL0 posts.

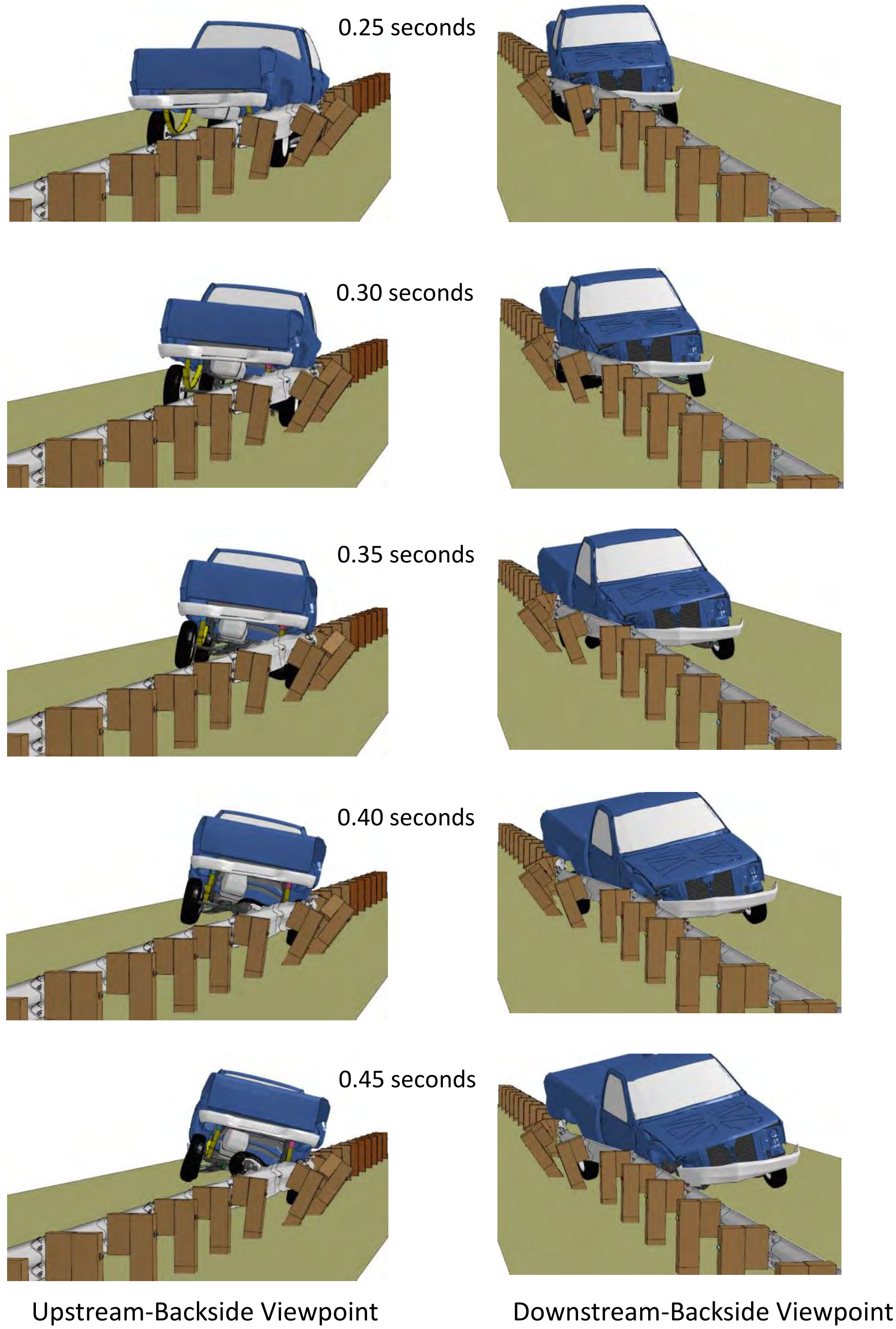


Figure D-2. [CONTINUED] Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: 47% baseline anchor strength and DL0 posts.

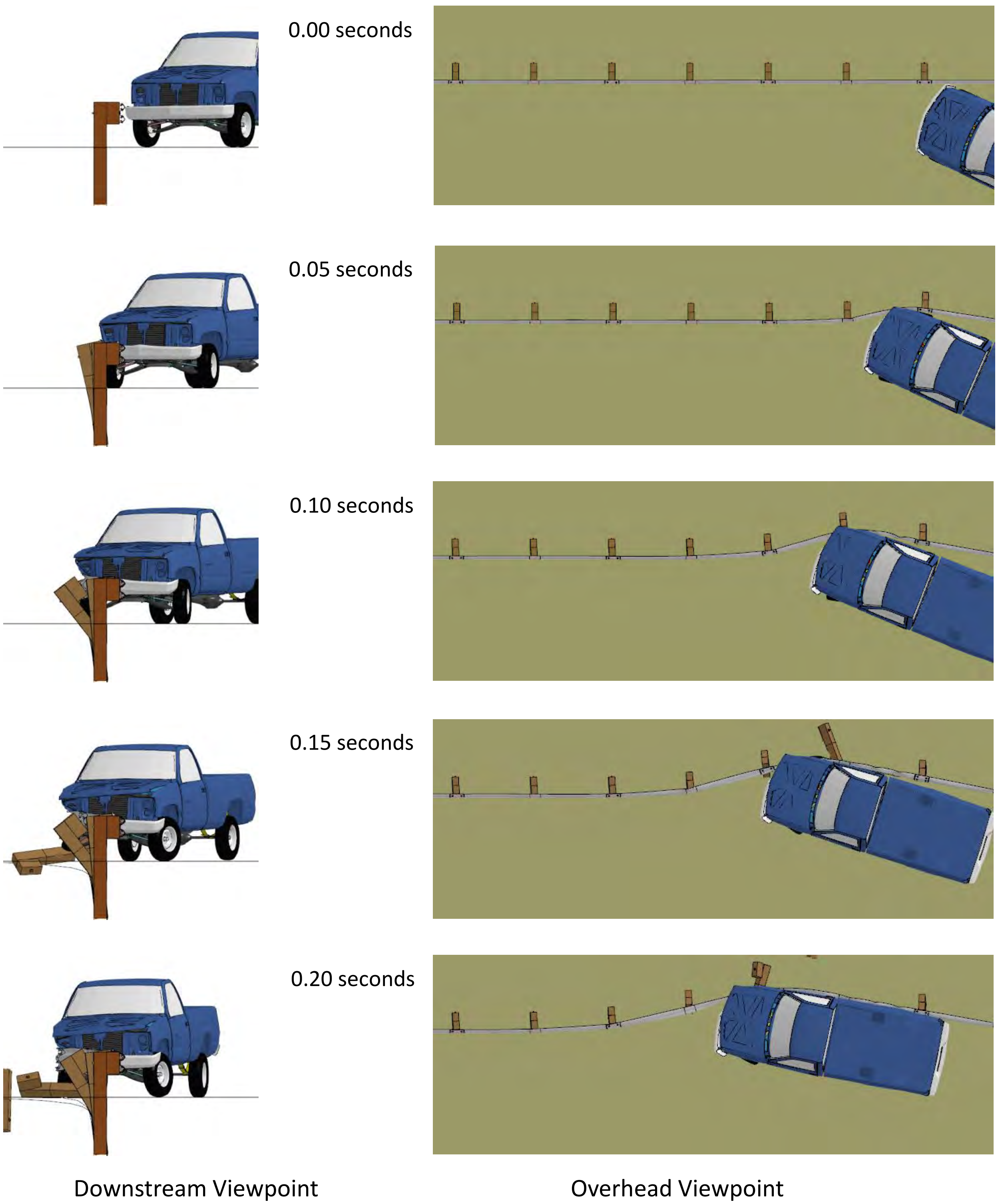


Figure D-3. Sequential views from a downstream and overhead viewpoint for analysis case: 47% baseline anchor strength and DL1 posts.

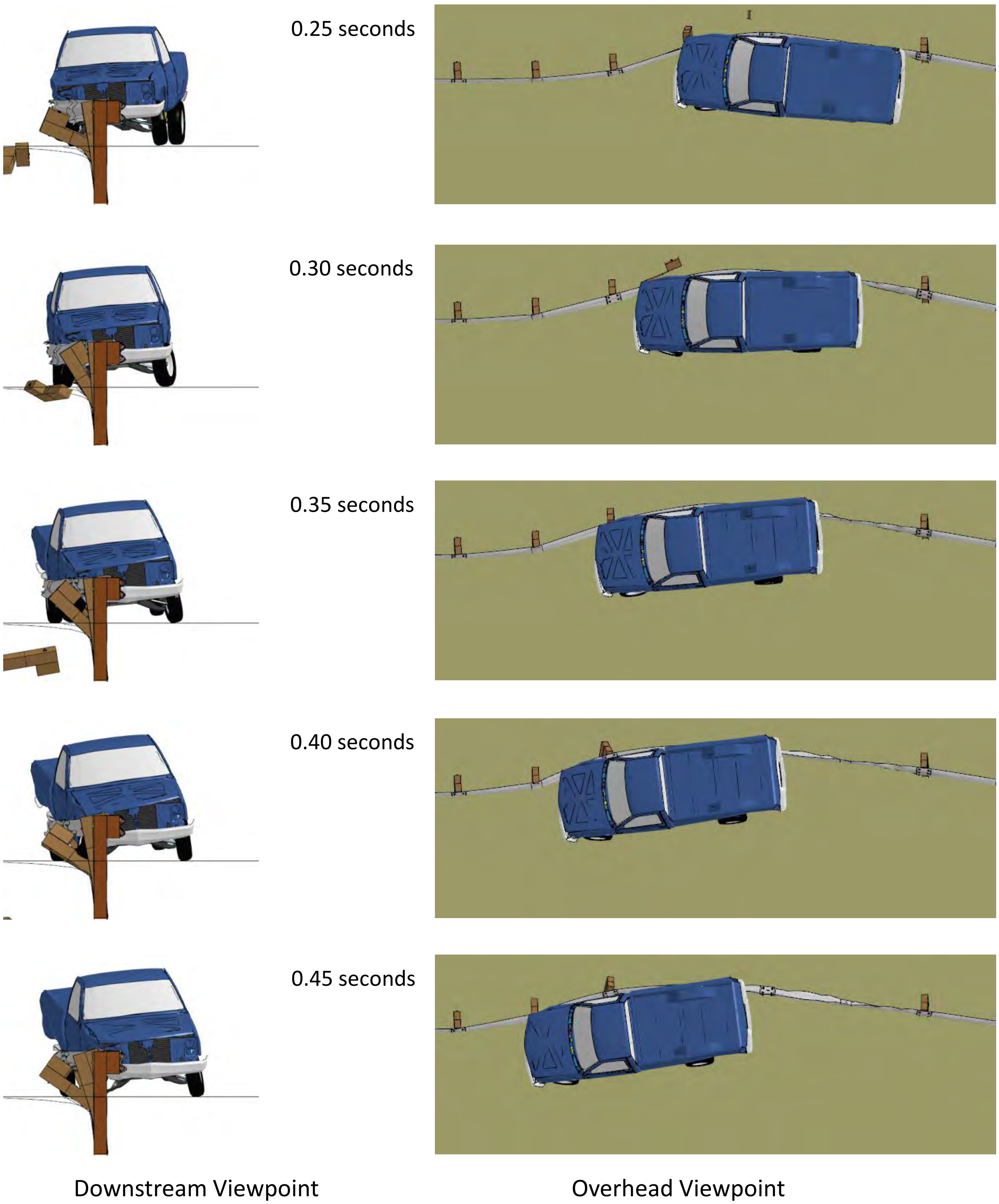


Figure D-3. **[CONTINUED] Sequential views from a downstream and overhead viewpoint for analysis case: 47% baseline anchor strength and DL1 posts.**

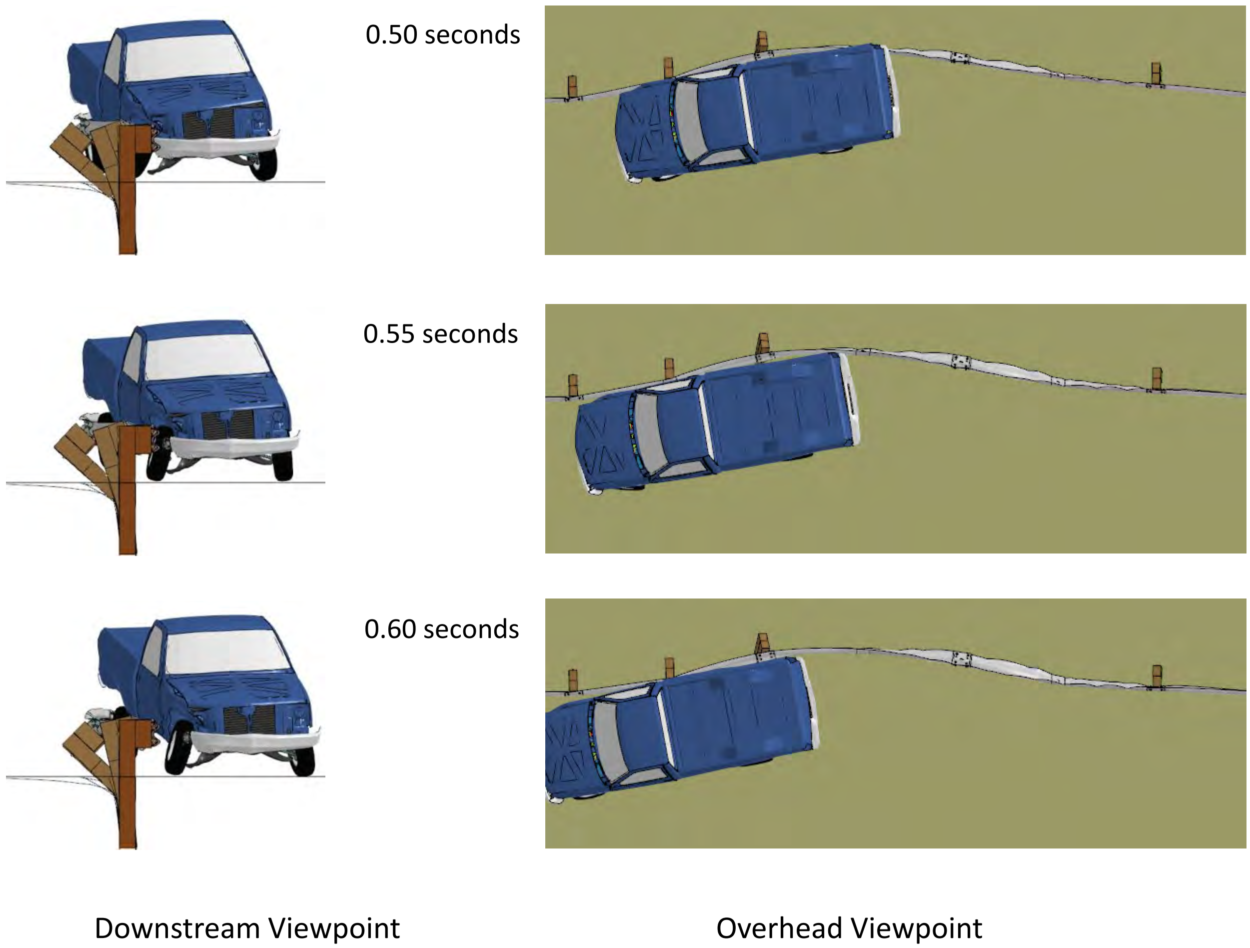


Figure D-3. **[CONTINUED] Sequential views from a downstream and overhead viewpoint for analysis case: 47% baseline anchor strength and DL1 posts.**

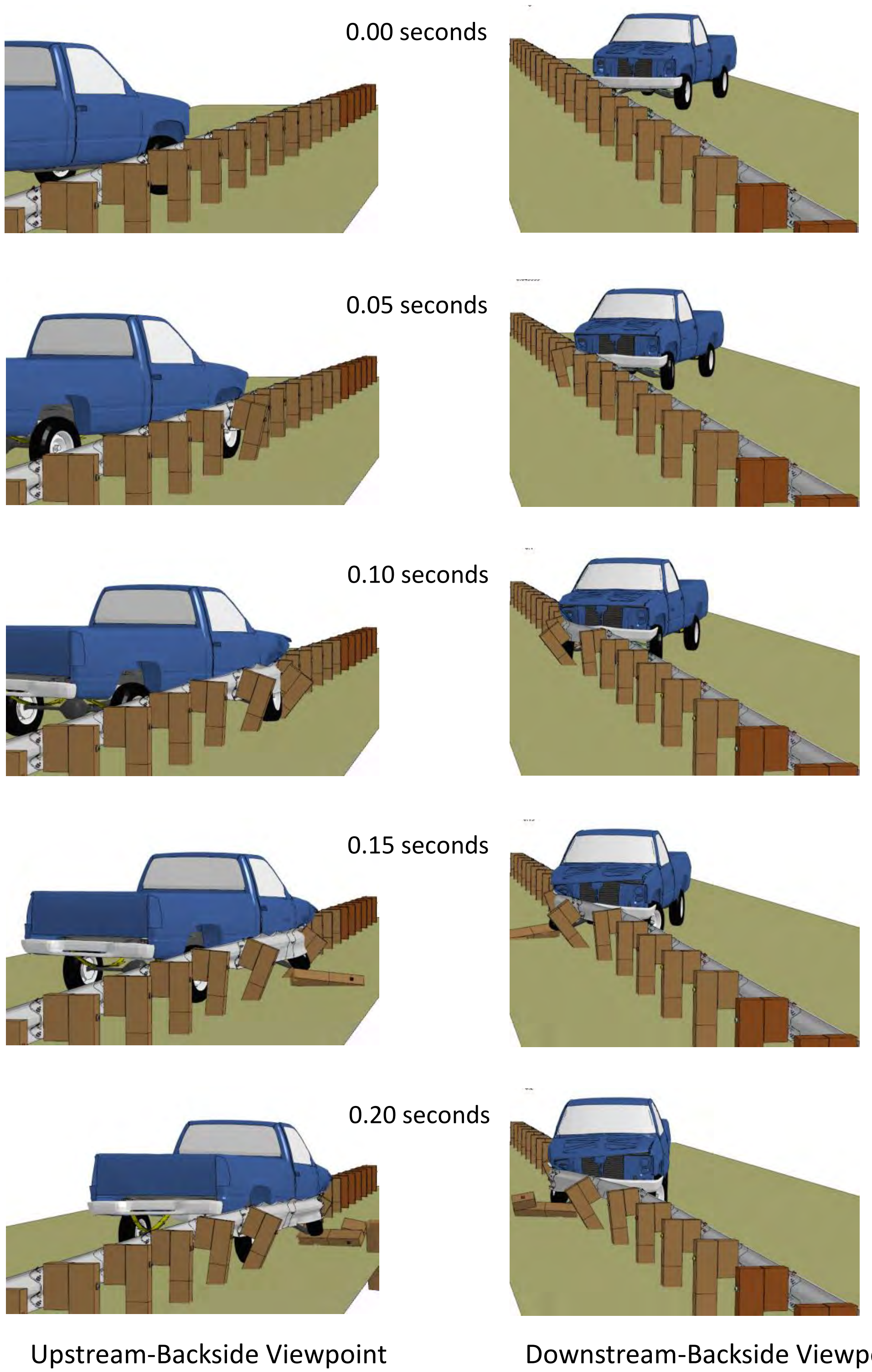


Figure D-4. Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: 47% baseline anchor strength and DL1 posts.

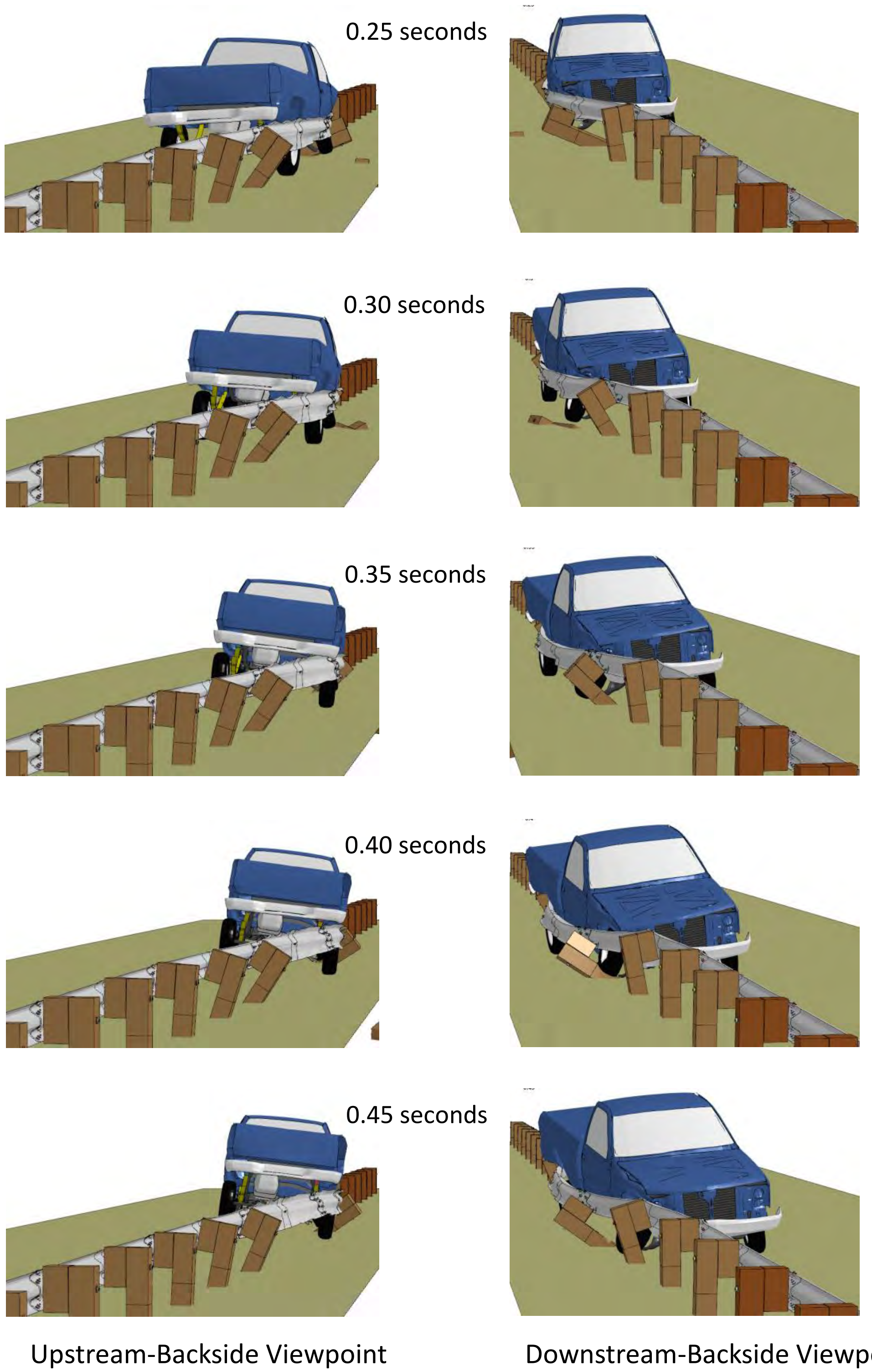


Figure D-4. [CONTINUED] Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: 47% baseline anchor strength and DL1 posts.

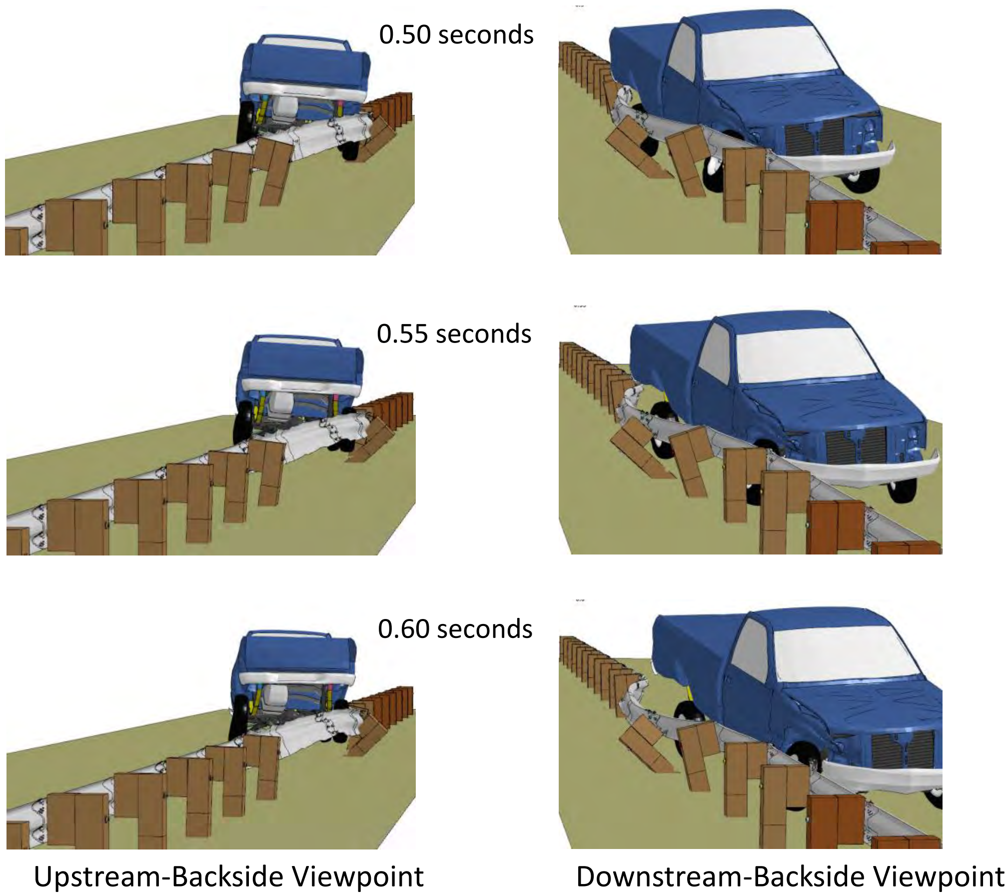


Figure D-4. [CONTINUED] Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: 47% baseline anchor strength and DL1 posts.

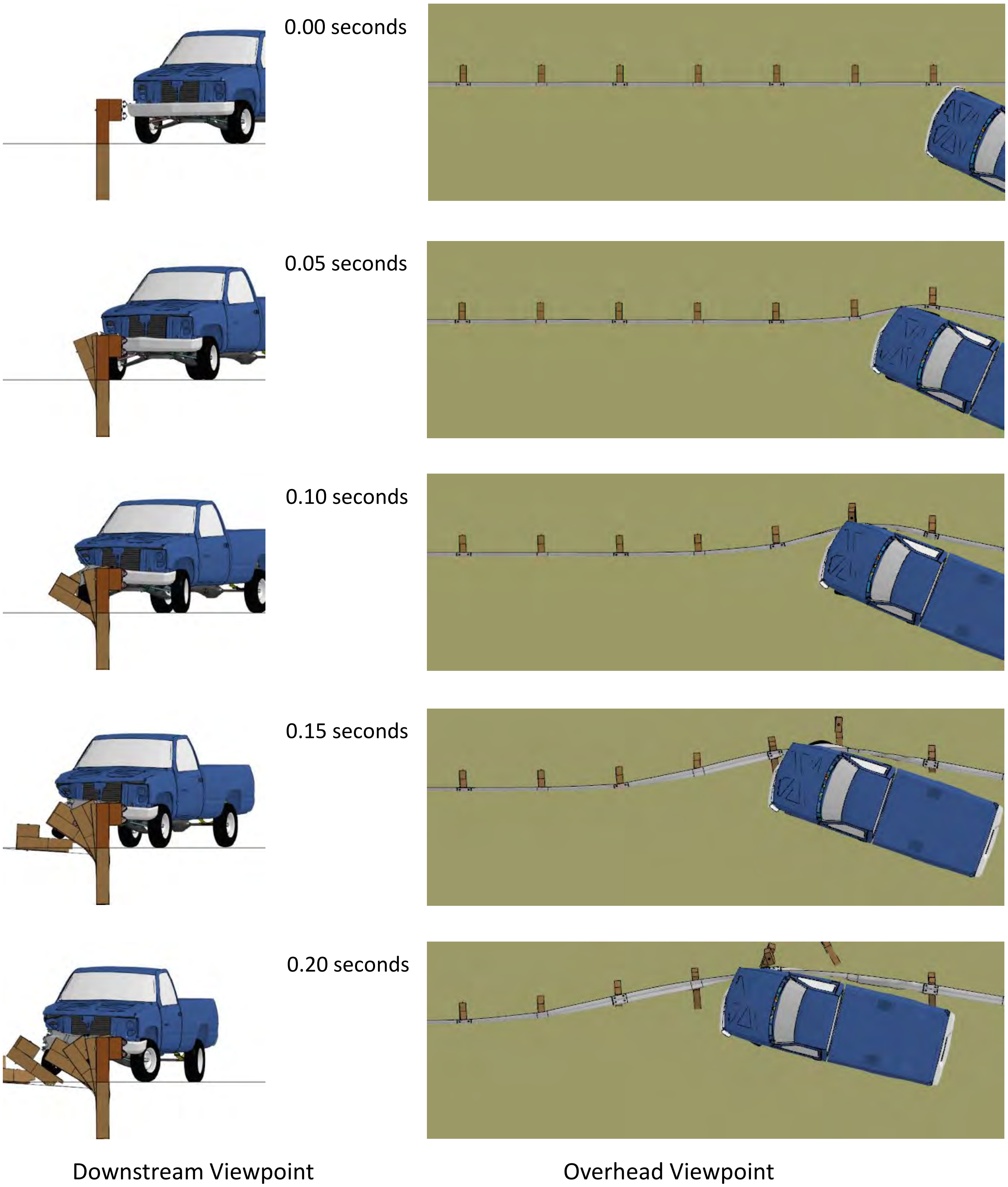


Figure D-5. Sequential views from a downstream and overhead viewpoint for analysis case: 47% baseline anchor strength and DL1 posts.

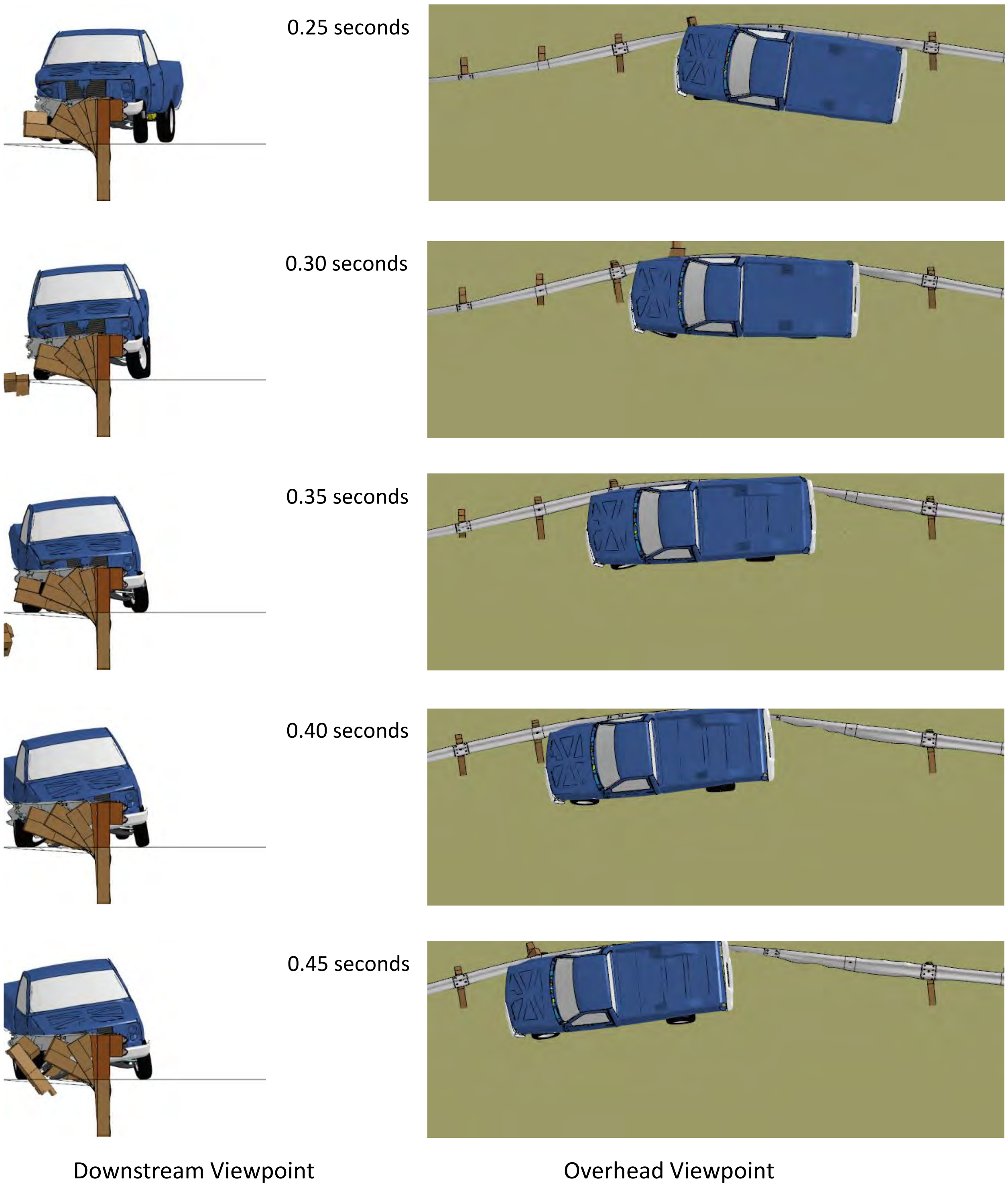


Figure D-5. [CONTINUED] Sequential views from a downstream and overhead viewpoint for analysis case: 47% baseline anchor strength and DL1 posts.

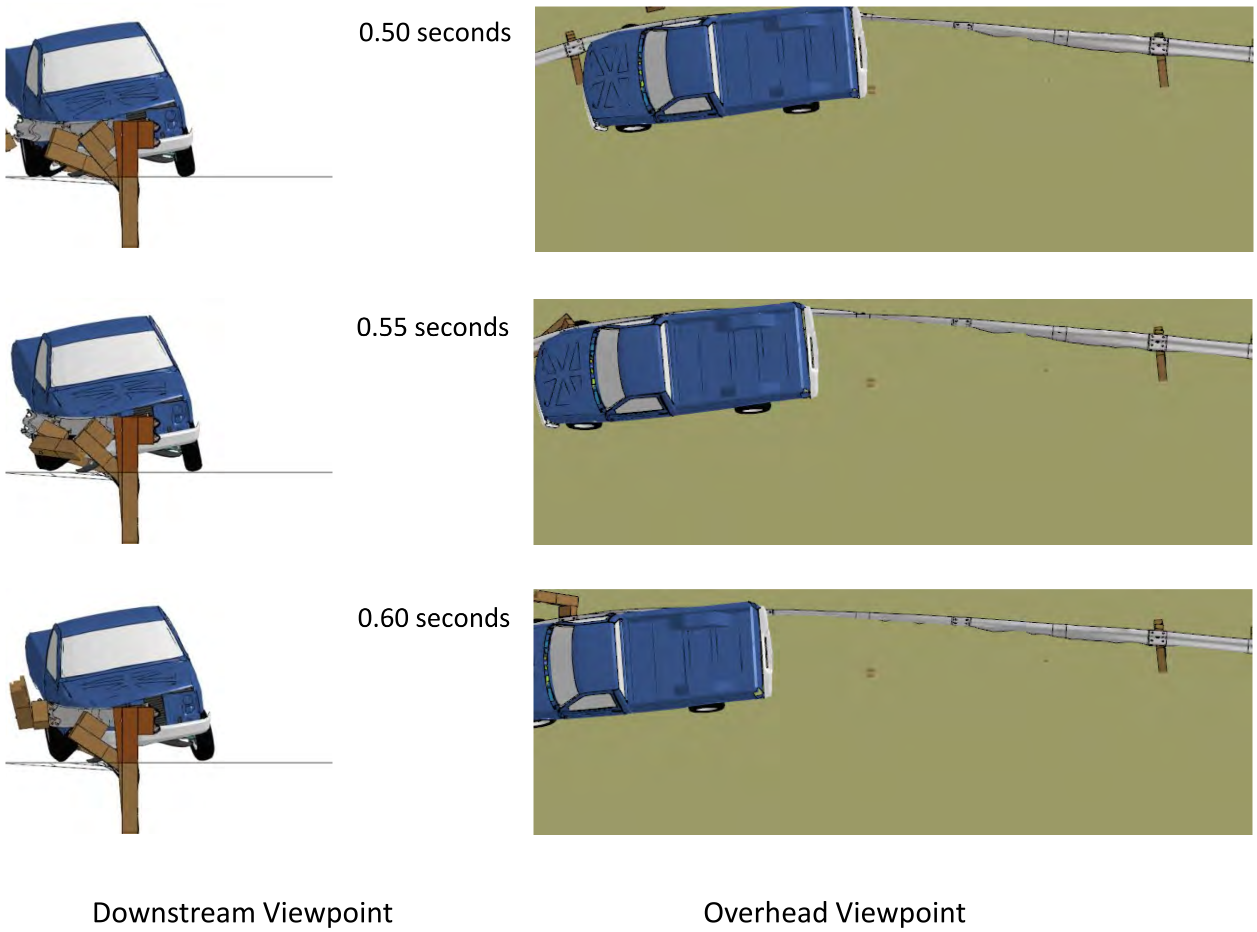


Figure D-5. [CONTINUED] Sequential views from a downstream and overhead viewpoint for analysis case: 47% baseline anchor strength and DL1 posts.

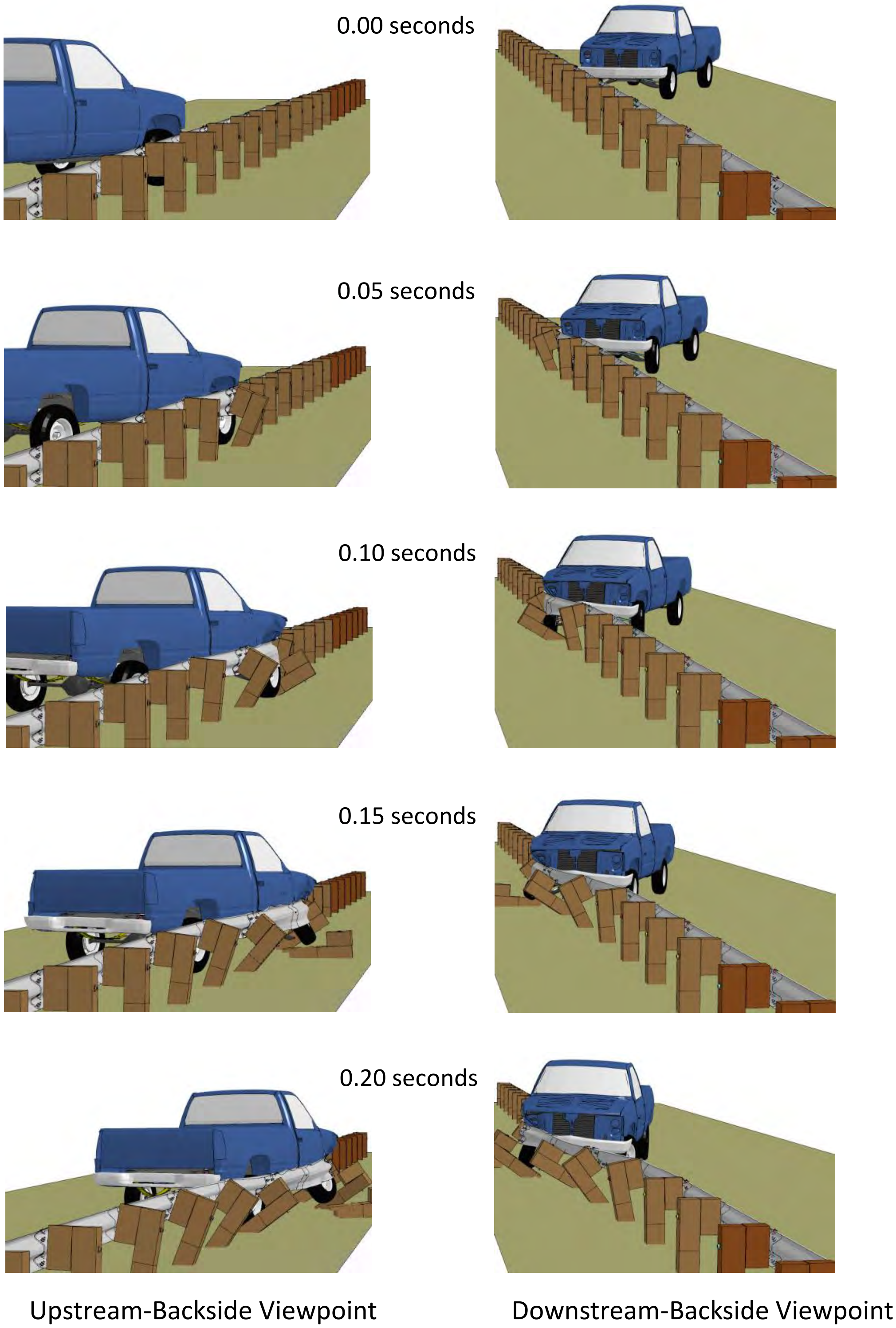


Figure D-6. Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: 47% baseline anchor strength and DL2 Posts.

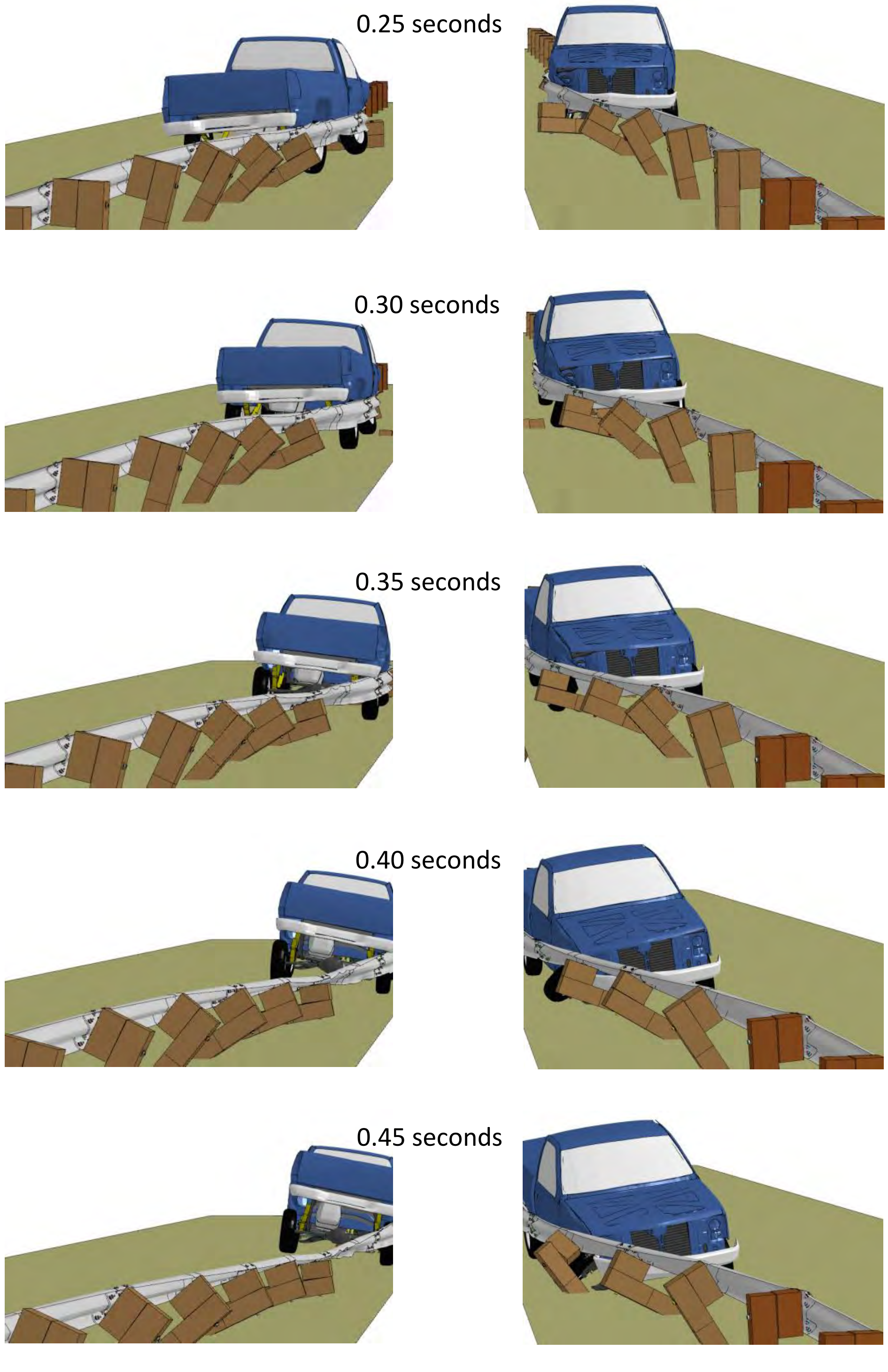
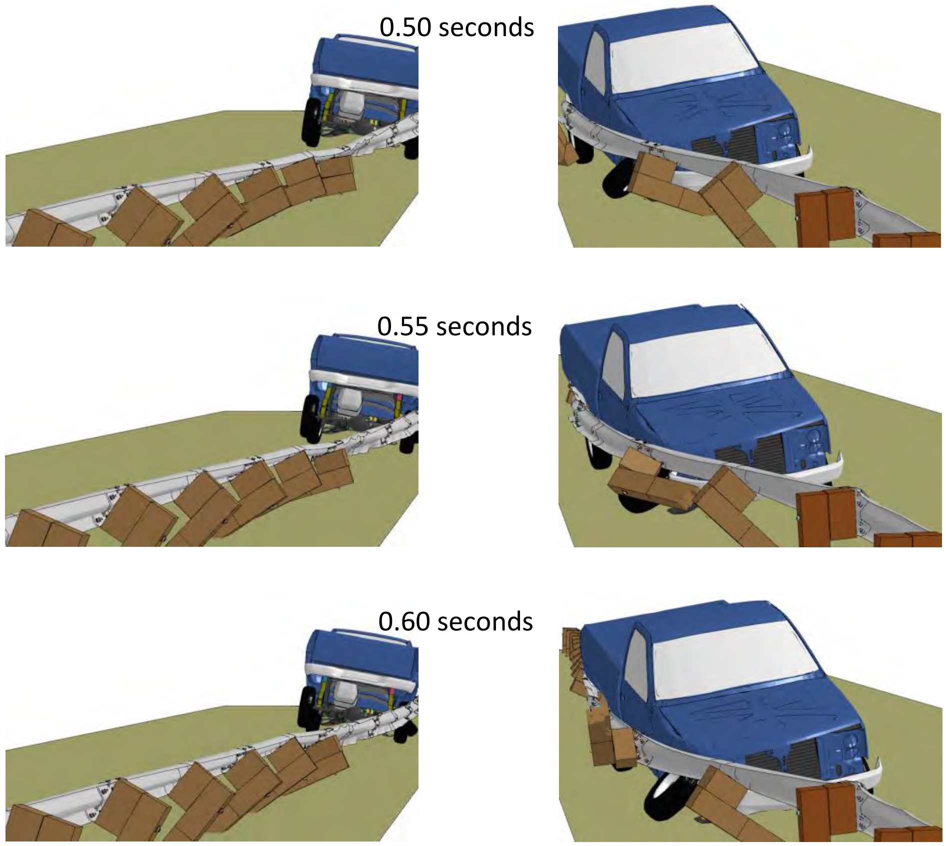


Figure D-6. **[CONTINUED] Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: 47% baseline anchor strength and DL2 Posts.**



Upstream-Backside Viewpoint Downstream-Backside Viewpoint

Figure D-6. [CONTINUED] Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: 47% baseline anchor strength and DL2 Posts.

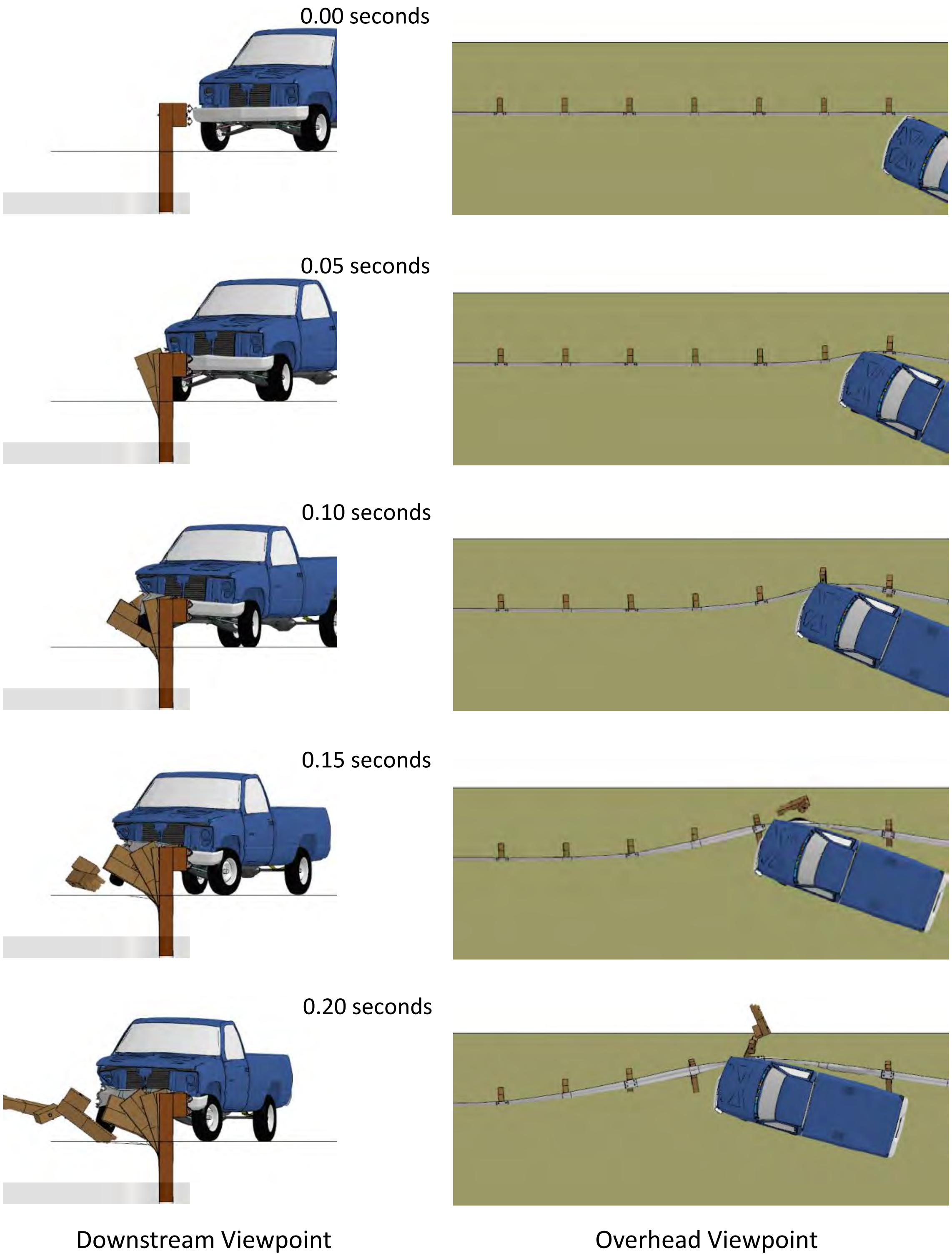


Figure D-7. Sequential views from a downstream and overhead viewpoint for analysis case: 47% baseline anchor strength and DL3 posts.

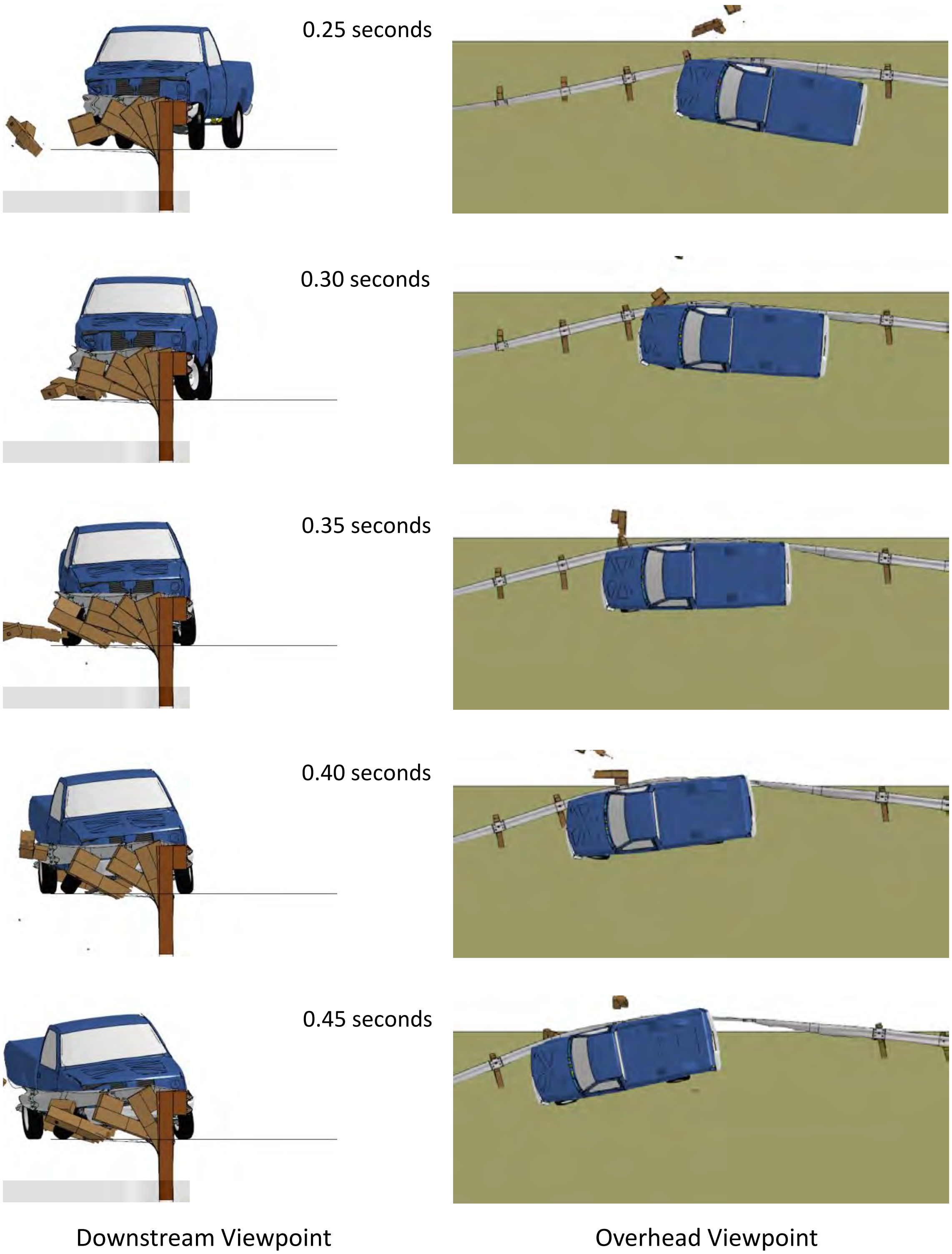


Figure D-7. [CONTINUED] Sequential views from a downstream and overhead viewpoint for analysis case: 47% baseline anchor strength and DL3 posts.

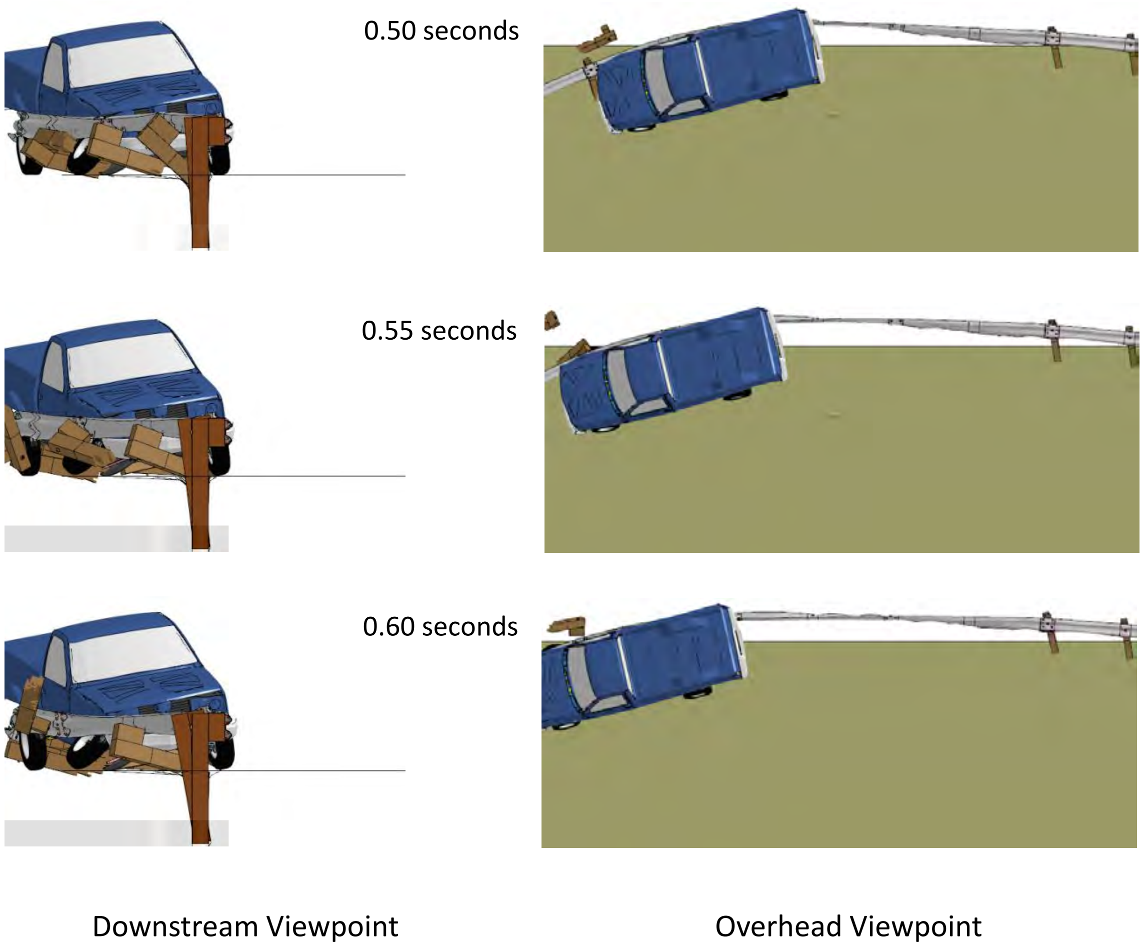


Figure D-7. [CONTINUED] Sequential views from a downstream and overhead viewpoint for analysis case: 47% baseline anchor strength and DL3 posts.

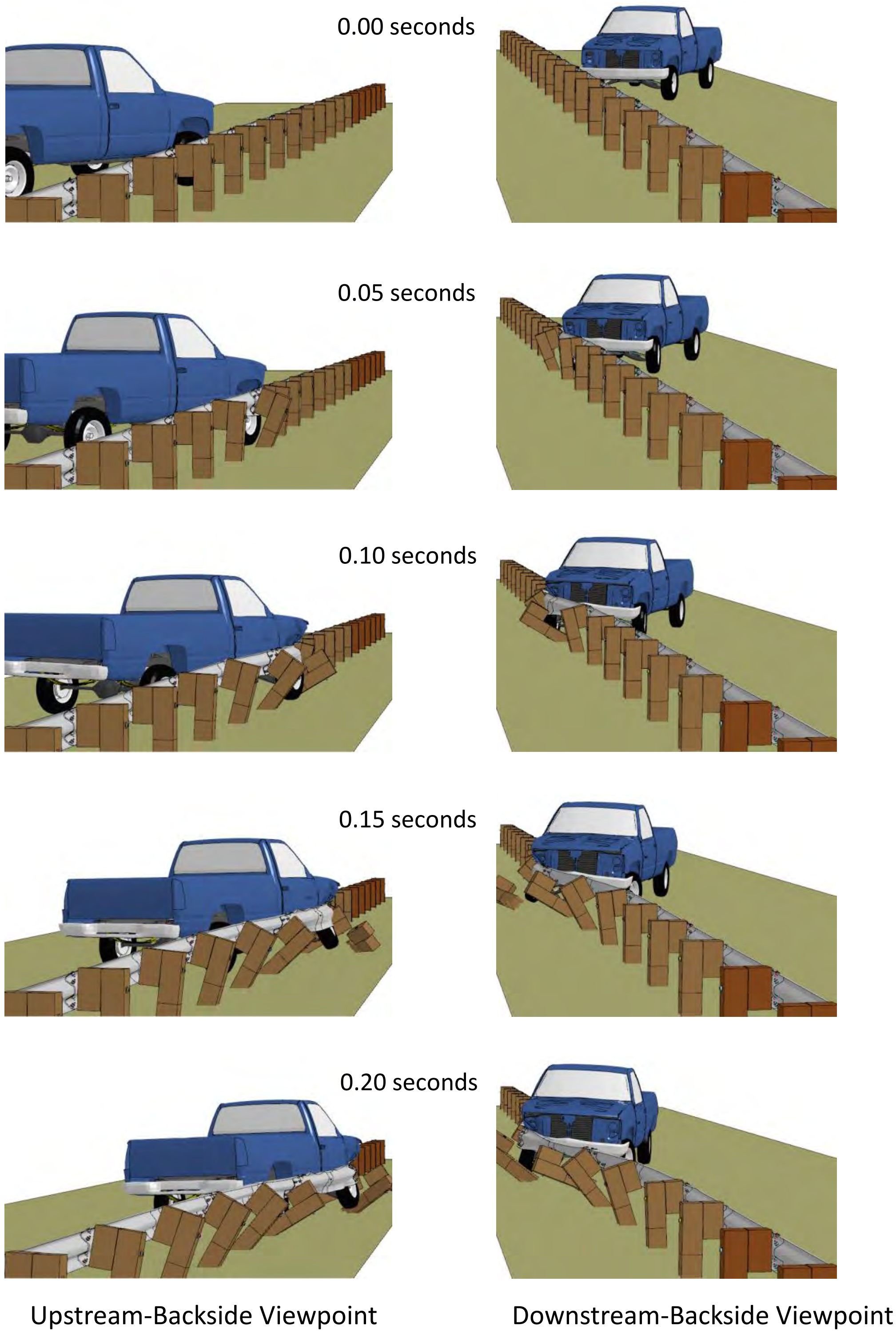


Figure D-8. Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: 47% baseline anchor strength and DL3 posts.

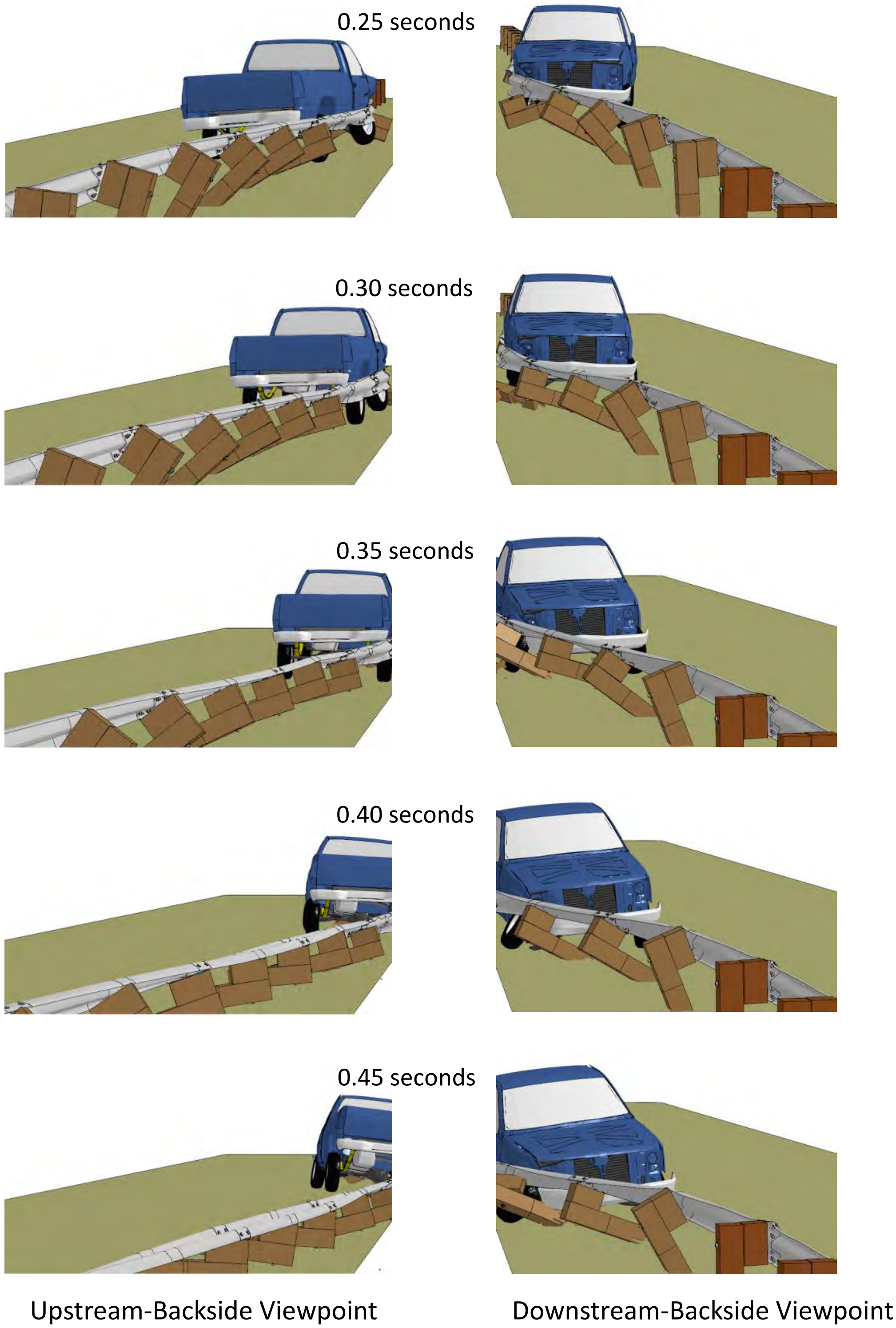


Figure D-8. [CONTINUED] Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: 47% baseline anchor strength and DL3 posts.

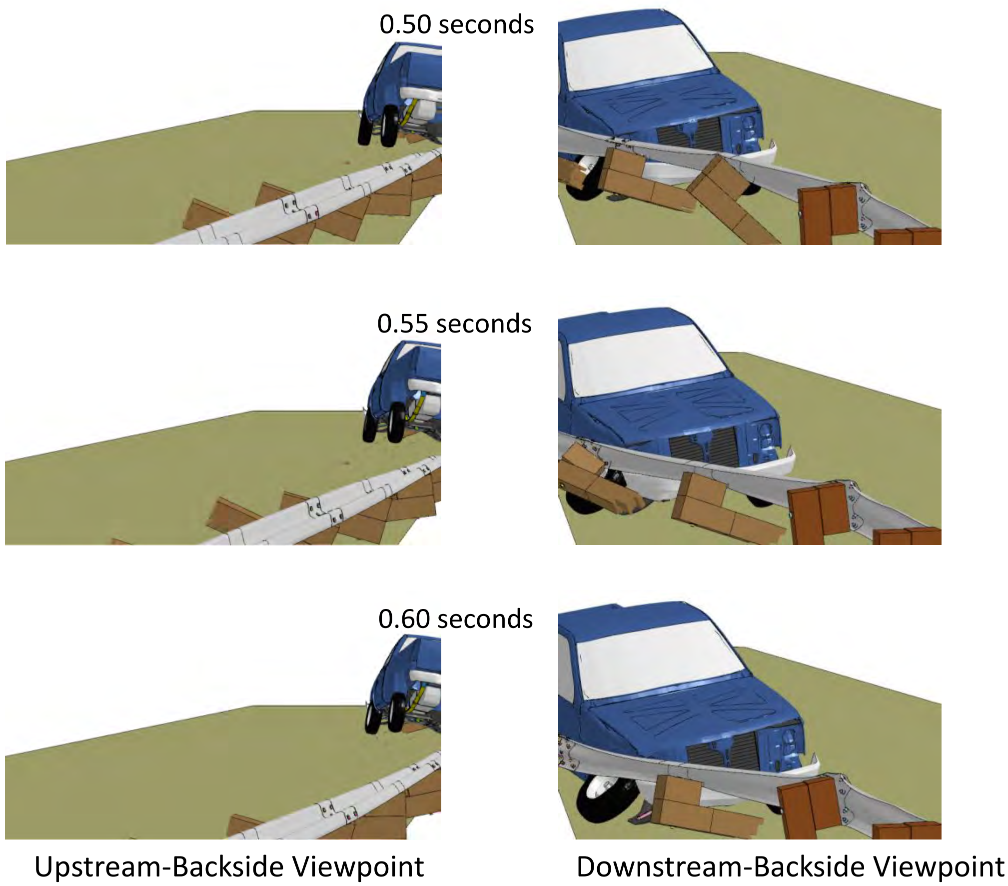


Figure D-8. [CONTINUED] Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: 47% baseline anchor strength and DL3 posts.

APPENDIX K

Sequential Views from FEA Analyses of G4(2W) under Low-Speed Impact (To Induce Low-Severity Rail Deflection)

Task 4A-2: Assess Effects of Rail Deflection and Rail-Post Connection on Performance of G4(2W)

By: Chuck A. Plaxico

February 2014

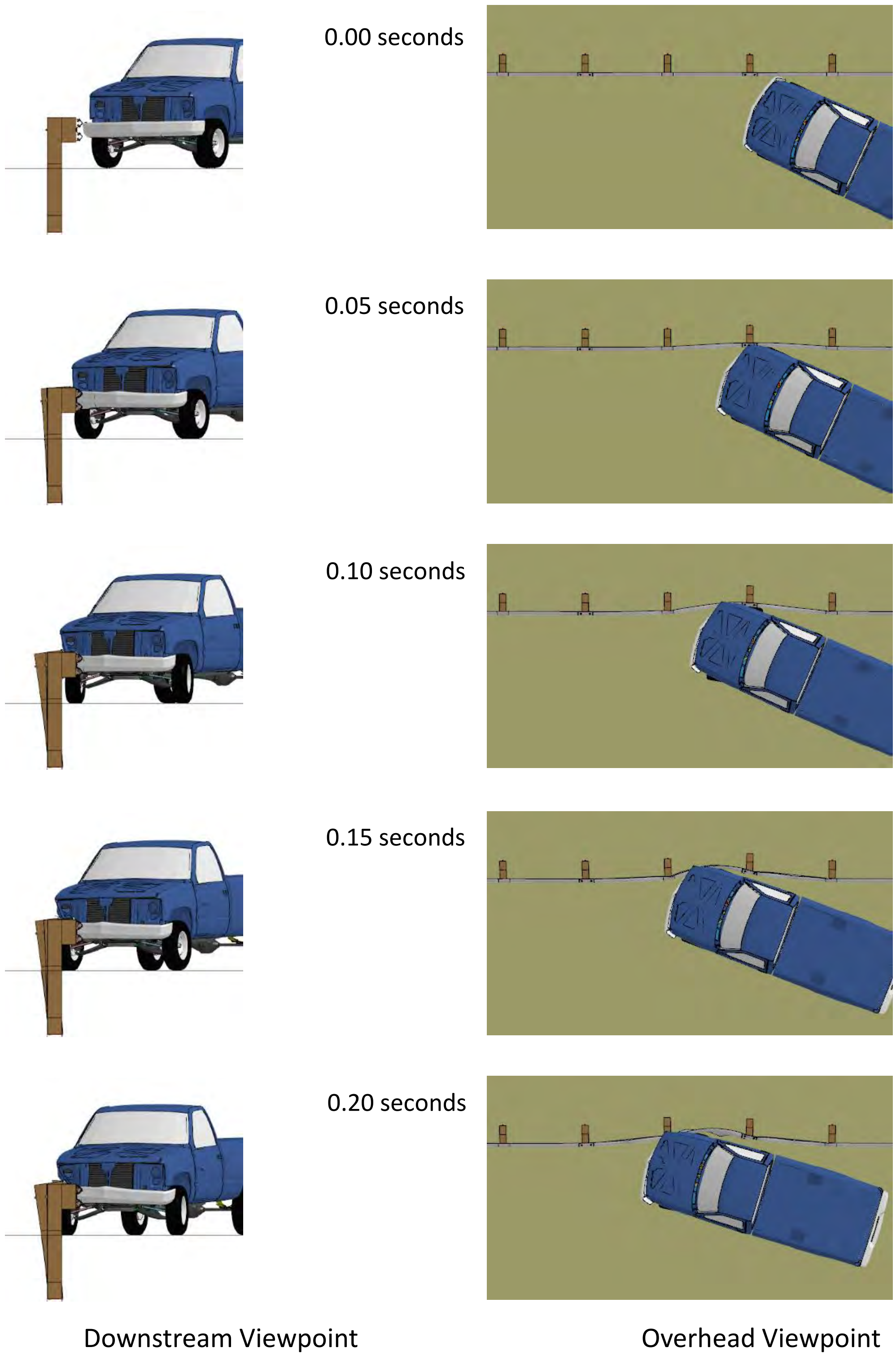


Figure J-1. Sequential views from a downstream and overhead viewpoint for analysis case: 30 mph at Impact Point 1.

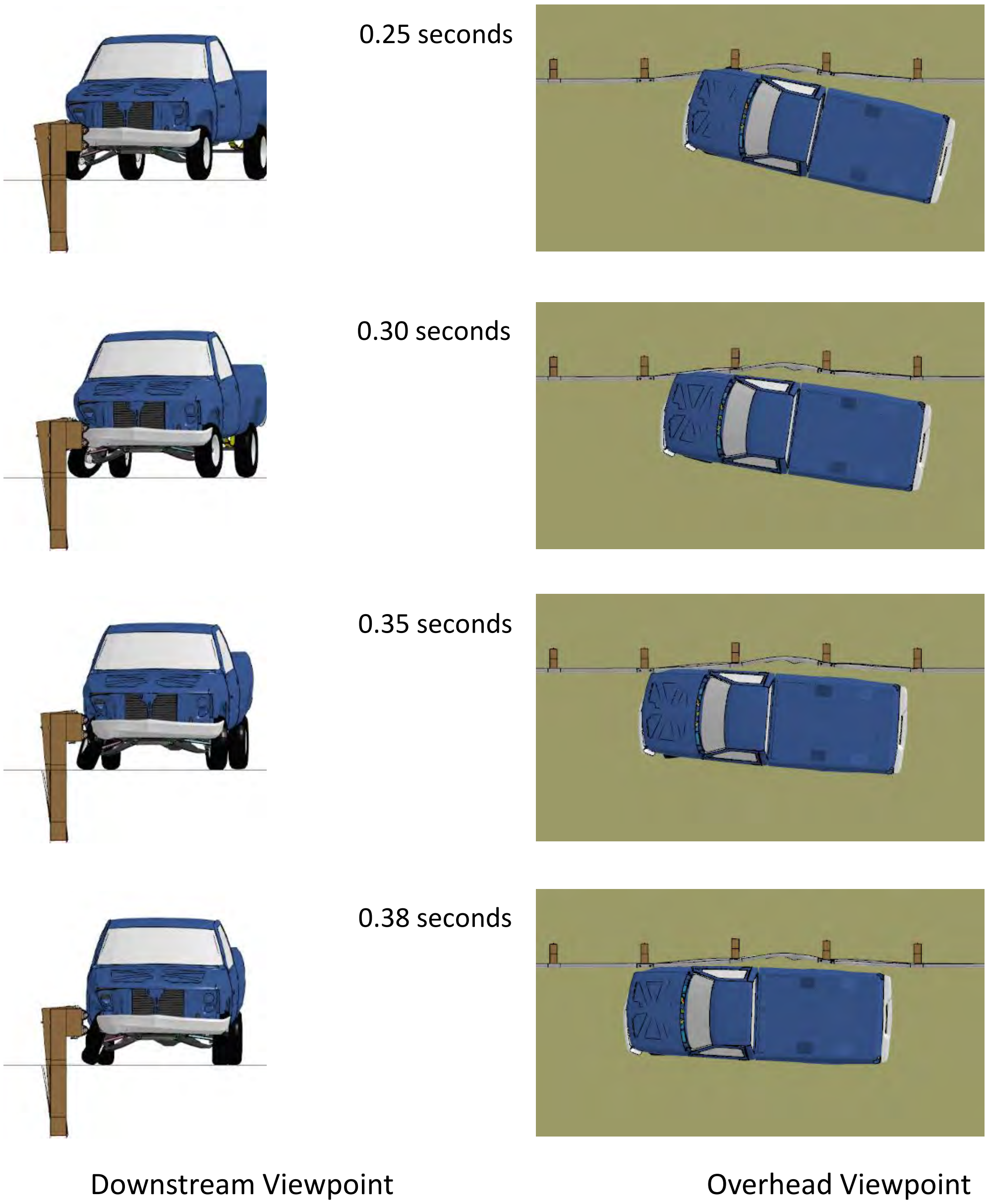


Figure J-1. [CONTINUED] Sequential views from a downstream and overhead viewpoint for analysis case: 30 mph at Impact Point 1.

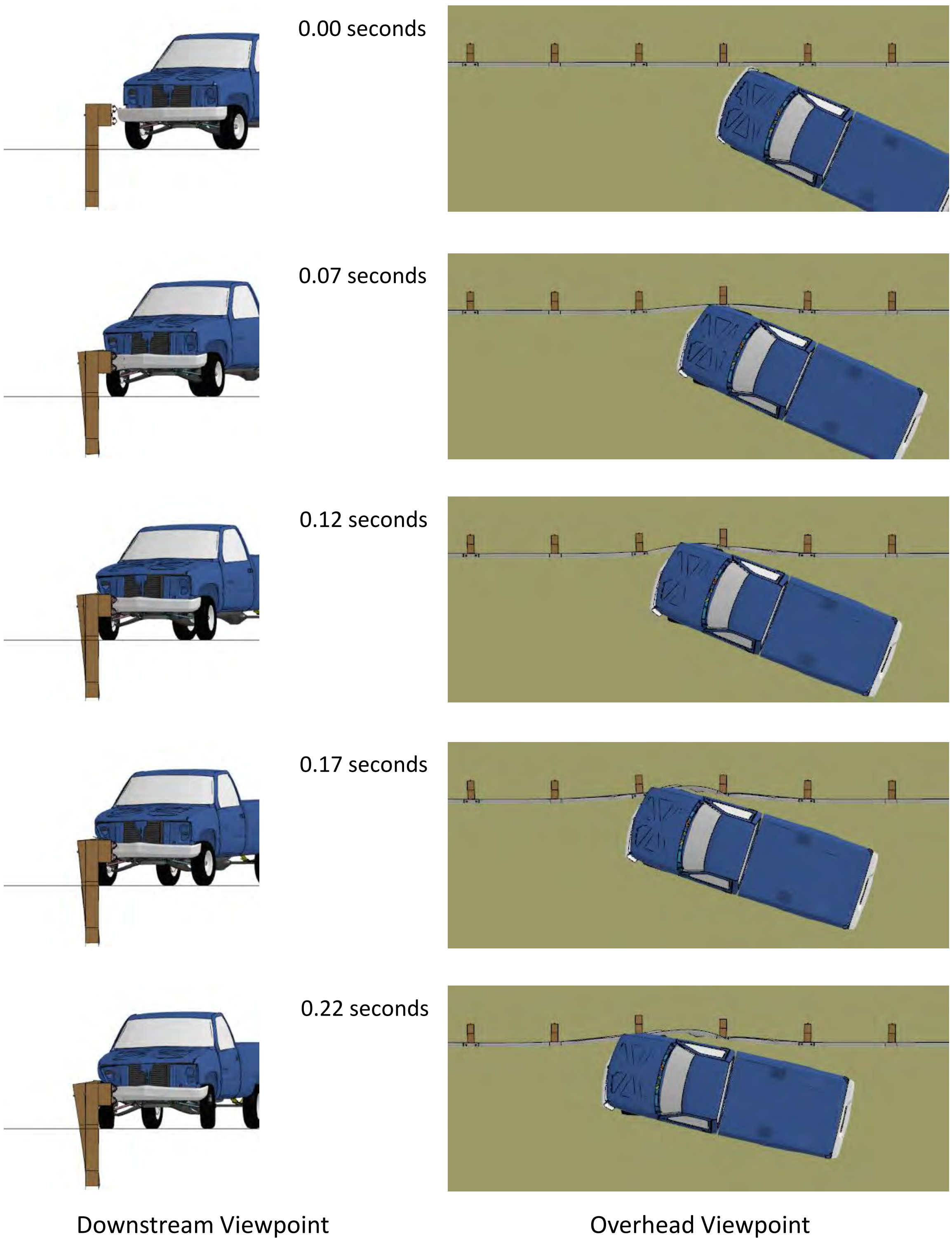


Figure J-2. Sequential views from a downstream and overhead viewpoint for analysis case: 30 mph at Impact Point 2.

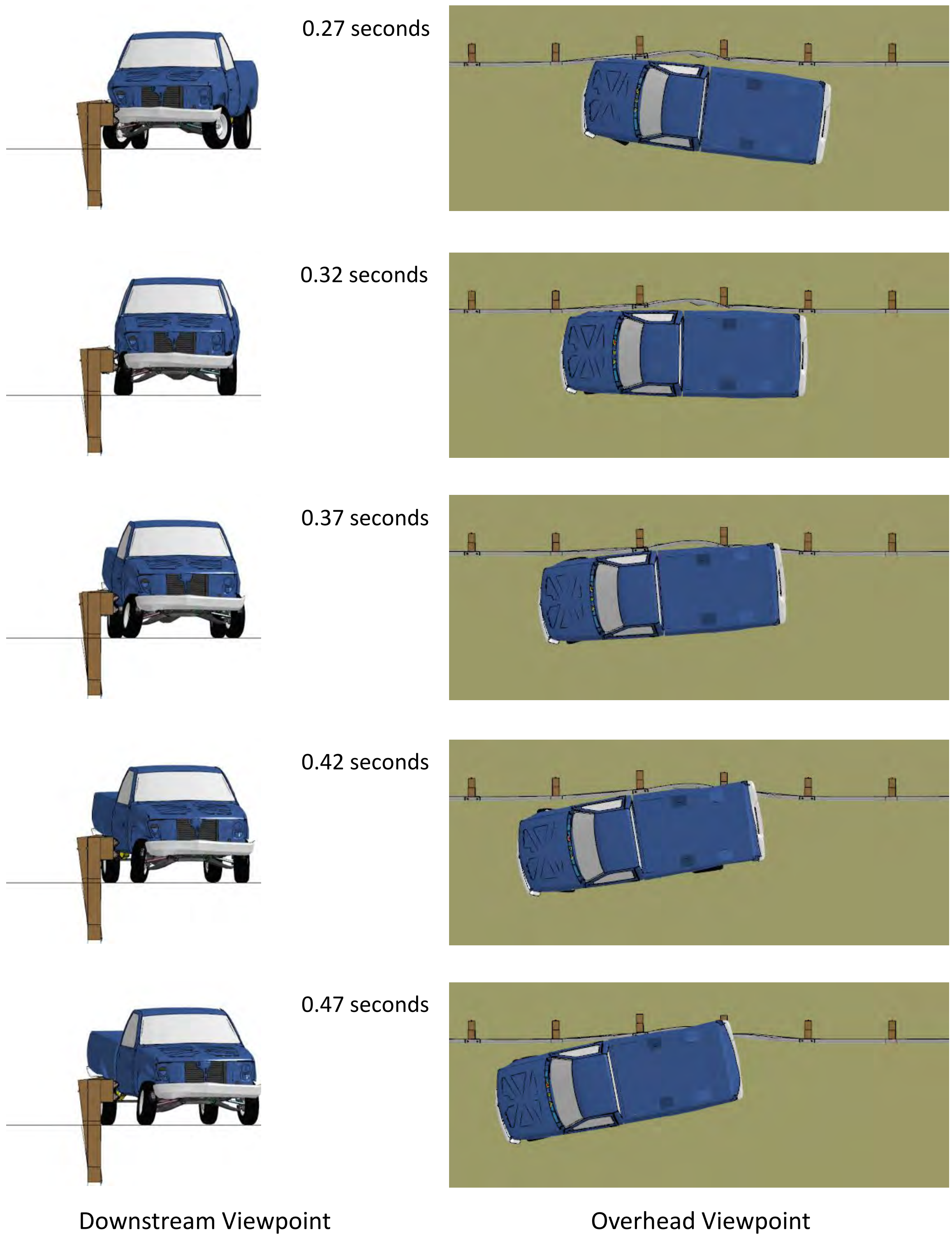


Figure J-2 [CONTINUED] Sequential views from a downstream and overhead viewpoint for analysis case: 30 mph at Impact Point 2.

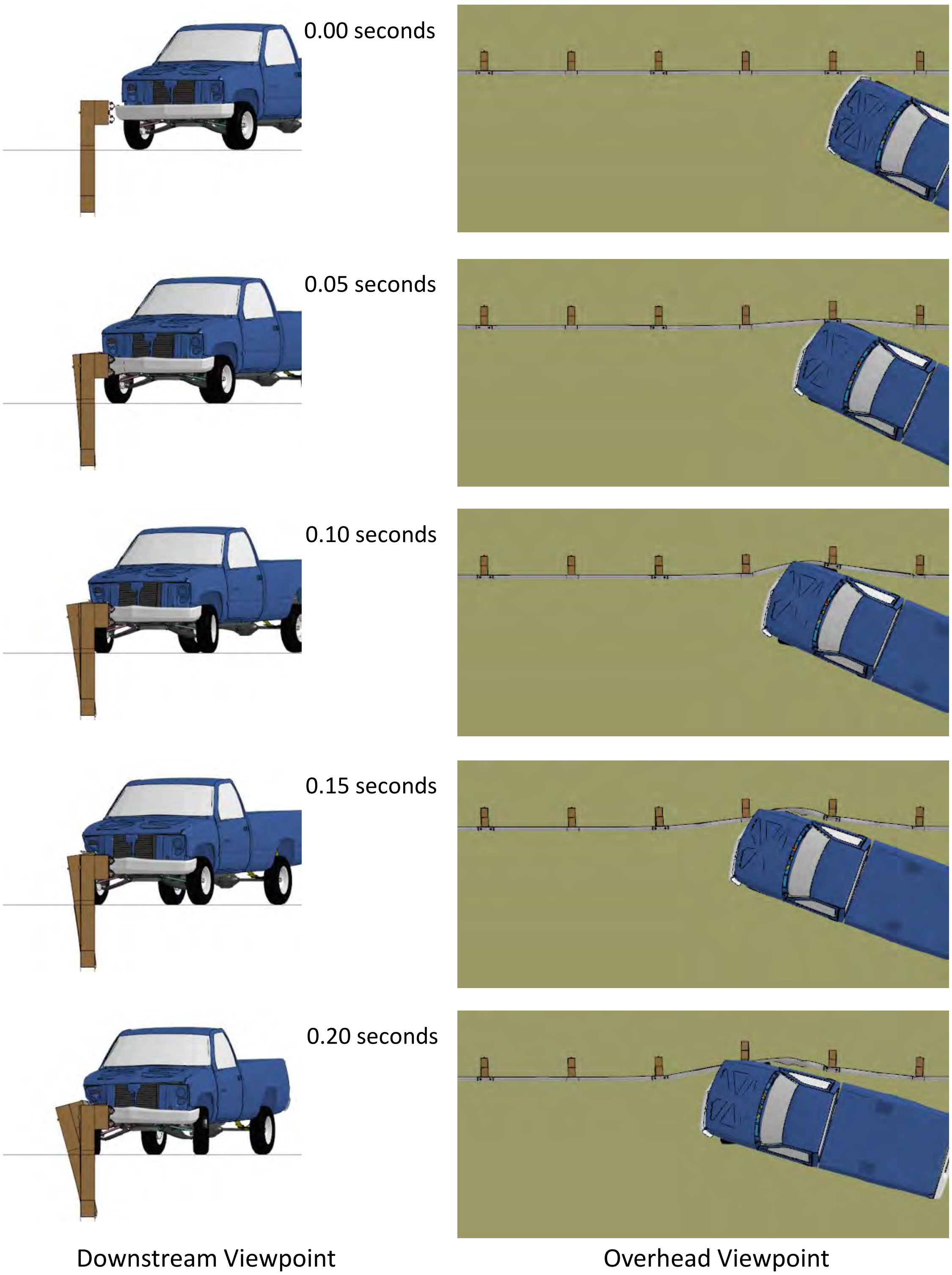


Figure J-3. Sequential views from a downstream and overhead viewpoint for analysis case: 35 mph at Impact Point 1.

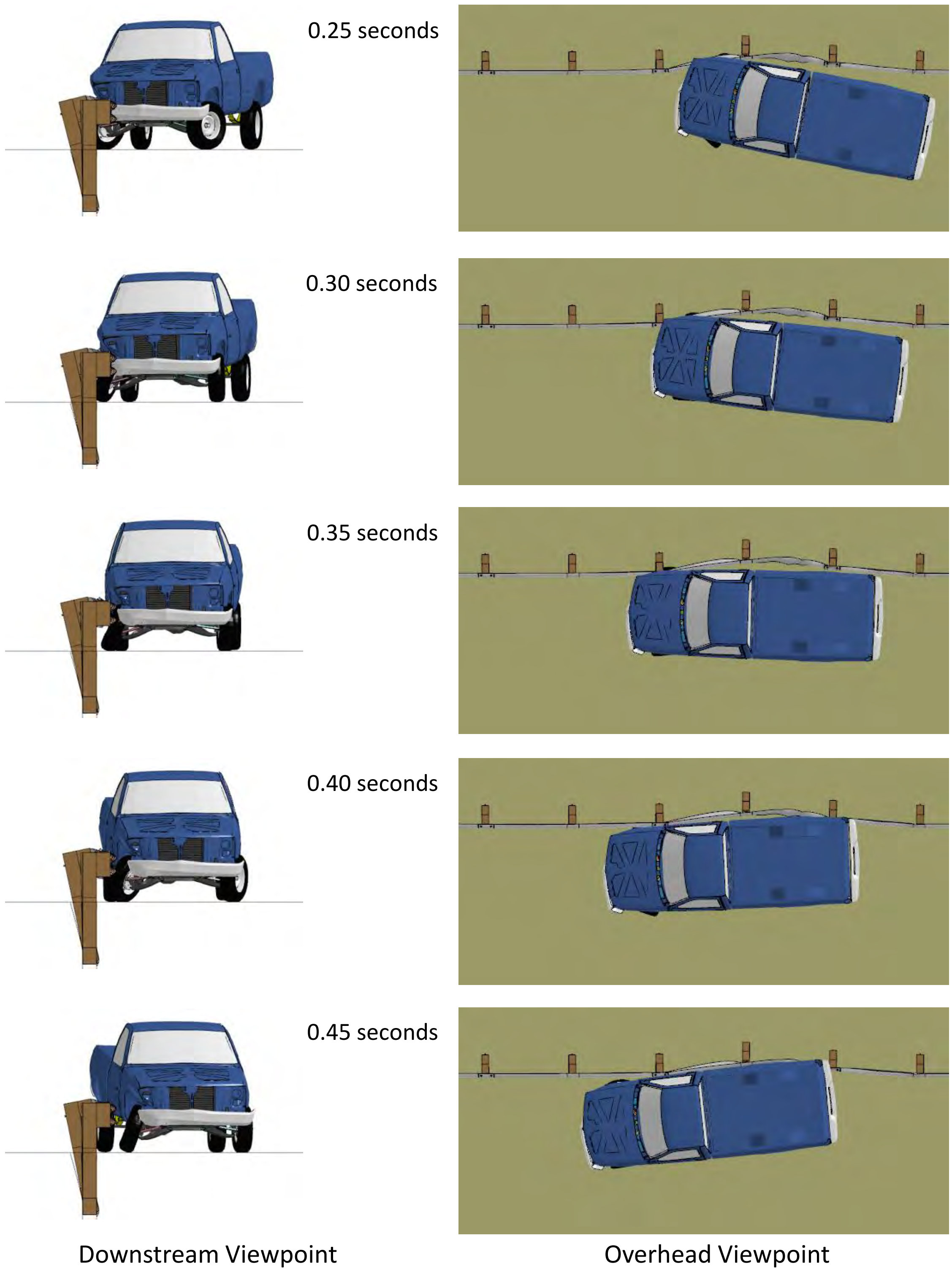


Figure J-3. [CONTINUED] Sequential views from a downstream and overhead viewpoint for analysis case: 35 mph at Impact Point 1.

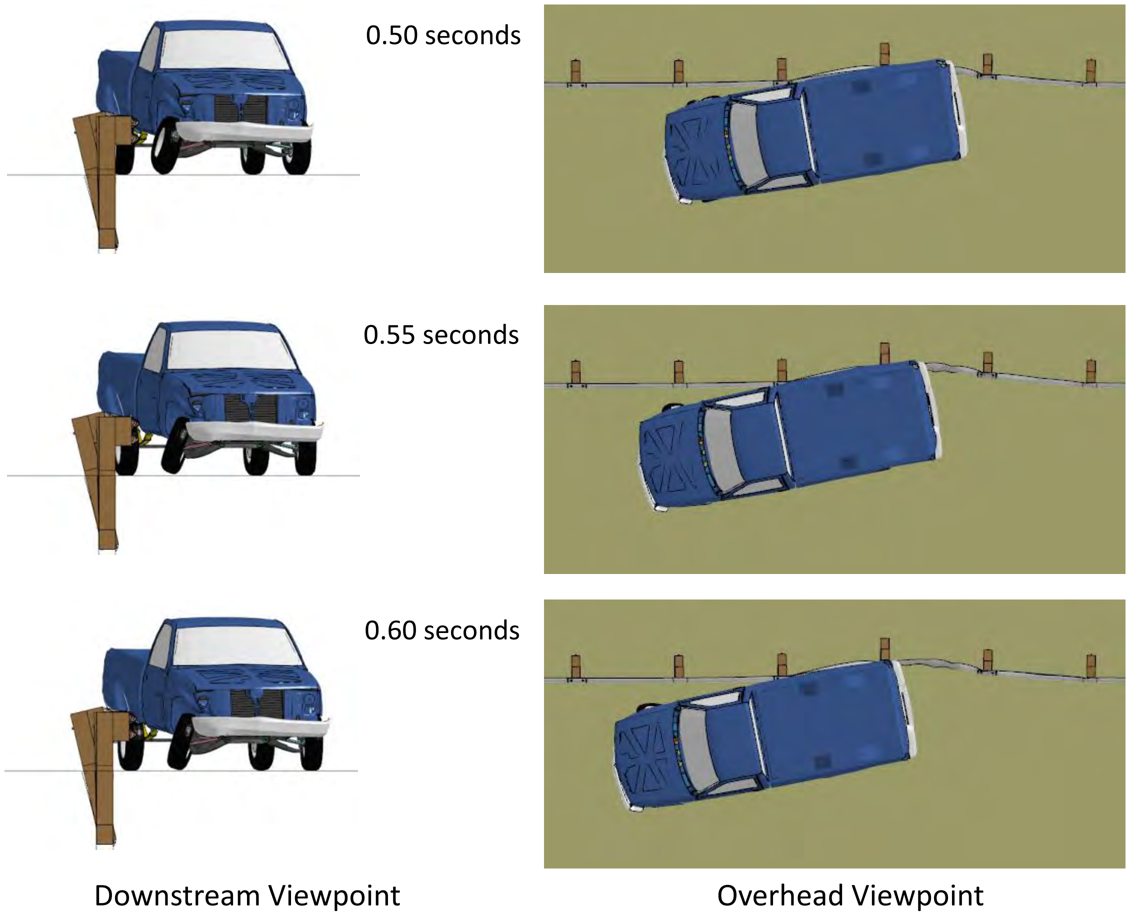


Figure J-3. [CONTINUED] Sequential views from a downstream and overhead viewpoint for analysis case: 35 mph at Impact Point 1.

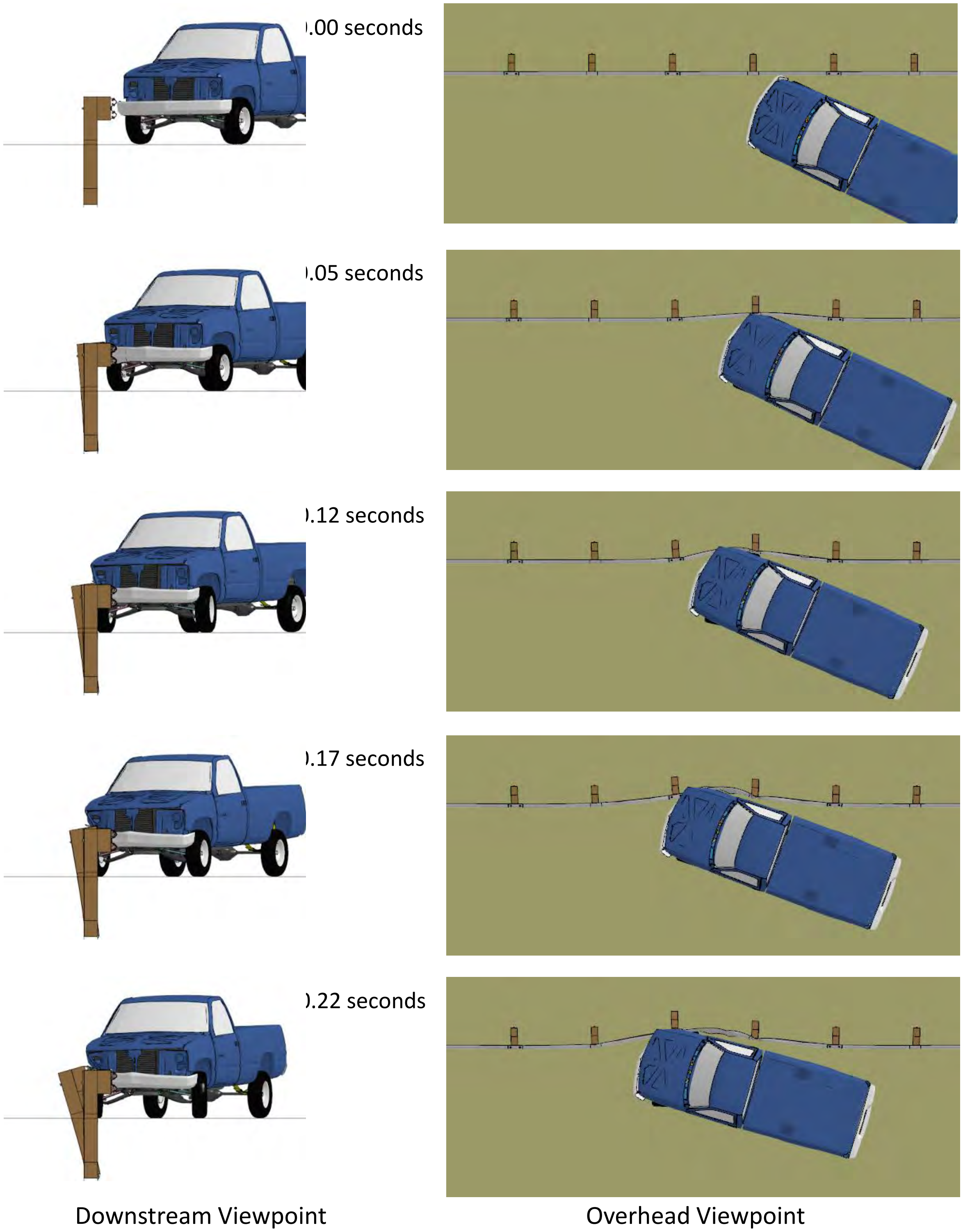


Figure J-4. Sequential views from a downstream and overhead viewpoint for analysis case: 35 mph at Impact Point 2.

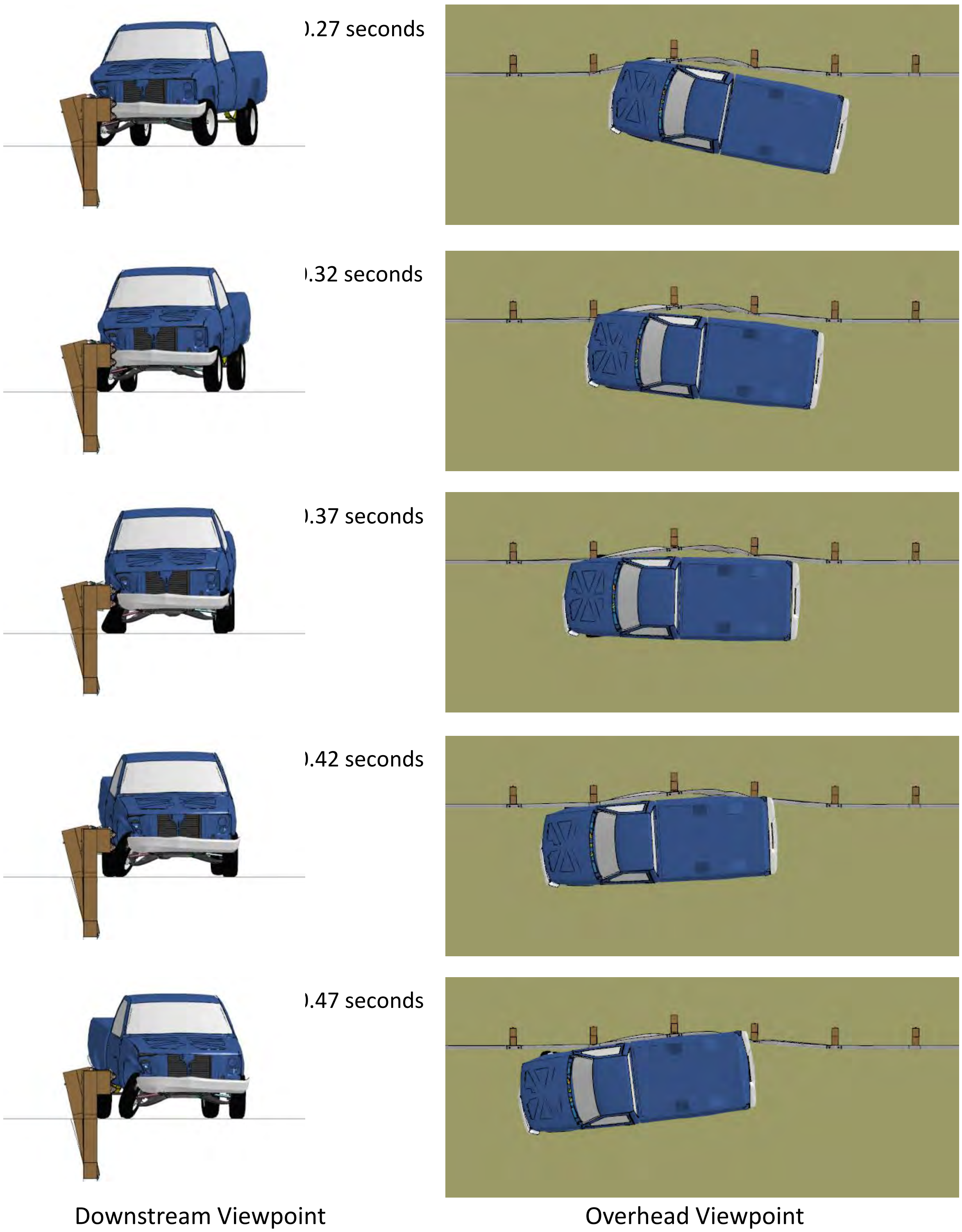


Figure J-4. [CONTINUED] Sequential views from a downstream and overhead viewpoint for analysis case: 35 mph at Impact Point 2.

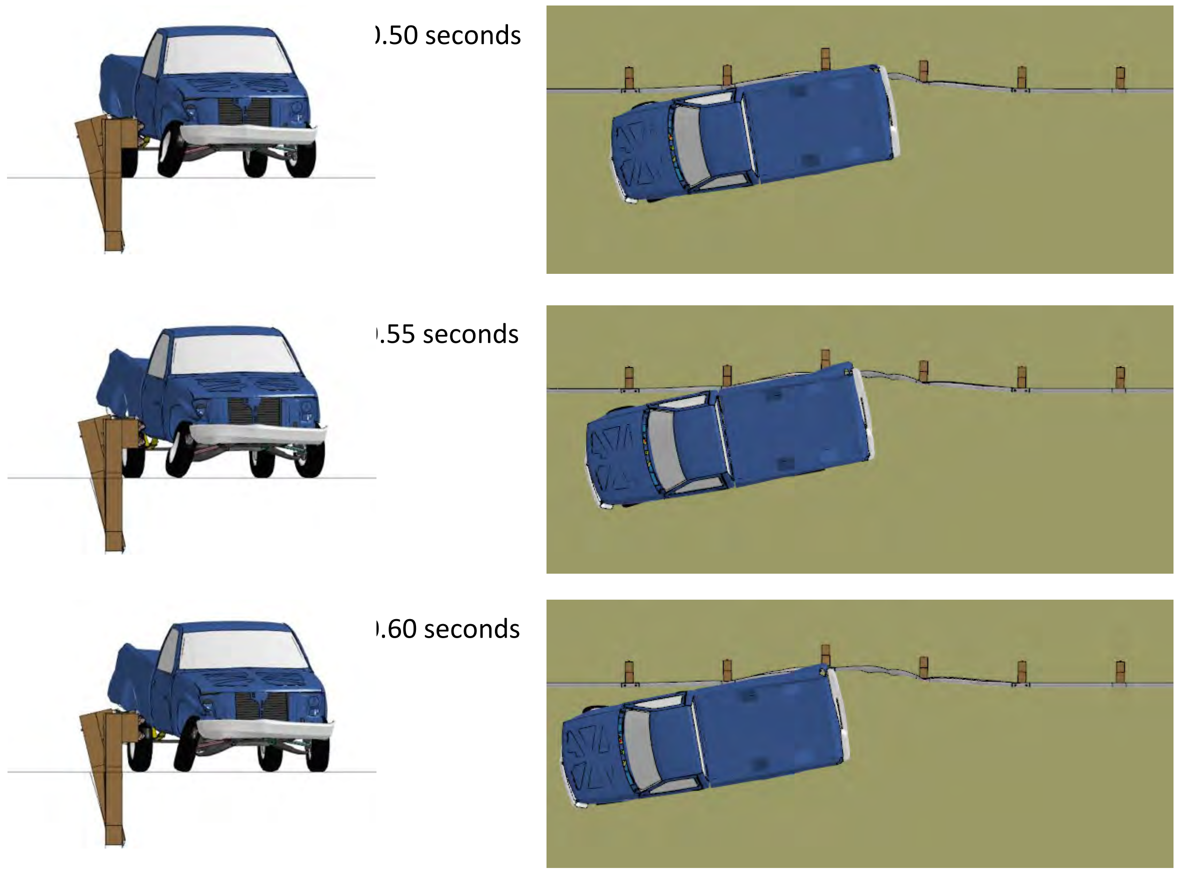


Figure J-4. [CONTINUED] Sequential views from a downstream and overhead viewpoint for analysis case: 35 mph at Impact Point 2.

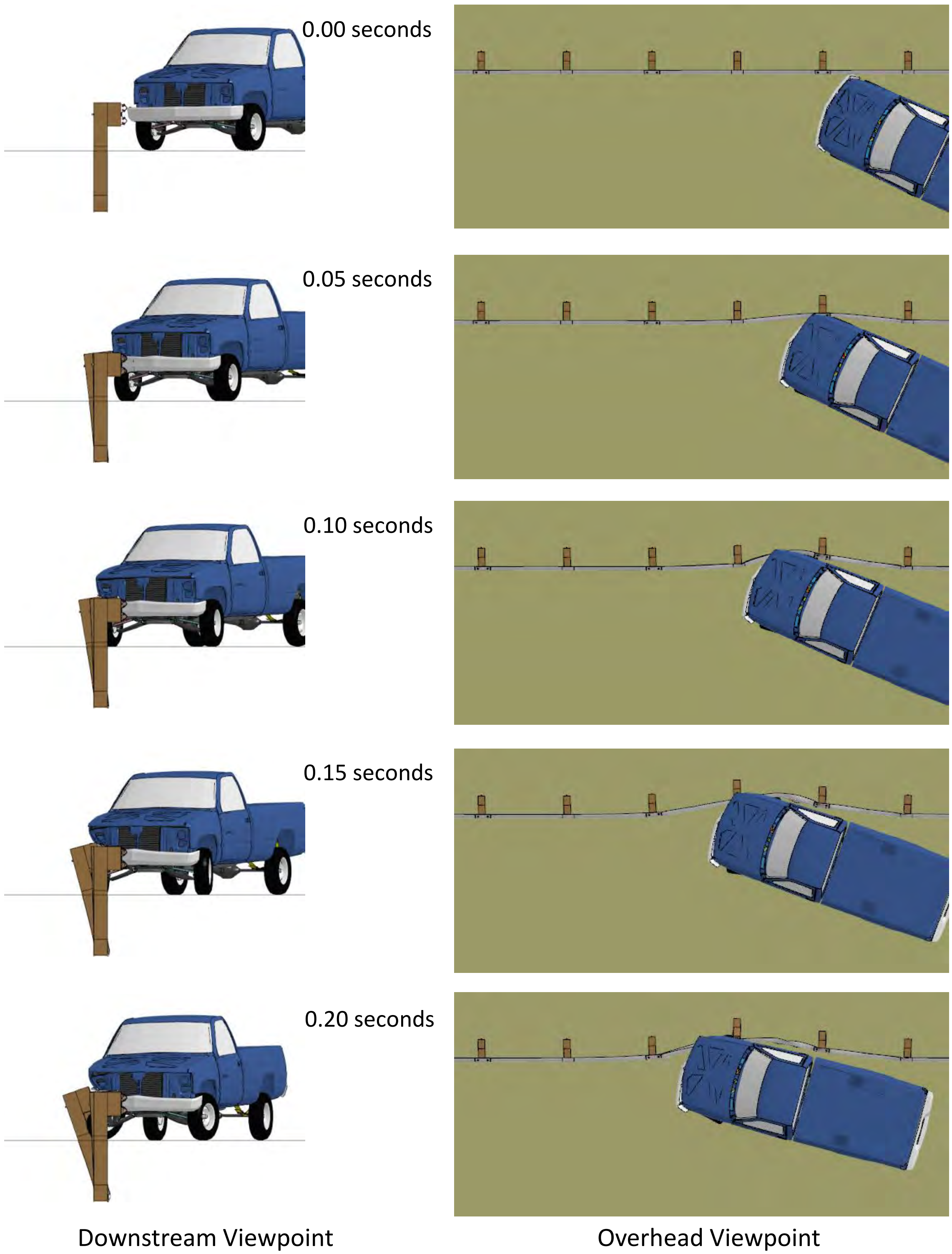


Figure J-5. Sequential views from a downstream and overhead viewpoint for analysis case: 40 mph at Impact Point 1.

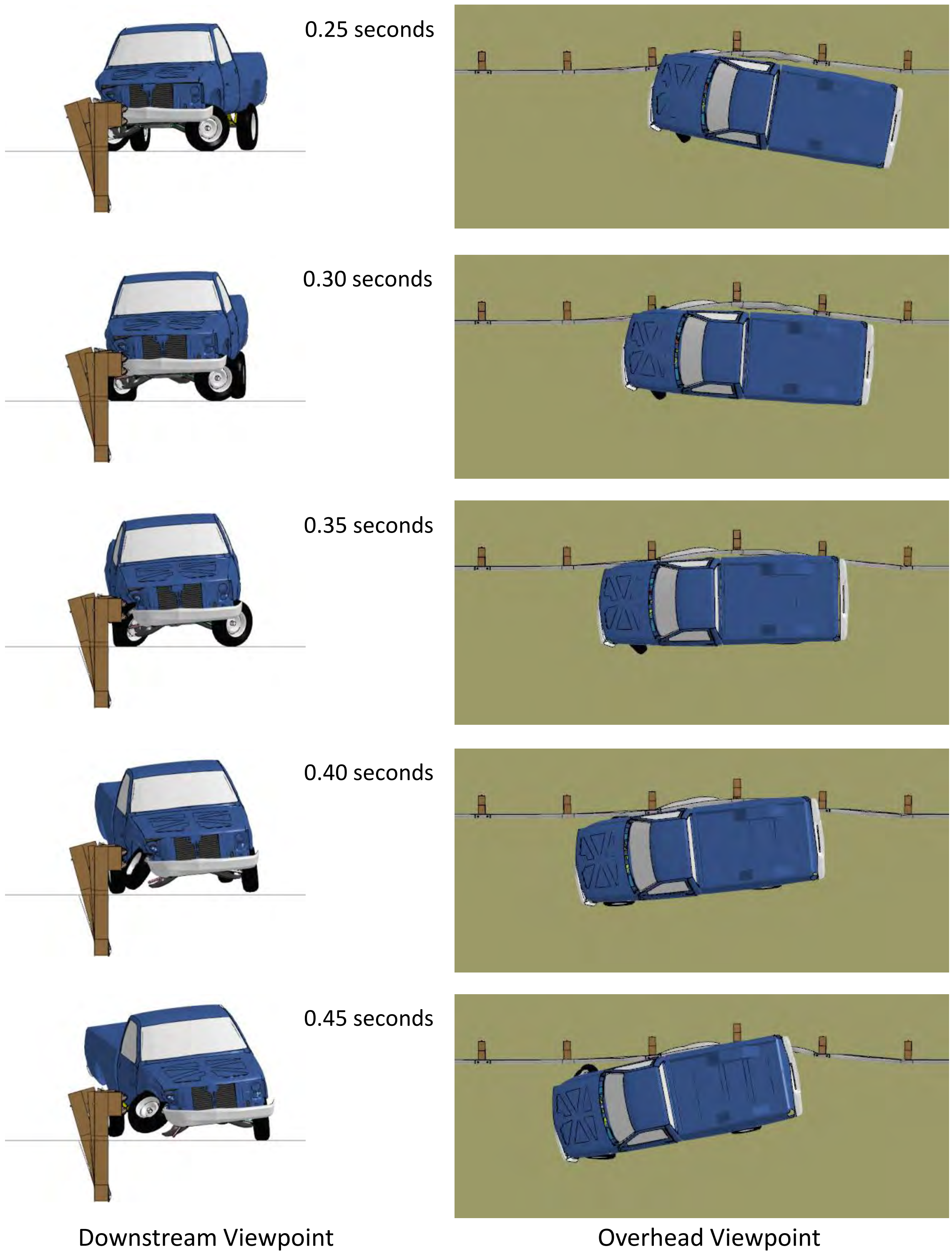


Figure J-5. [CONTINUED] Sequential views from a downstream and overhead viewpoint for analysis case: 40 mph at Impact Point 1.

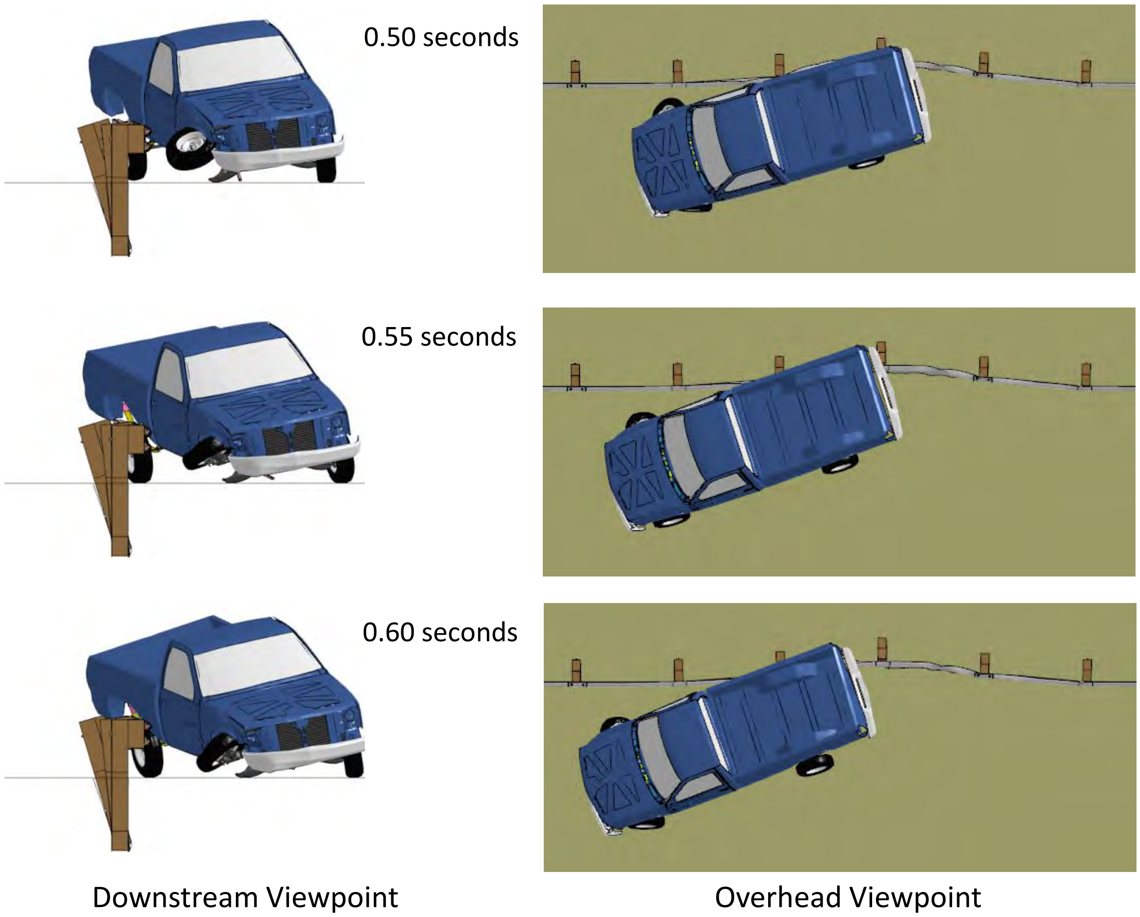


Figure J-5. [CONTINUED] Sequential views from a downstream and overhead viewpoint for analysis case: 40 mph at Impact Point 1.

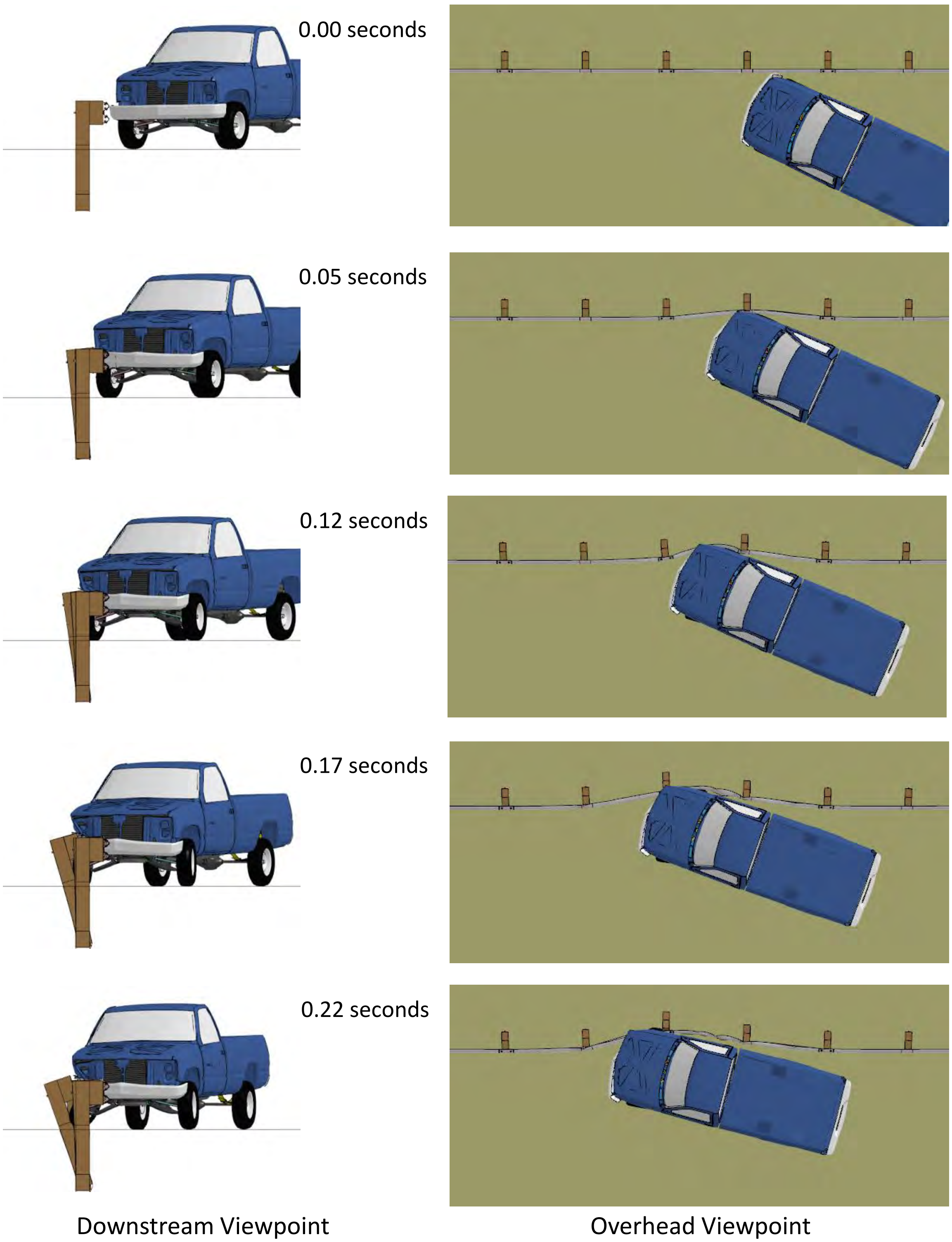


Figure J-6. Sequential views from a downstream and overhead viewpoint for analysis case: 40 mph at Impact Point 2.

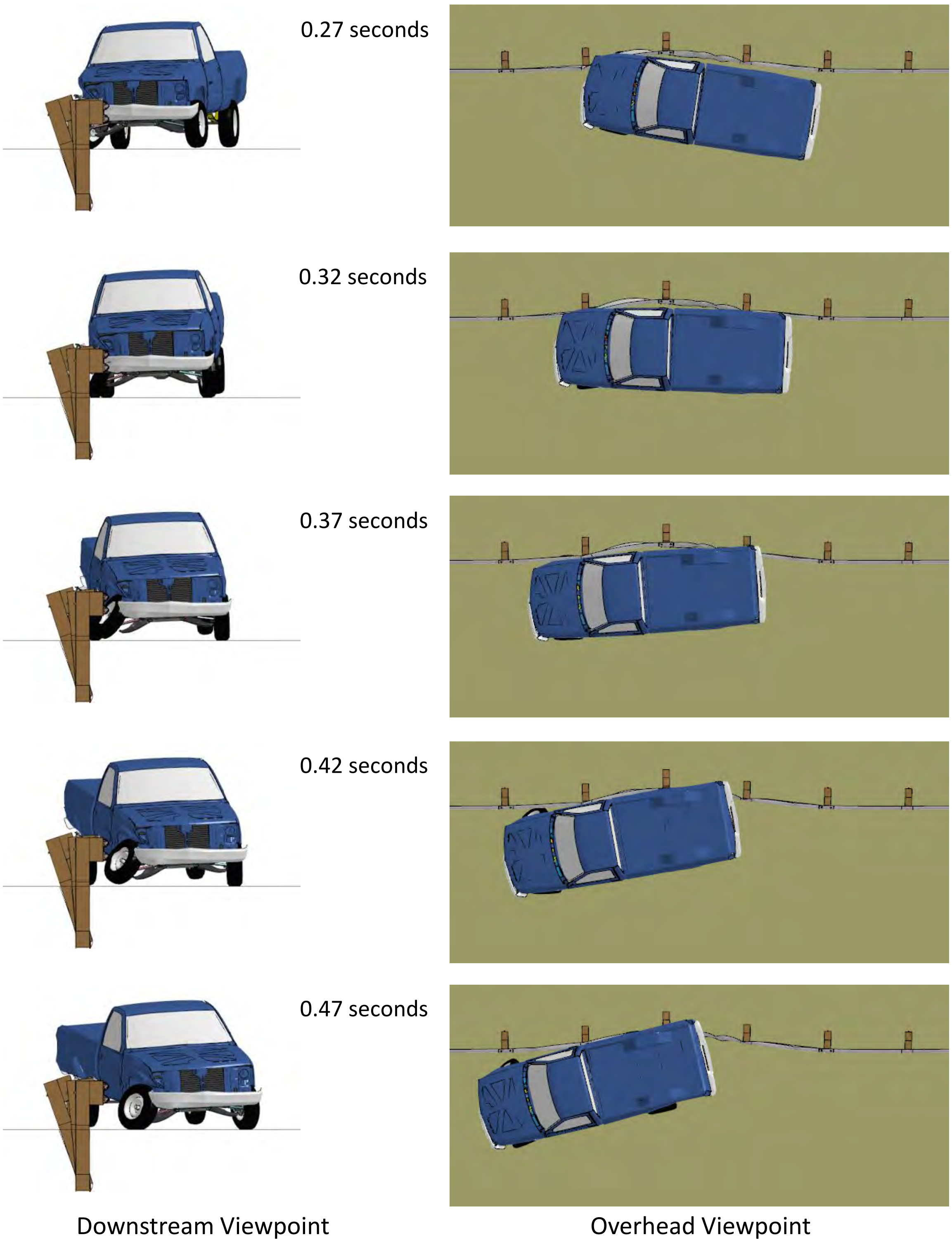


Figure J-6. [CONTINUED] Sequential views from a downstream and overhead viewpoint for analysis case: 40 mph at Impact Point 2.

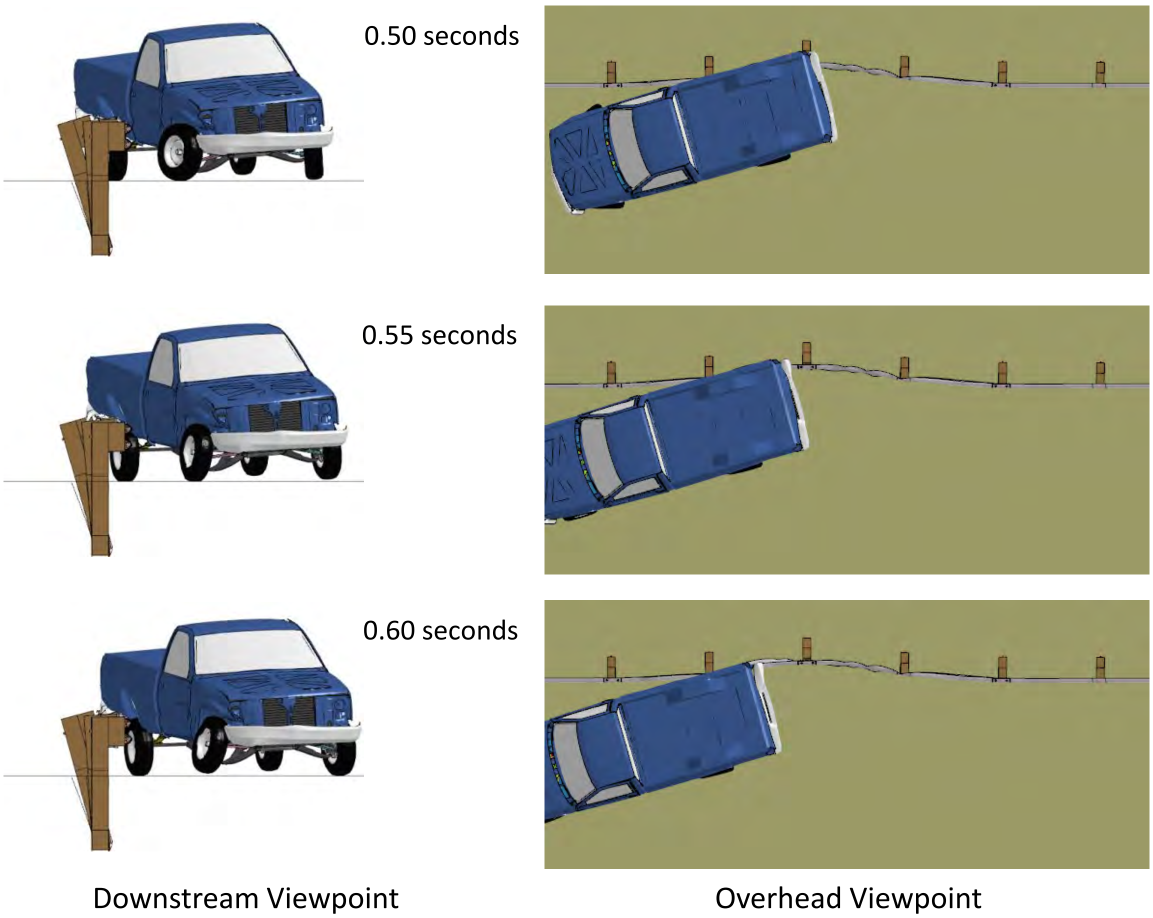


Figure J-6. [CONTINUED] Sequential views from a downstream and overhead viewpoint for analysis case: 40 mph at Impact Point 2.

APPENDIX L

Sequential Views from FEA Analyses of High-Speed Impact into G4(2W) with Low-Severity Rail Deflections

Task 4A-2: Assess Effects of Rail Deflection and Rail-Post Connection on Performance of G4(2W)

By: Chuck A. Plaxico

February 2014

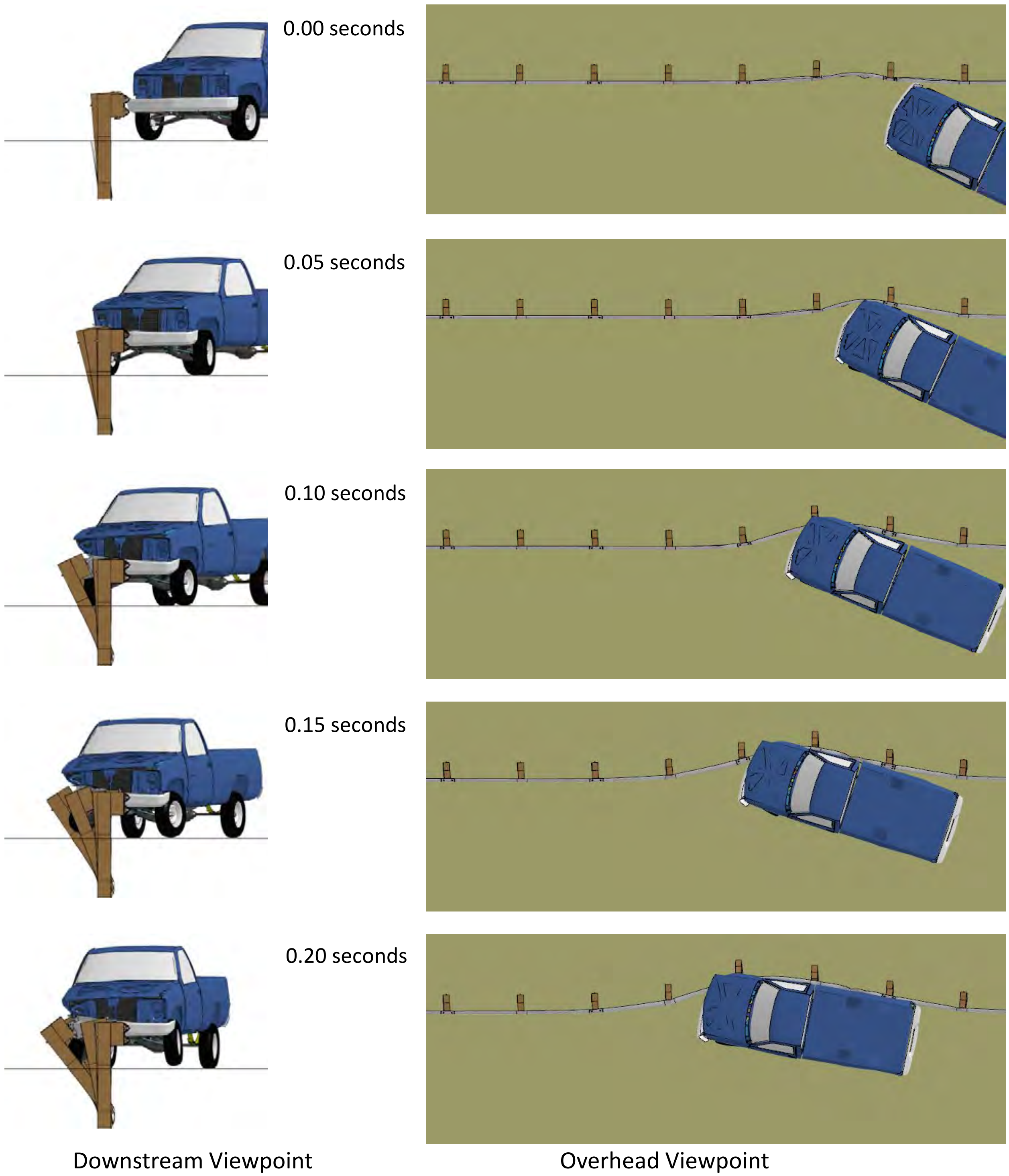


Figure K-1. Sequential views from a downstream and overhead viewpoint for analysis case: Test 3-11 of 30 mph-Damaged G4(2W) at Impact Point 1.

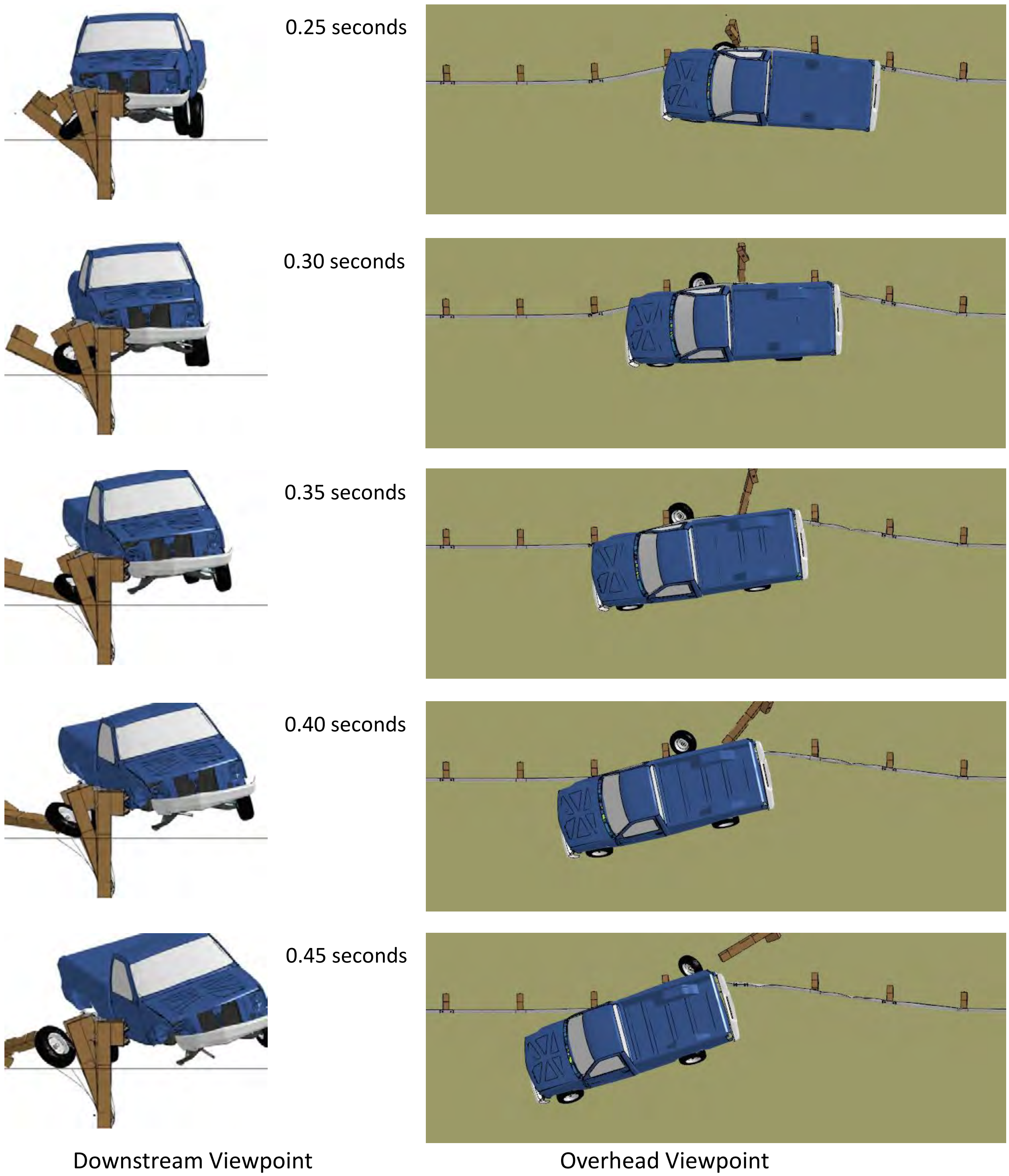


Figure K-1. [CONTINUED] Sequential views from a downstream and overhead viewpoint for analysis case: Test 3-11 of 30 mph-Damaged G4(2W) at Impact Point 1.

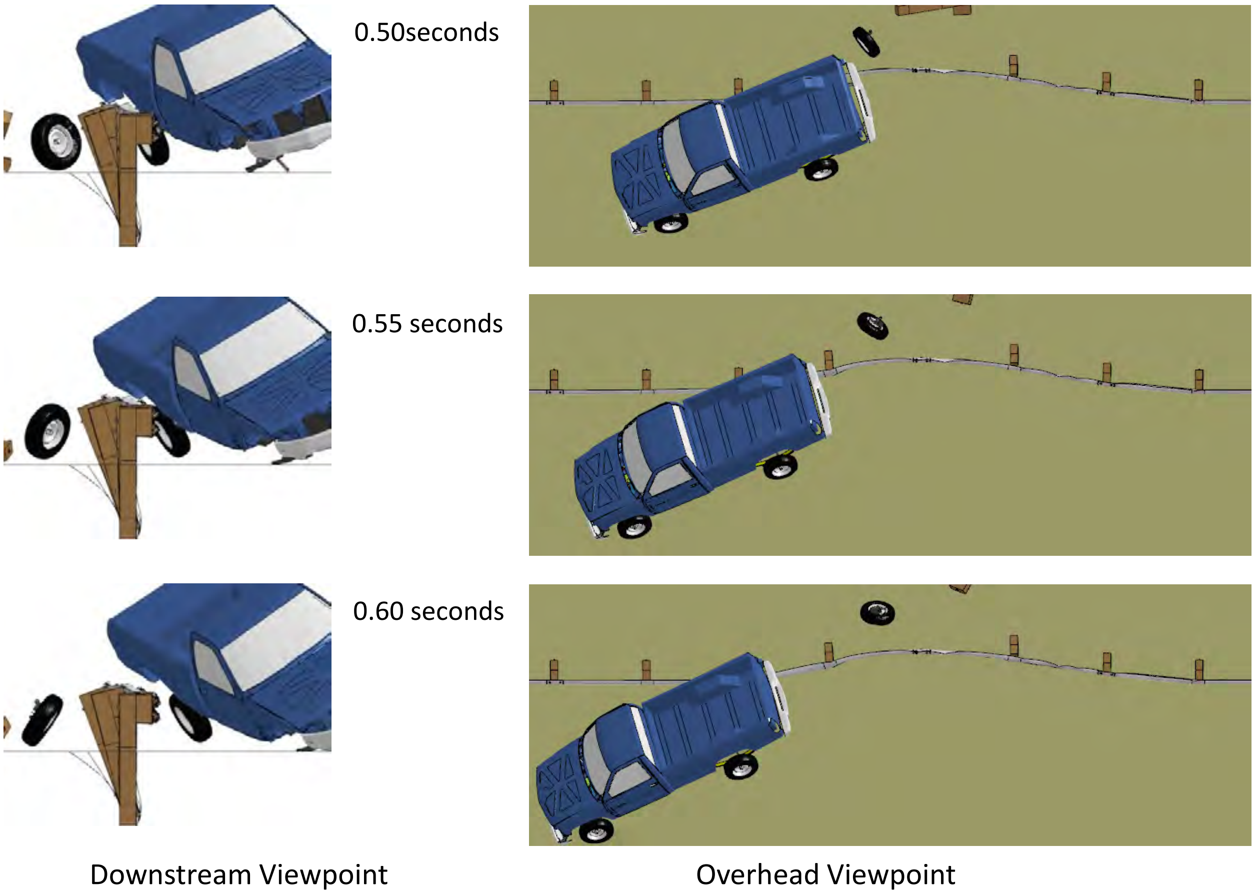


Figure K-1. [CONTINUED] Sequential views from a downstream and overhead viewpoint for analysis case: Test 3-11 of 30 mph-Damaged G4(2W) at Impact Point 1.

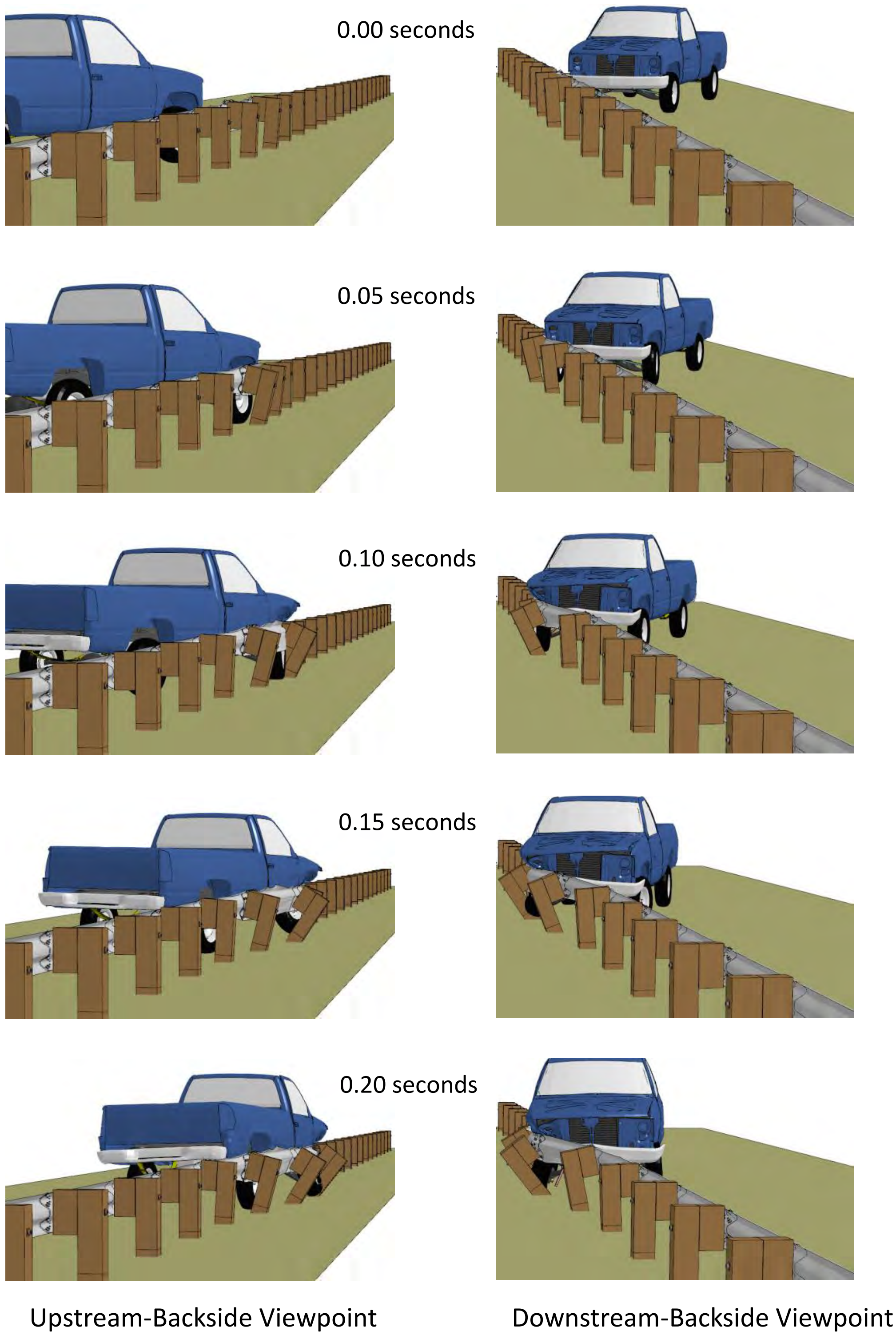
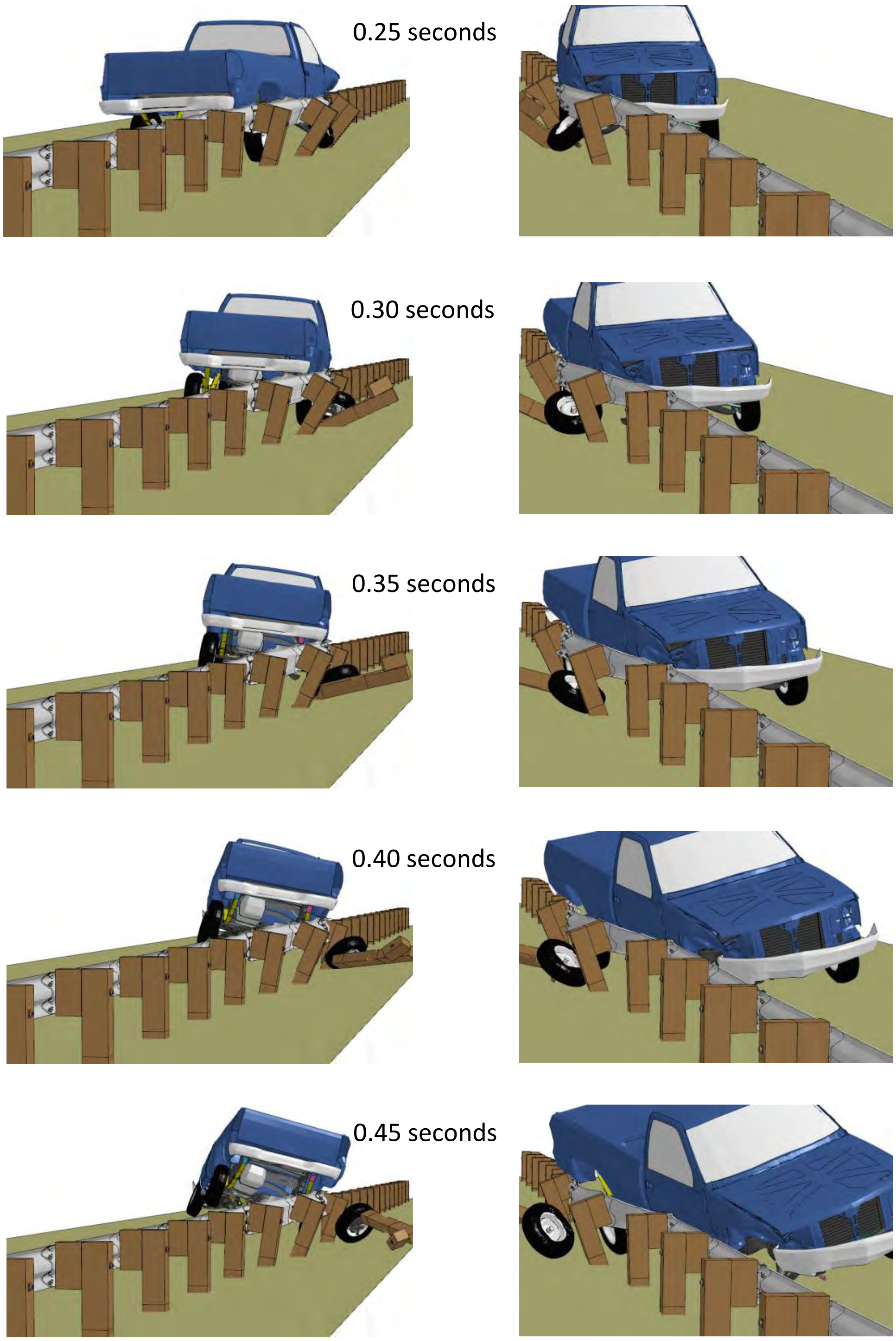


Figure K-2. Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: Test 3-11 of 30 mph-Damaged G4(2W) at Impact Point 1.



Upstream-Backside Viewpoint Downstream-Backside Viewpoint

Figure K-2. [CONTINUED] Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: Test 3-11 of 30 mph-Damaged G4(2W) at Impact Point 1.

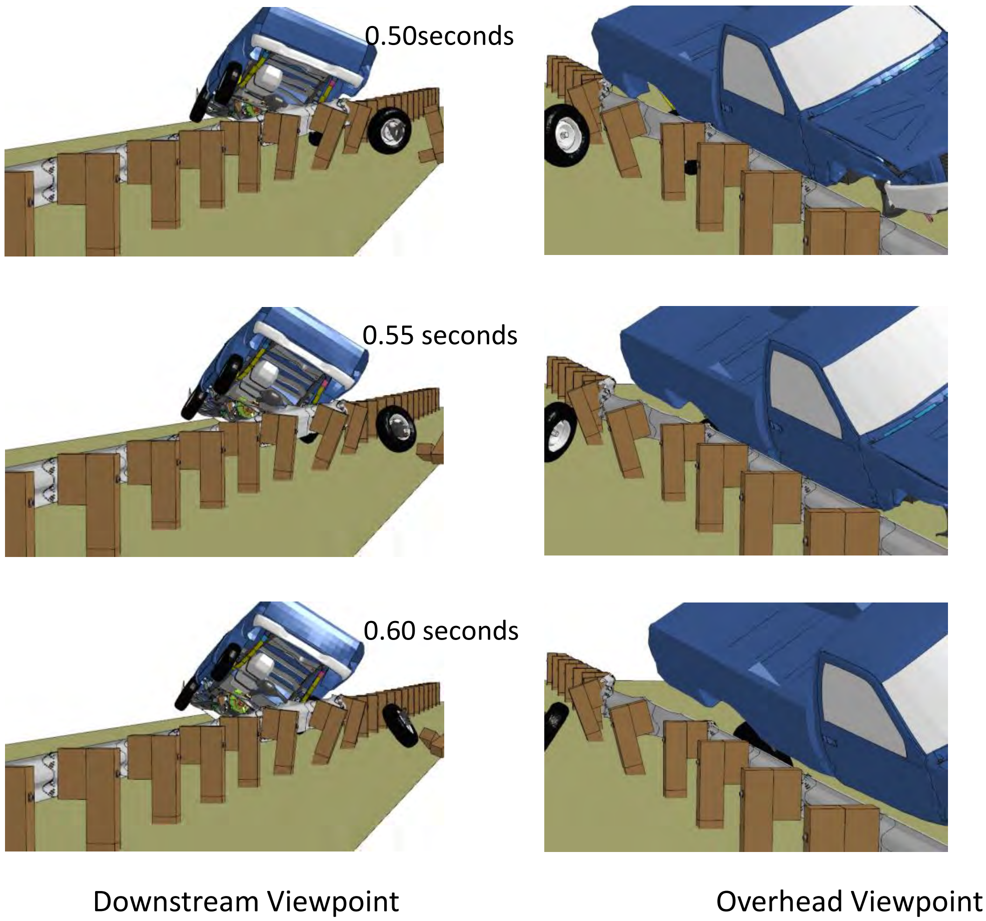


Figure K-2. [CONTINUED] Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: Test 3-11 of 30 mph-Damaged G4(2W) at Impact Point 1.

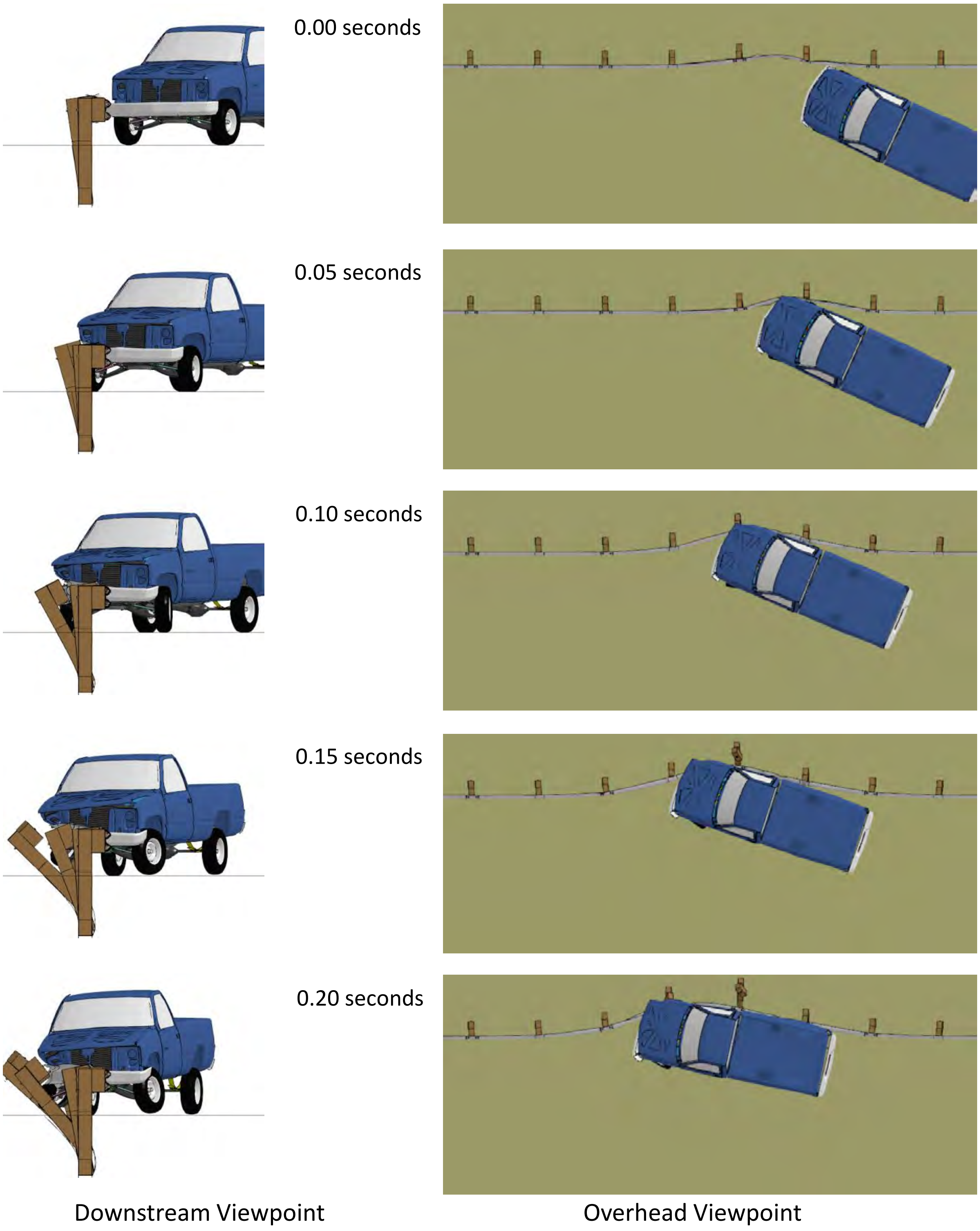


Figure K-3. Sequential views from a downstream and overhead viewpoint for analysis case: Test 3-11 of 30 mph-Damaged G4(2W) at Impact Point 2.

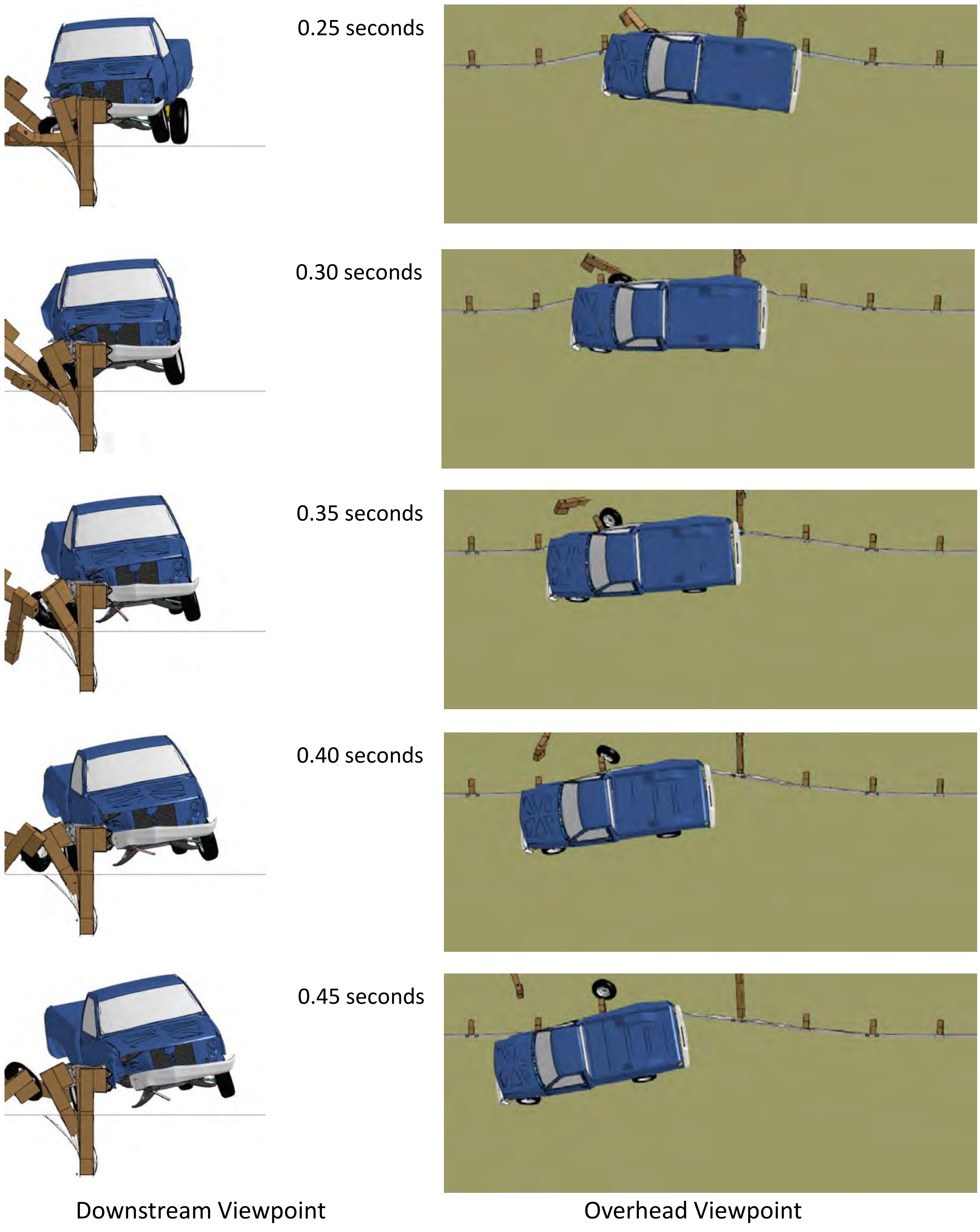


Figure K-3. [CONTINUED] Sequential views from a downstream and overhead viewpoint for analysis case: Test 3-11 of 30 mph-Damaged G4(2W) at Impact Point 2.

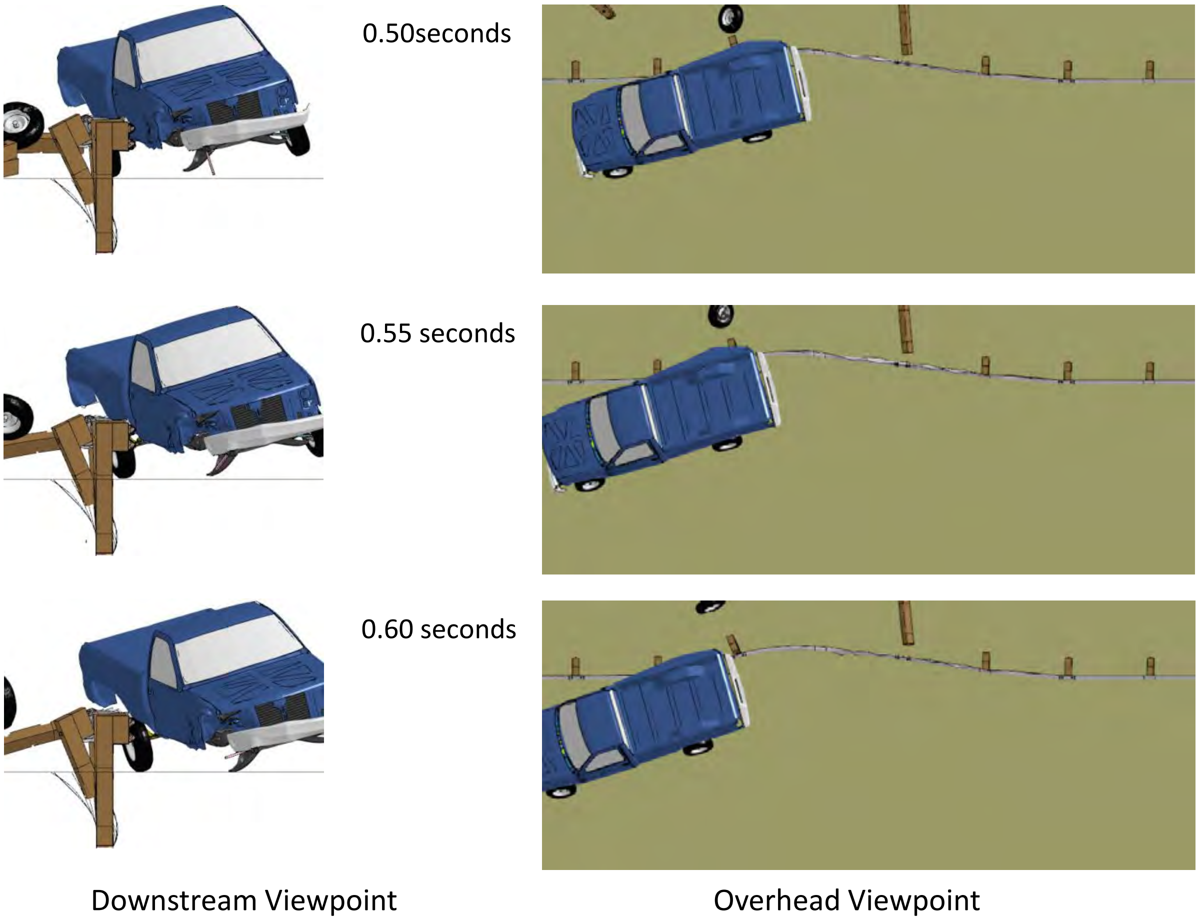


Figure K-3. [CONTINUED] Sequential views from a downstream and overhead viewpoint for analysis case: Test 3-11 of 30 mph-Damaged G4(2W) at Impact Point 2.

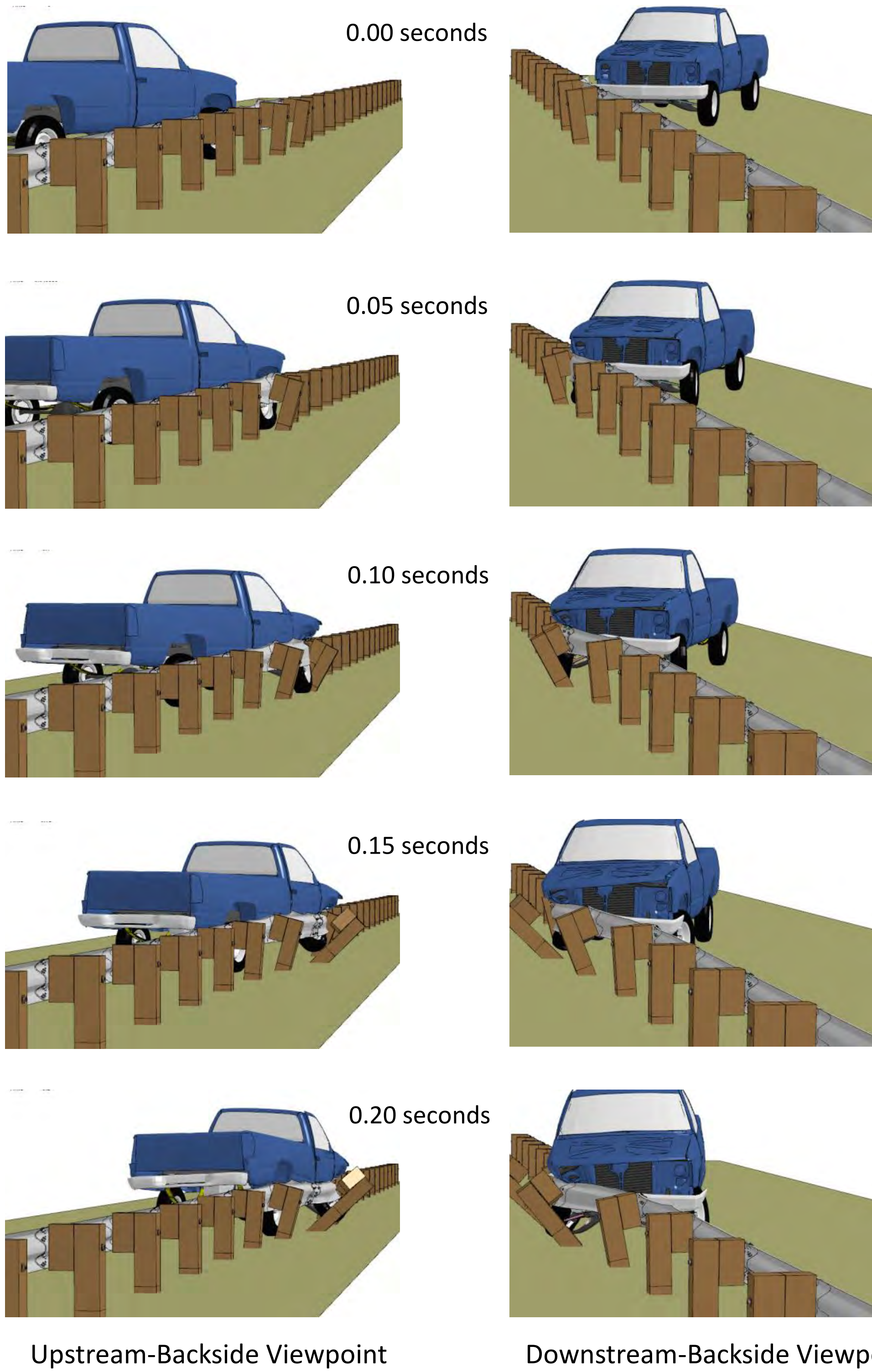


Figure K-4. Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: Test 3-11 of 30 mph-Damaged G4(2W) at Impact Point 2.

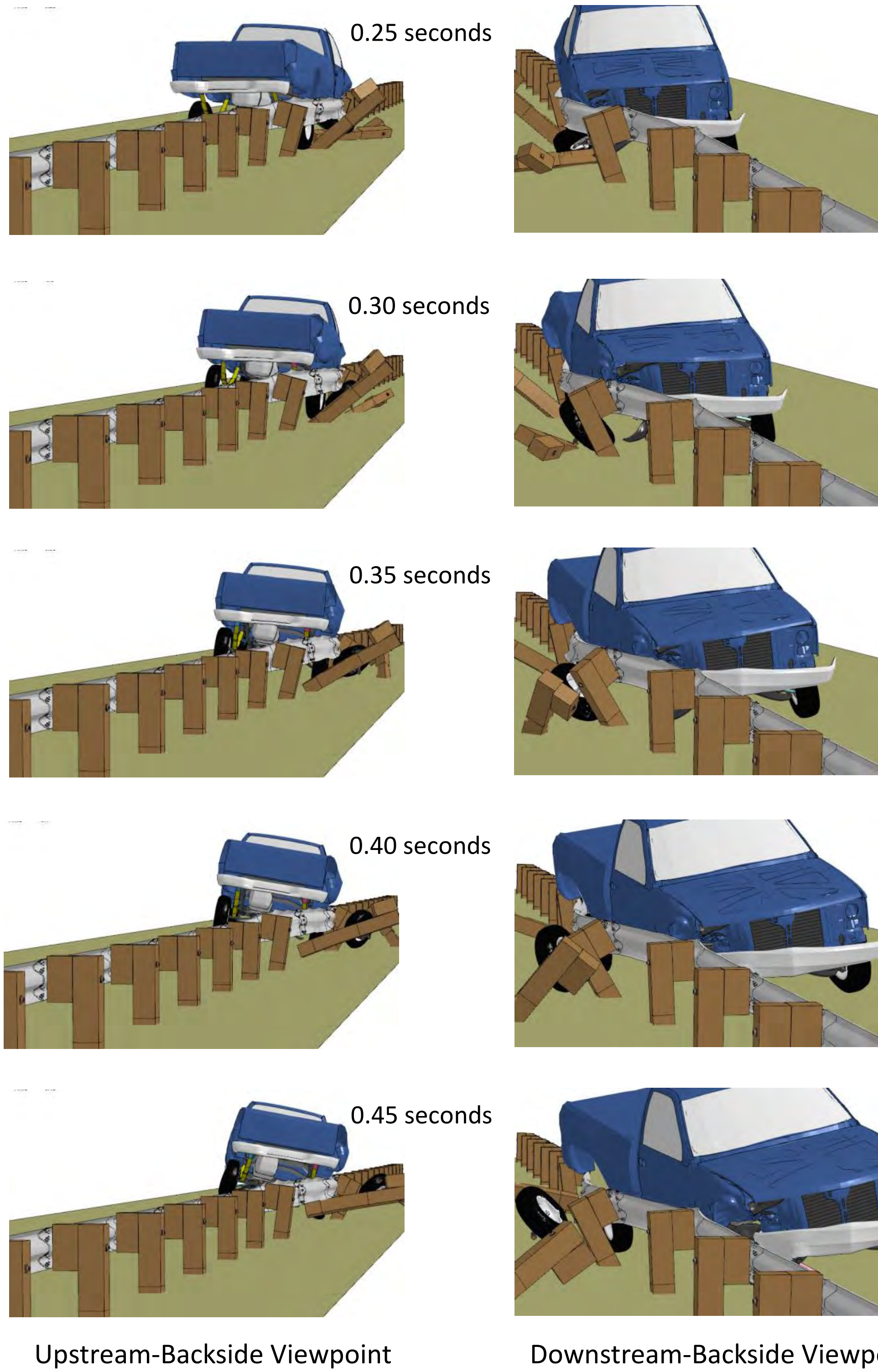


Figure K-4. [CONTINUED] Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: Test 3-11 of 30 mph-Damaged G4(2W) at Impact Point 2.

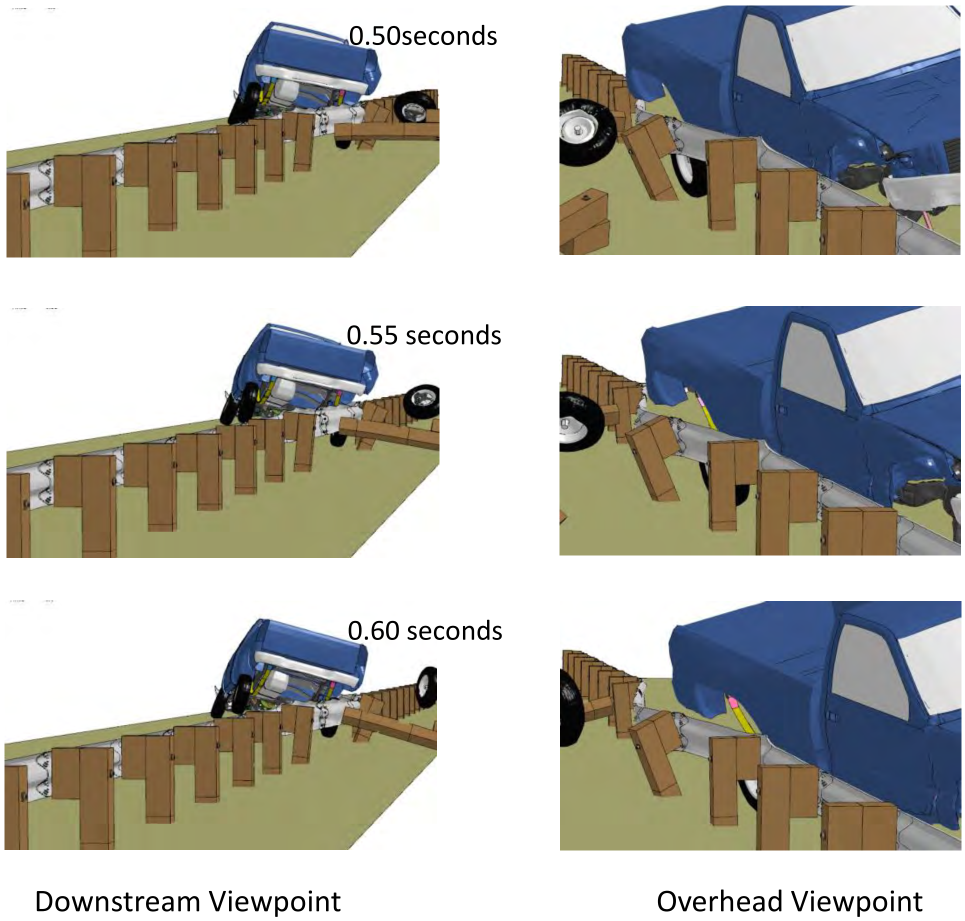


Figure K-4. [CONTINUED] Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: Test 3-11 of 30 mph-Damaged G4(2W) at Impact Point 2.

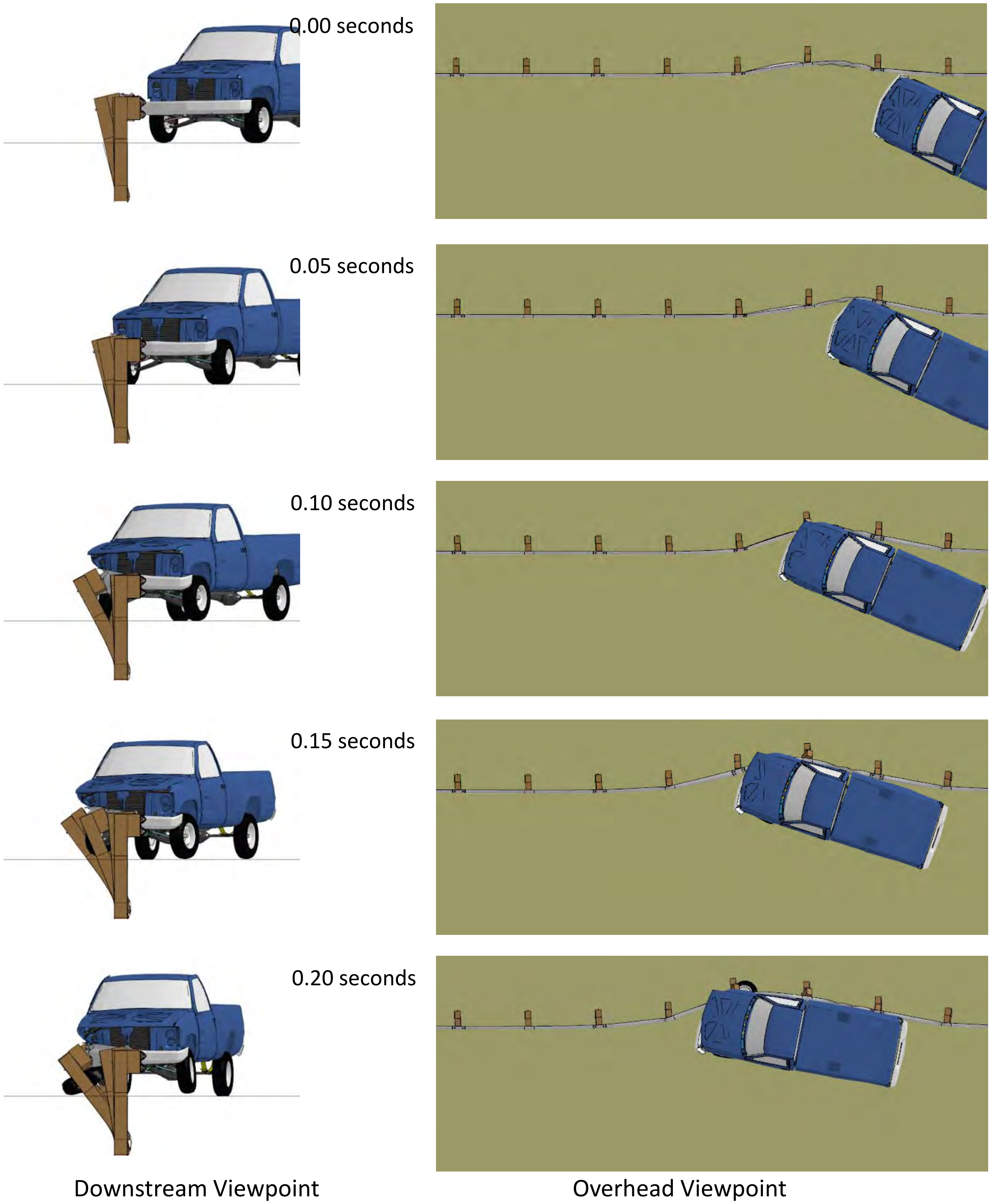
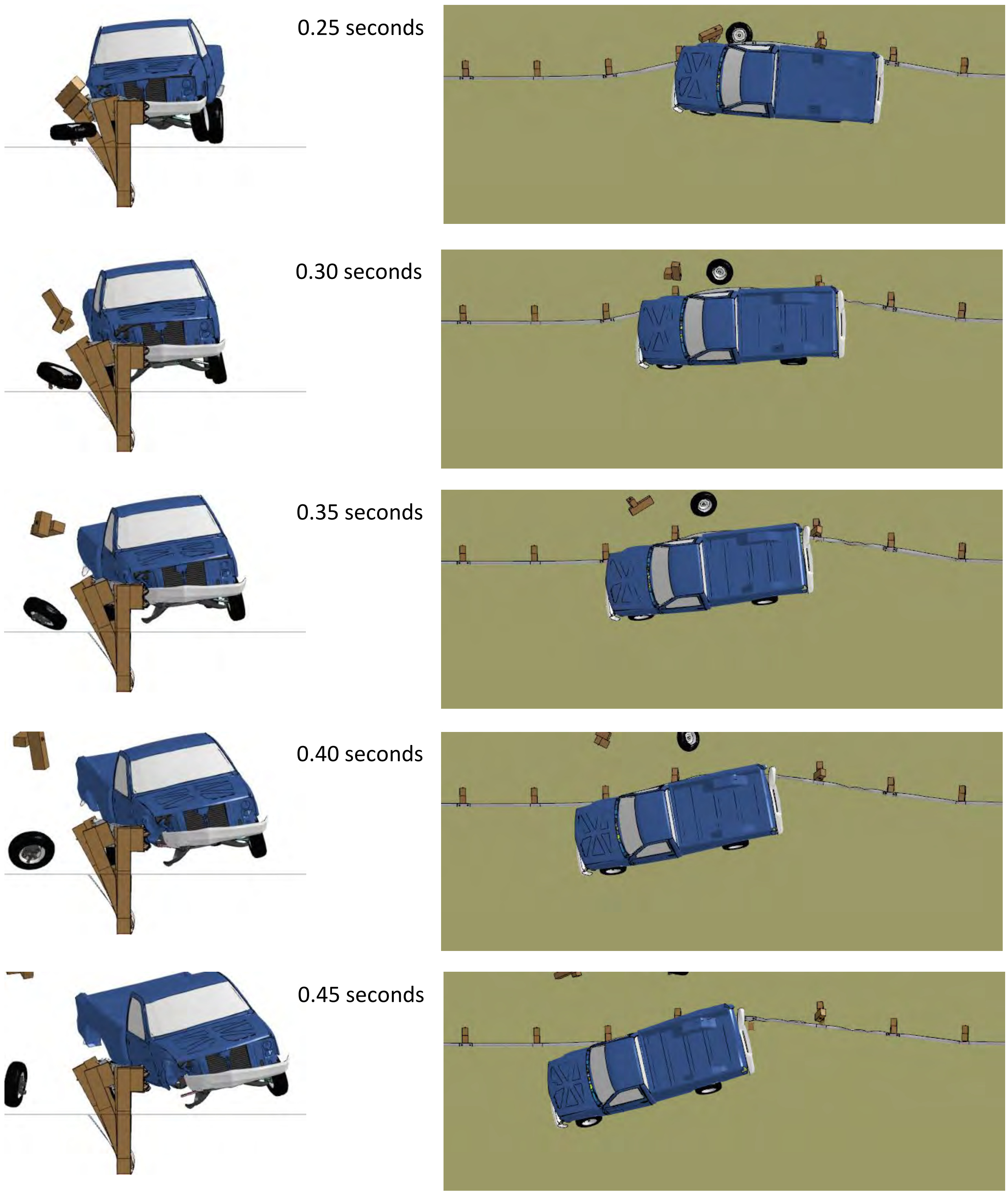


Figure K-5. Sequential views from a downstream and overhead viewpoint for analysis case: Test 3-11 of 35 mph-Damaged G4(2W) at Impact Point 1.



Downstream Viewpoint Overhead Viewpoint

Figure K-5. [CONTINUED] Sequential views from a downstream and overhead viewpoint for analysis case: Test 3-11 of 35 mph-Damaged G4(2W) at Impact Point 1.

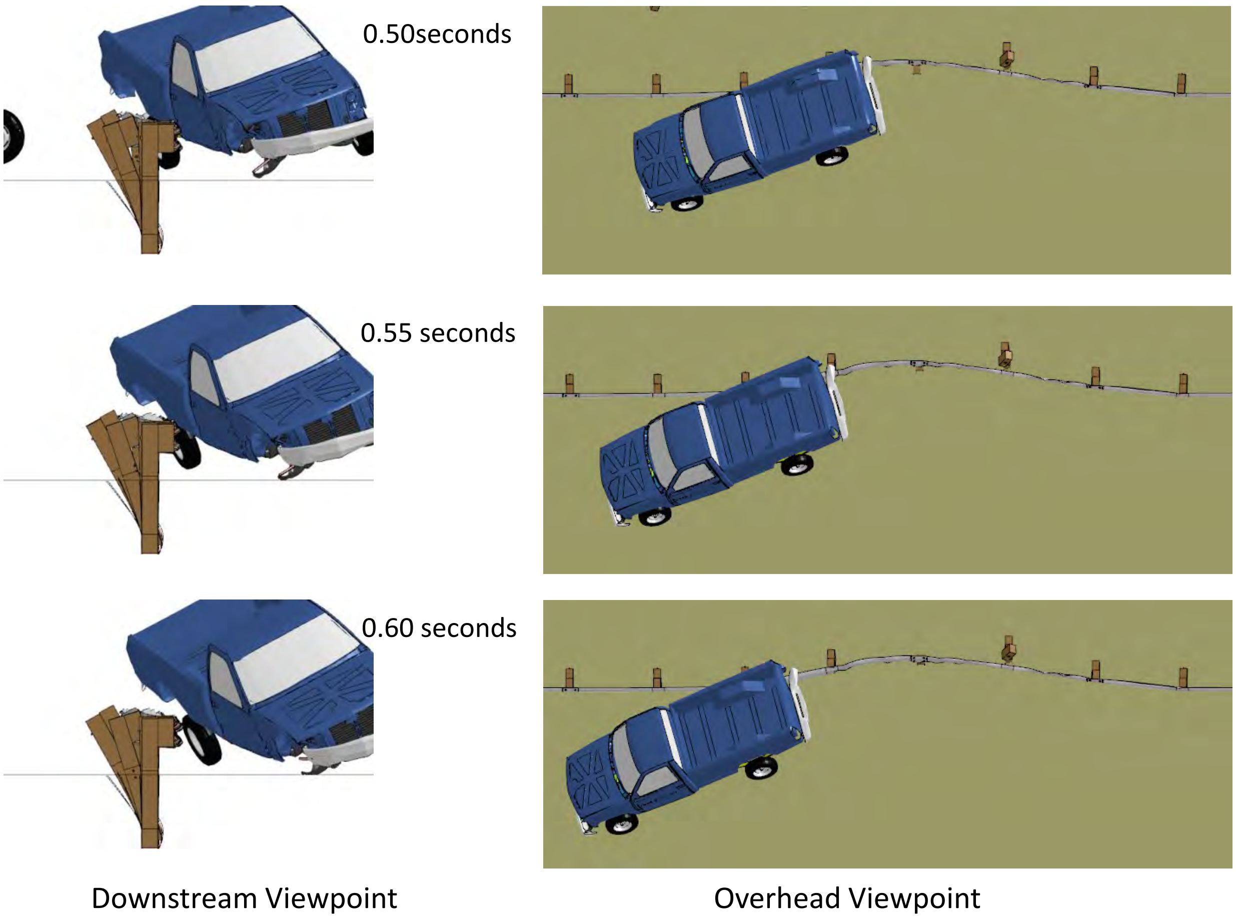


Figure K-5. [CONTINUED] Sequential views from a downstream and overhead viewpoint for analysis case: Test 3-11 of 35 mph-Damaged G4(2W) at Impact Point 1.

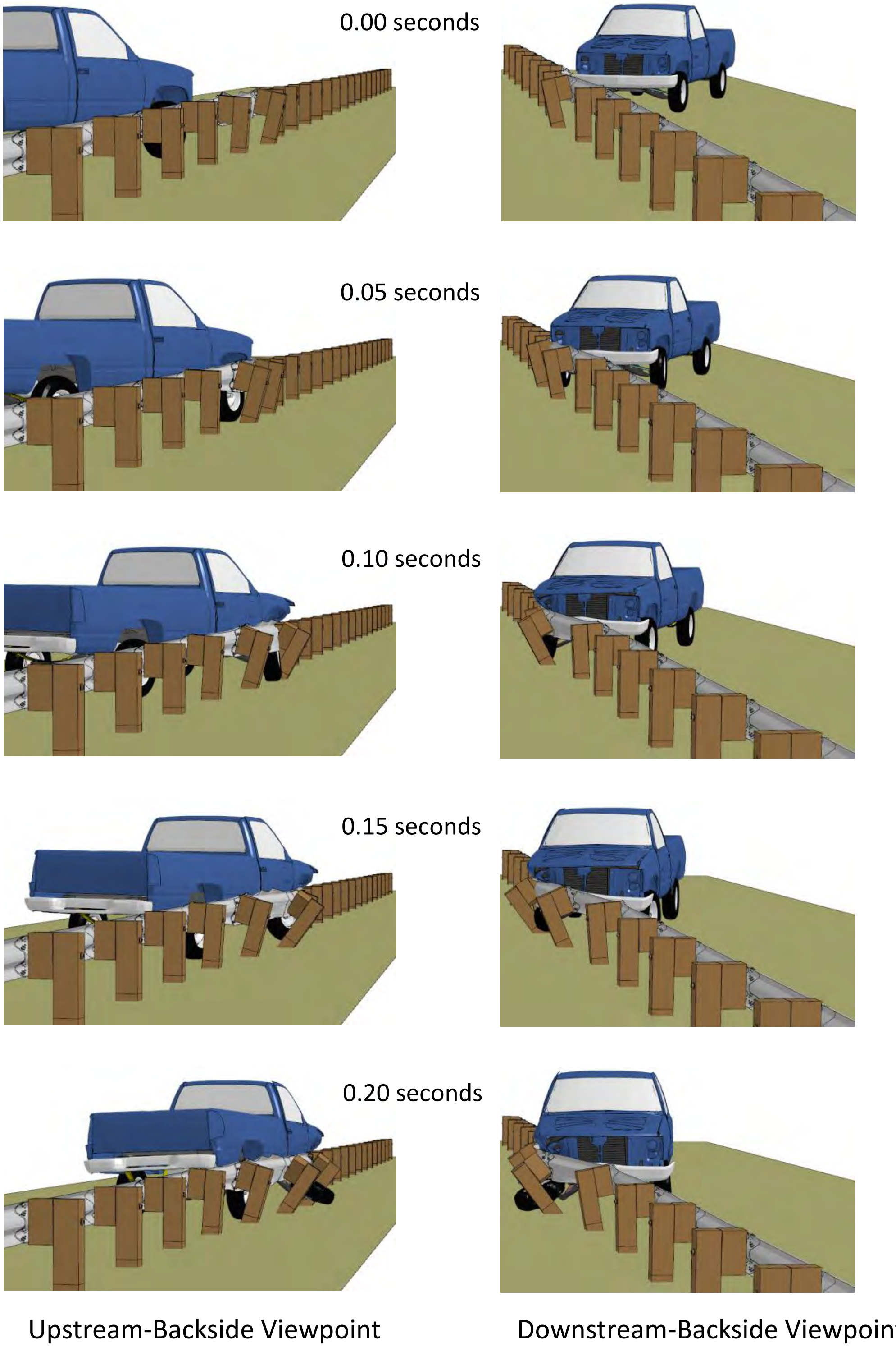


Figure K-6. Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: Test 3-11 of 35 mph-Damaged G4(2W) at Impact Point 1.

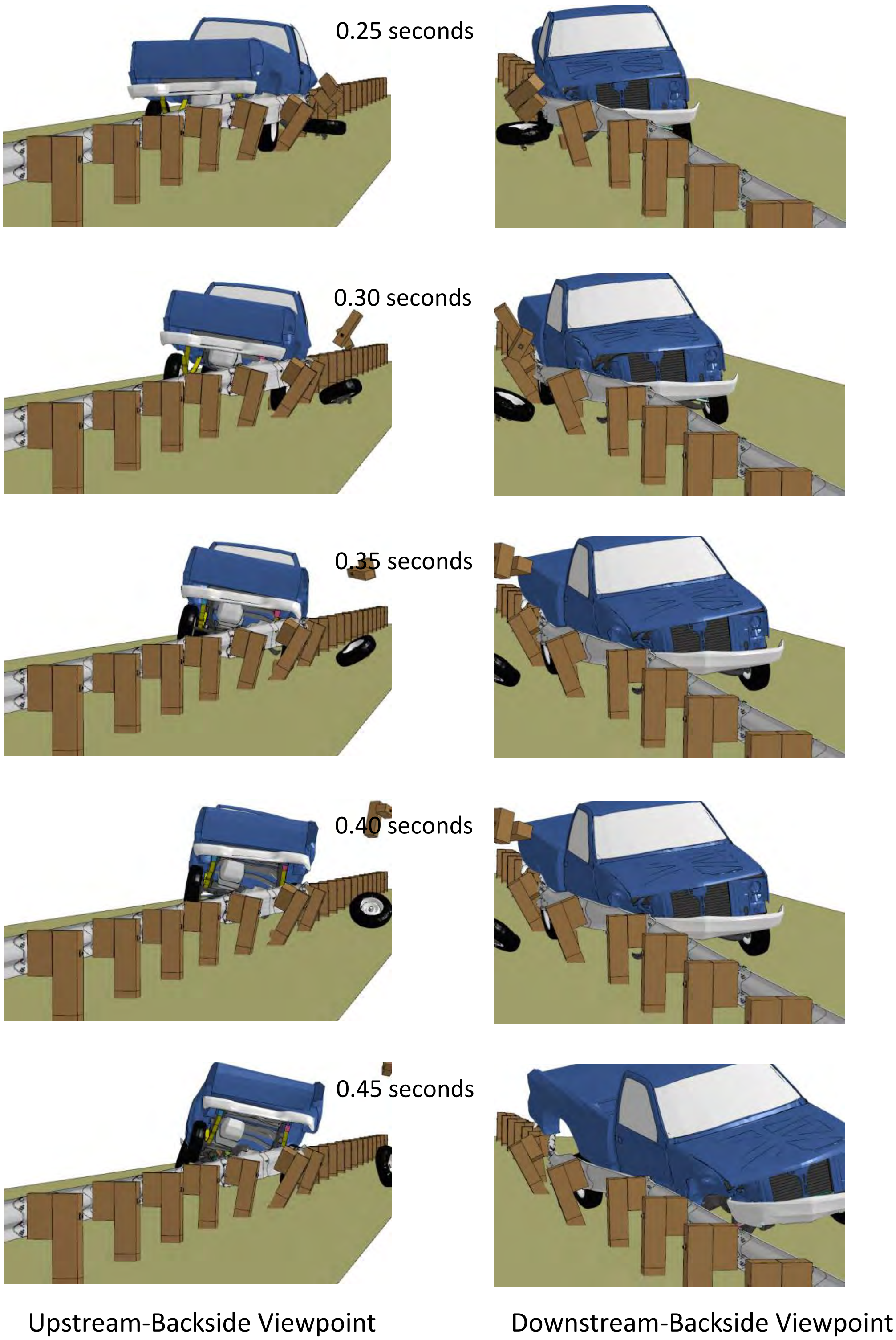


Figure K-6. [CONTINUED] Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: Test 3-11 of 35 mph-Damaged G4(2W) at Impact Point 1.

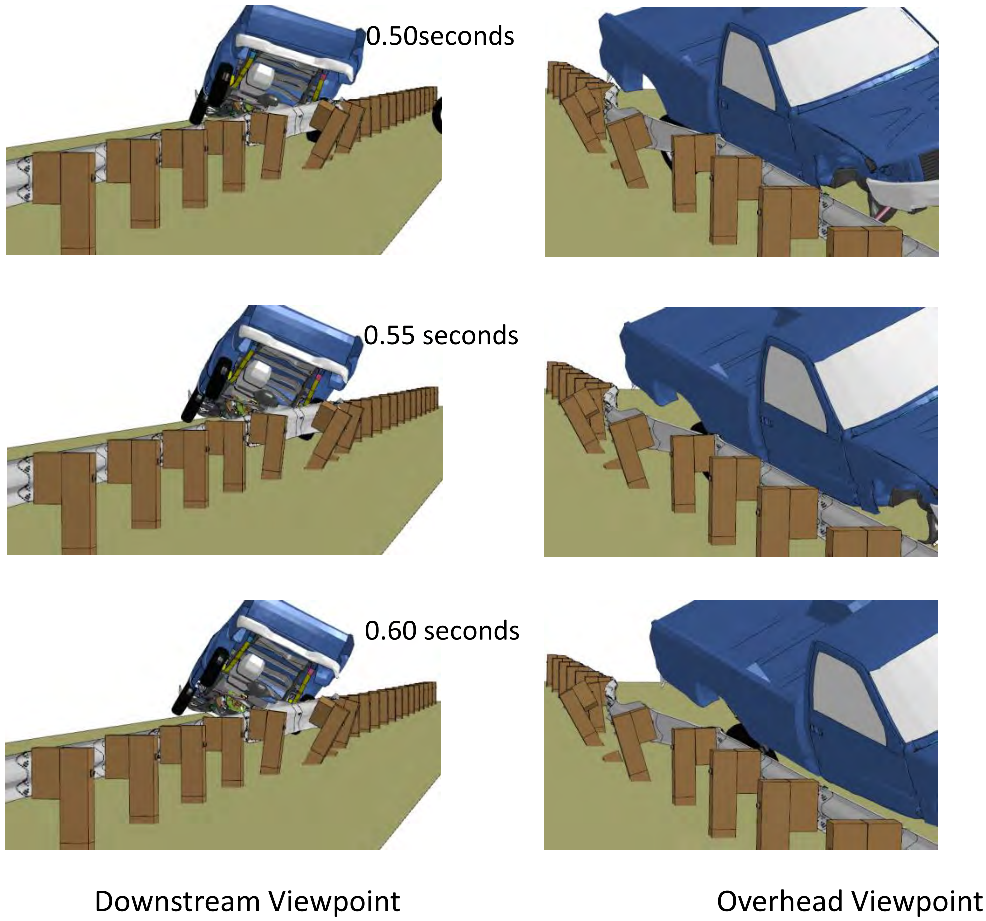


Figure K-6. [CONTINUED] Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: Test 3-11 of 35 mph-Damaged G4(2W) at Impact Point 1.

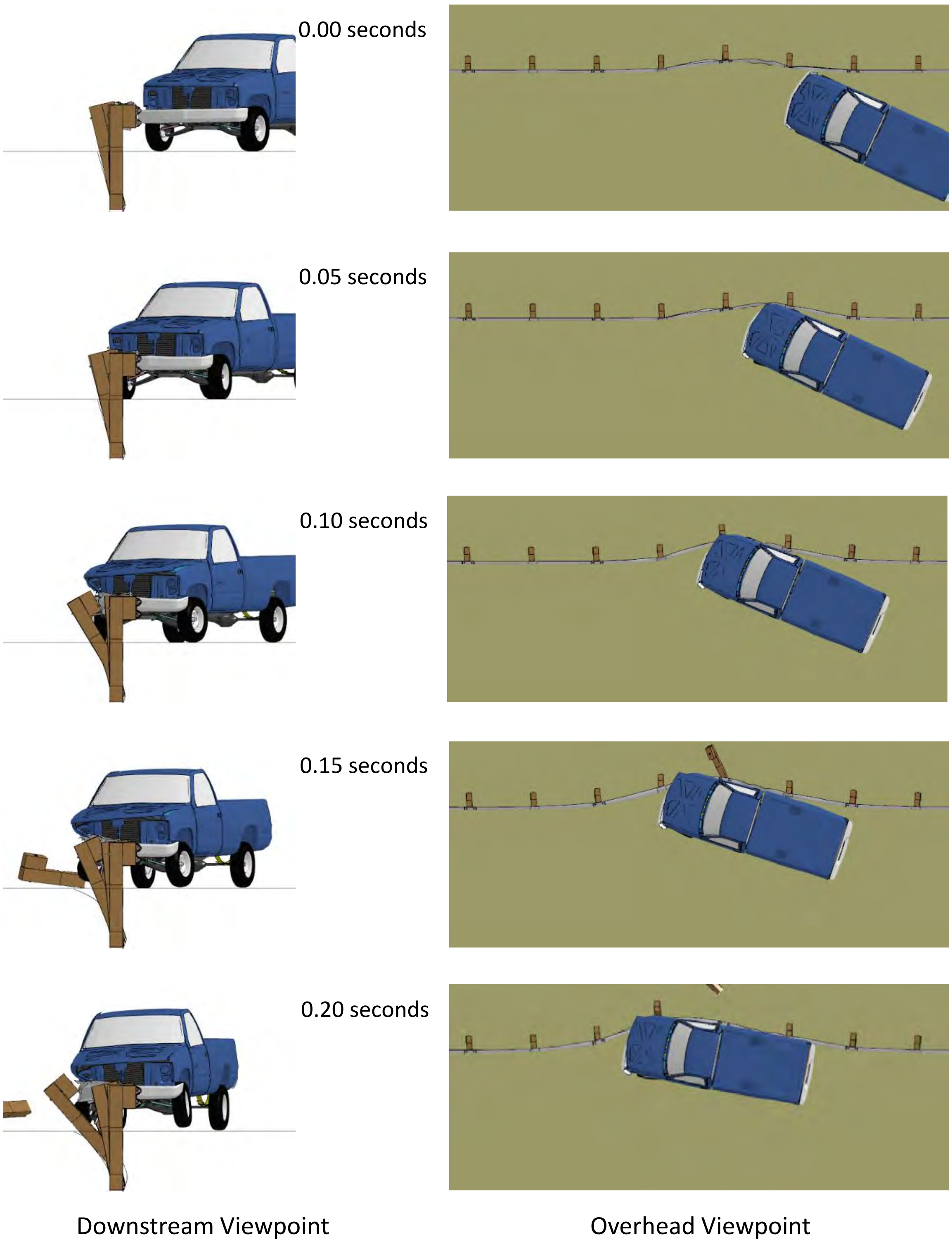


Figure K-7. Sequential views from a downstream and overhead viewpoint for analysis case: Test 3-11 of 35 mph-Damaged G4(2W) at Impact Point 2.

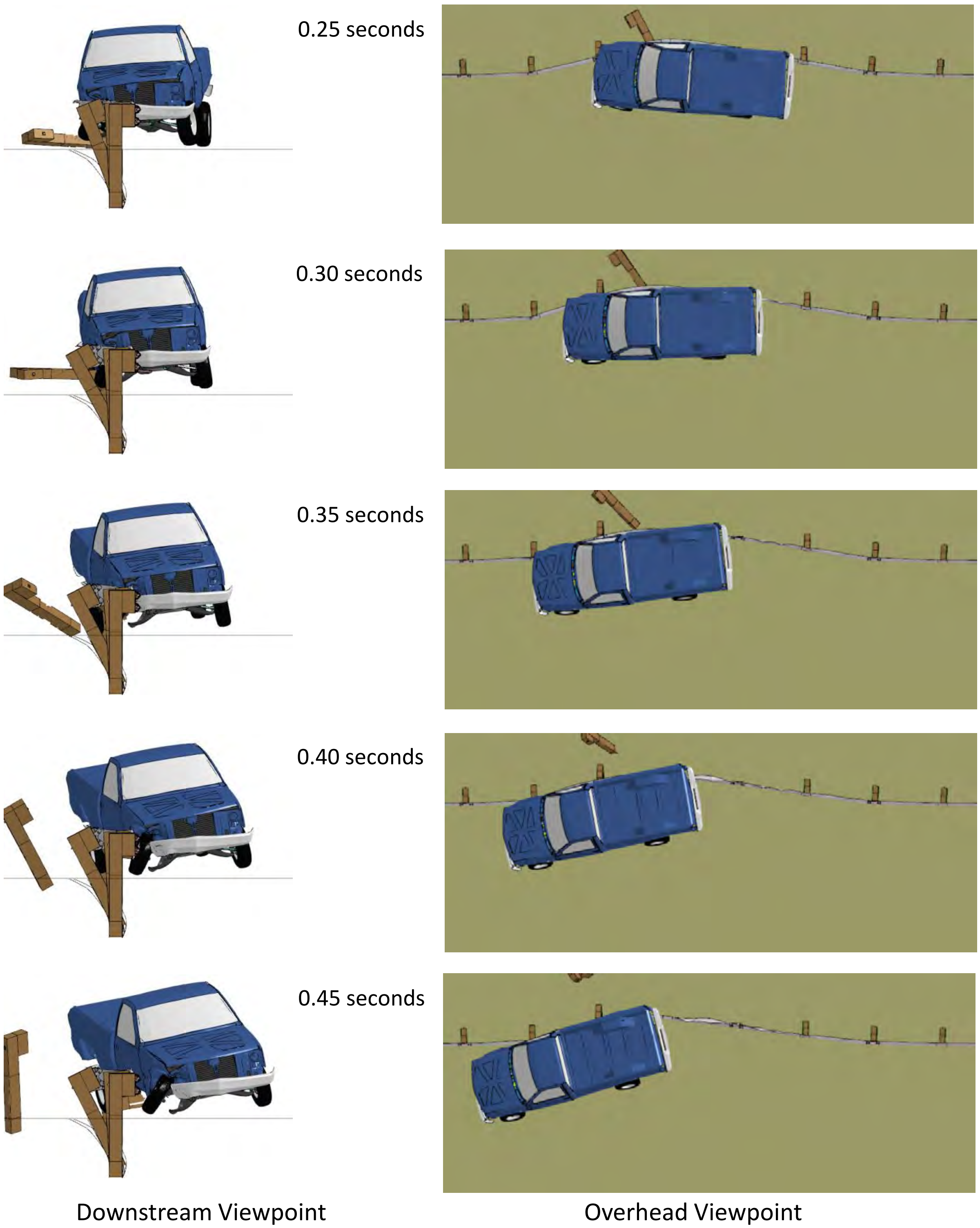


Figure K-7. [CONTINUED] Sequential views from a downstream and overhead viewpoint for analysis case: Test 3-11 of 35 mph-Damaged G4(2W) at Impact Point 2.

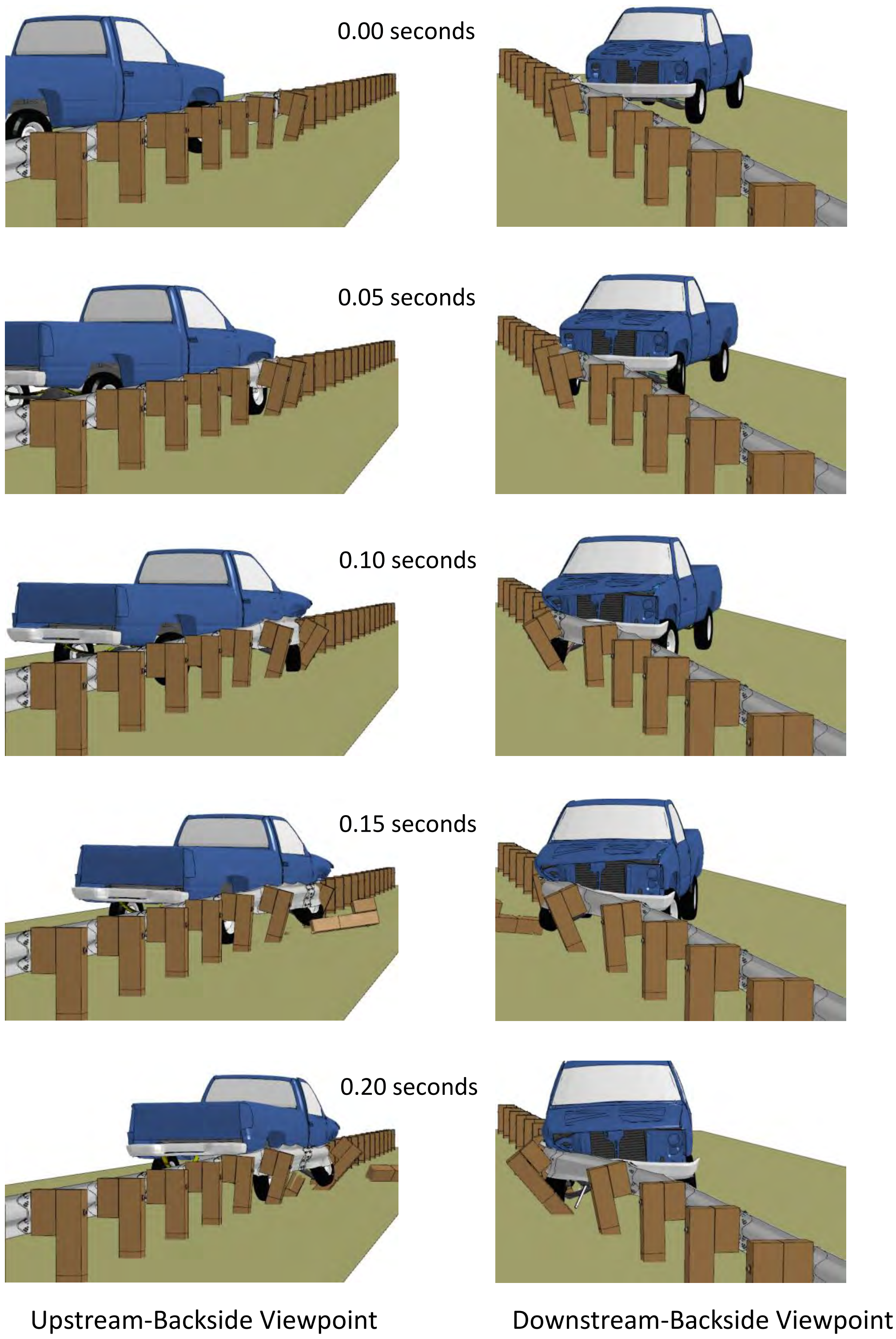


Figure K-8. Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: Test 3-11 of 35 mph-Damaged G4(2W) at Impact Point 2.

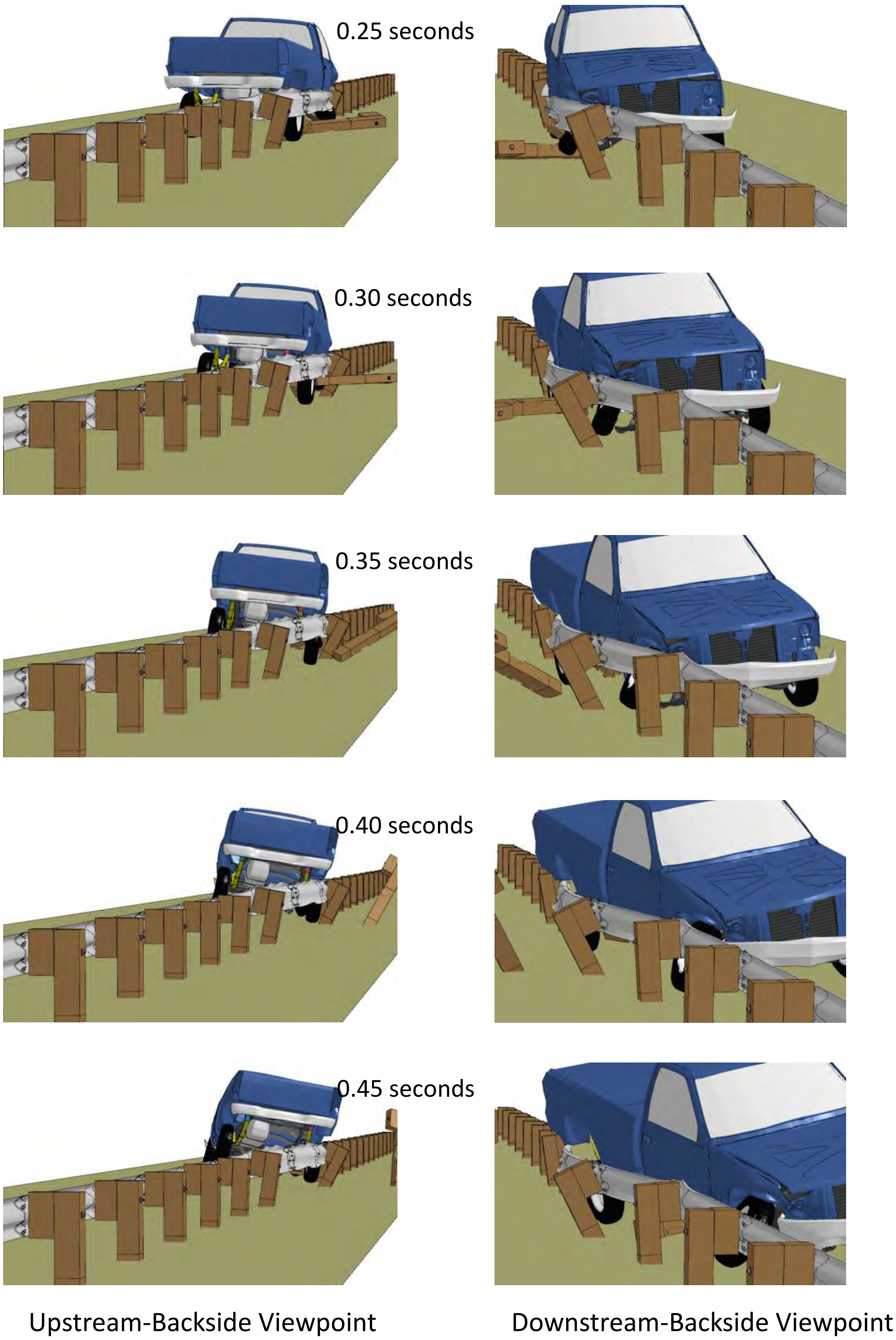


Figure K-8. [CONTINUED] Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: Test 3-11 of 35 mph-Damaged G4(2W) at Impact Point 2.

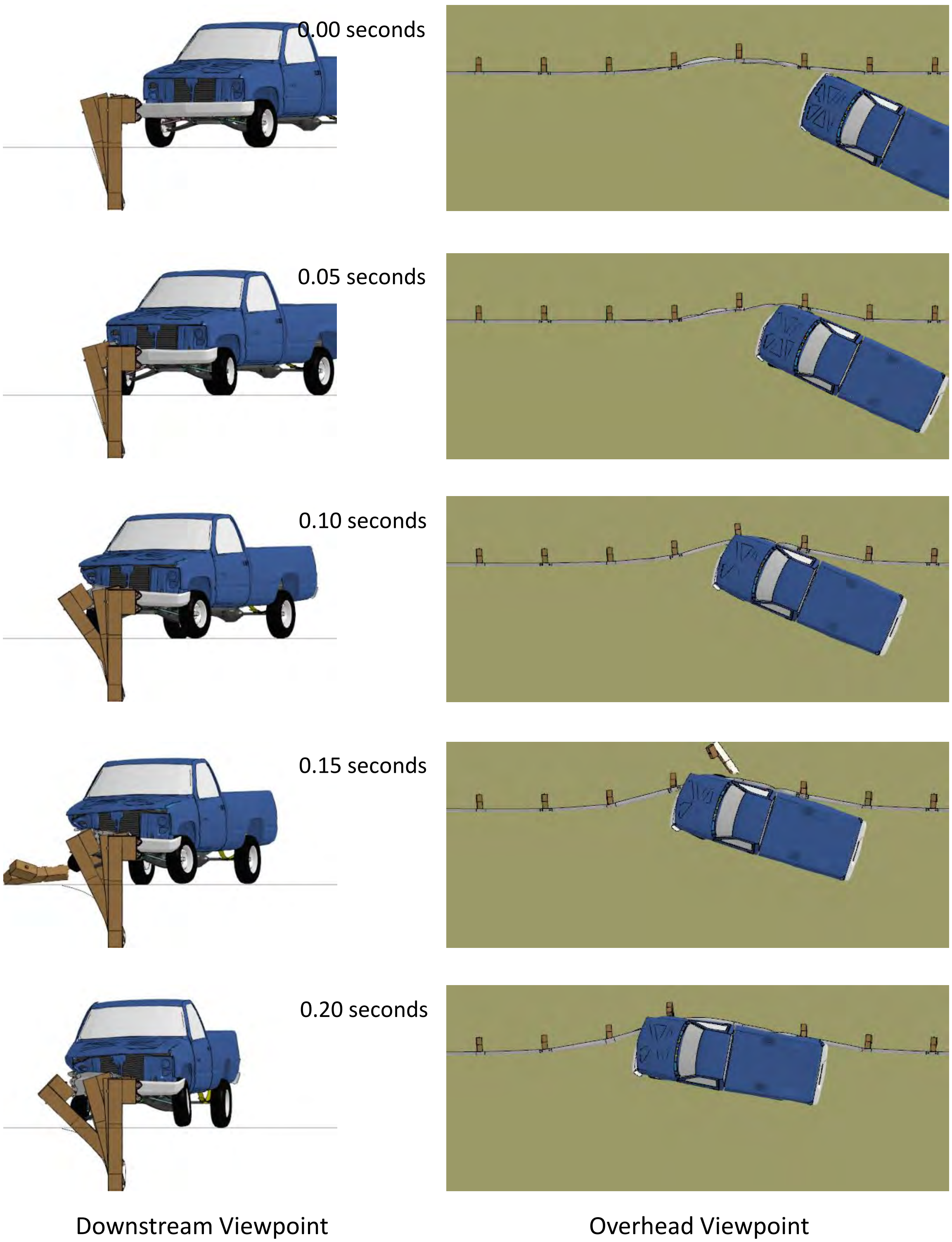


Figure K-9. Sequential views from a downstream and overhead viewpoint for analysis case: Test 3-11 of 40 mph-Damaged G4(2W) at Impact Point 1.

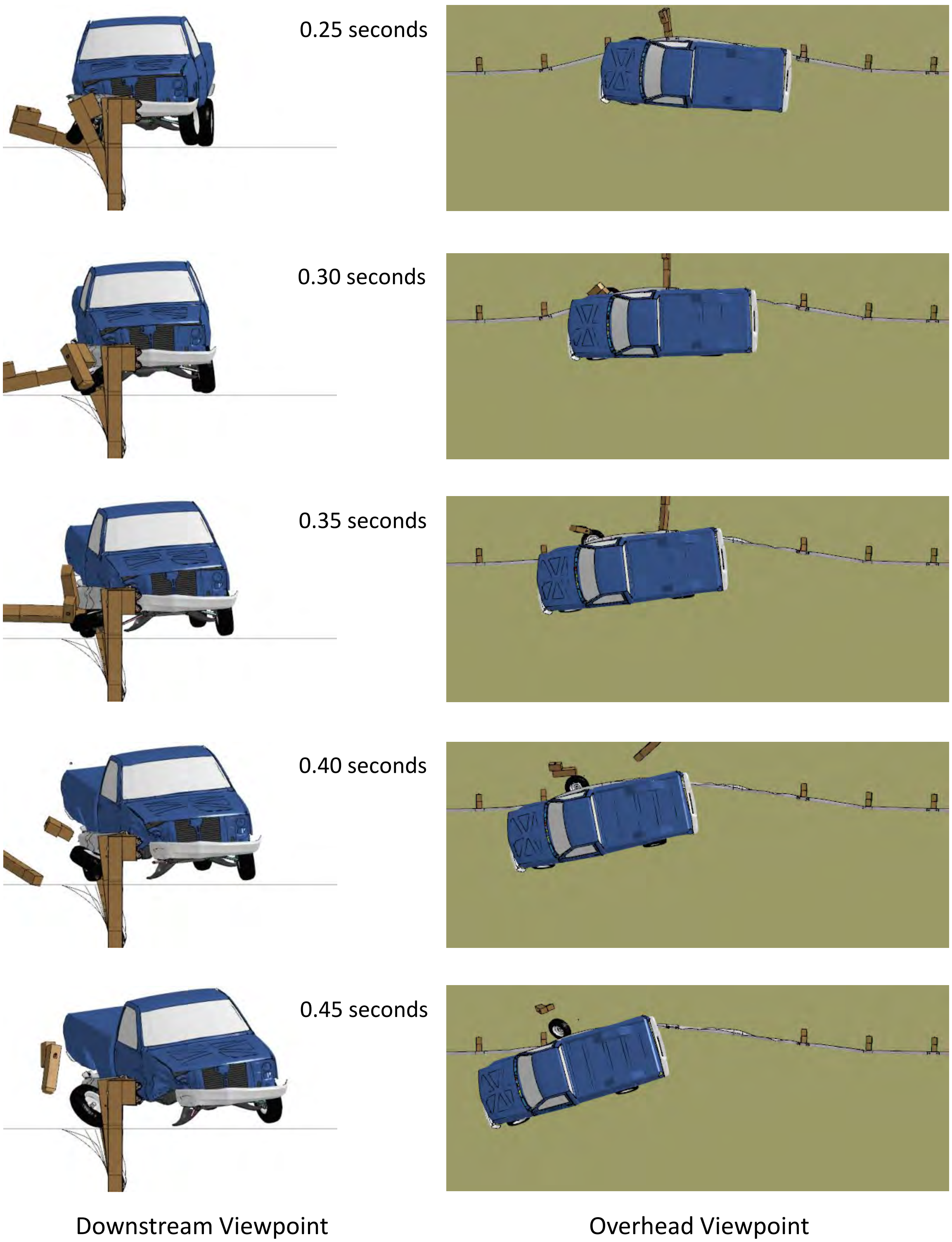


Figure K-9. [CONTINUED] Sequential views from a downstream and overhead viewpoint for analysis case: Test 3-11 of 40 mph-Damaged G4(2W) at Impact Point 1.

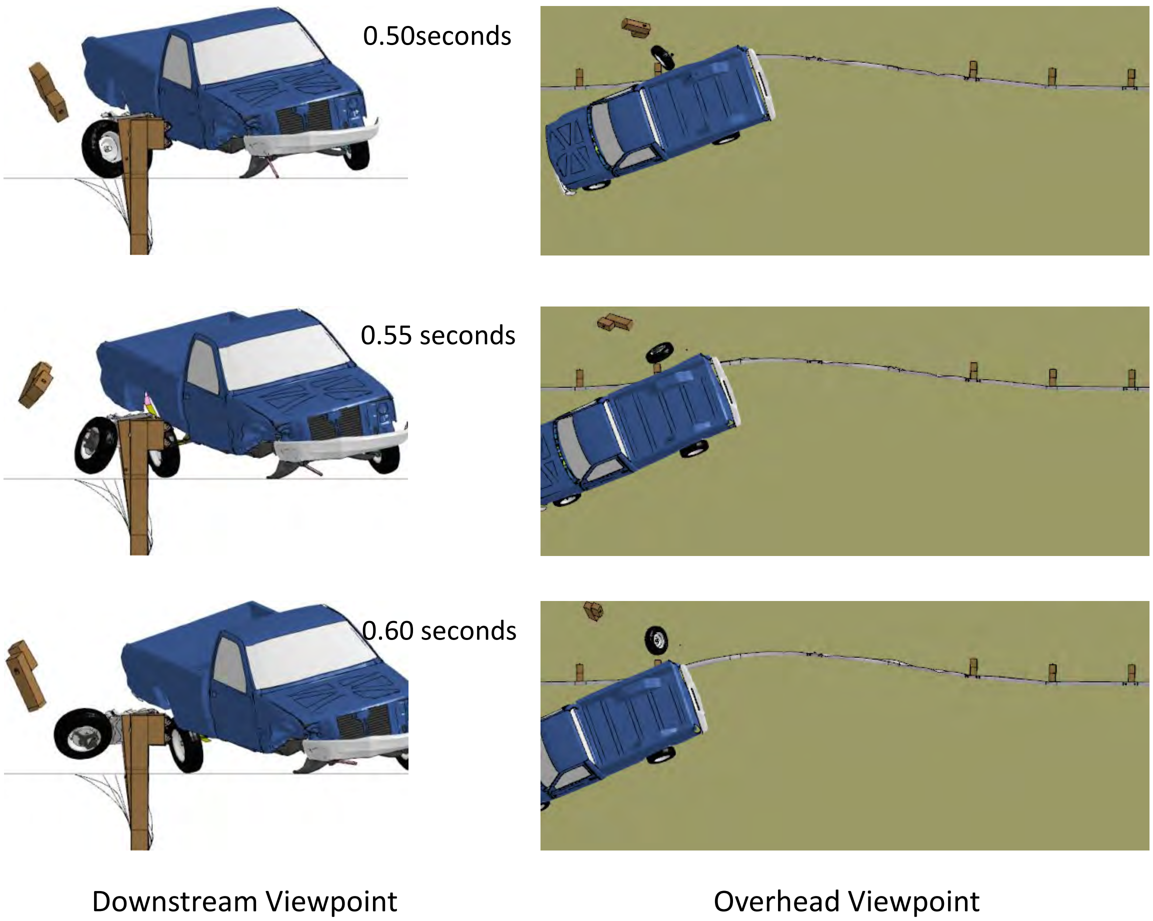


Figure K-9. [CONTINUED] Sequential views from a downstream and overhead viewpoint for analysis case: Test 3-11 of 40 mph-Damaged G4(2W) at Impact Point 1.

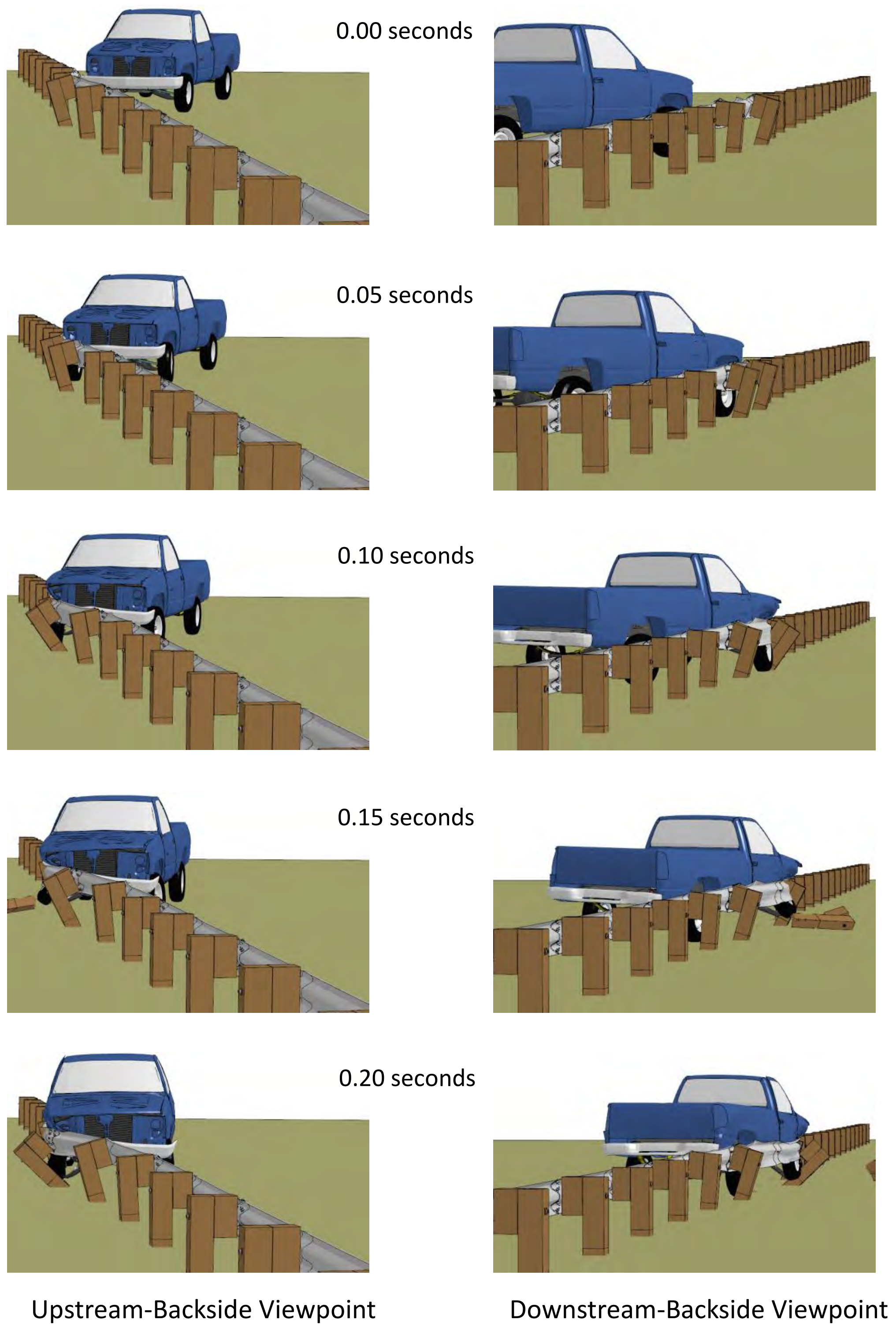


Figure K-10. **Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: Test 3-11 of 40 mph-Damaged G4(2W) at Impact Point 1.**

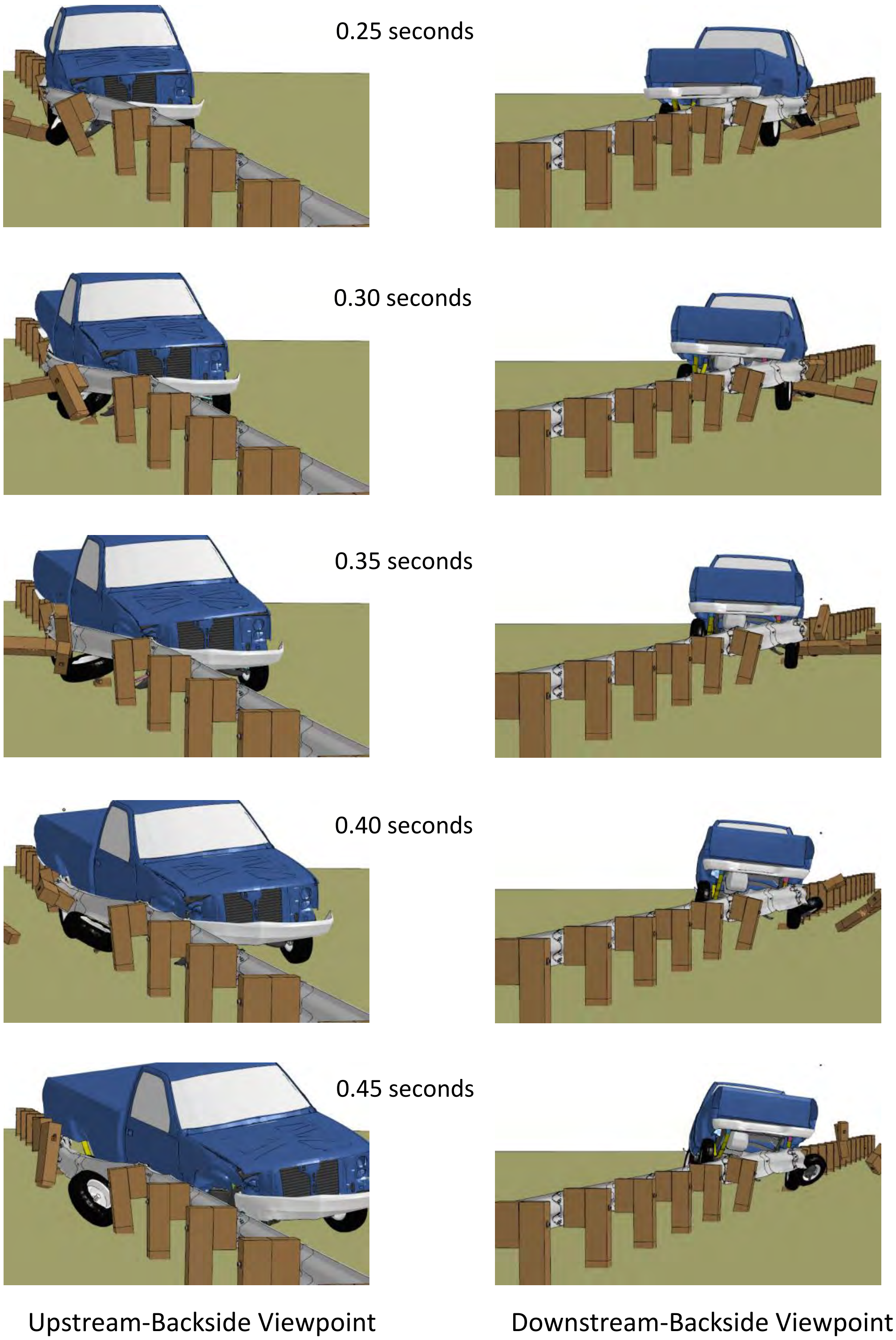


Figure K-10. [CONTINUED] Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: Test 3-11 of 40 mph-Damaged G4(2W) at Impact Point 1.

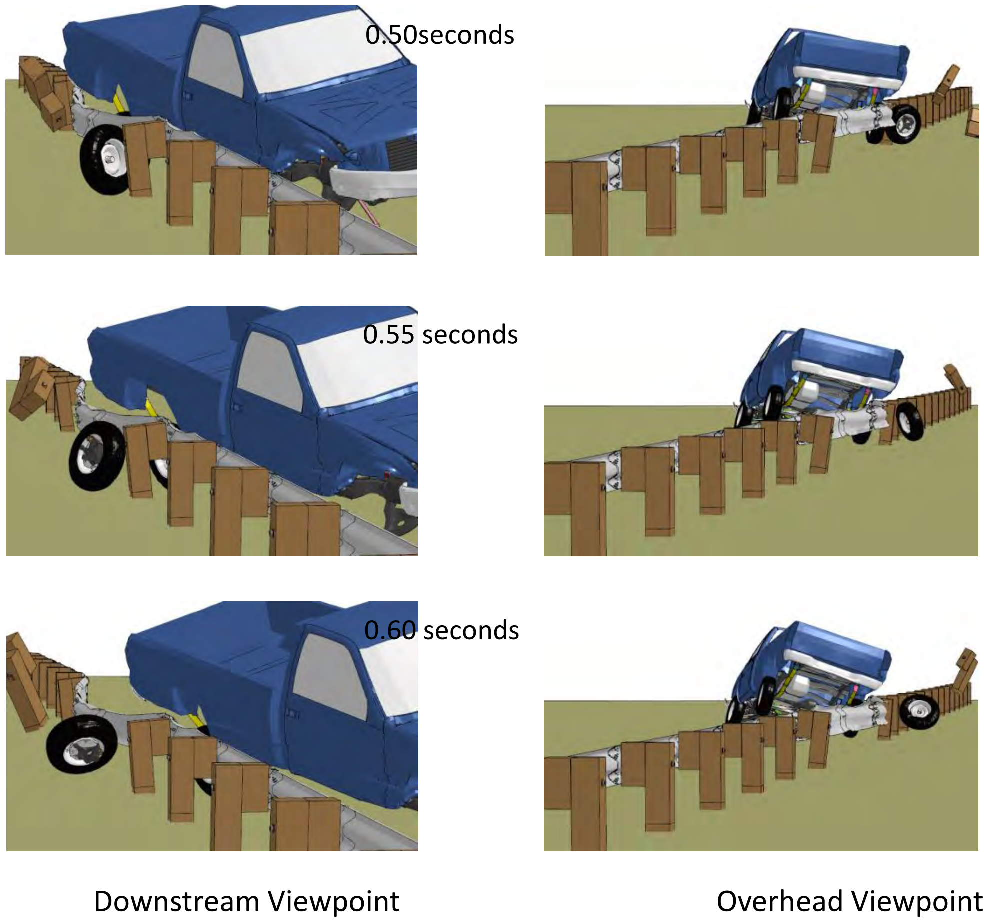


Figure K-10. [CONTINUED] Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: Test 3-11 of 40 mph-Damaged G4(2W) at Impact Point 1.

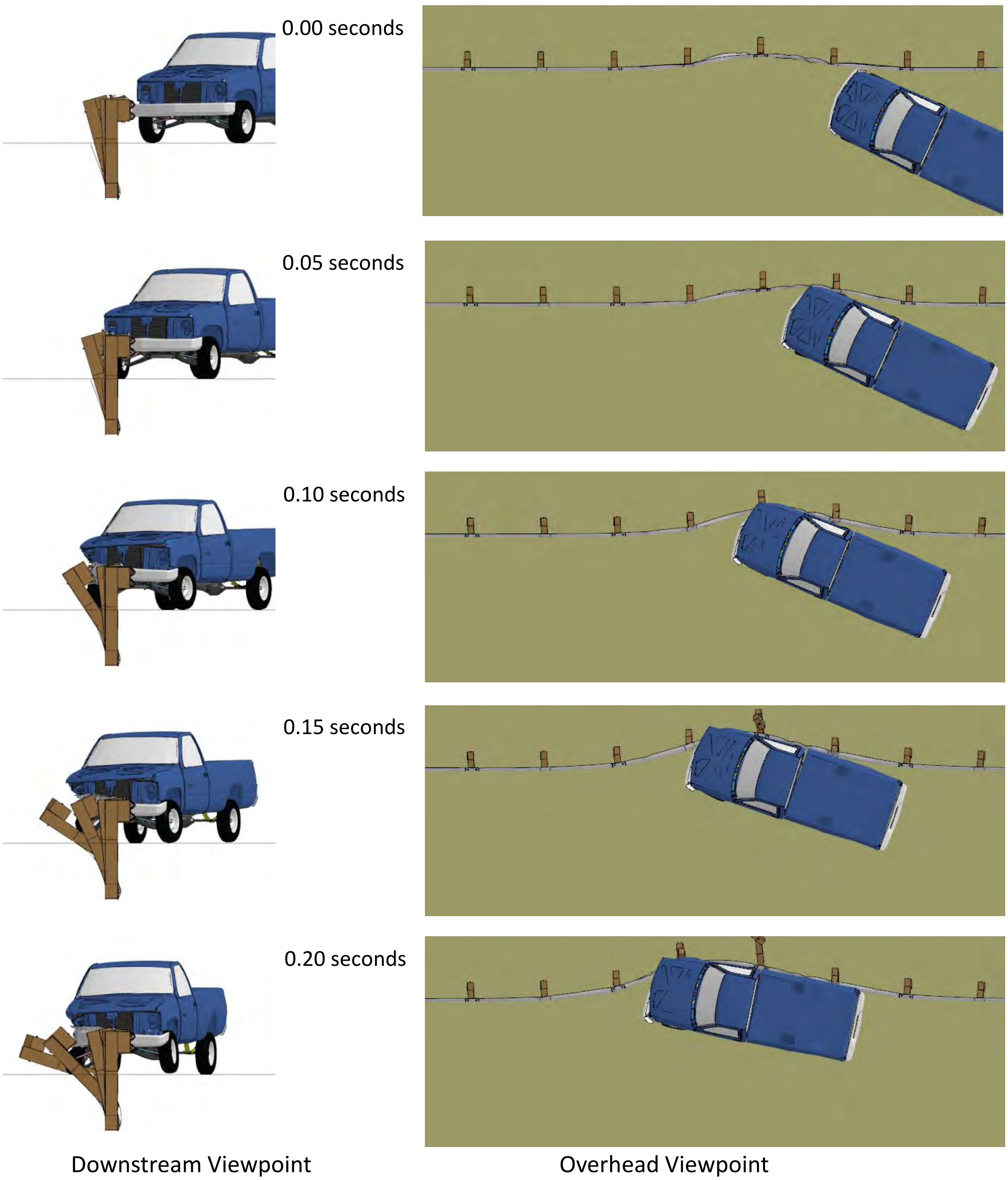


Figure K-11. Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: Test 3-11 of 40 mph-Damaged G4(2W) at Impact Point 2.

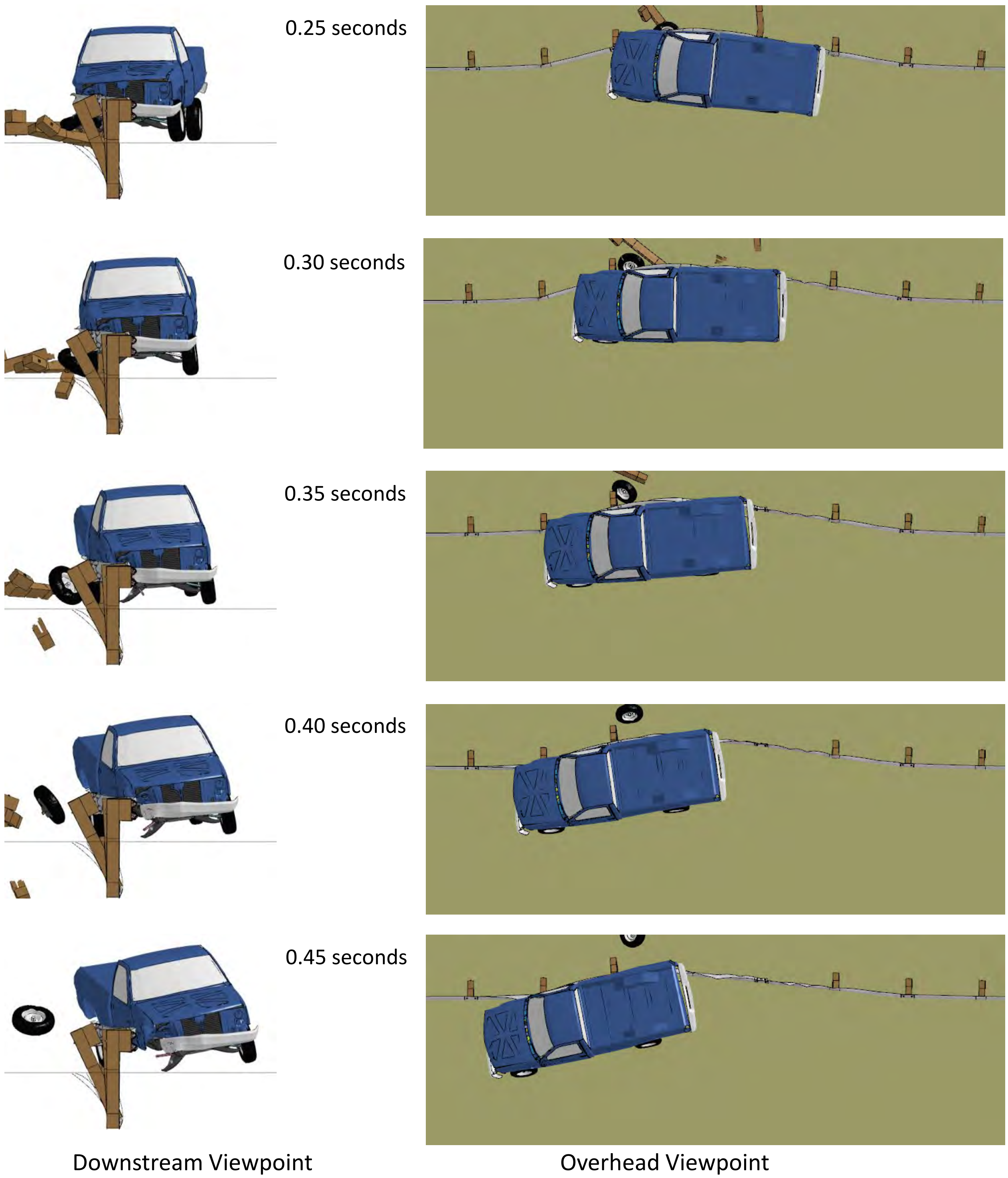


Figure K-11. **[CONTINUED] Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: Test 3-11 of 40 mph-Damaged G4(2W) at Impact Point 2.**

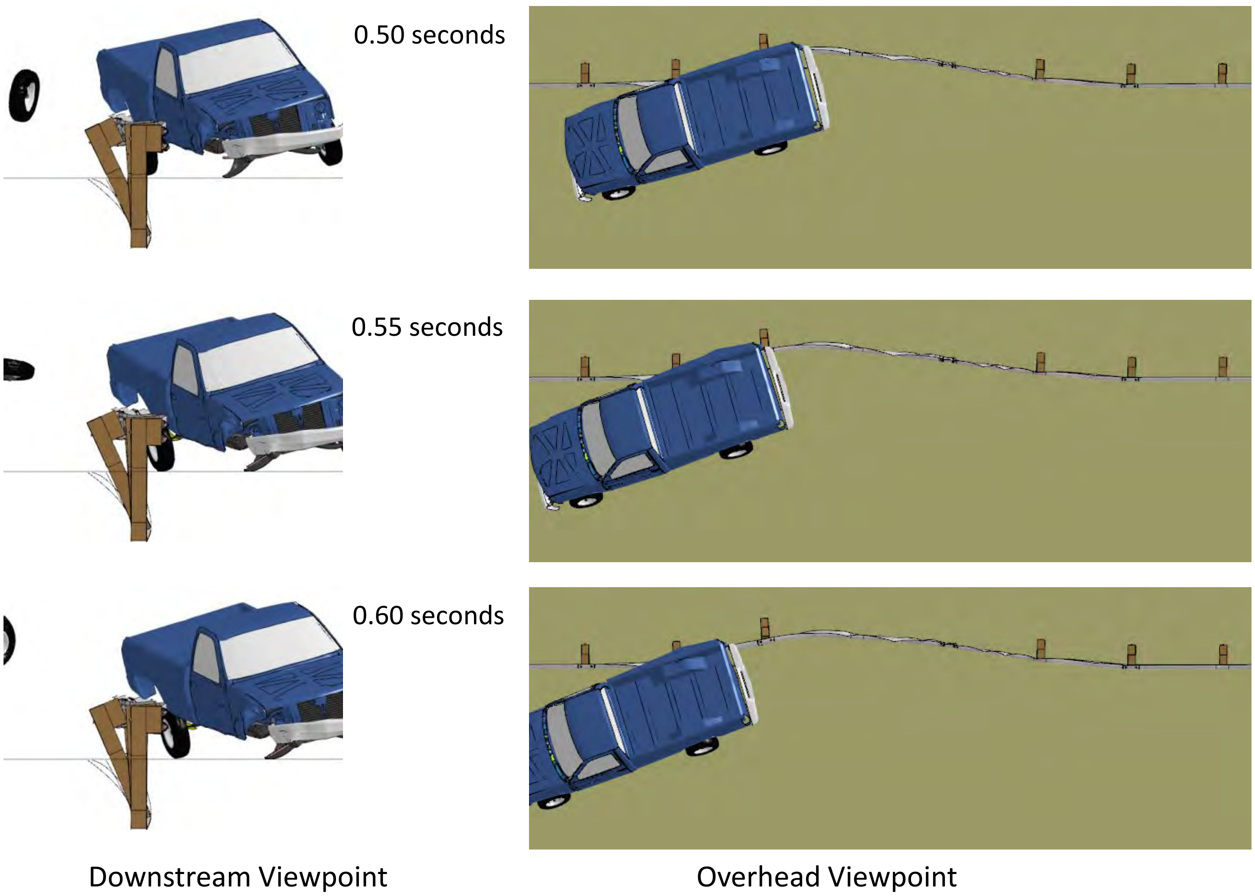


Figure K-11. **[CONTINUED] Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: Test 3-11 of 40 mph-Damaged G4(2W) at Impact Point 2.**

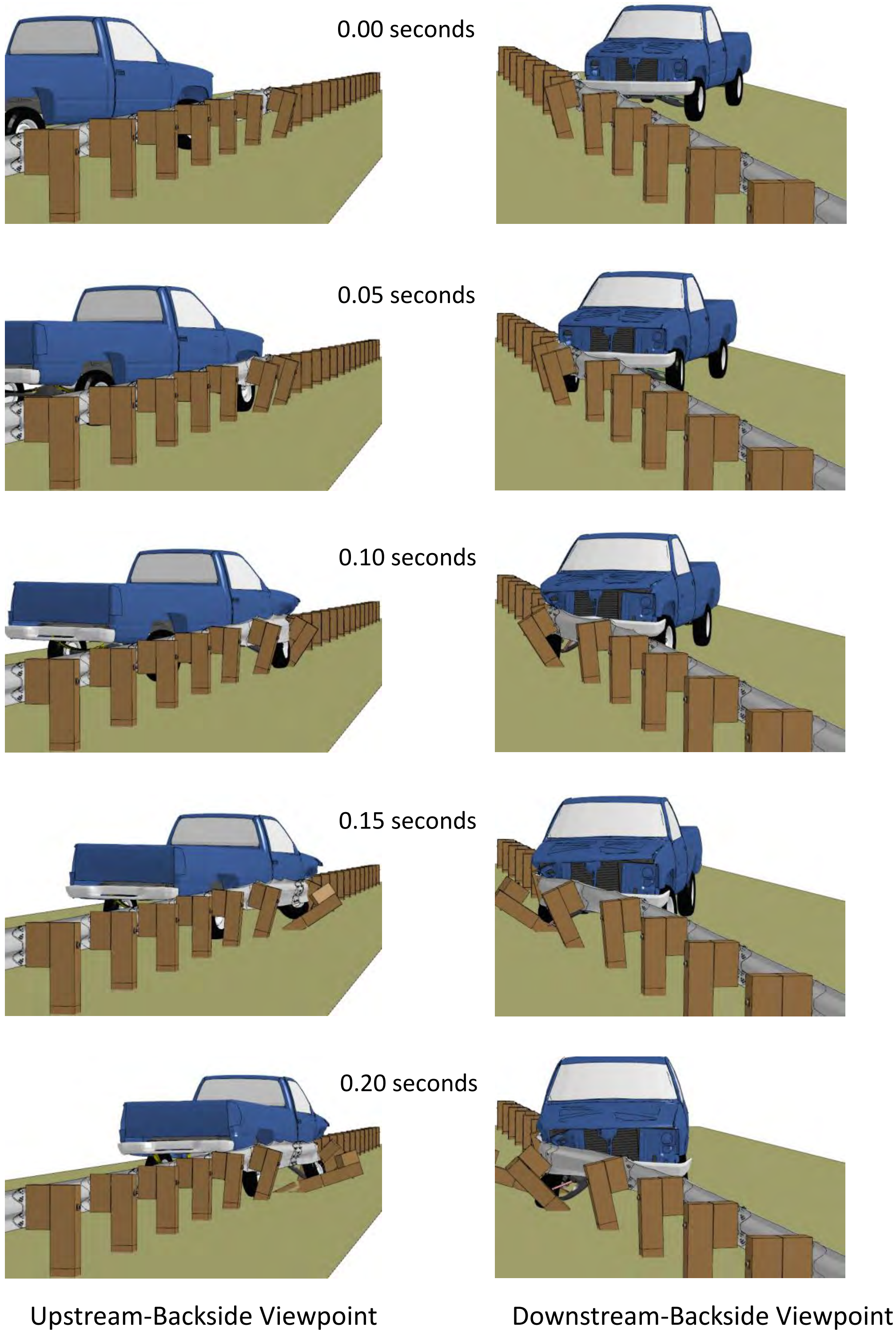
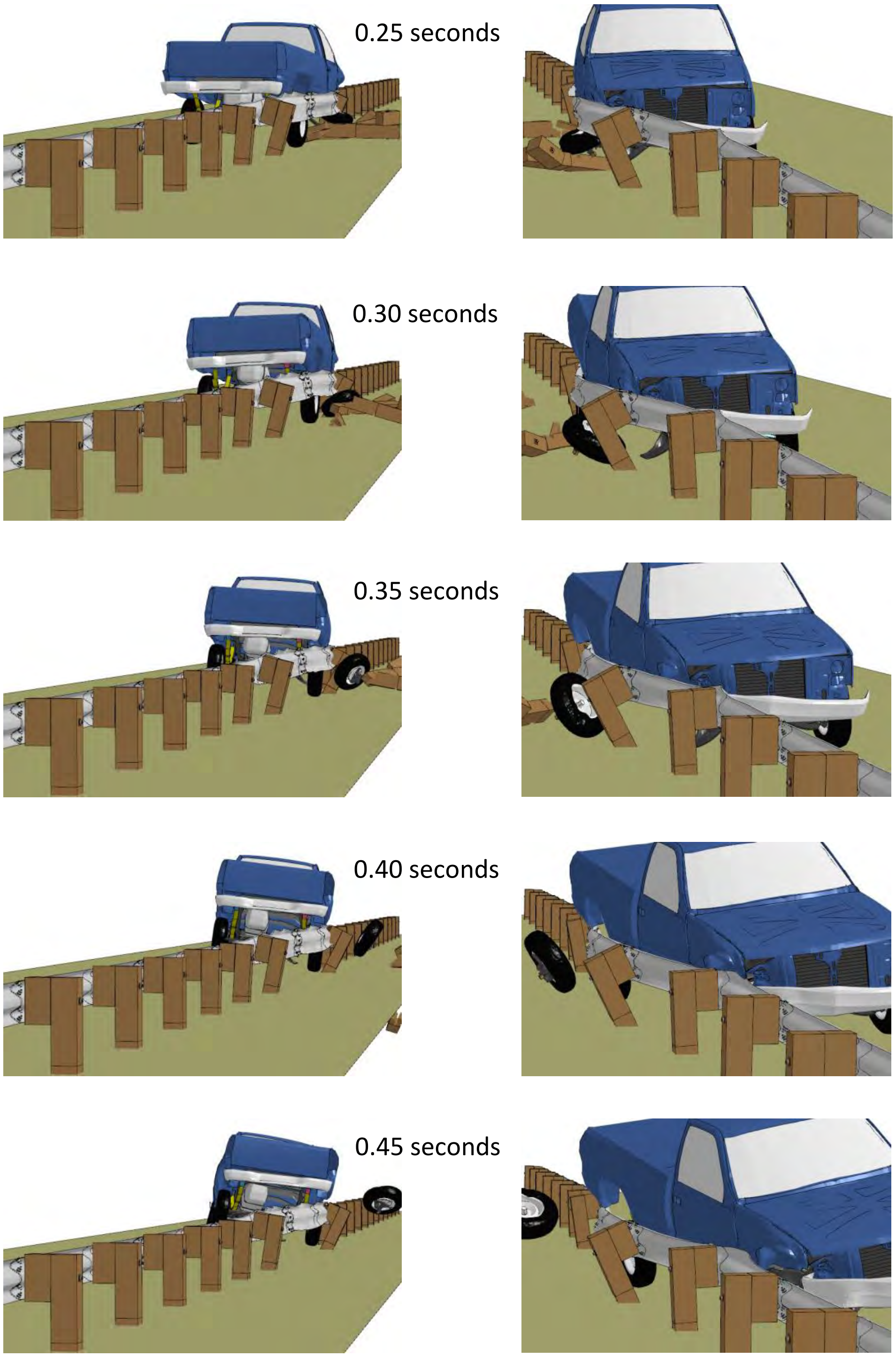


Figure B-12. Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: Test 3-11 of 40 mph-Damaged G4(2W) at Impact Point 2.



Upstream-Backside Viewpoint Downstream-Backside Viewpoint

Figure B-12. [CONTINUED] **Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: Test 3-11 of 40 mph-Damaged G4(2W) at Impact Point** 2.

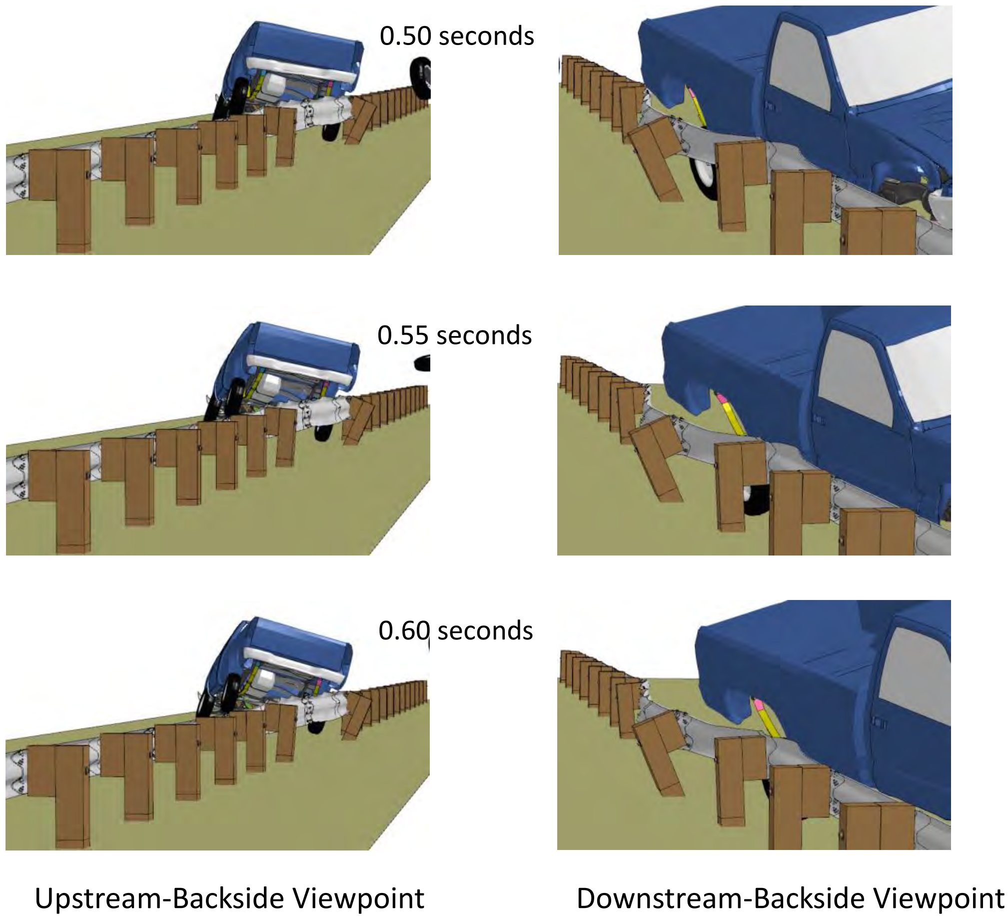


Figure B-12. [CONTINUED] **Sequential views from an upstream-backside and a downstream-backside viewpoint for analysis case: Test 3-11 of 40 mph-Damaged G4(2W) at Impact Point** 2.

APPENDIX M

Task 4A-6
Assess Effects of Soil Eroded Away from Posts on Performance of G4(2W)

FOIL Tests 14003 Summary Sheets
Pendulum Tests on Post-in-Soil

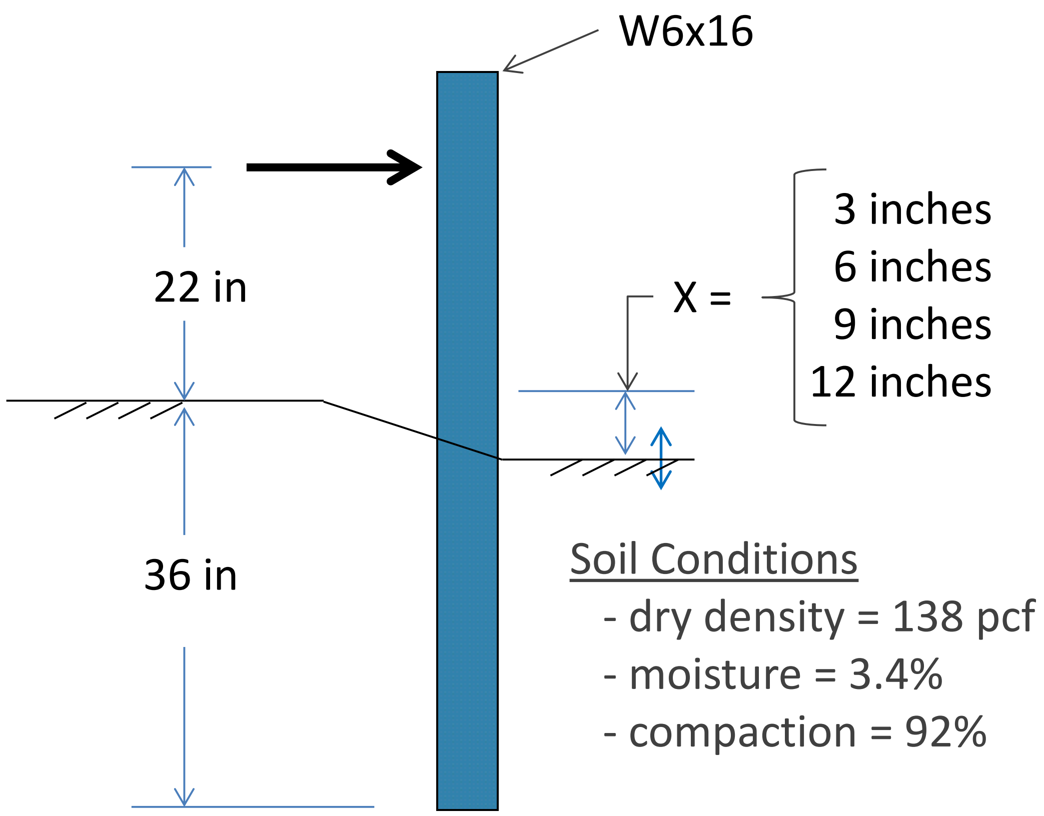
Chuck A. Plaxico, Ph.D.

RoadSafe LLC
Canton, ME

Chris Story
Federal Outdoor Impact Laboratory
McLean, VA

May 2014

Test Setup


W6x16
22 in
36 in
X =
3 inches
6 inches
9 inches
12 inches
Soil Conditions
- dry density = 138 pcf
- moisture = 3.4%
- compaction = 92%

Test Information

Project Case Number:	4A6_000a
FOIL Test Number:	14003B
Test Date:	15-May-2014

Damage Type

Category:	Erosion
Level:	Baseline (0 in)

Post Properties

Post Type:	W6x16	
Post Length (in):	72	
	Front	Rear
Embedment Depth (in):	36	36

Pendulum Properties

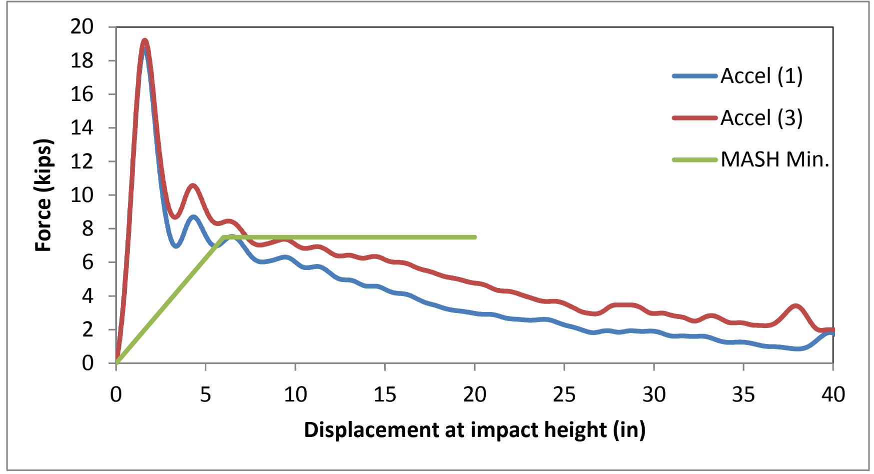
Weight:	2,372 lb
Impact Speed (mph):	20
Impact Height (in):	22.0
Kinetic Energy (kip-in):	380.3

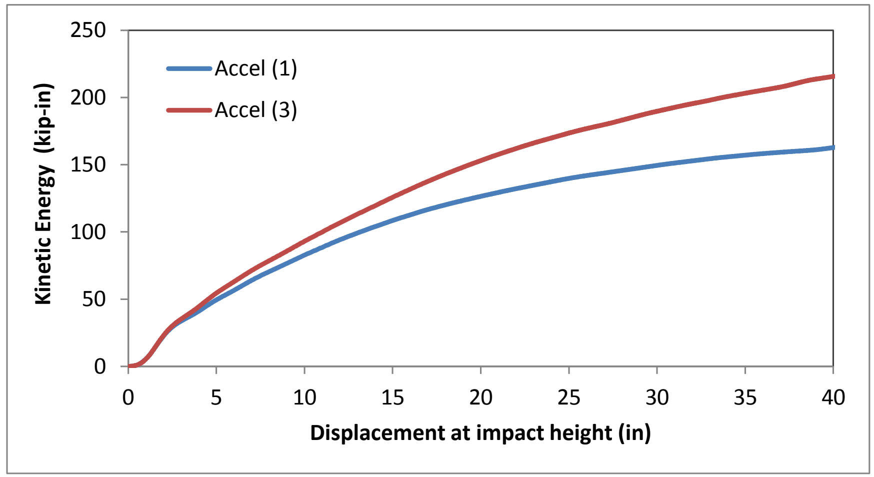
Soil Properties

Dry Density (pcf):	143.0
Wet Density (pcf):	148.2
Moisture Content (%):	3.6
Compaction (%):	92.6

Result

Peak Load (kips):	19.2
Avg. Tot. Energy (kip-in):	167.9





0.04 s / 12.8 in / 6.4 kips

0.08 s / 23.9 in / 3.7 kips

0.12 s / 33.9 in / 2.5 kips

0.16 s / 43.3 in / 1.4 kips

Test Information

Project Case Number:	4A6_000b	
FOIL Test Number:	14003F	
Test Date:	23-May-2014	

Damage Type

Category:	Erosion	
Level:	Baseline (0 in)	

Post Properties

Post Type:	W6x16	
Post Length (in):	72	
	Front	Rear
Embedment Depth (in):	36	36

Pendulum Properties

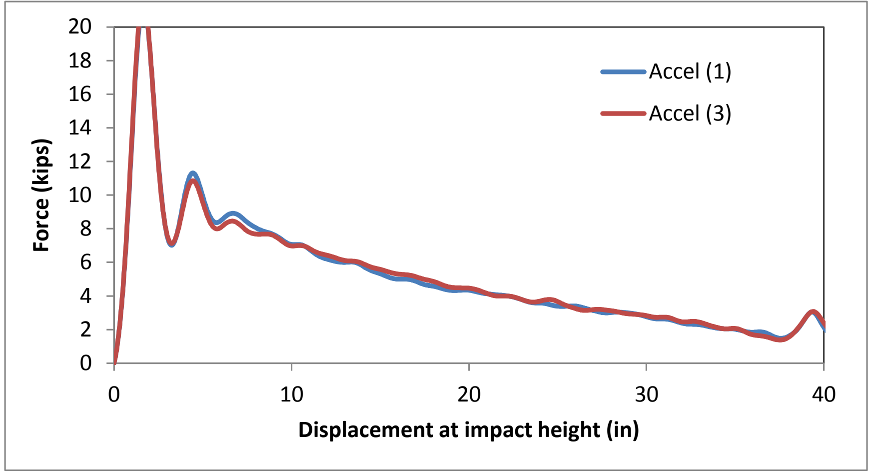
Weight:	2,372 lb	
Impact Speed (mph):	20	
Impact Height (in):	22.0	
Kinetic Energy (kip-in):	380.3	

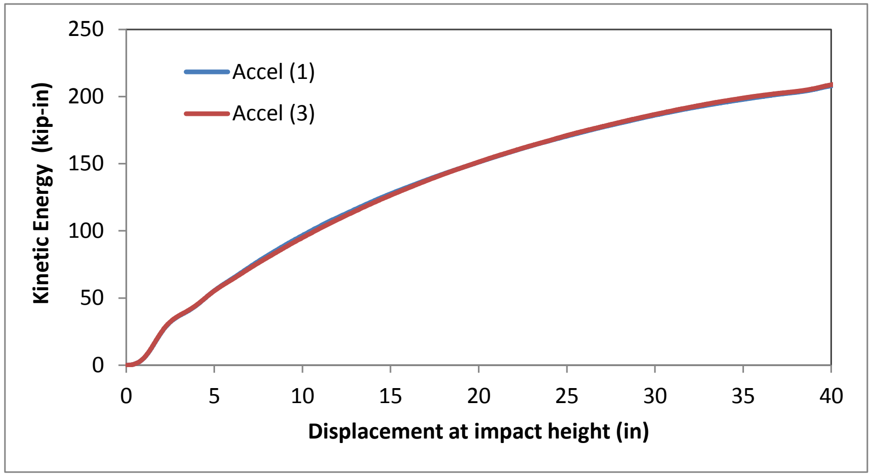
Soil Properties

Dry Density (pcf):	145.6	
Wet Density (pcf):	149.9	
Moisture Content (%):	3.0	
Compaction (%):	94.2	

Result

Peak Load (kips):	21.6	
Avg. Tot. Energy (kip-in):	183.4	





0.04 s / 12.7 in / 7.0 kips

0.08 s / 23.5 in / 4.5 kips

0.12 s / 33.1 in / 3.0 kips

0.16 s / 41.8 in / 2.0 kips

Test Information

Project Case Number:	4A6_003
FOIL Test Number:	14003A
Test Date:	13-May-2014

Damage Type

Category:	Erosion
Level:	3 inches

Post Properties

Post Type:	W6x16	
Post Length (in):	72	
	Front	Rear
Embedment Depth (in):	34	33

Pendulum Properties

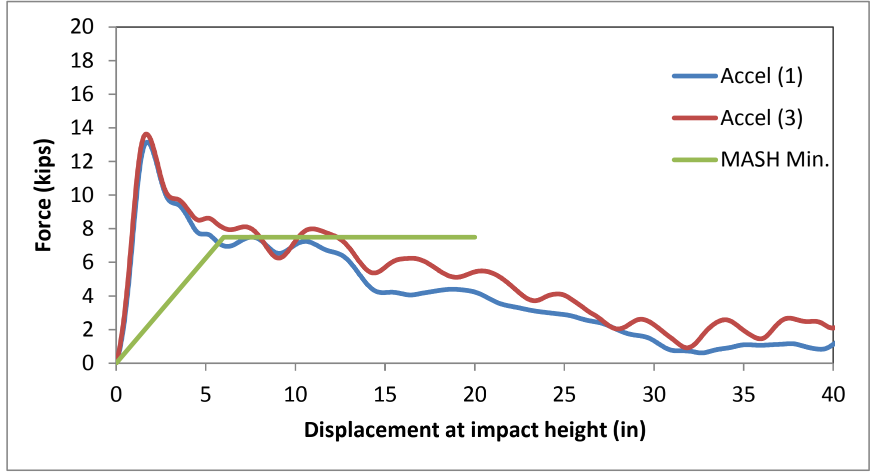
Weight:	2,372 lb
Impact Speed (mph):	20
Impact Height (in):	22.0
Kinetic Energy (kip-in):	380.3

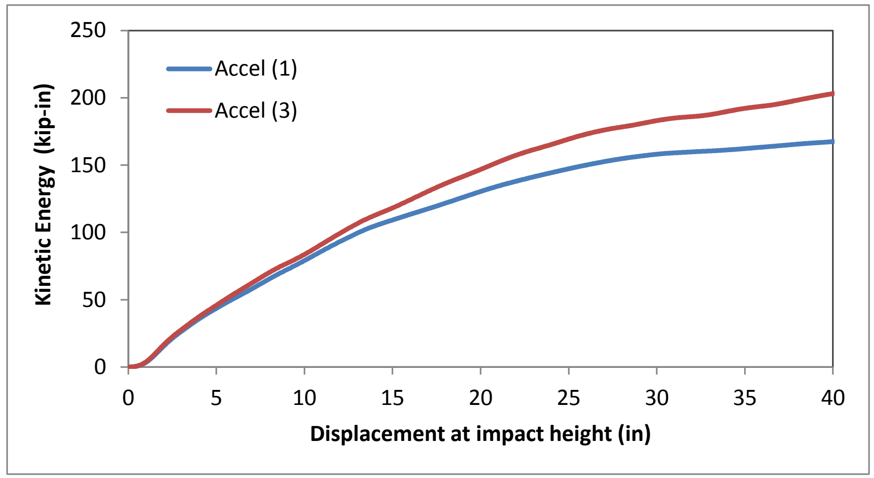
Soil Properties

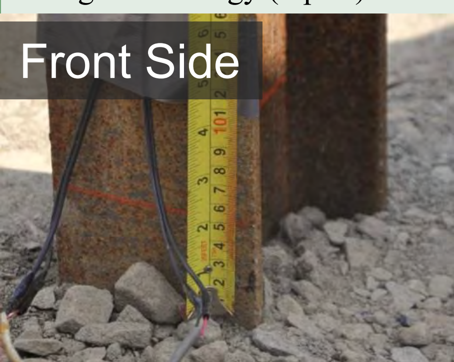
Dry Density (pcf):	143.9
Wet Density (pcf):	149.8
Moisture Content (%):	4.1
Compaction (%):	93.1

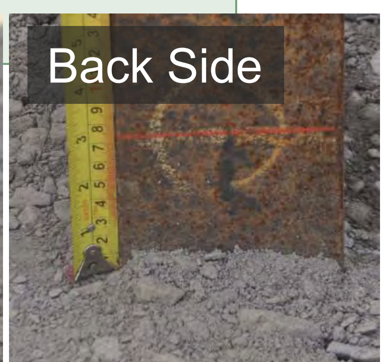
Result

Peak Load (kips):	13.6
Avg. Tot. Energy (kip-in):	169.6









0.04 s / 12.9 in / 7.5 kips

0.08 s / 23.8 in / 4.7 kips

0.12 s / 33.6 in / 3.1 kips

0.16 s / 42.7 in / 1.2 kips

Test Information

Project Case Number:	4A6_006	
FOIL Test Number:	14003C	
Test Date:	19-May-2014	

Damage Type

Category:	Erosion	
Level:	6 inches	

Post Properties

Post Type:	W6x16	
Post Length (in):	72	
	Front	Rear
Embedment Depth (in):	34	30

Pendulum Properties

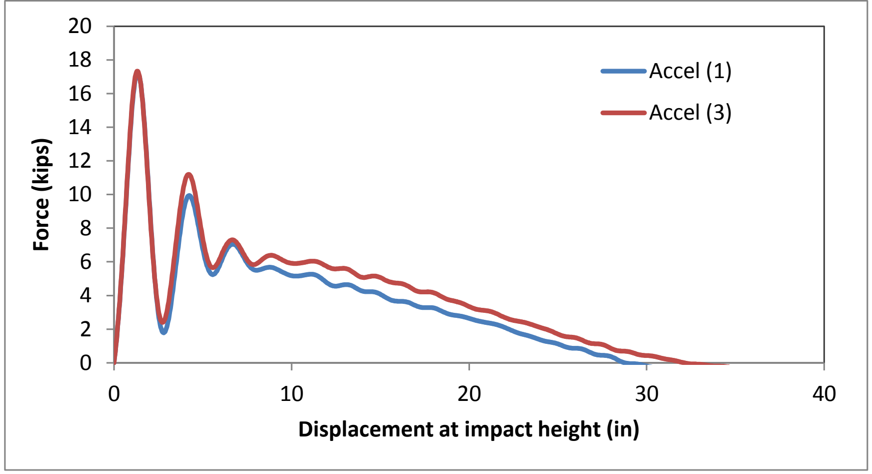
Weight:	2,372 lb
Impact Speed (mph):	20
Impact Height (in):	22.0
Kinetic Energy (kip-in):	380.3

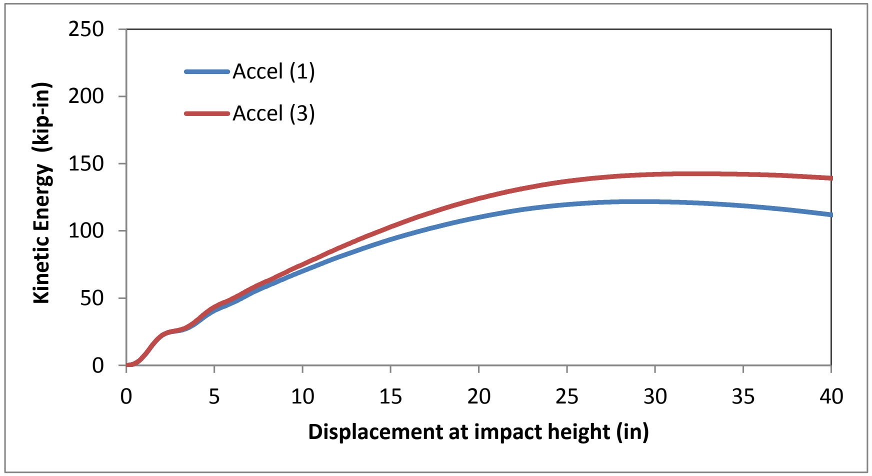
Soil Properties

Dry Density (pcf):	144.1
Wet Density (pcf):	150.1
Moisture Content (%):	4.2
Compaction (%):	93.3

Result

Peak Load (kips):	17.3
Avg. Tot. Energy (kip-in):	132.0





0.04 s / 13.0 in / 6.1 kips

0.08 s / 24.5 in / 2.3 kips

0.12 s / 35.3 in / 0.2 kips

0.16 s / 46.1 in / 0.0 kips

Front Side

Back Side

Test Information

Project Case Number:	4A6_009
FOIL Test Number:	14003D
Test Date:	20-May-2014

Damage Type

Category:	Erosion
Level:	9 inches

Post Properties

Post Type:	W6x16	
Post Length (in):	72	
	Front	Rear
Embedment Depth (in):	36	27

Pendulum Properties

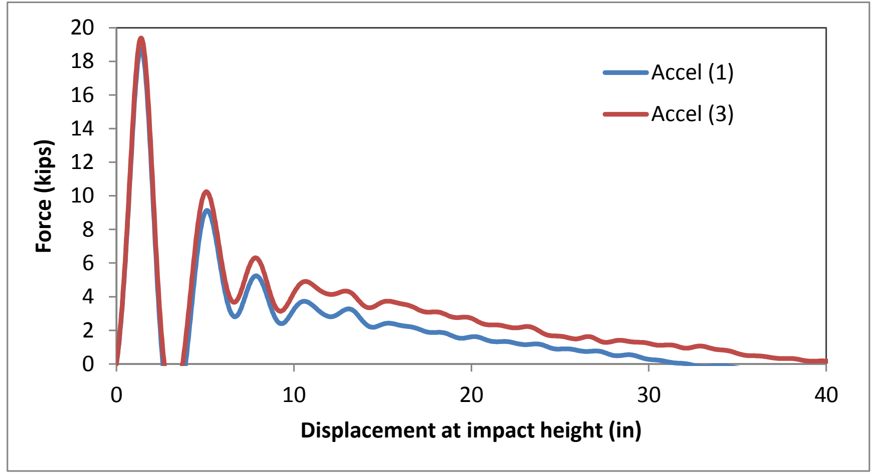
Weight:	2,372 lb
Impact Speed (mph):	20
Impact Height (in):	22.0
Kinetic Energy (kip-in):	380.3

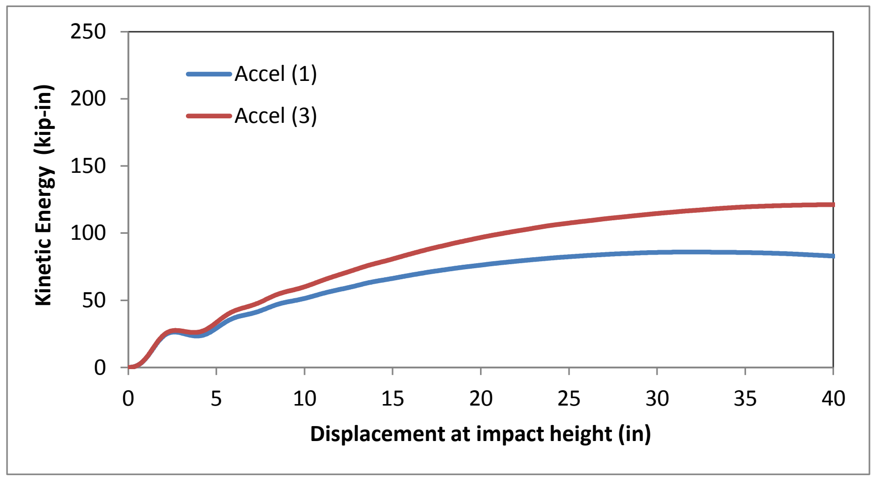
Soil Properties

Dry Density (pcf):	143.6
Wet Density (pcf):	148.9
Moisture Content (%):	3.8
Compaction (%):	92.9

Result

Peak Load (kips):	19.4
Avg. Tot. Energy (kip-in):	101.0





0.04 s / 13.2in / 4.2 kips

0.08 s / 25.5 in / 1.6 kips

0.12 s / 37.1 in / 0.4 kips

0.16 s / 48.8 in / 0.1 kips

Test Information

Project Case Number: 4A6_012
FOIL Test Number: 14003E
Test Date: 22-May-2014

Damage Type

Category: Erosion
Level: 12 inches

Post Properties

Post Type: W6x16
Post Length (in): 72

	Front	Rear
Embedment Depth (in):	35	24

Pendulum Properties

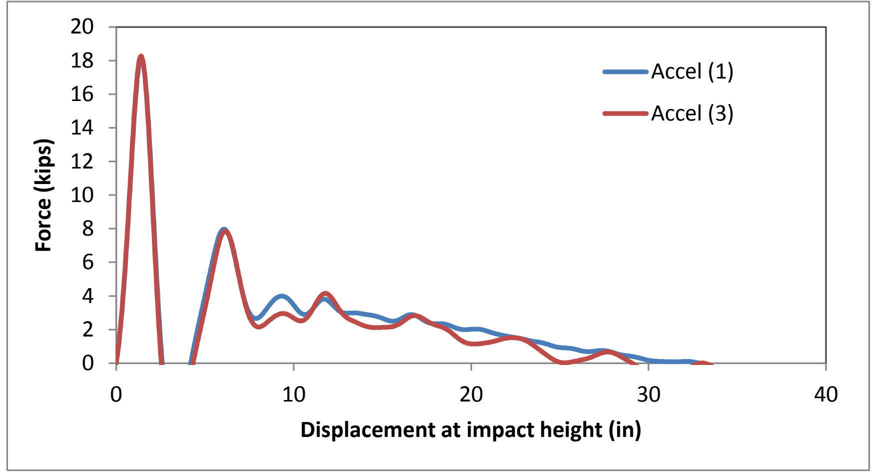
Weight: 2,372 lb
Impact Speed (mph): 20
Impact Height (in): 22.0
Kinetic Energy (kip-in): 380.3

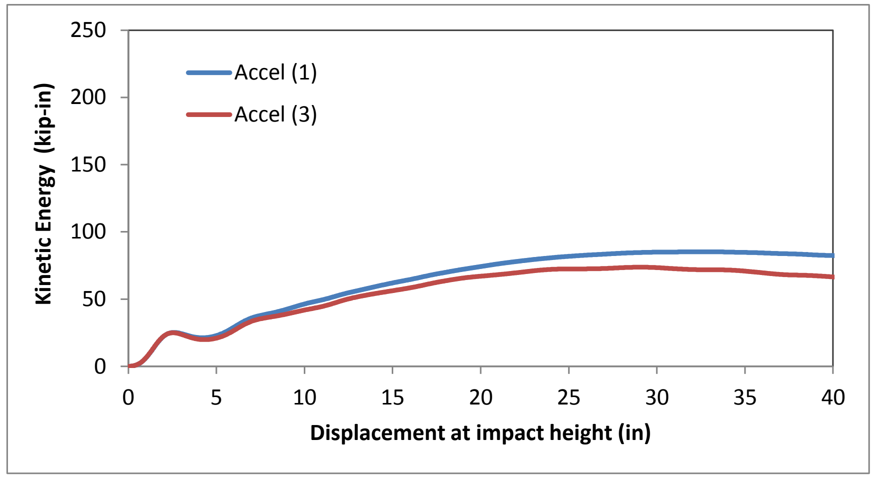
Soil Properties

Dry Density (pcf): 143.0
Wet Density (pcf): 148.2
Moisture Content (%): 3.6
Compaction (%): 92.6

Result

Peak Load (kips): 18.3
Avg. Tot. Energy (kip-in): 73.7





0.04 s / 13.3in / 3.8 kips

0.08 s / 25.7 in / 1.5 kips

0.12 s / 37.6 in / 0.1 kips

0.16 s / 49.5 in / 0.1 kips

APPENDIX N

Sequential Views from FEA Evaluation of G4(2W) with Various Levels of Erosion at a Single Post

Task 4A-6: Assess Effects of Soil Eroded Away from Posts on Performance of G4(2W)

By: Chuck A. Plaxico

July 2014

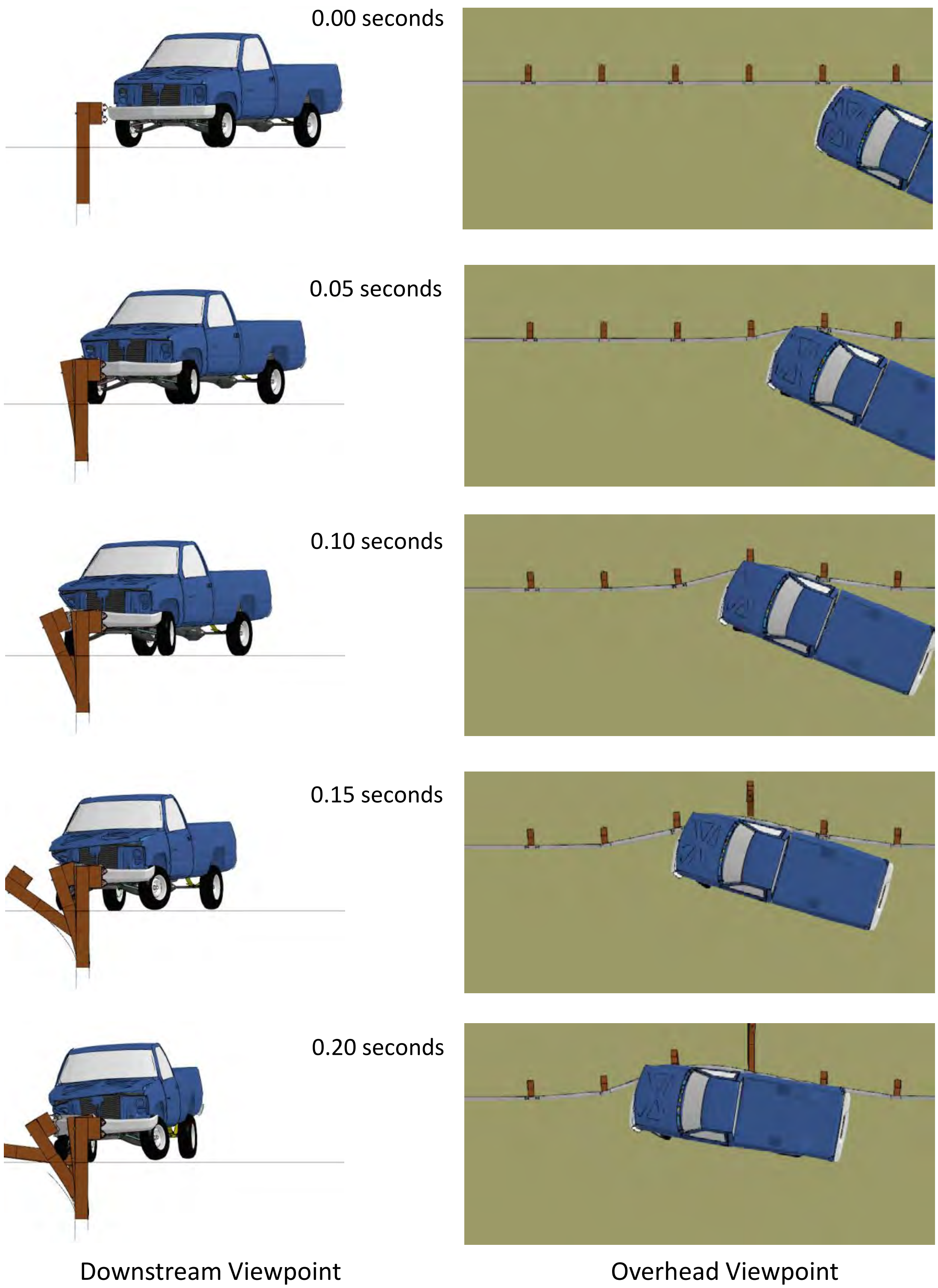


Figure M-1: Sequential views from a downstream and overhead viewpoint for 6-inch erosion at a single post **analysis case.**

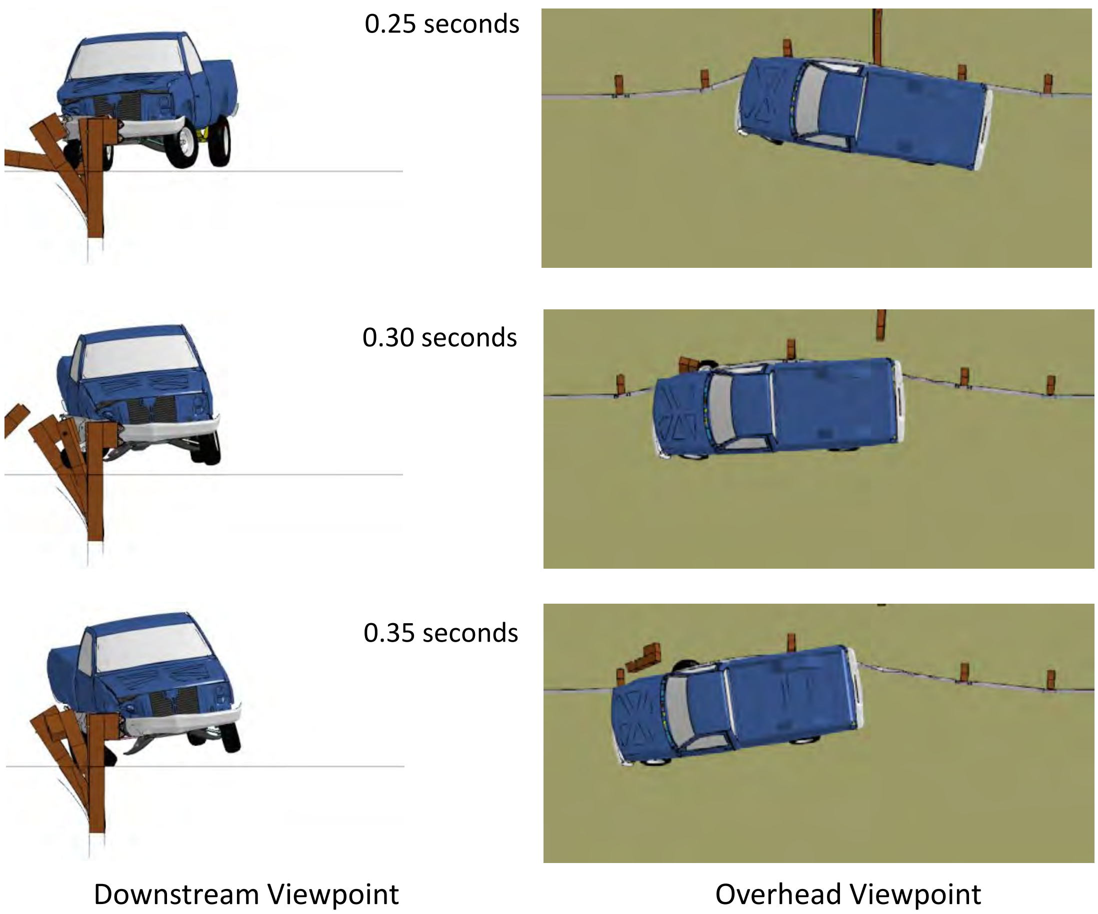


Figure M-1: [CONTINUED] Sequential views from a downstream and overhead viewpoint for <u>6-inch erosion a single post</u> **analysis case.**

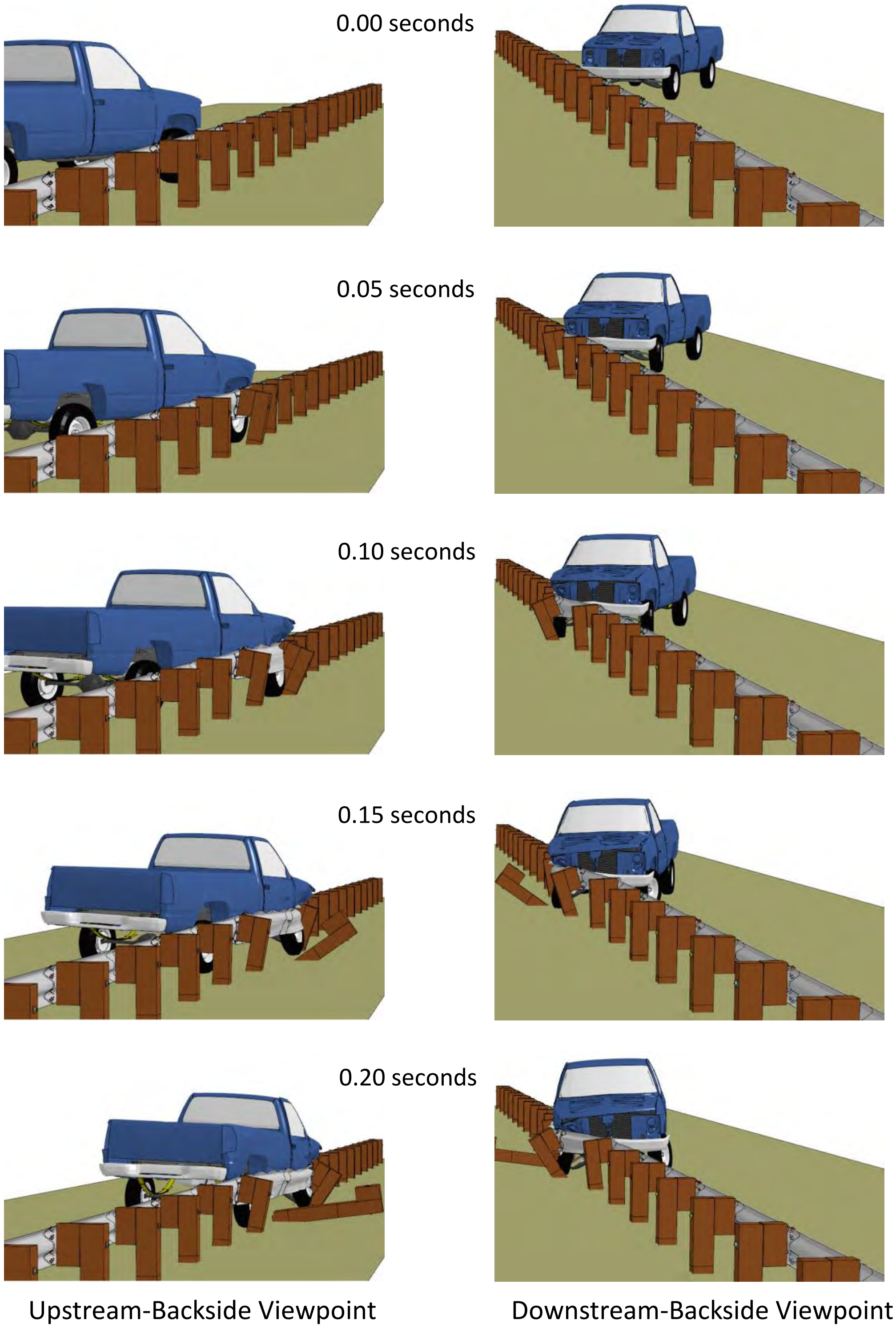


Figure M-2: Sequential views from an upstream-backside and a downstream-backside viewpoint for 6-inch erosion at a single post **analysis case.**

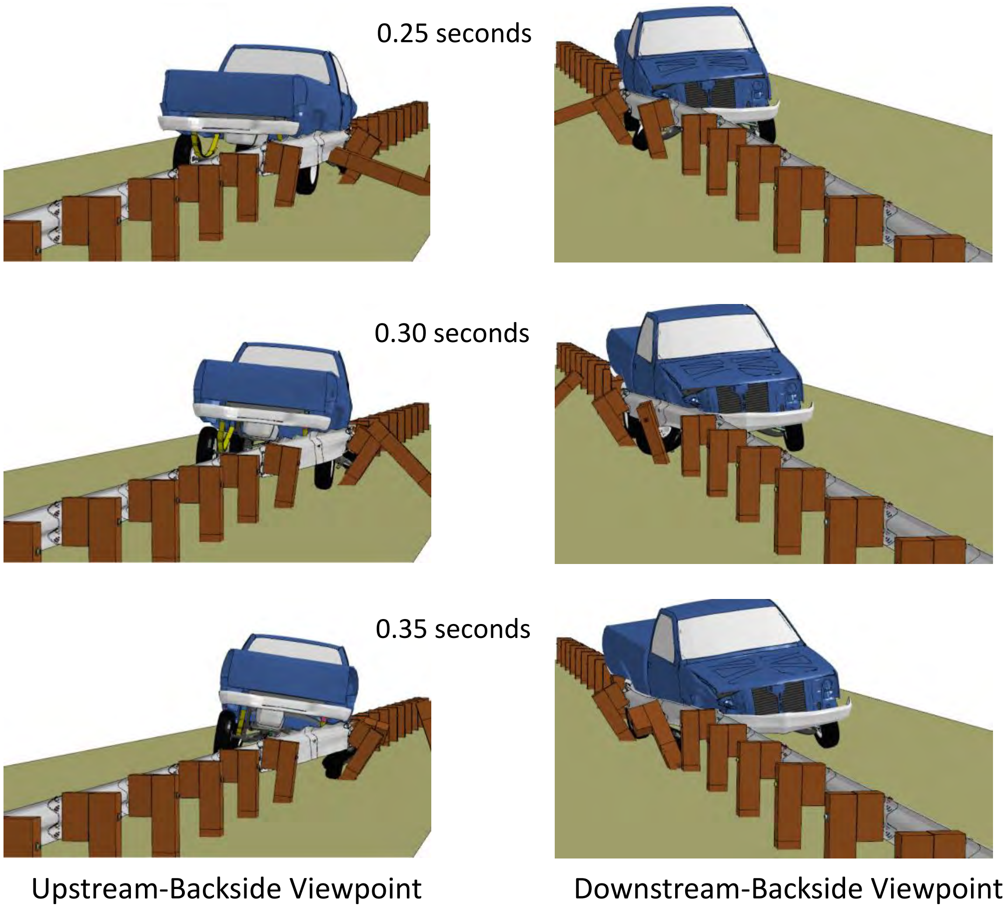


Figure M-2: [CONTINUED] Sequential views from an upstream-backside and a downstream-backside viewpoint for <u>6-inch erosion at a single post</u> analysis case.

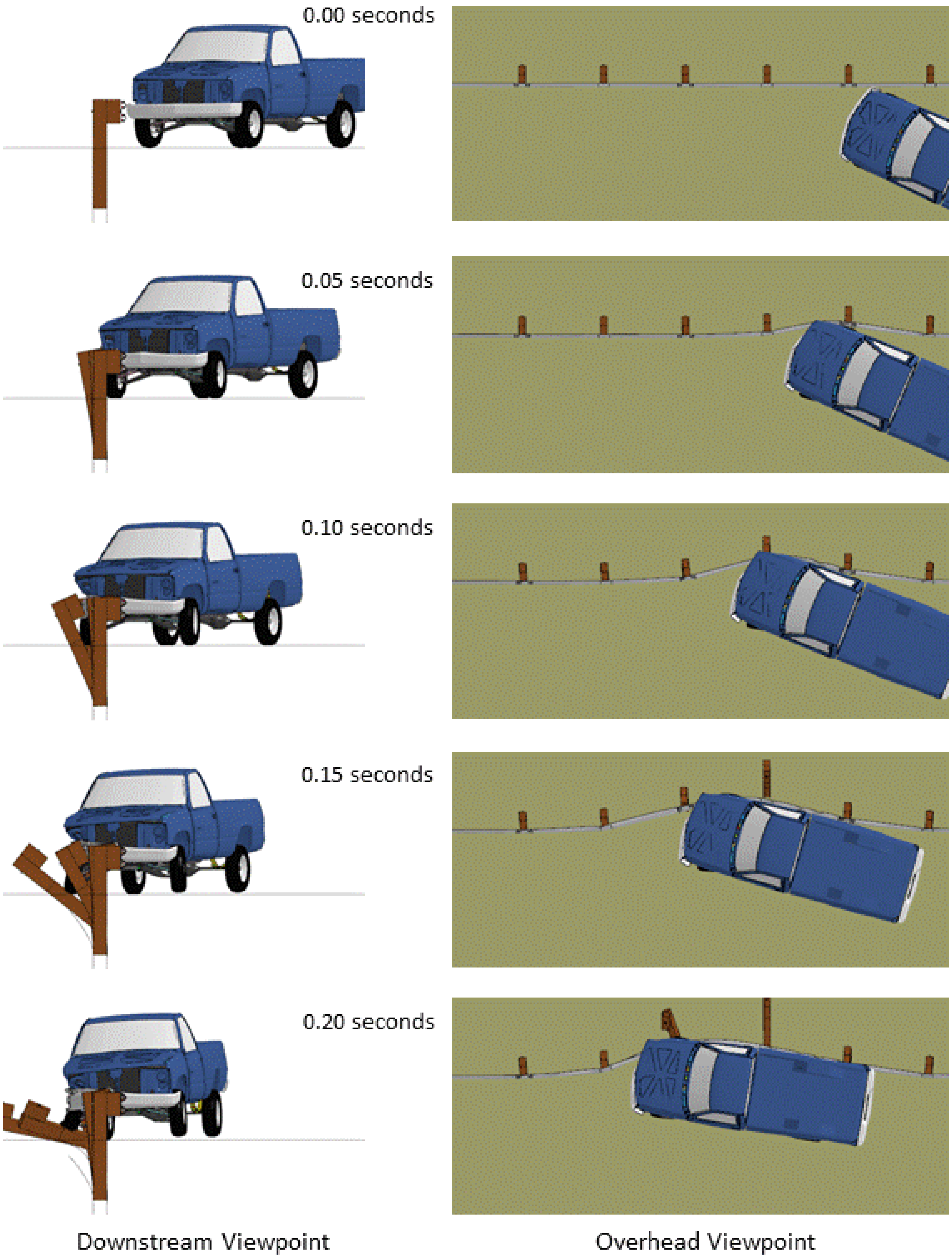


Figure M-3: Sequential views from a downstream and overhead viewpoint for 9-inch erosion at a single post **analysis case.**

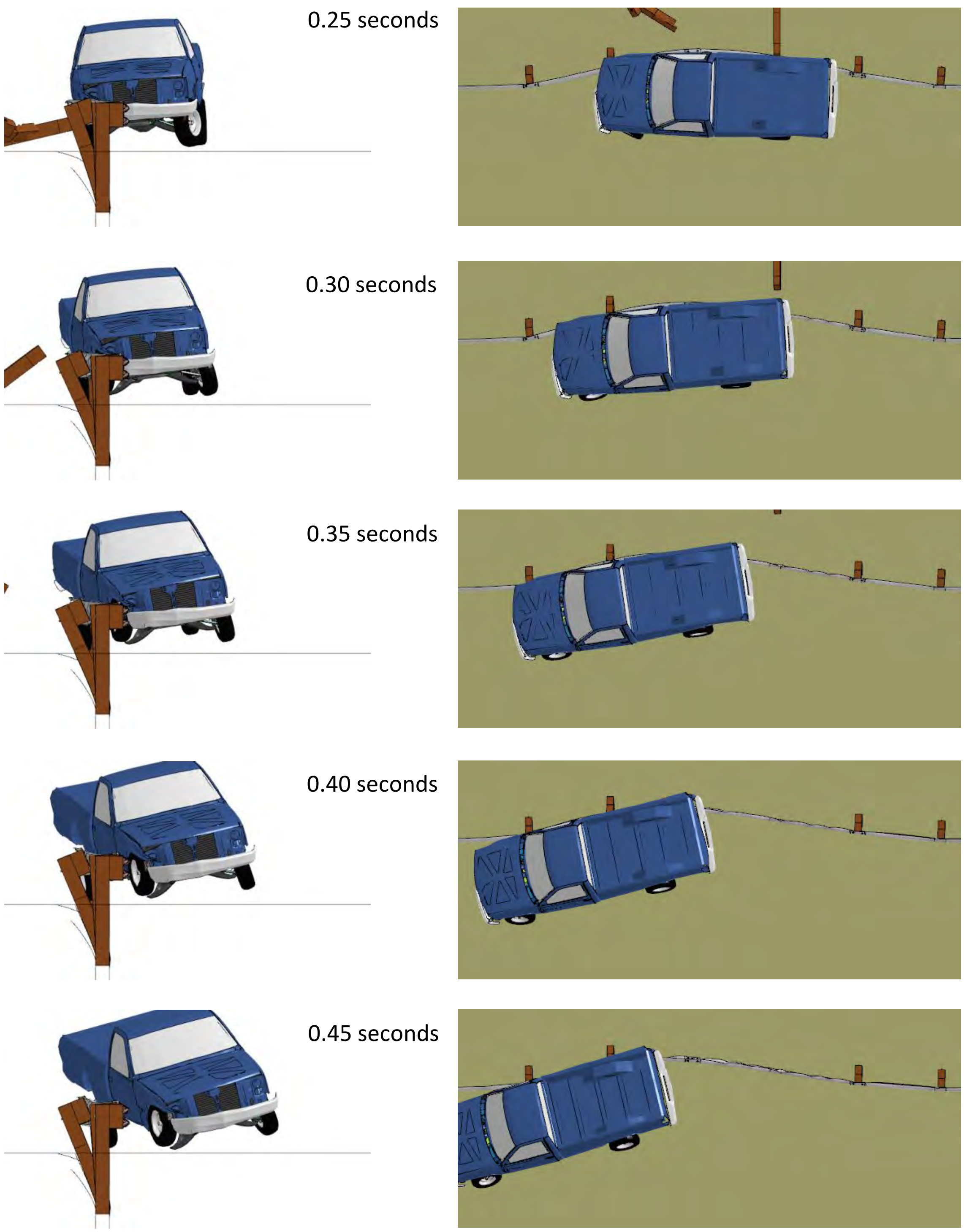


Figure M-3. [CONTINUED] Sequential views from a downstream and overhead viewpoint for <u>9-inch erosion a single post</u> analysis case.

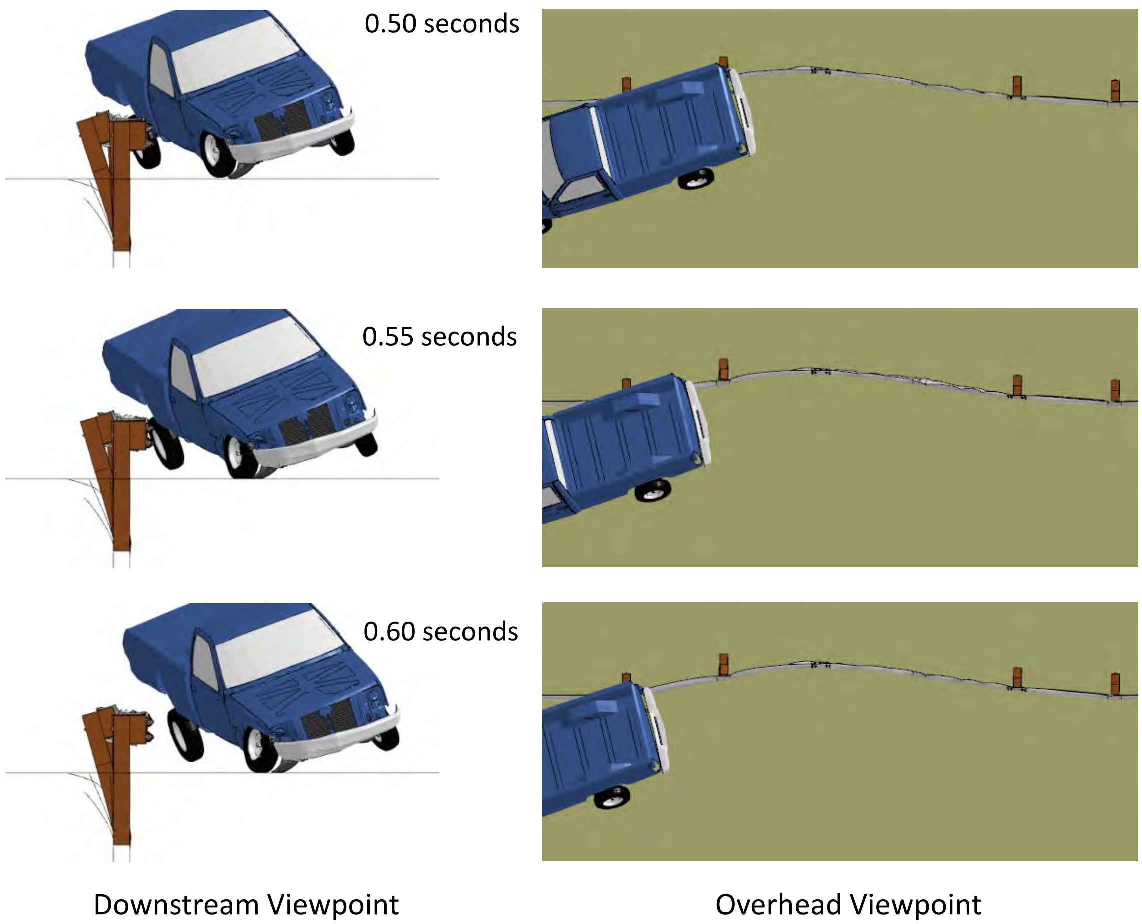


Figure M-3. [CONTINUED] Sequential views from a downstream and overhead viewpoint for 9-inch erosion at a single post analysis case.

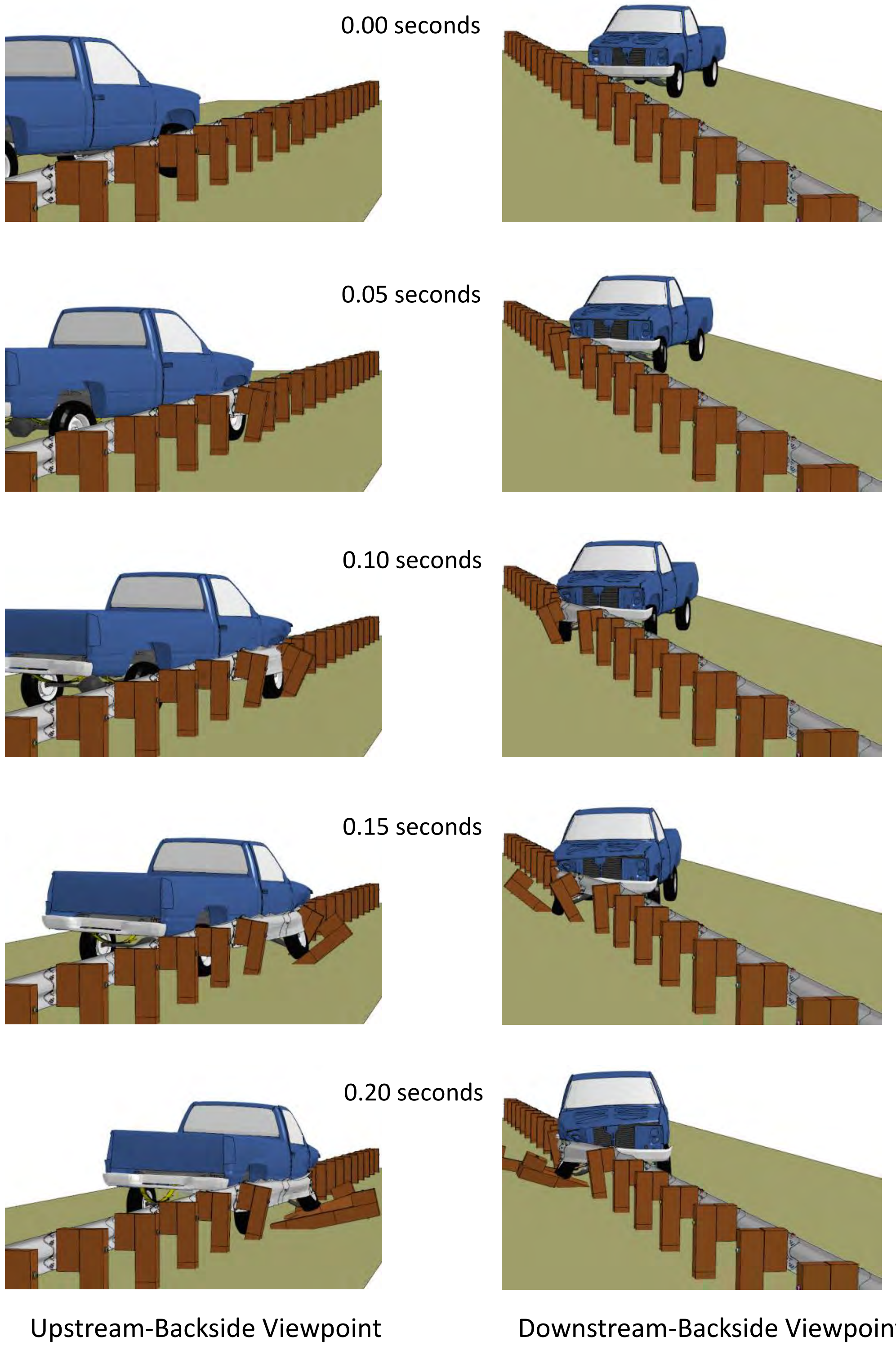


Figure M-4: Sequential views from an upstream-backside and a downstream-backside viewpoint for <u>9-inch erosion at a single post</u> **analysis case.**

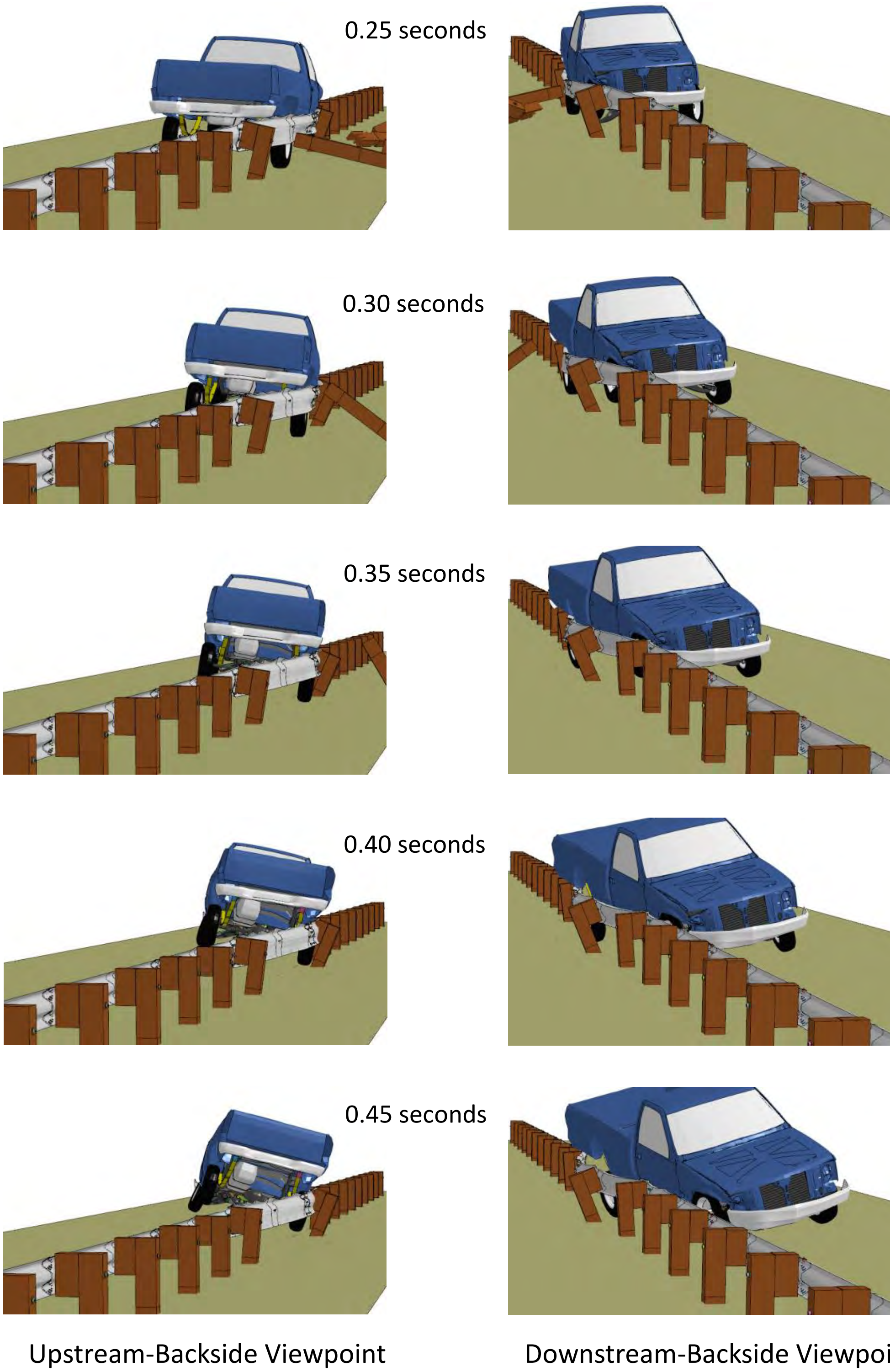


Figure M-4: [CONTINUED] Sequential views from an upstream-backside and a downstream-backside viewpoint for <u>9-inch erosion at a single post</u> analysis case.

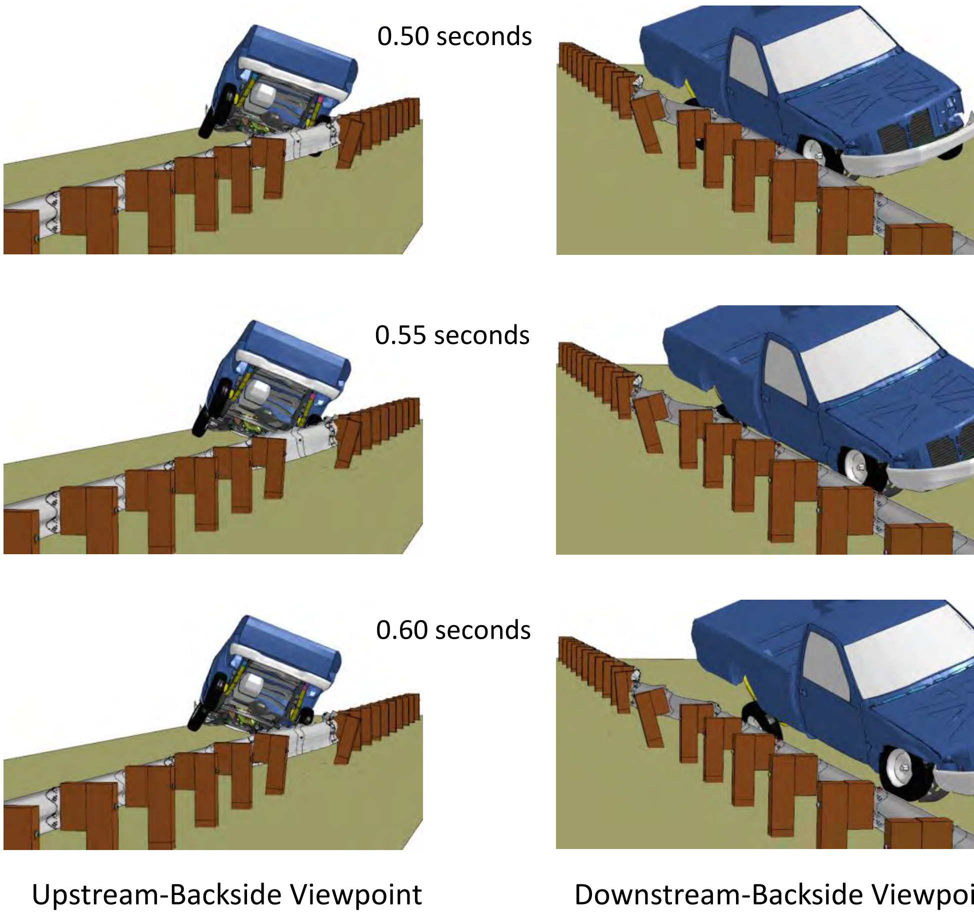


Figure M-4: [CONTINUED] Sequential views from an upstream-backside and a downstream-backside viewpoint for <u>9-inch erosion at a single post</u> analysis case.

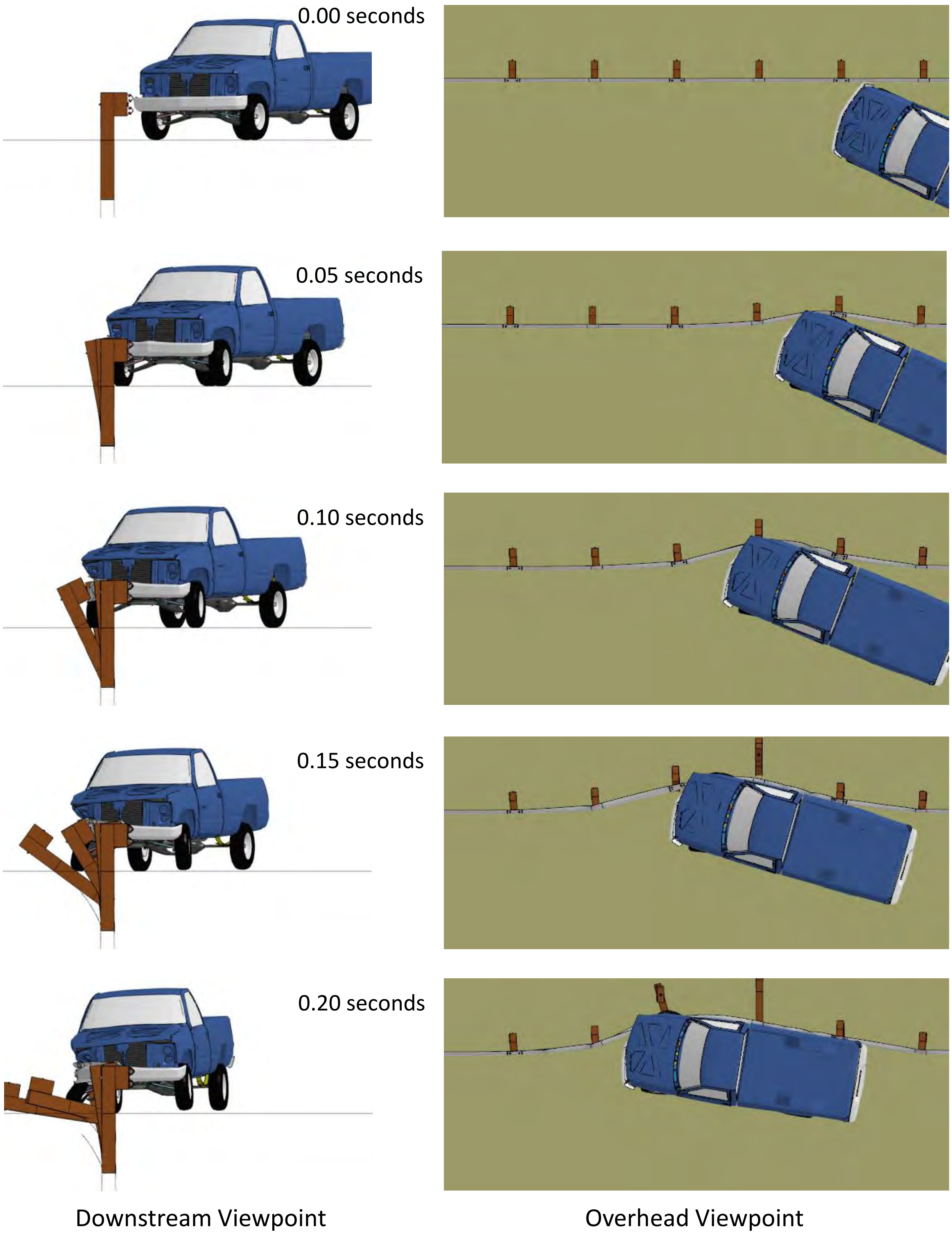


Figure M-5: Sequential views from a downstream and overhead viewpoint for 12-inch erosion at a single post **analysis case.**

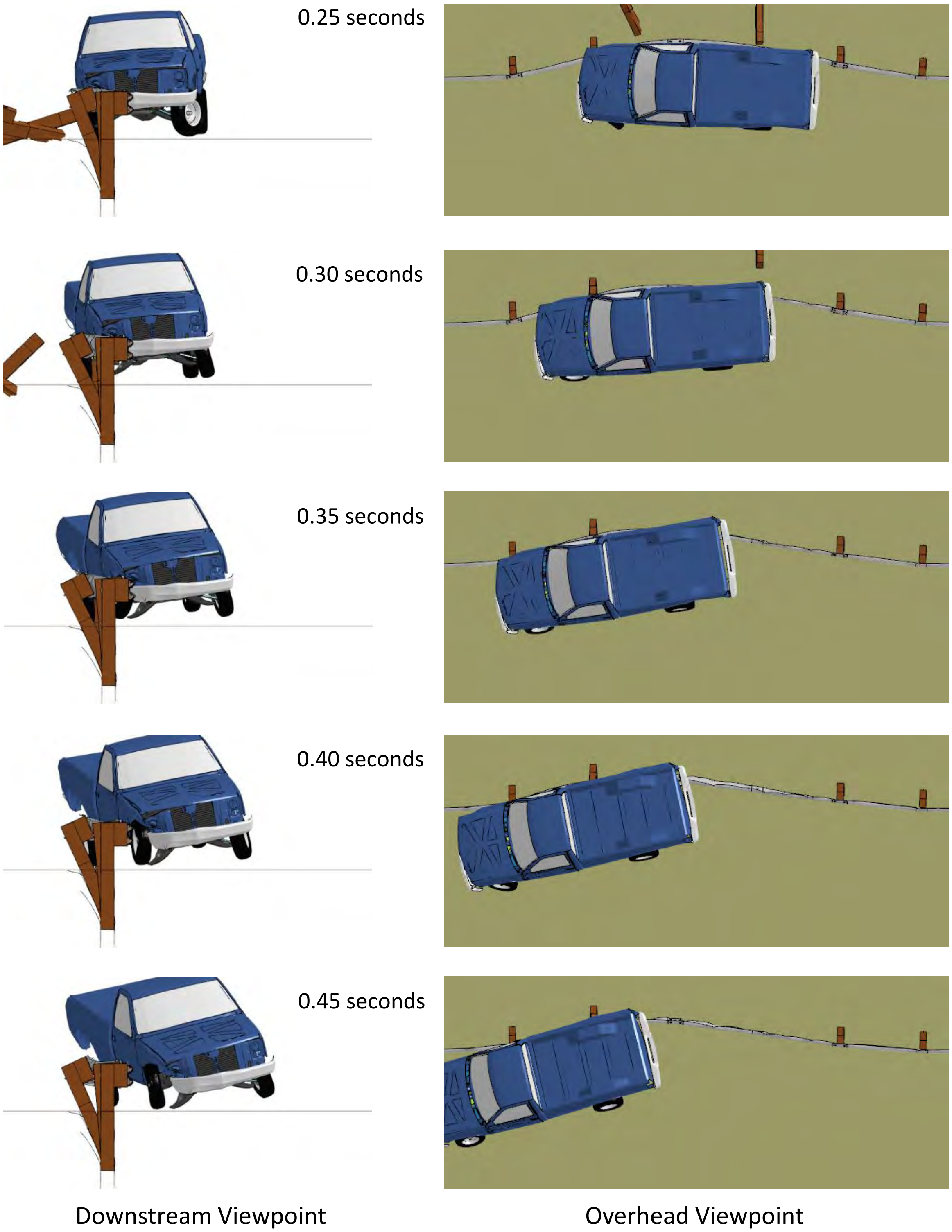


Figure M-5: [CONTINUED] Sequential views from a downstream and overhead viewpoint for 12-inch erosion at a single post **analysis case.**

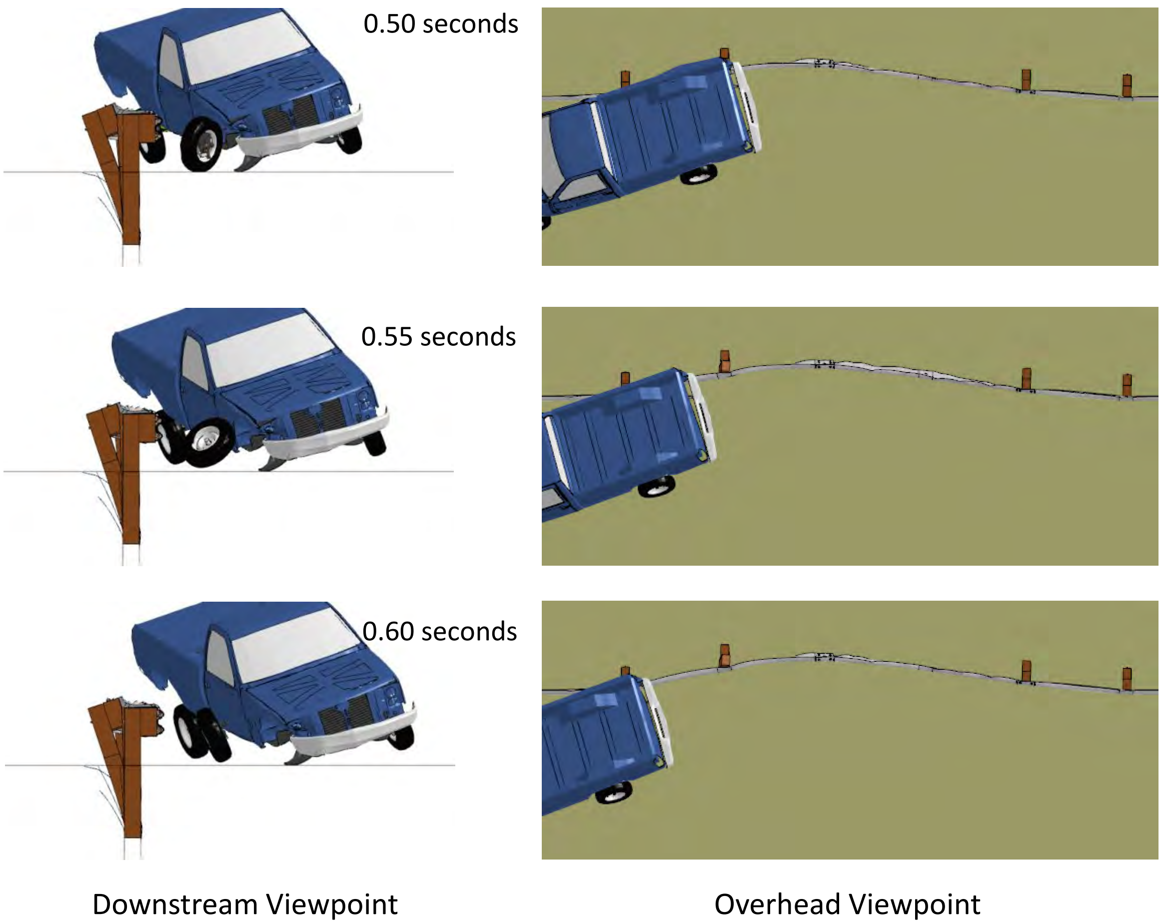


Figure M-5: [CONTINUED] Sequential views from a downstream and overhead viewpoint for 12-inch erosion at a single post **analysis case.**

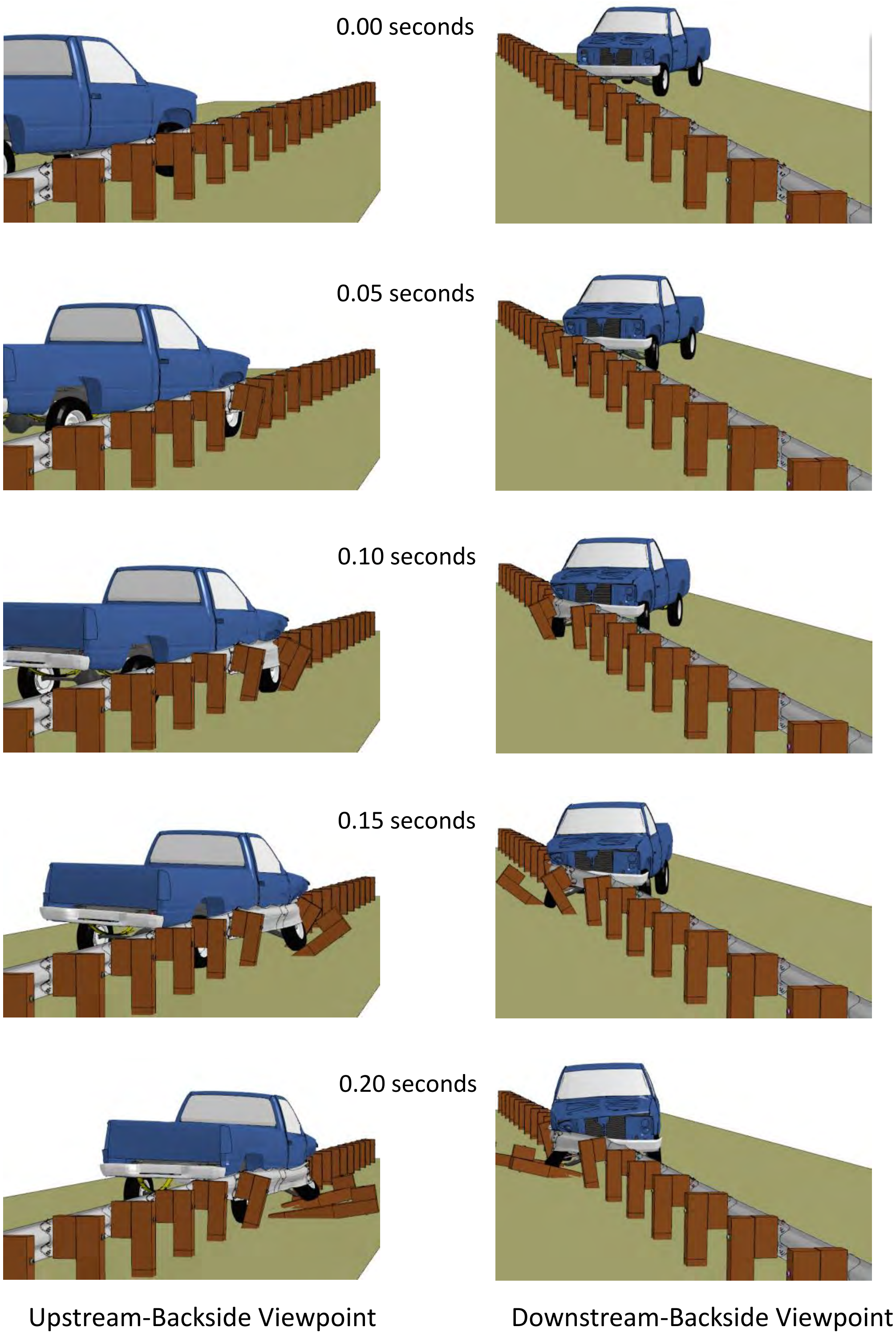


Figure M-6: Sequential views from an upstream-backside and a downstream-backside viewpoint for 12-inch erosion at a single post **analysis case.**

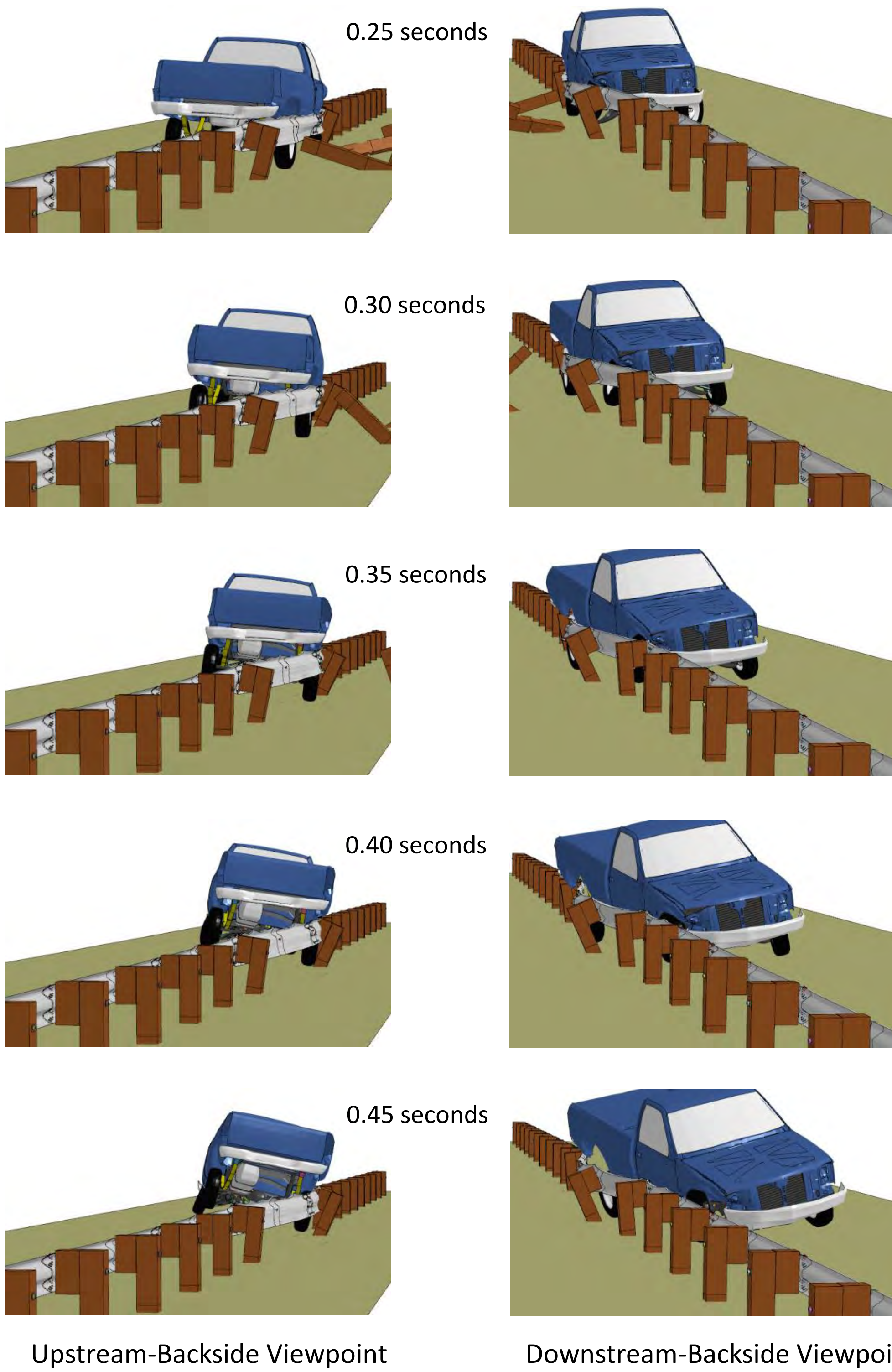


Figure M-6: [CONTINUED] Sequential views from an upstream-backside and a downstream-backside viewpoint for <u>12-inch erosion at a single post</u> analysis case.

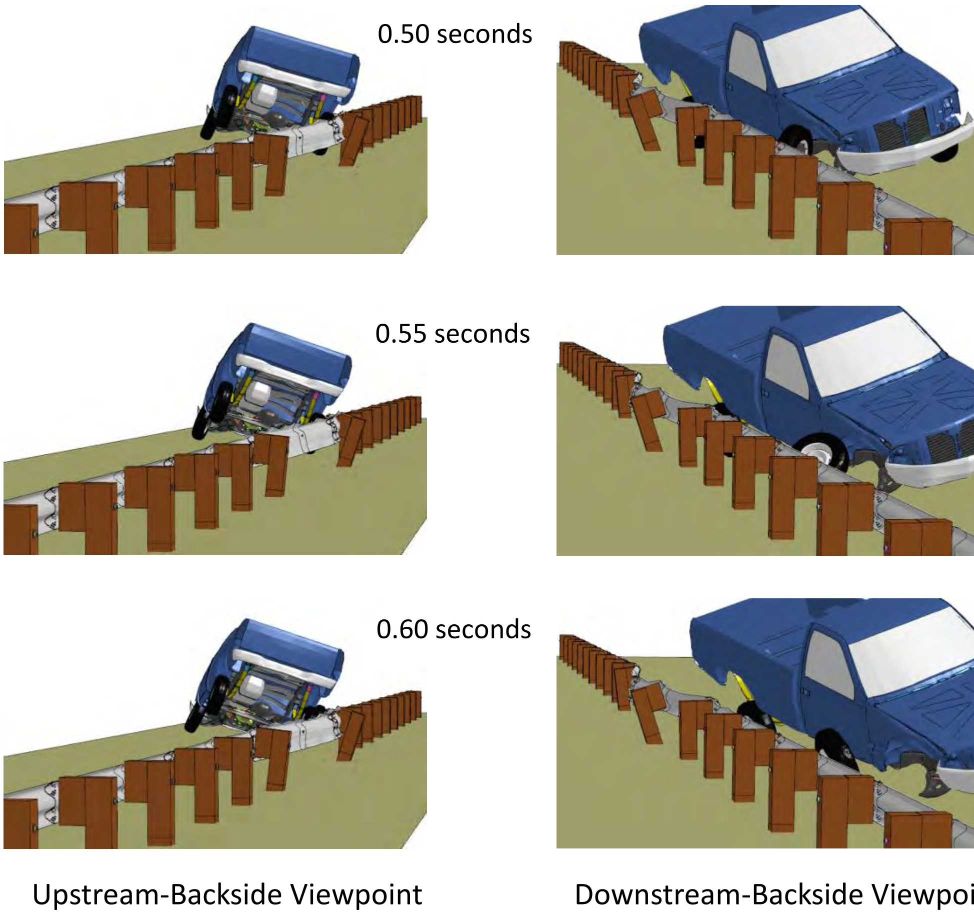


Figure M-6: [CONTINUED] Sequential views from an upstream-backside and a downstream-backside viewpoint for <u>12-inch erosion at a single post</u> analysis case.

APPENDIX O

Sequential Views from FEA Evaluation of G4(2W) with Various Levels of Erosion at Two Consecutive Posts

Task 4A-6: Assess Effects of Soil Eroded Away from Posts on Performance of G4(2W)

By: Chuck A. Plaxico

June 2014

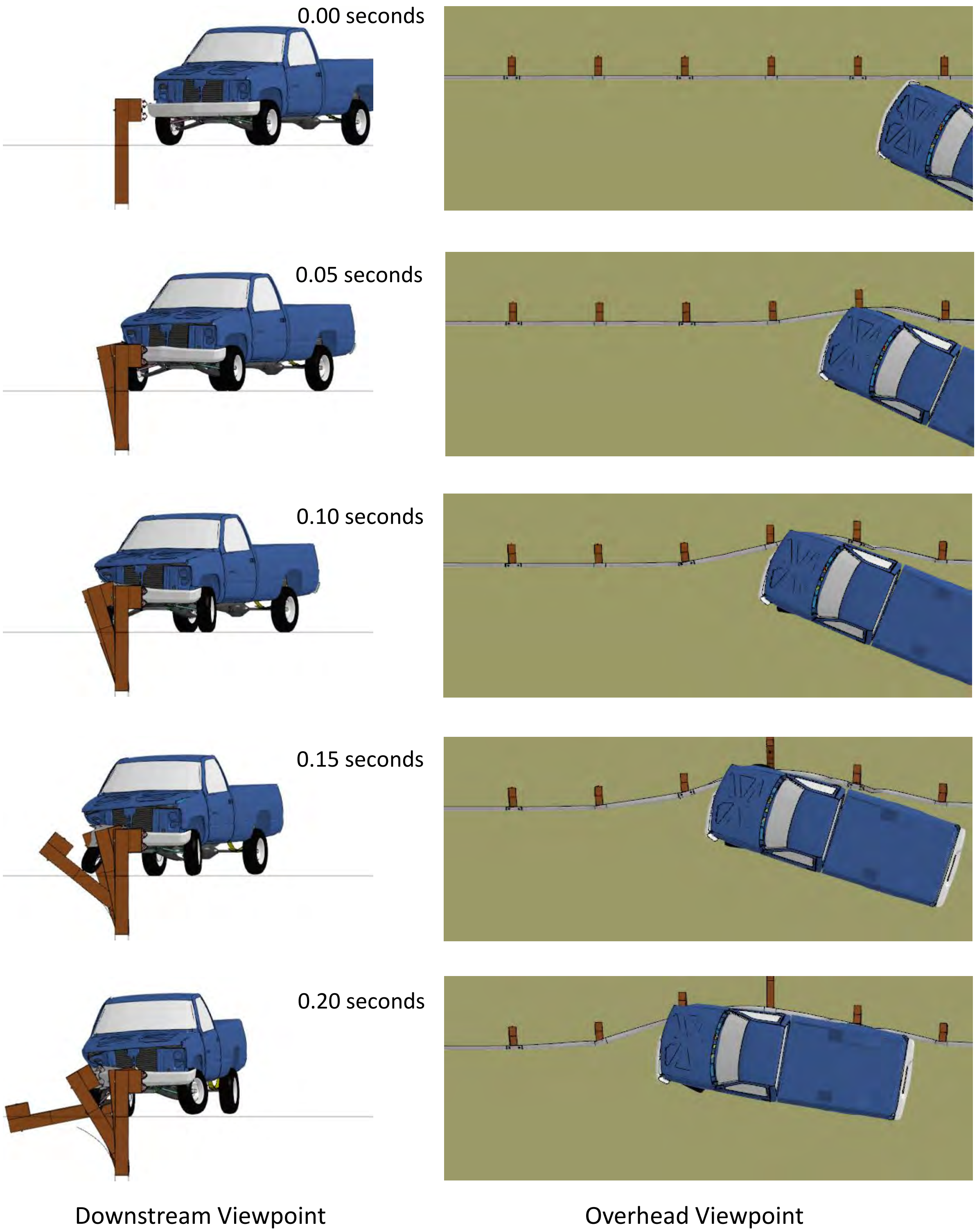


Figure N-1: Sequential views from a downstream and overhead viewpoint for 6-inch erosion at two posts **analysis case.**

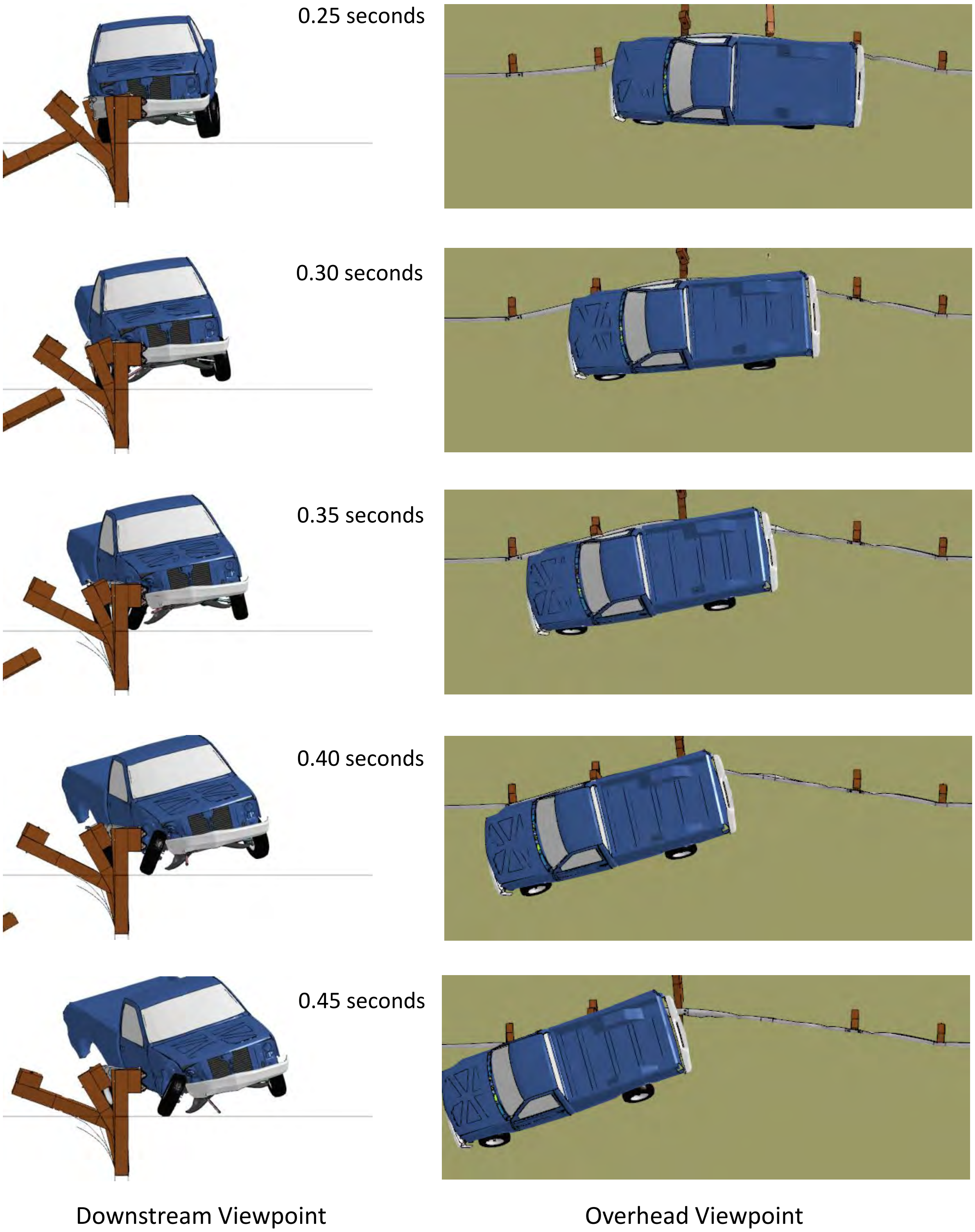


Figure N-1: [CONTINUED] Sequential views from a downstream and overhead viewpoint for 6-inch erosion at two posts **analysis case.**

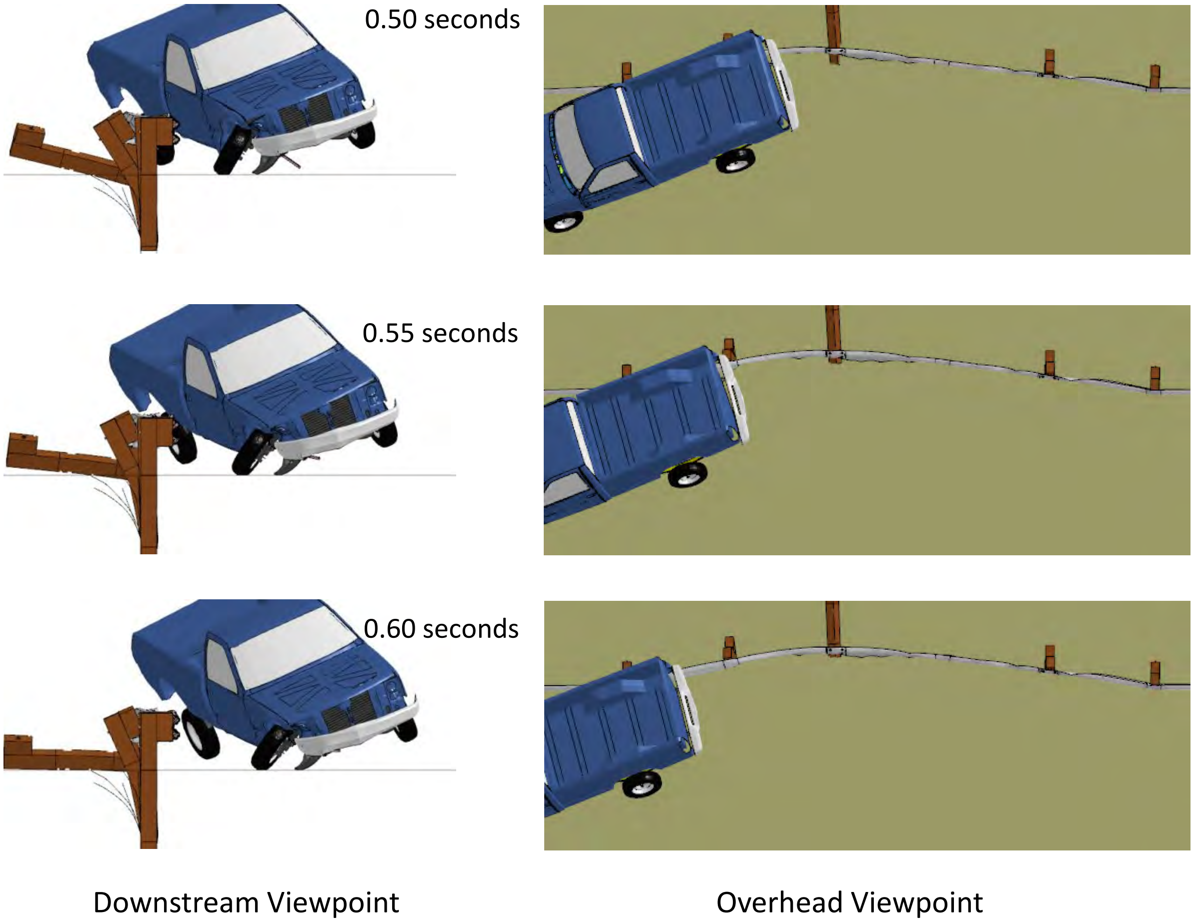


Figure N-1: [CONTINUED] Sequential views from a downstream and overhead viewpoint for 6-inch erosion at two posts **analysis case.**

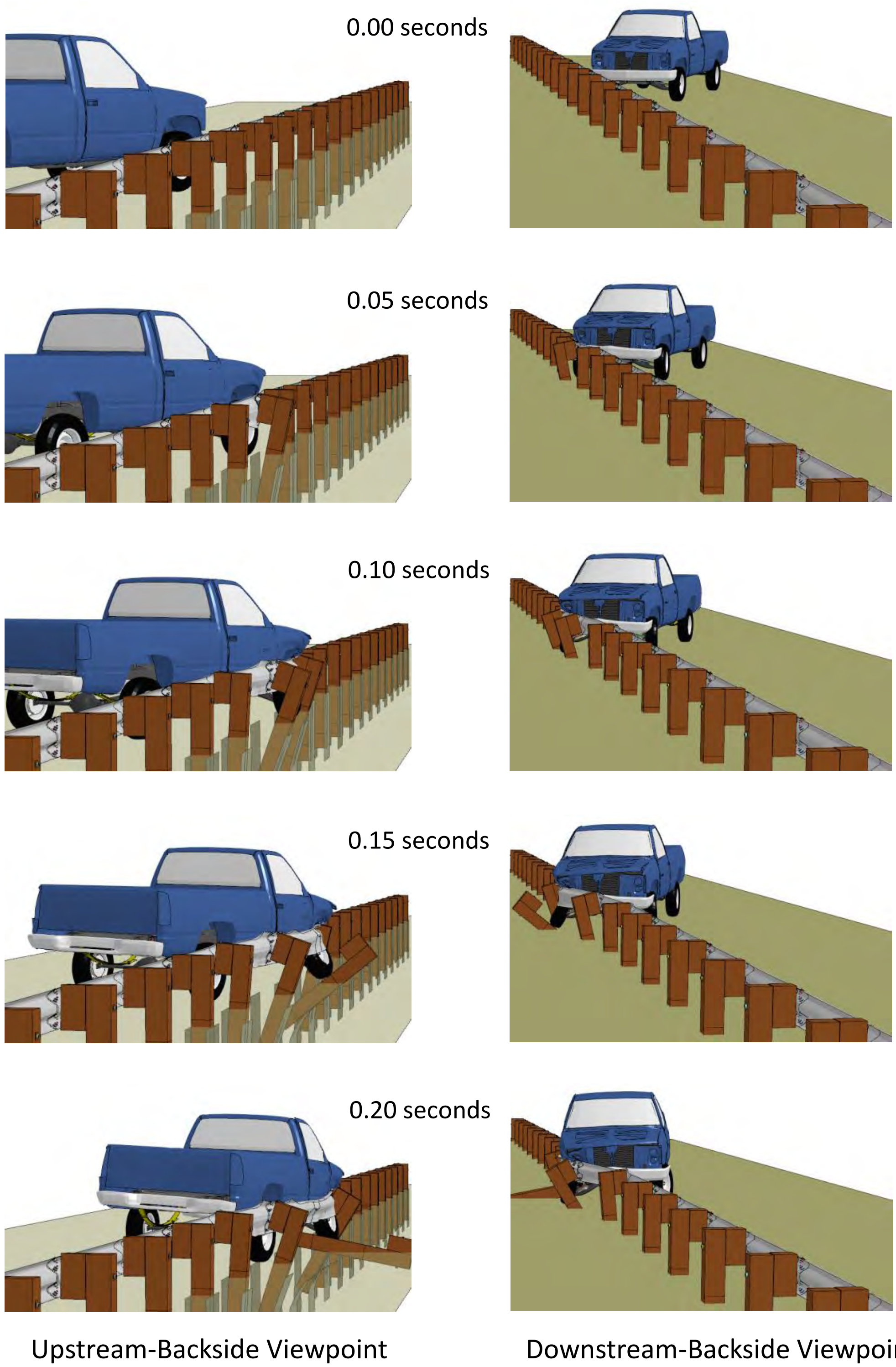


Figure N-2: Sequential views from an upstream-backside and a downstream-backside viewpoint for 6-inch erosion at two posts **analysis case.**

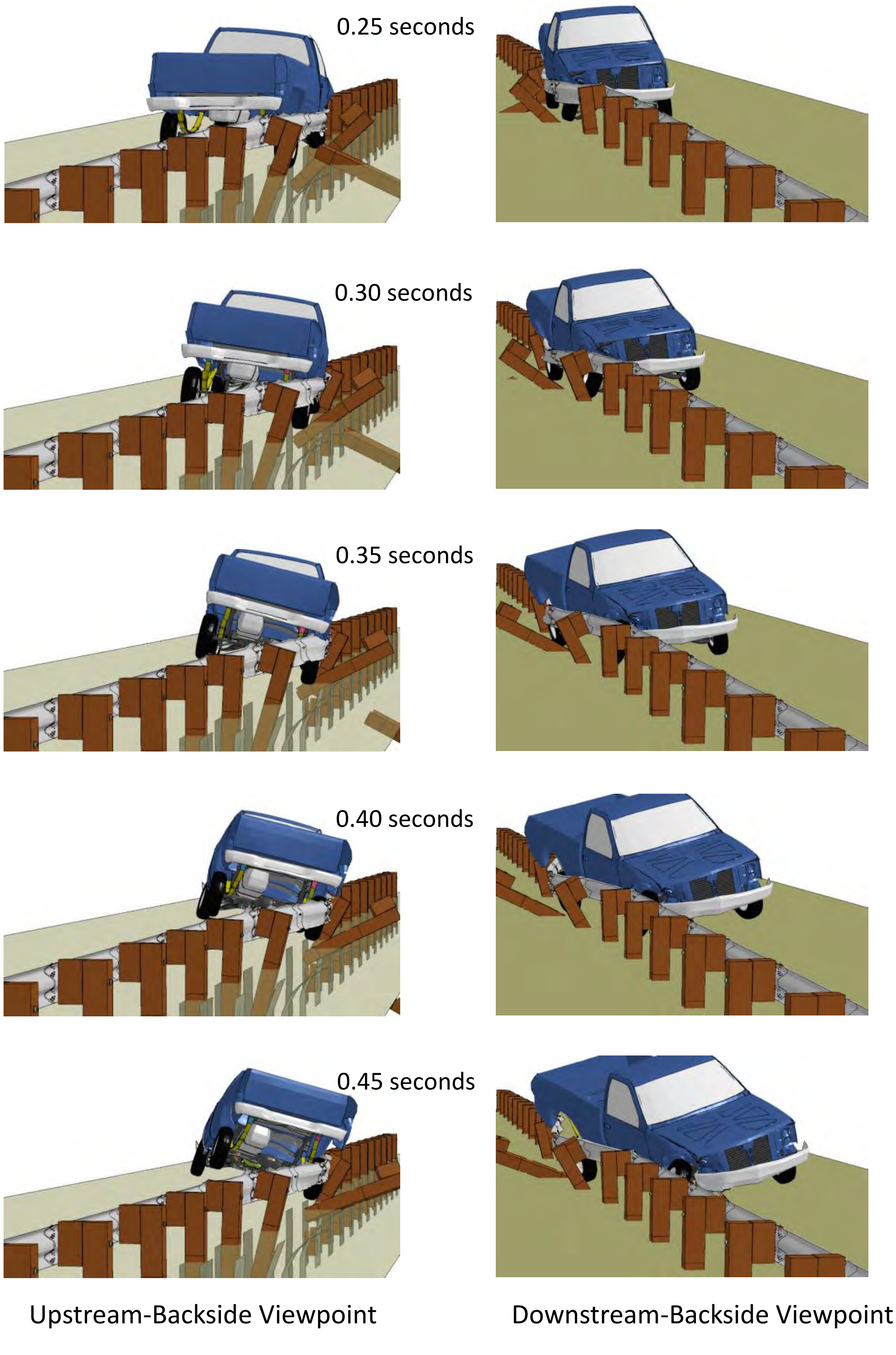


Figure N-2: [CONTINUED] Sequential views from an upstream-backside and a downstream-backside viewpoint for <u>6-inch erosion at two posts</u> analysis case.

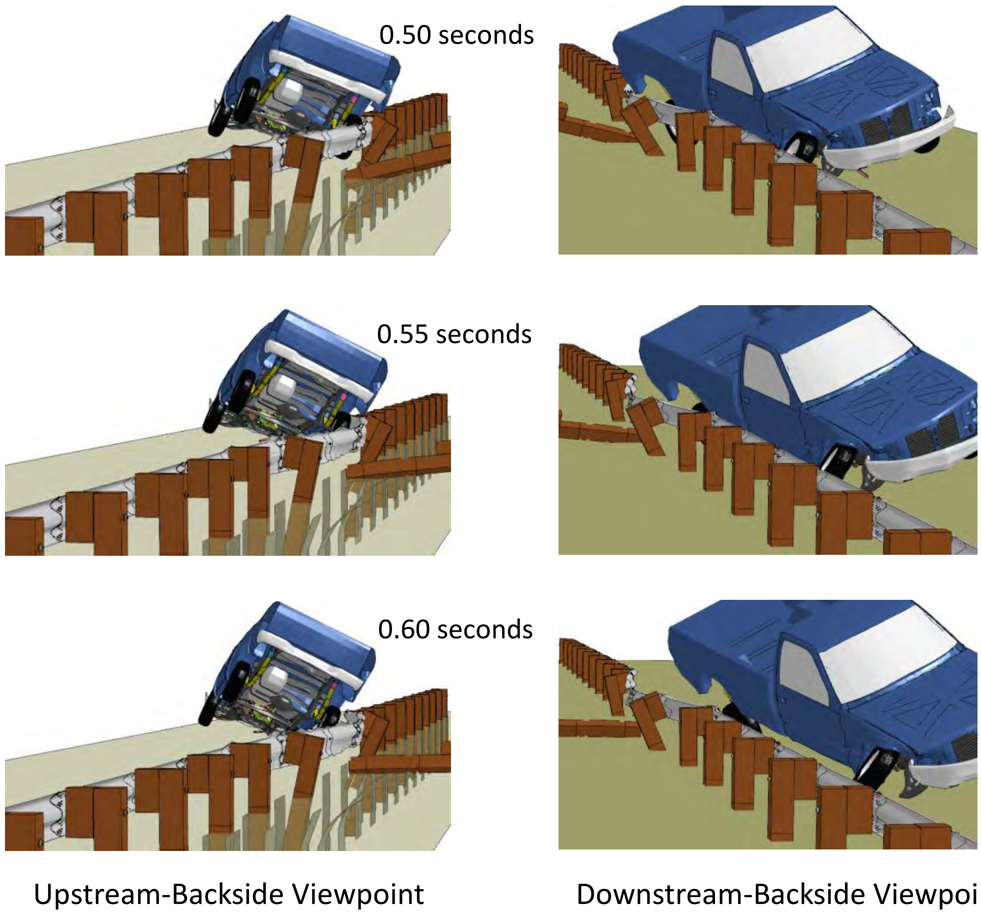


Figure N-2: [CONTINUED] Sequential views from an upstream-backside and a downstream-backside viewpoint for <u>6-inch erosion at two posts</u> analysis case.

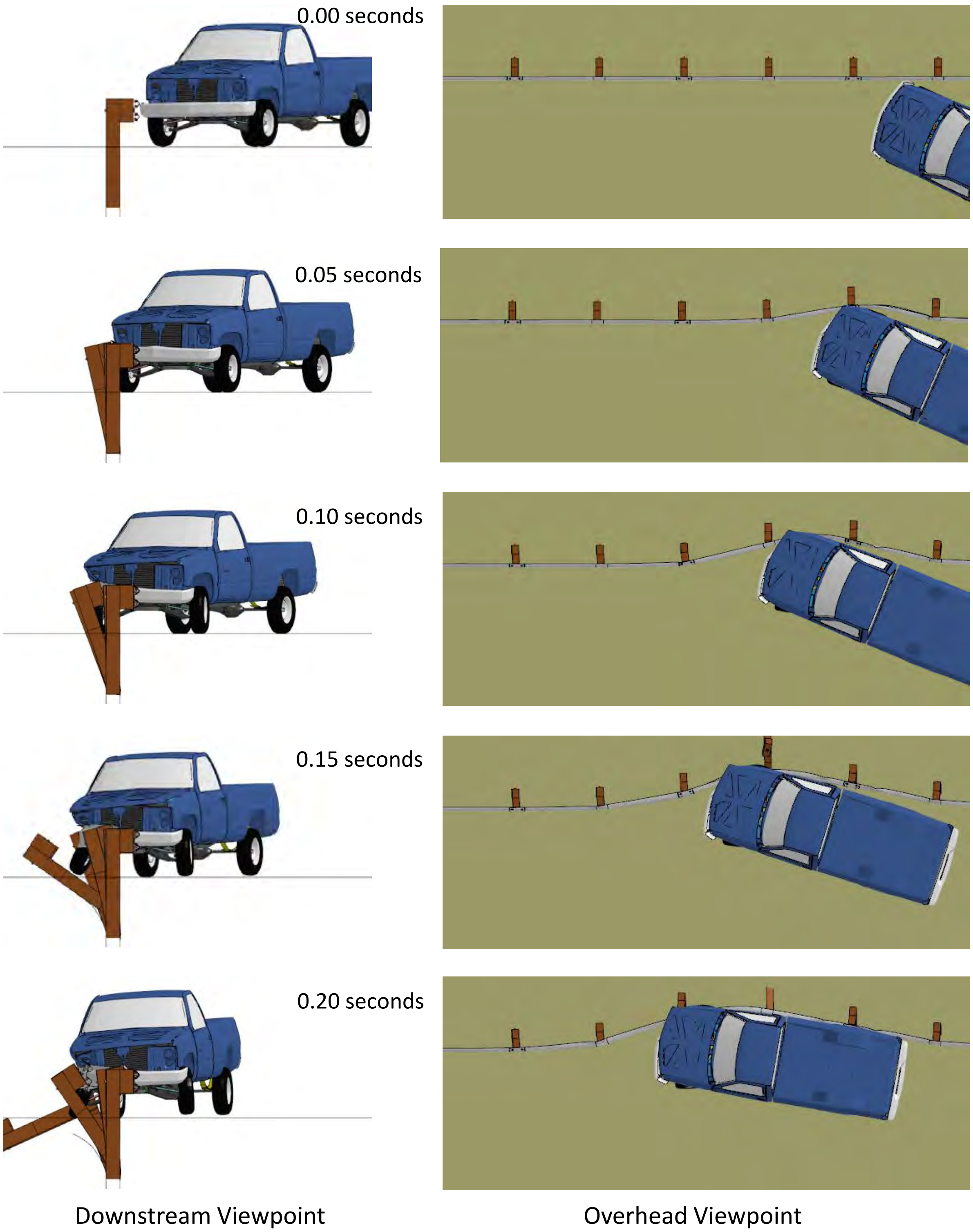


Figure N-3: Sequential views from a downstream and overhead viewpoint for 9-inch erosion at two posts **analysis case.**

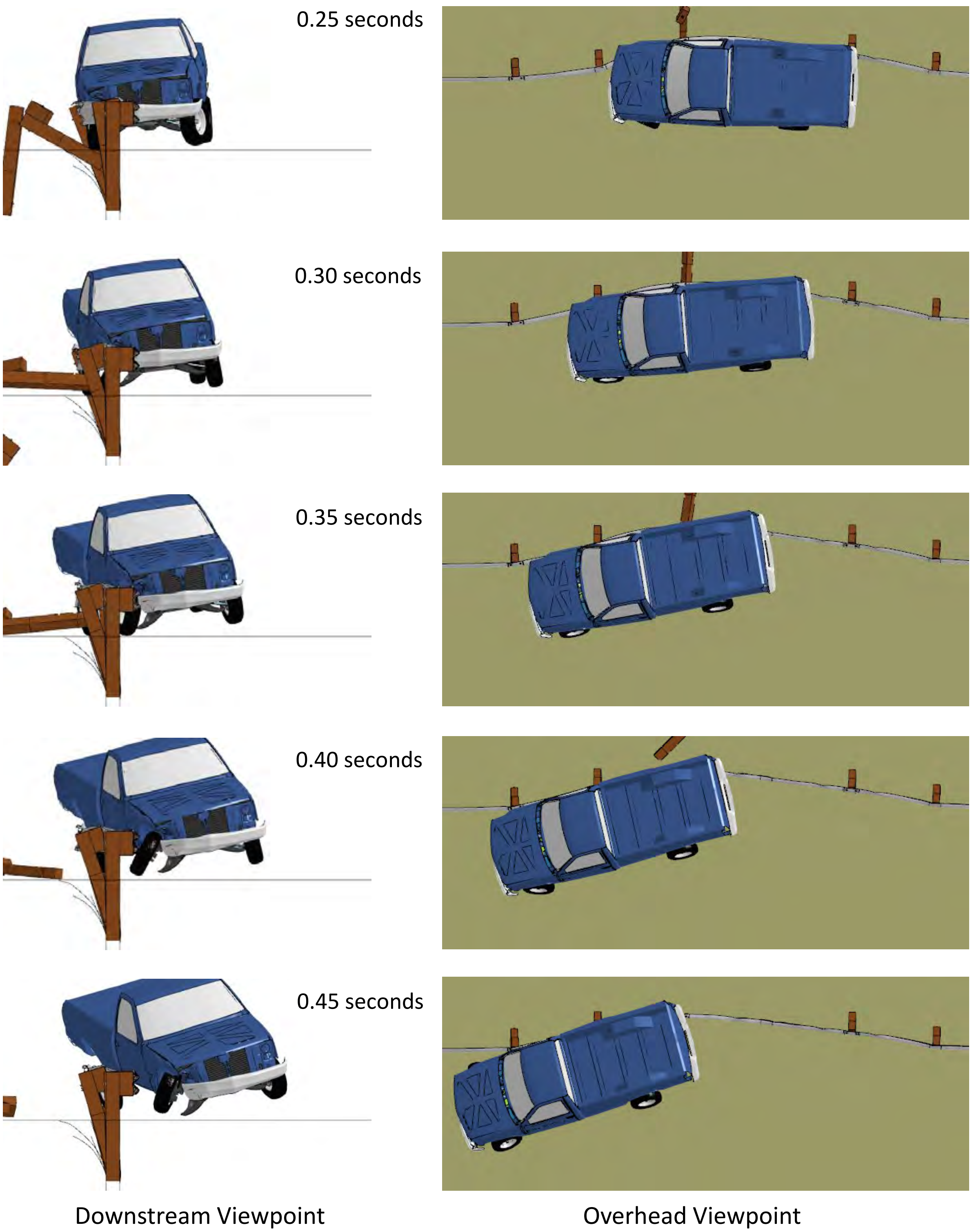


Figure N-3. [CONTINUED] Sequential views from a downstream and overhead viewpoint for 9-inch erosion at two posts analysis case.

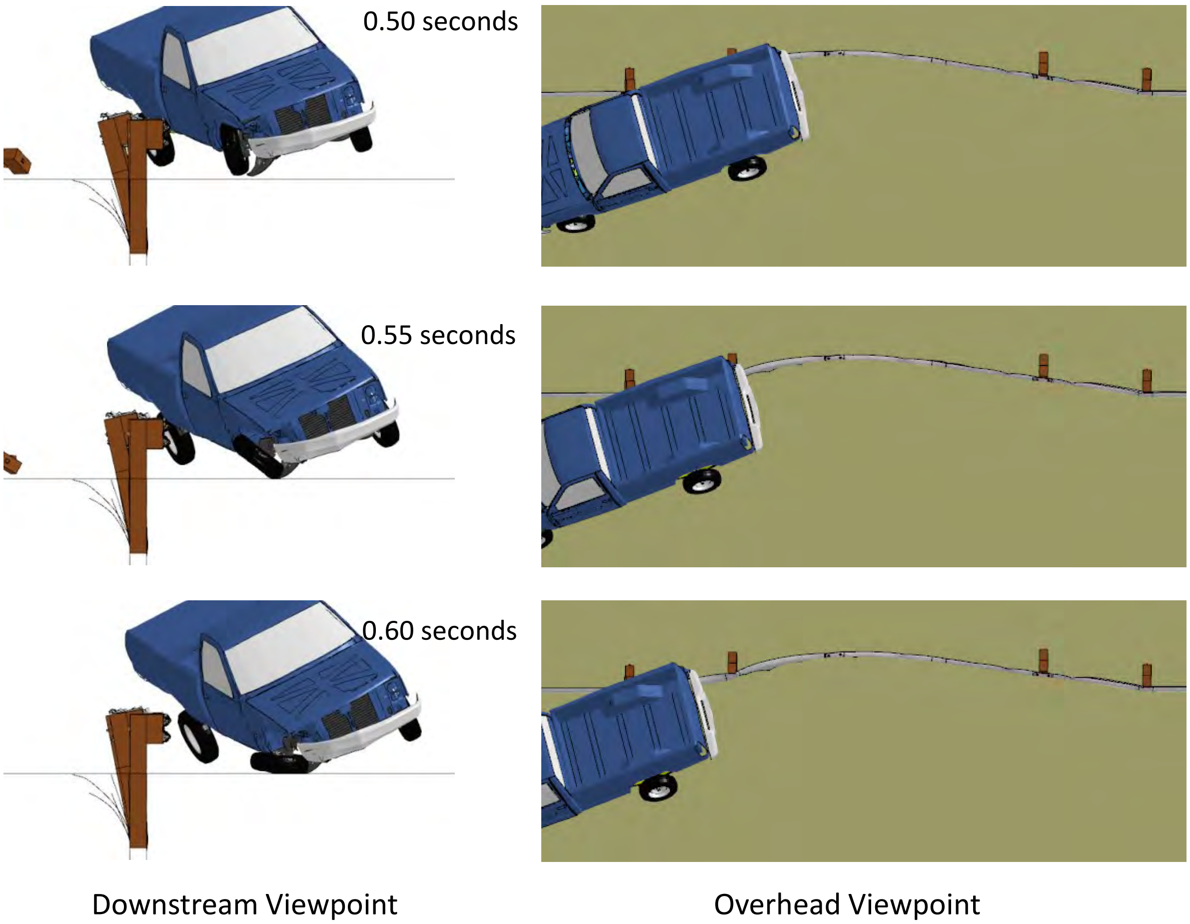


Figure N-3. [CONTINUED] Sequential views from a downstream and overhead viewpoint for 9-inch erosion at two posts analysis case.

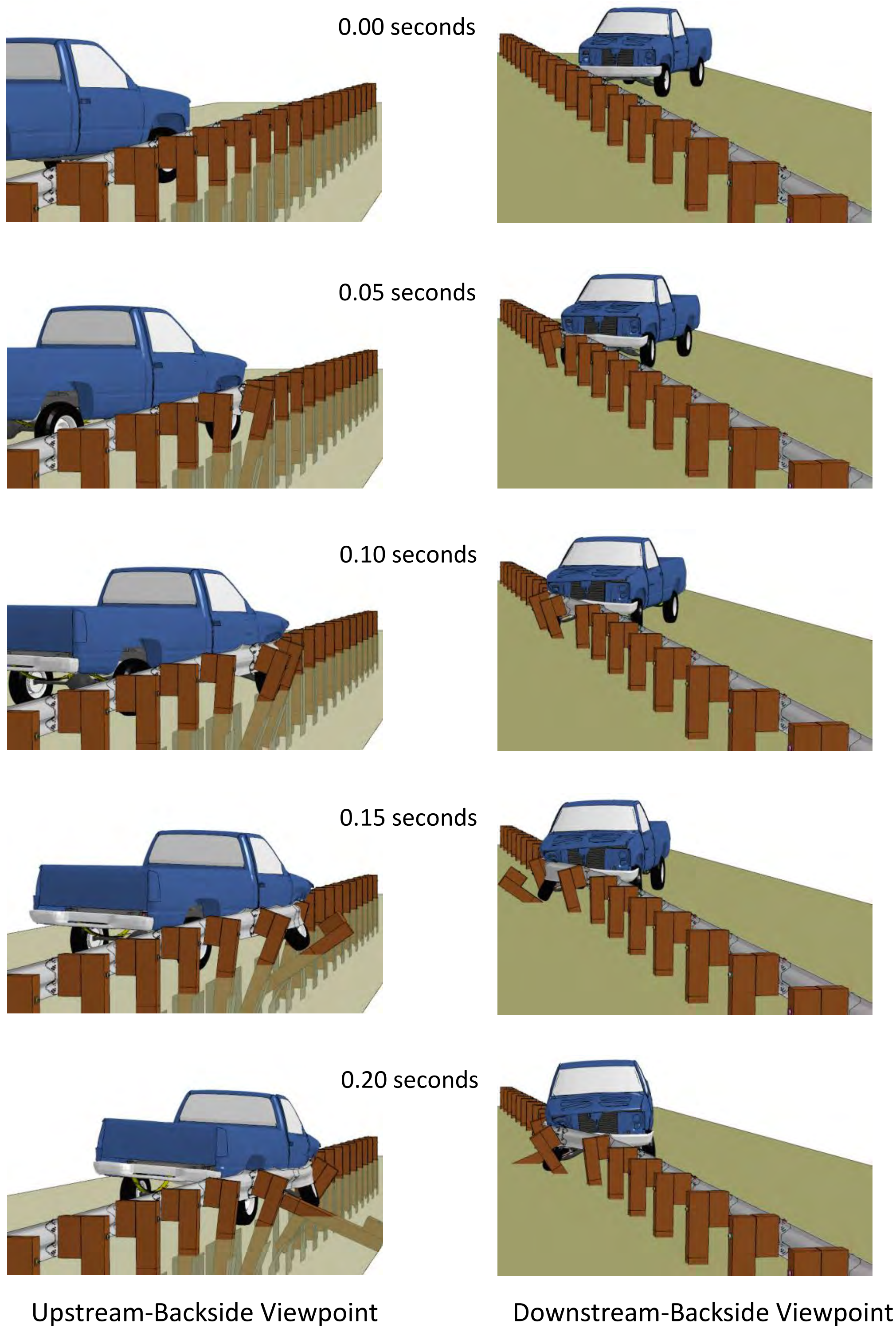


Figure N-4: Sequential views from an upstream-backside and a downstream-backside viewpoint for 9-inch erosion at two posts **analysis case.**

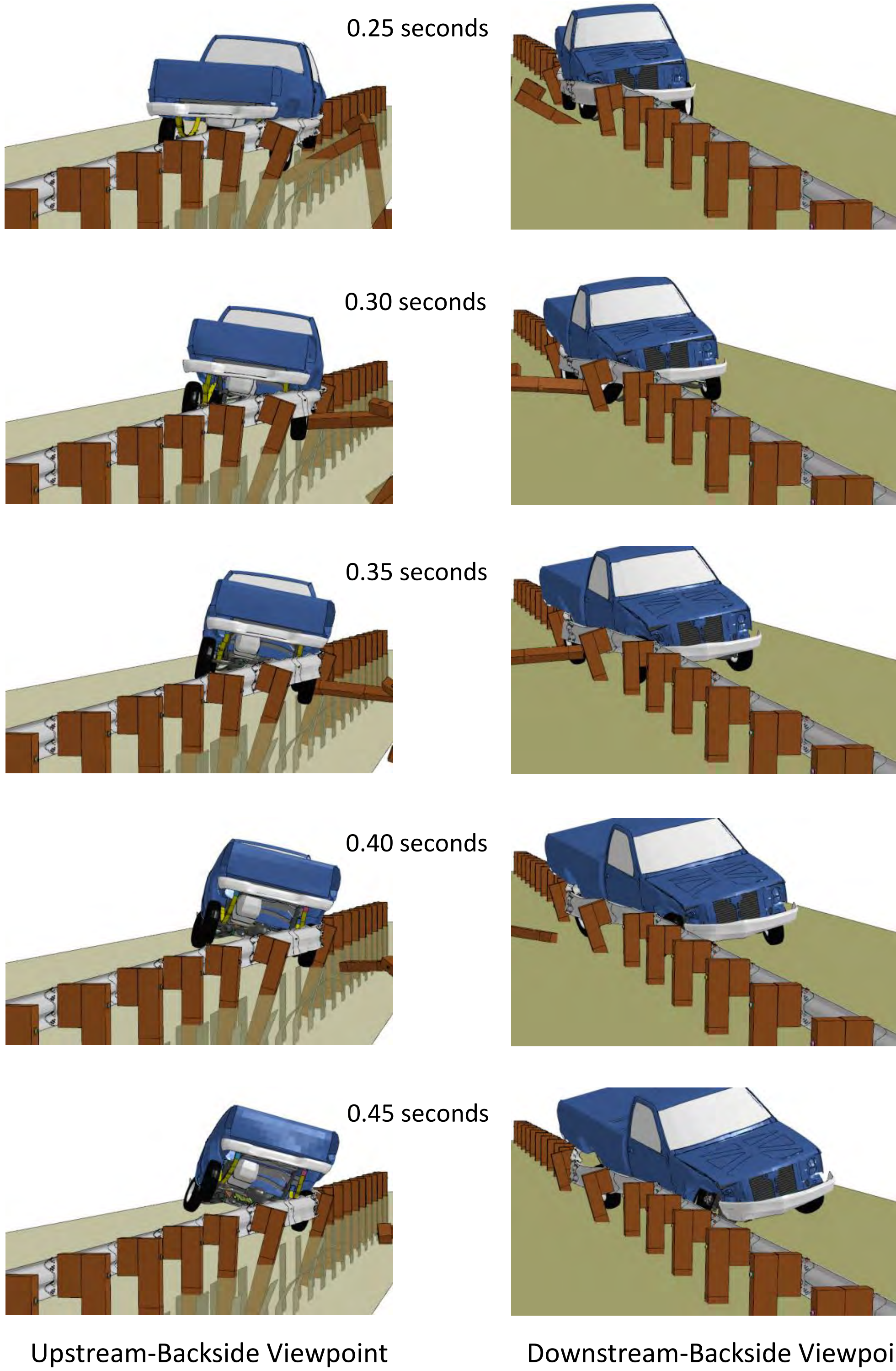


Figure N-4: [CONTINUED] Sequential views from an upstream-backside and a downstream-backside viewpoint for 9-inch erosion at two posts analysis case.

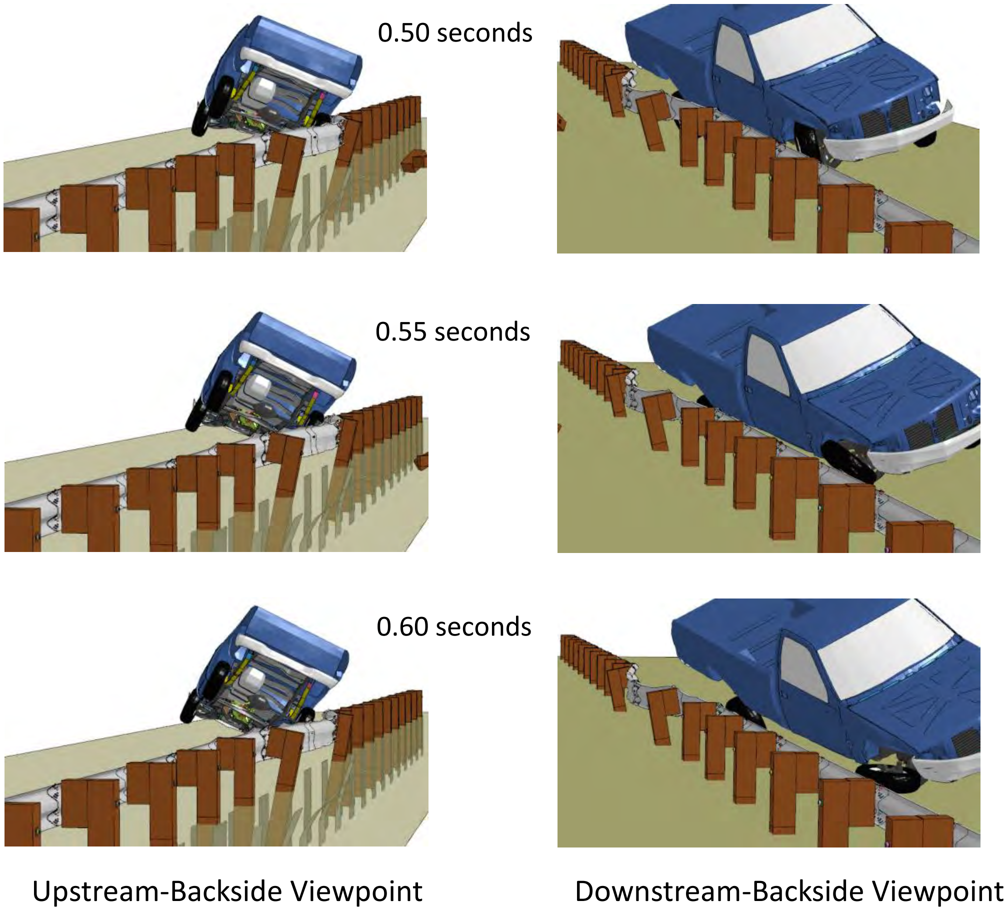


Figure N-4: [CONTINUED] Sequential views from an upstream-backside and a downstream-backside viewpoint for 9-inch erosion at two posts analysis case.

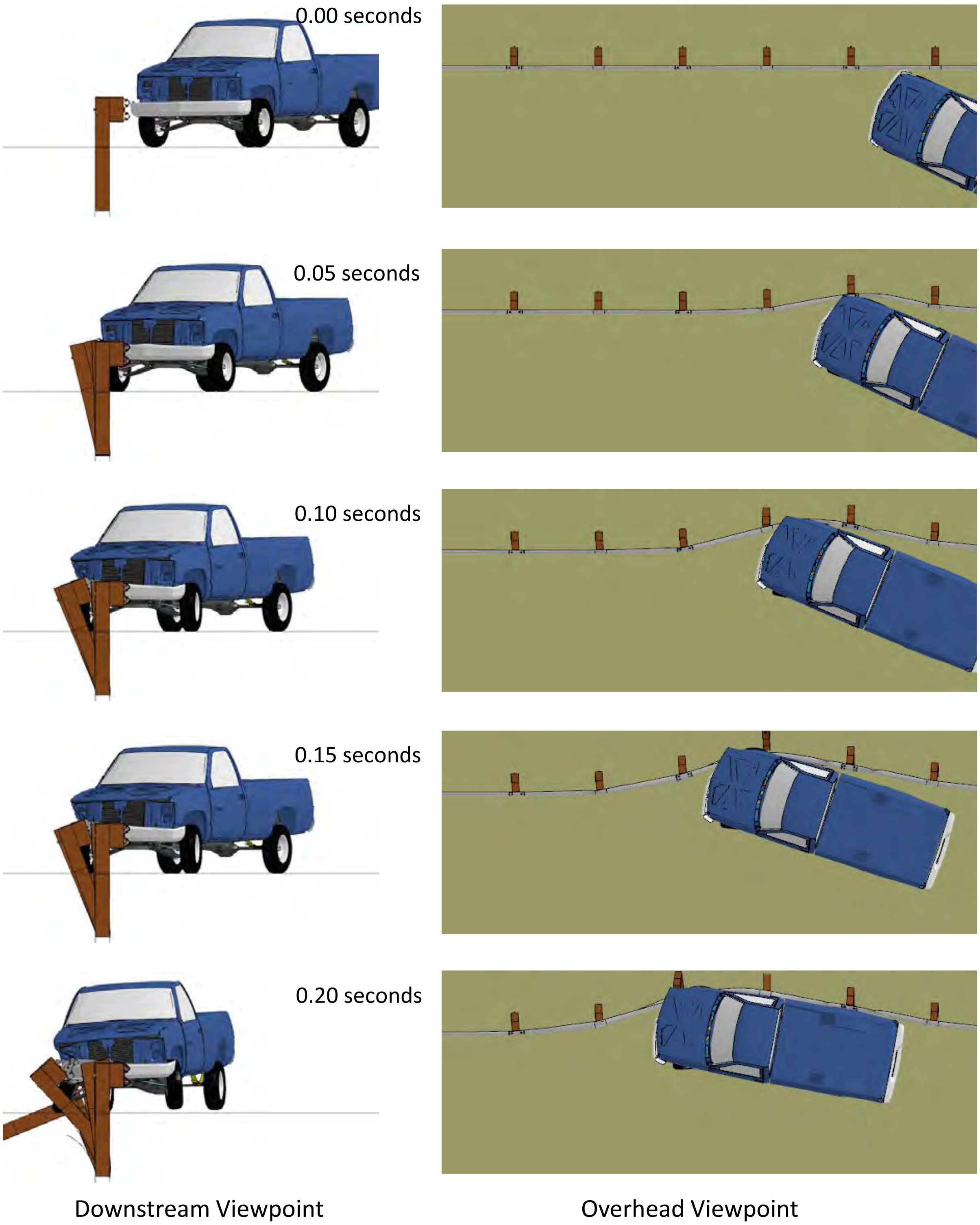
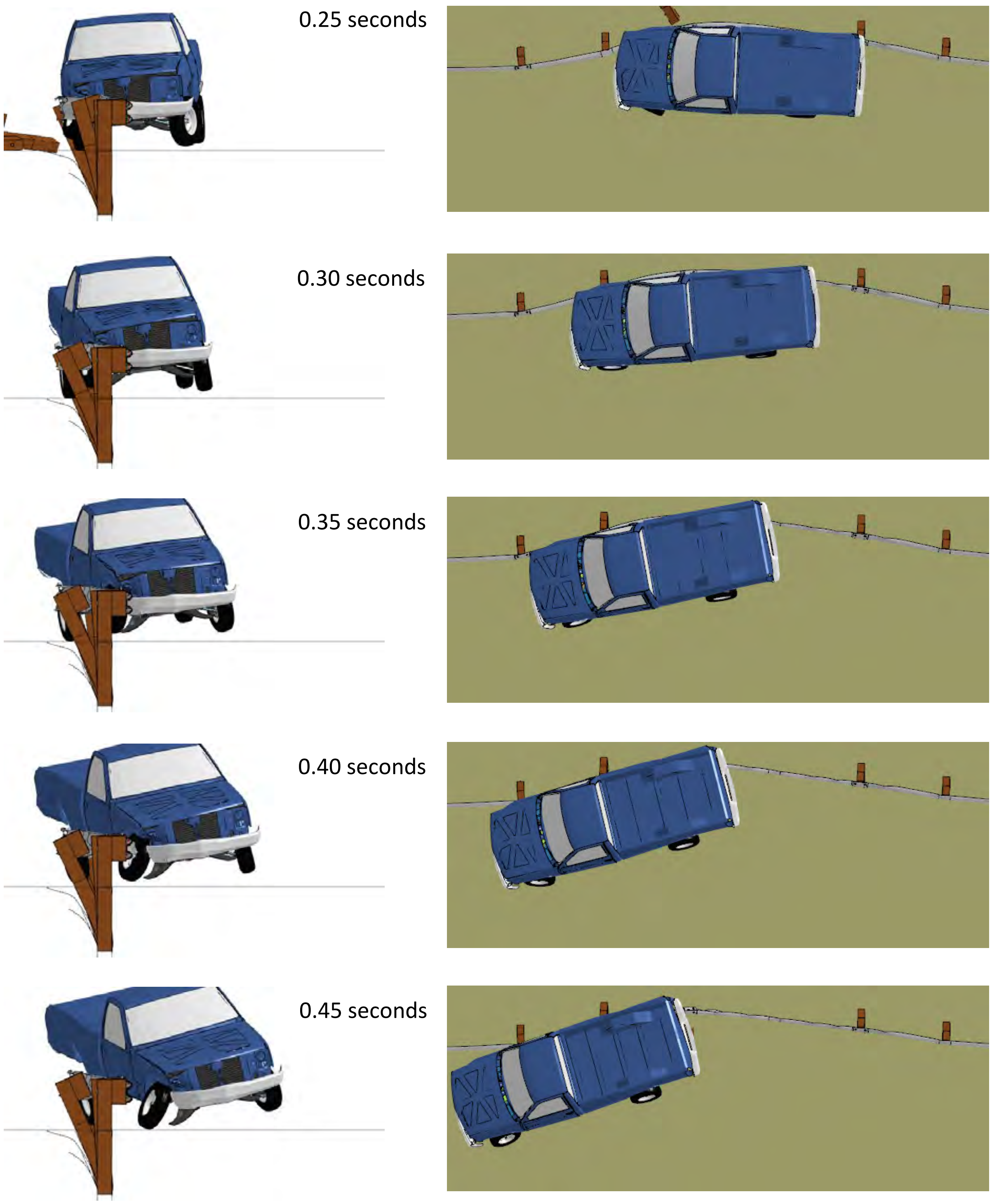


Figure N-5: Sequential views from a downstream and overhead viewpoint for 12-inch erosion at two posts **analysis case.**



Downstream Viewpoint   Overhead Viewpoint

Figure N-5: [CONTINUED] Sequential views from a downstream and overhead viewpoint for 12-inch erosion at two posts **analysis case.**

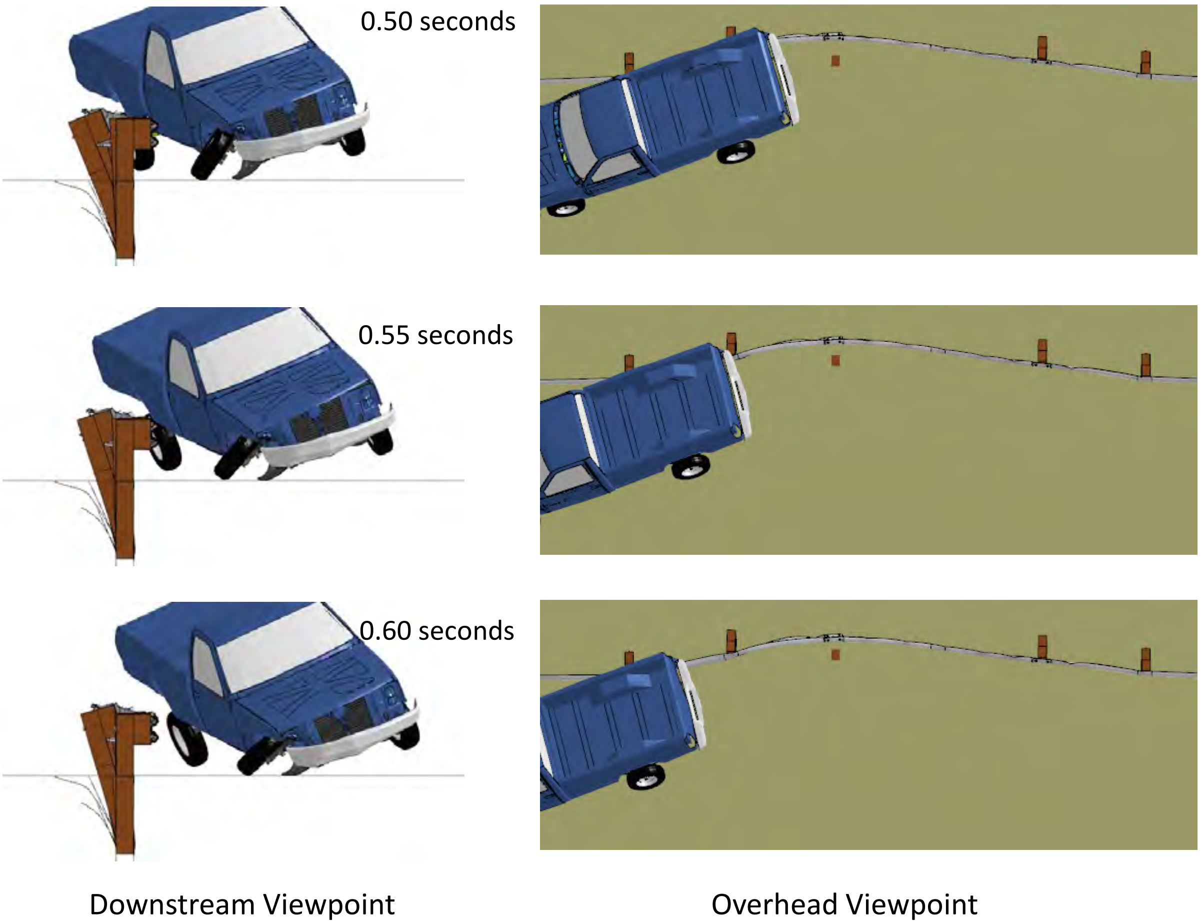


Figure N-5: [CONTINUED] Sequential views from a downstream and overhead viewpoint for 12-inch erosion at two posts **analysis case.**

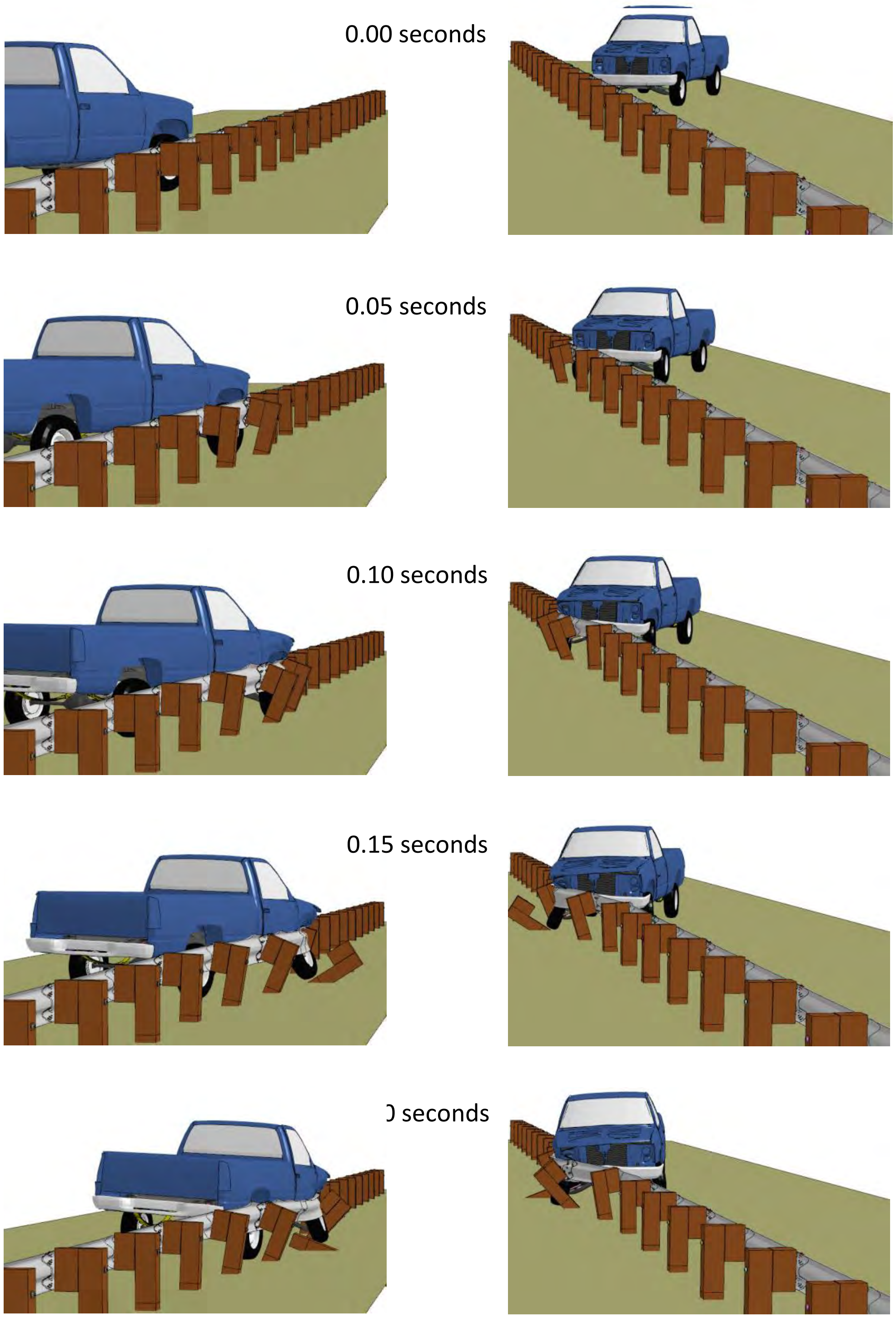


Figure N-6: Sequential views from an upstream-backside and a downstream-backside viewpoint for 12-inch erosion at two posts **analysis case.**

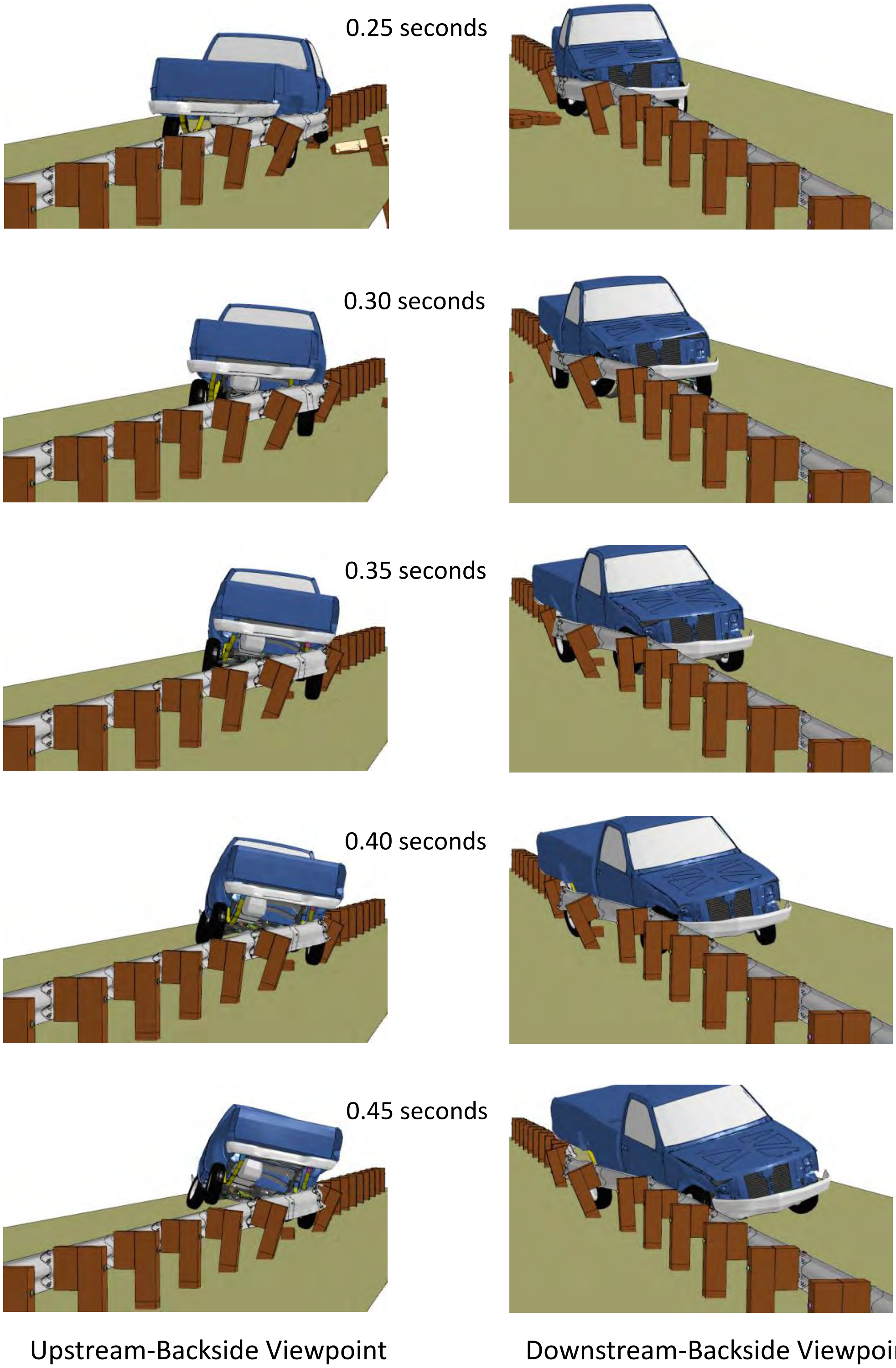


Figure N-6: [CONTINUED] Sequential views from an upstream-backside and a downstream-backside viewpoint for <u>12-inch erosion at two posts</u> analysis case.

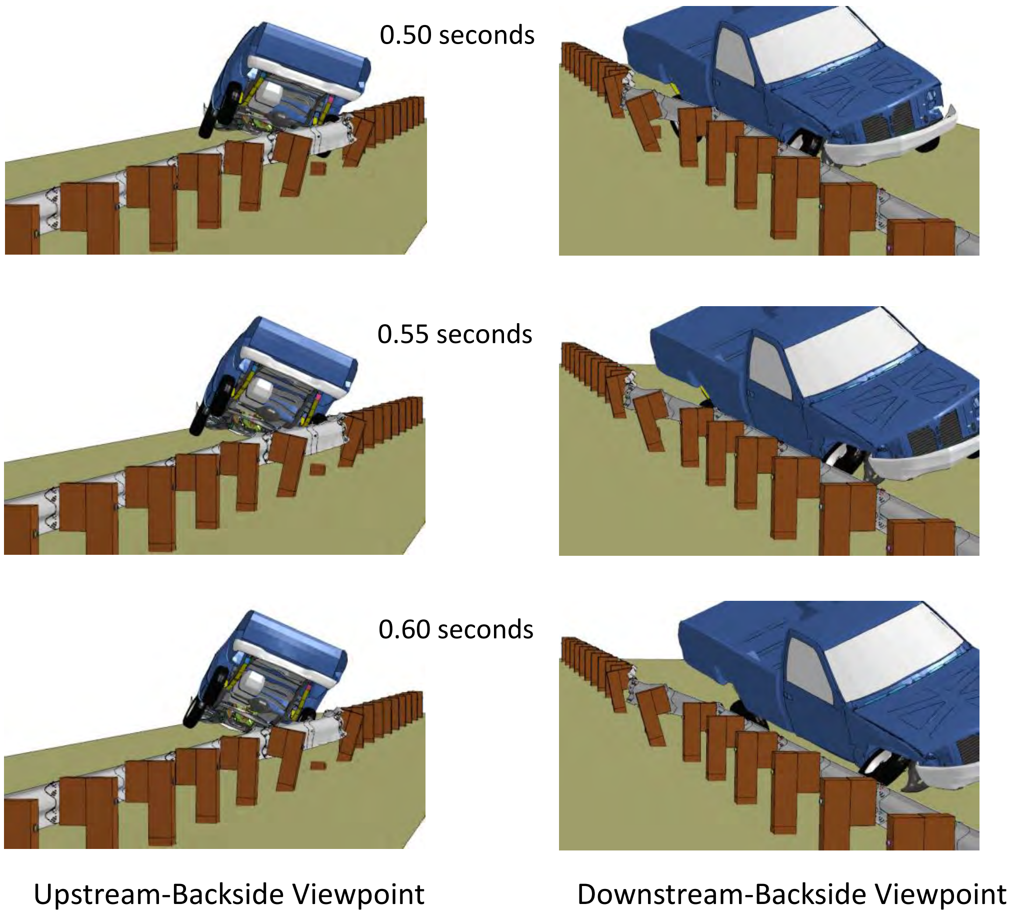


Figure N-6: [CONTINUED] Sequential views from an upstream-backside and a downstream-backside viewpoint for <u>12-inch erosion at two posts</u> analysis case.

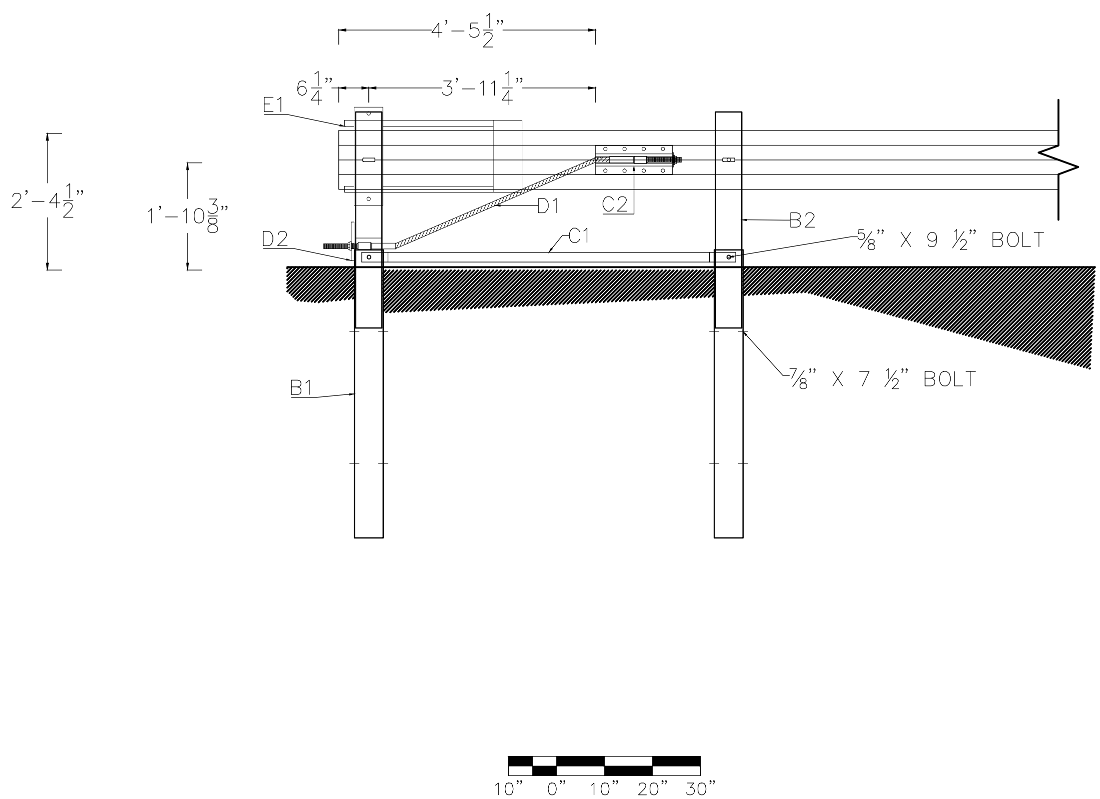
APPENDIX P

Construction Drawings for the Baseline Generic End-Terminal

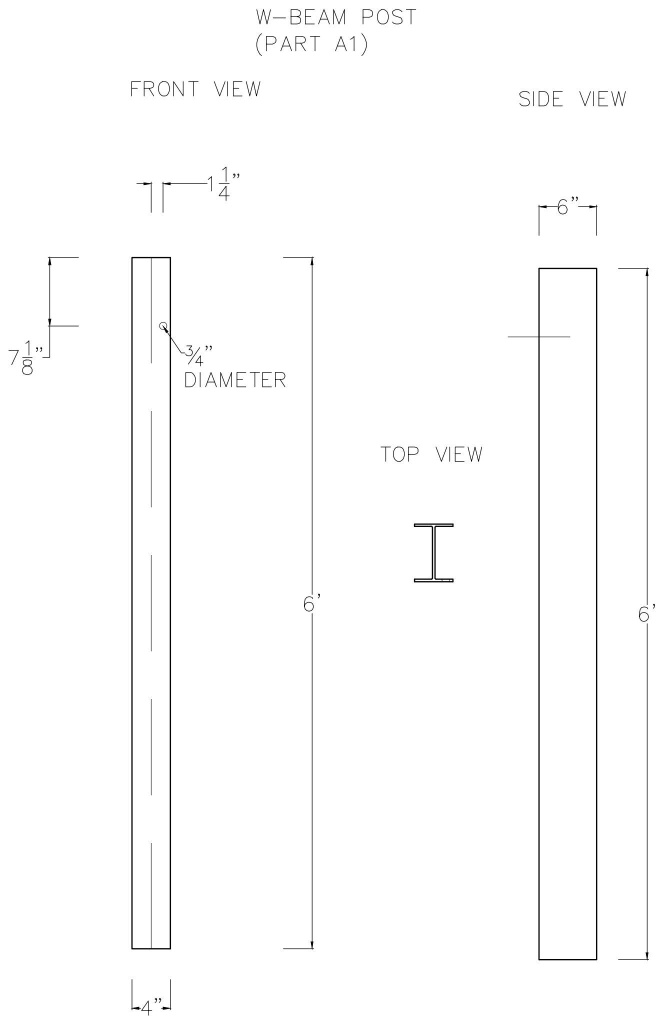
Task 4B: Quantify Anchor Strength in Terms of Anchor Damage Modes

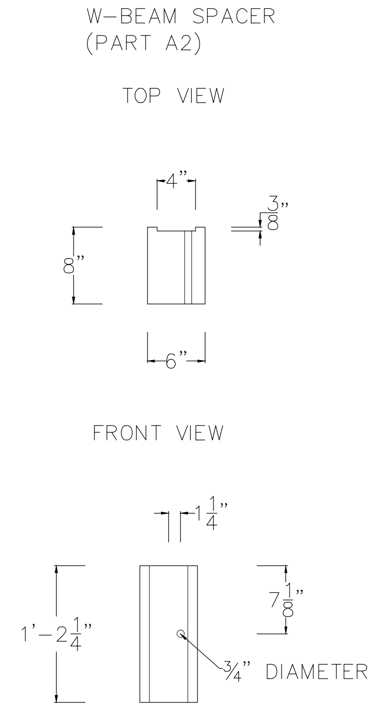
By: Archie Ray

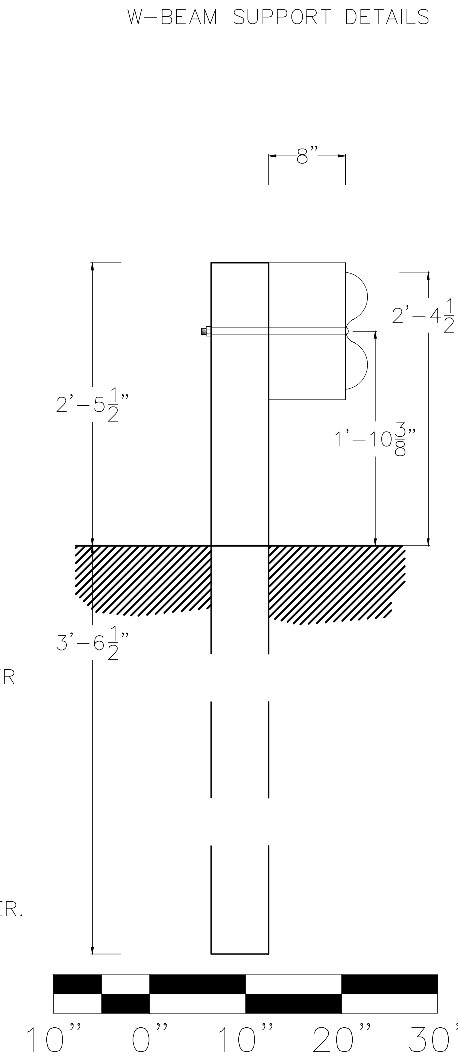
June 25, 2014



DRAWN BY: ROADSAFE LLC. AMR DATE: JUNE 25, 2014	SCALE: 40/1	WOOD POST AND RAIL ASSEMBLY	SHEET NO. 1/6

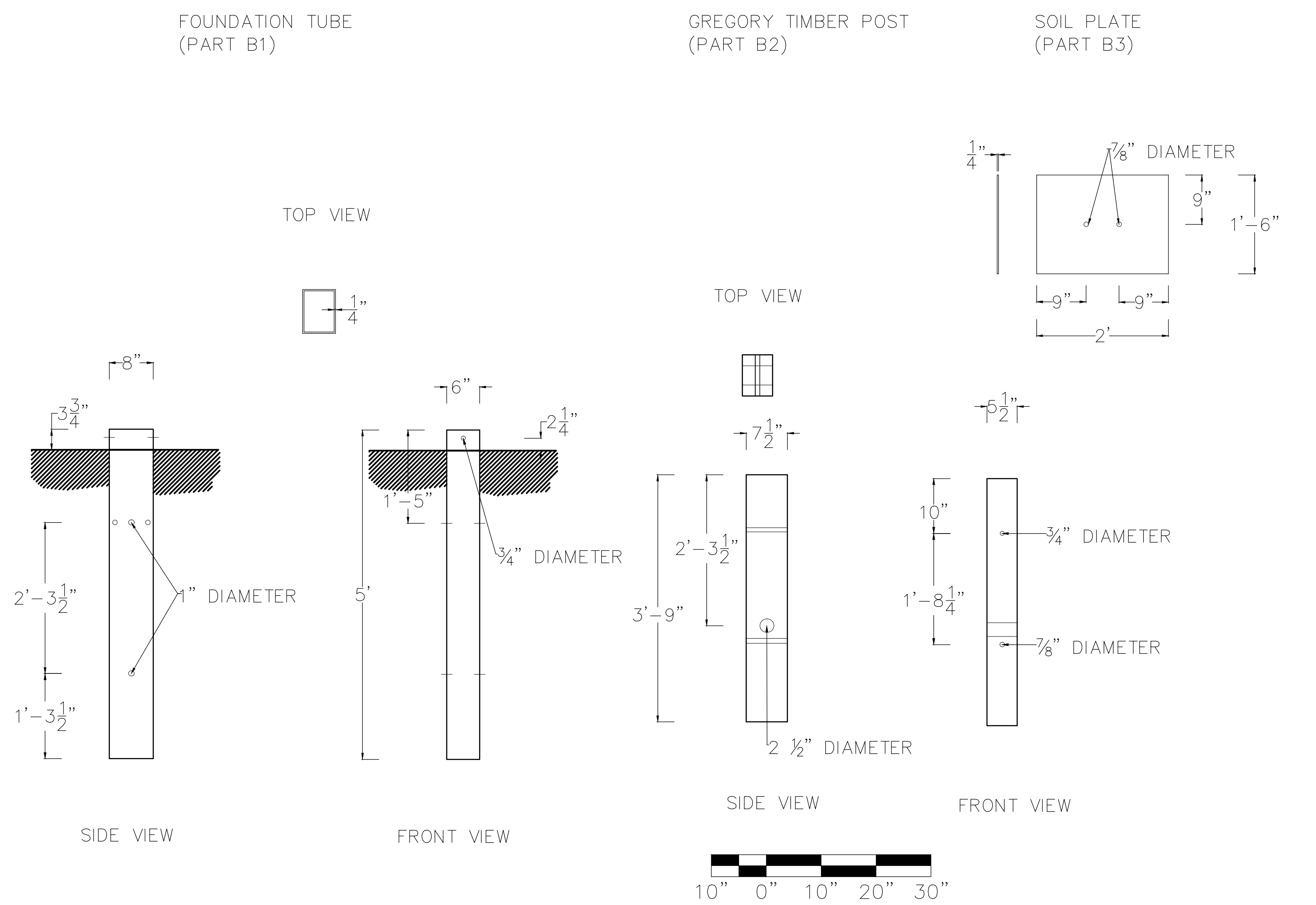




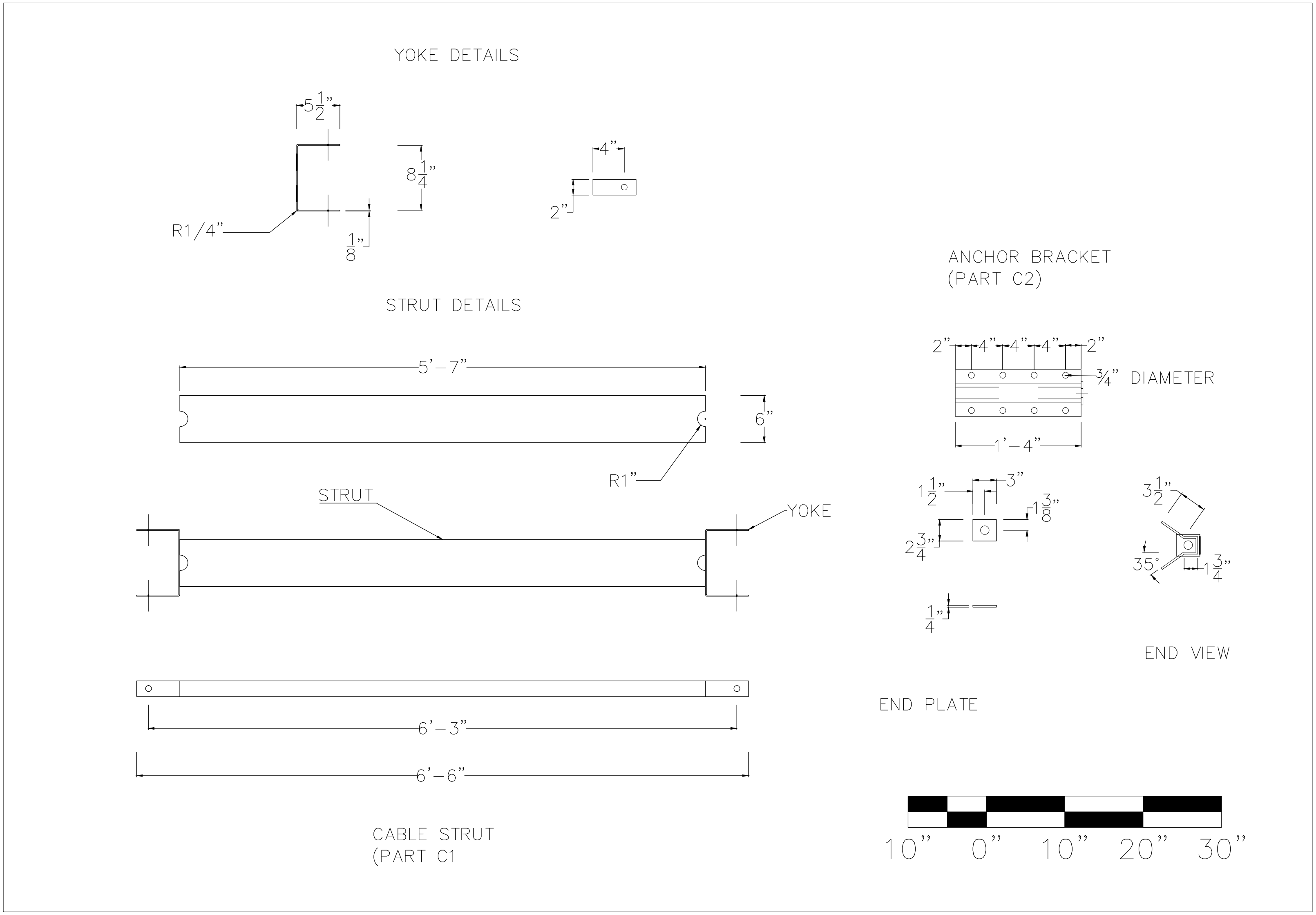


NOTES:
(1) STEEL FOR WIDE FLANGE SHALL MEET ASTM A36.
(2) ALL HOLES DRILLED OR PUNCHED TO ¾" DIAMETER.
(3) ALL BOLTS ARE ⅝" DIAMETER.
(4) BLOCKOUT DIMENSION MAY VARY.
(5) BLOCKOUT MATERIAL AND GRADE: SYP GRADE NO.1 OR BETTER.

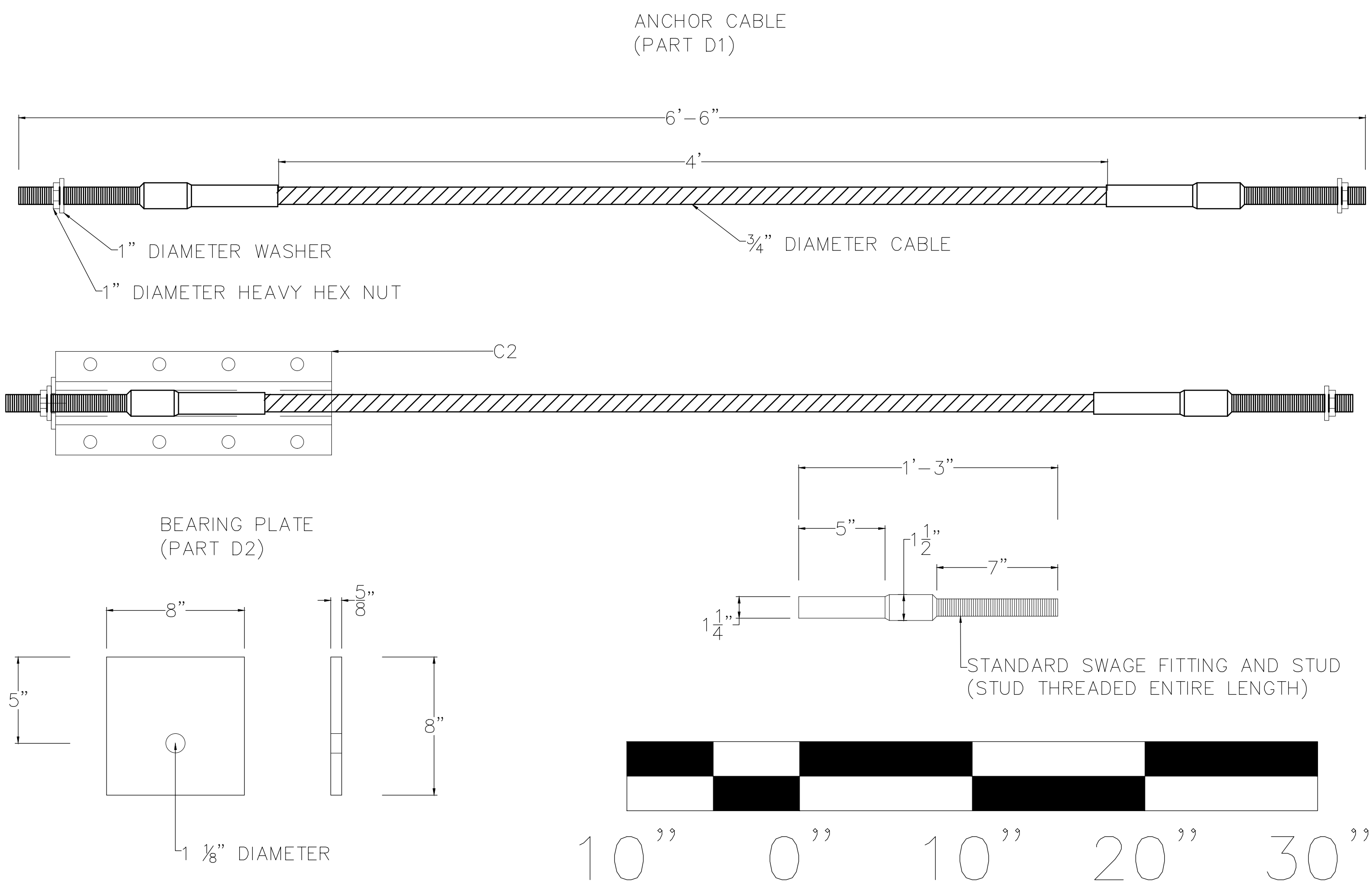
DRAWN BY: ROADSAFE LLC. AMR	SCALE: 20/1	W6X9 POST AND BLOCK OUT	SHEET NO.
DATE: JUNE 25, 2014		PART A1 AND A2	2/6



DRAWN BY: ROADSAFE LLC. AMR DATE: JUNE 25, 2014	SCALE: 30/1	FOUNDATION TUBE, WOOD POST, AND SOIL PLATE PART B1, B2, AND B3	SHEET NO. 3/6

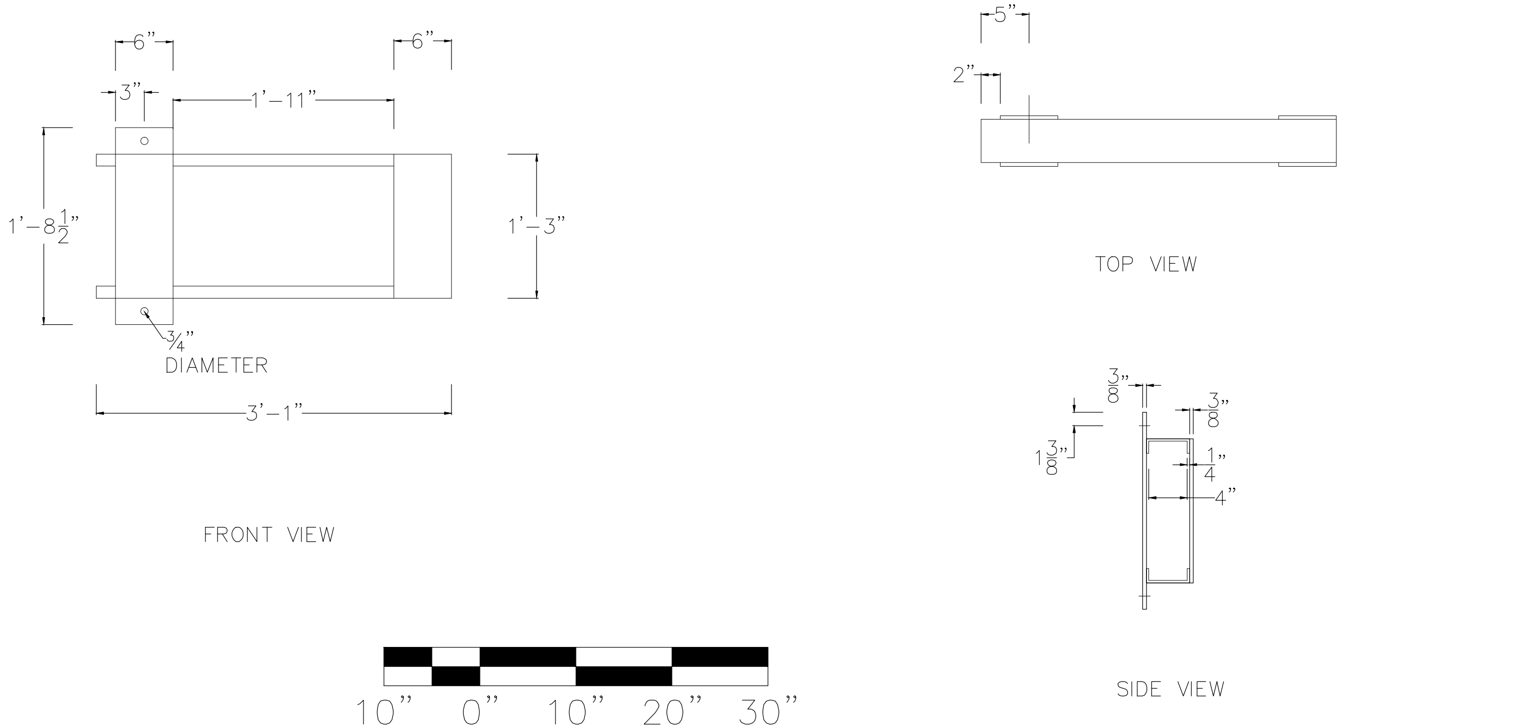


DRAWN BY: ROADSAFE LLC. AMR	SCALE: 20/1	GROUND LINE STRUT AND ANCHOR BRACKET	SHEET NO.
DATE: JUNE 25, 2014		PART C1 AND C2	4/6



DRAWN BY: ROADSAFE LLC. AMR DATE: JUNE 25, 2014	SCALE: 10/1	ANCHOR CABLE AND BEARING PLATE PART D1 AND D2	SHEET NO. 5/6

SIMULATED IMPACT HEAD
(PART E1)



DRAWN BY: ROADSAFE LLC. AMR DATE: JUNE 25, 2014	SCALE: 20/1	SIMULATED IMPACT HEAD PART E1	SHEET NO. 6/6

APPENDIX Q

Task 4B
Quantify Anchor Strength in Terms of Anchor Damage Modes

FOIL Tests 14001 Summary Sheets
Quasi-Static End-Terminal Tests

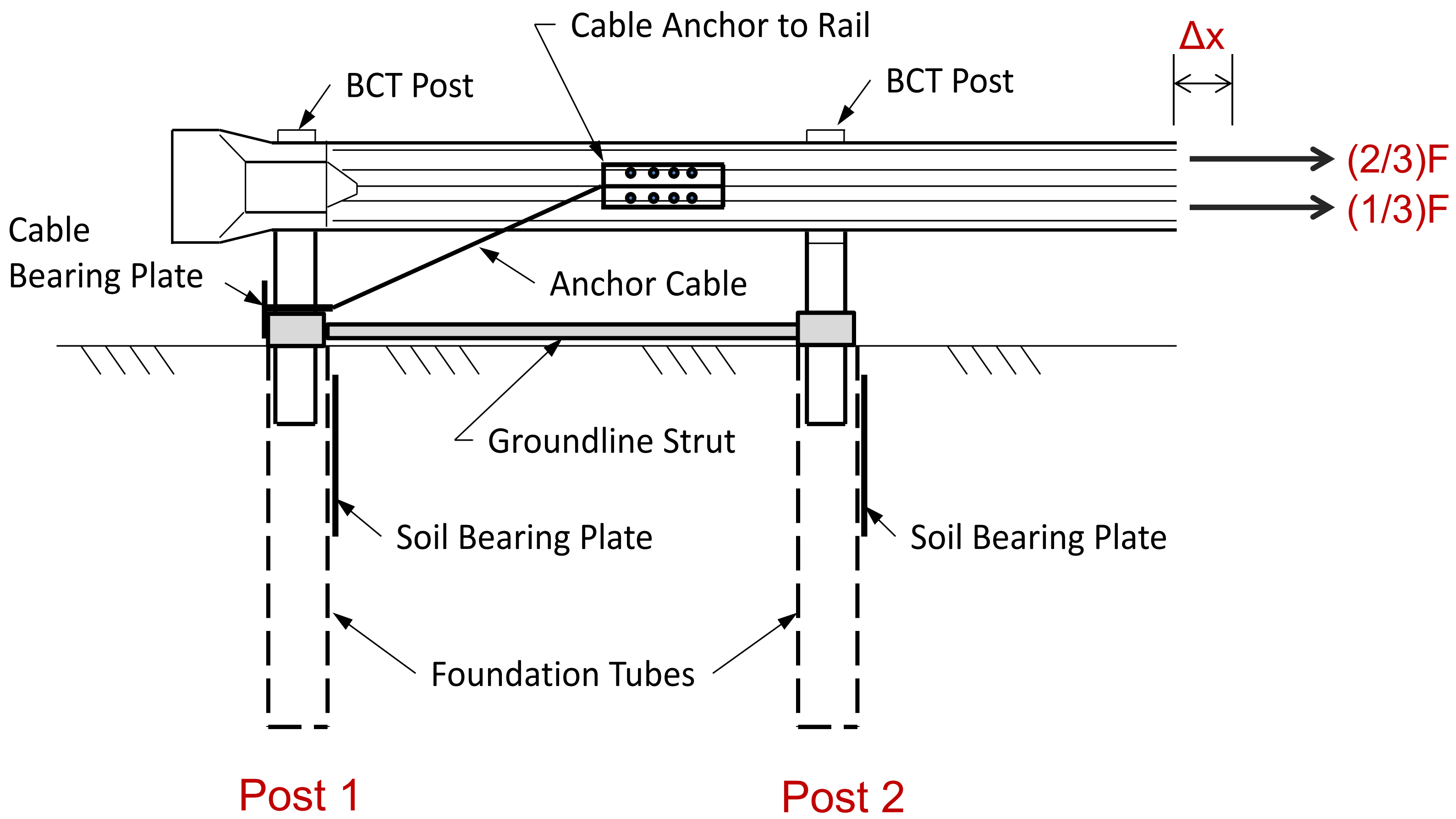
Chuck A. Plaxico, Ph.D.

RoadSafe LLC
Canton, ME

Chris Story
Federal Outdoor Impact Laboratory
McLean, VA

June 25, 2014

Test Setup



Cable Anchor to Rail
Δx
BCT Post
BCT Post
(2/3)F
(1/3)F
Cable
Bearing Plate
Anchor Cable
Groundline Strut
Soil Bearing Plate
Soil Bearing Plate
Foundation Tubes
Post 1
Post 2

Summary Table (1 of 2)

Case No.	Test No.	Test Date	Damage Mode	Soil Properties						RESULTS							
				Post 1			Post 2			Stiffness			Force				Failure
				Dry Density (pcf)	Moisture (%)	Compaction (%)	Dry Density (pcf)	Moisture (%)	Compaction (%)	0"-2" (k/in)	2"-4" (k/in)	4"-6" (k/in)	@2" (k/in)	@4" (k/in)	@6" (k/in)	Peak (k)	
4B1_000	13011B	12/16/2013	Baseline Test (used in Task 4A-2)	142.2	6.3	94.7	-	-	-	6.0	2.4	2.1	12.0	16.8	21.0	22.2	Post 1 Extraction
4B1_004	14001E	4/18/2014	Undamaged System Test	142.1	6.4	94.6	144	4.6	93.2	4.9	4.5	1.7	9.7	18.9	22.0	24.0	Soil Only
4B2_001	14001D	4/16/2014	No groundline strut	143.4	5.4	95.5	143.5	4.4	93.2	4.5	1.9	1.8	8.7	12.8	12.0	14.8	Post 2 Split
4B1_002	14001M	6/23/2014	2" reduced embedment	138.8	5.3	92.5	140.3	4.1	90.8	4.8	1.9	0.8	9.7	13.4	15.0	18.8	Post 1 Extraction
4B1_003	14001F	5/6/2014	4" reduced embedment	145.2	5.7	96.6	143.4	4.0	92.8	5.0	1.5	0.6	9.9	12.8	14.0	15.7	Post 1 Extraction
4B1_004	14001L	6/20/2014	6" reduced embedment	141.3	5.1	94.1	142.8	4.5	92.4	5.2	0.9	1.3	10.4	12.3	15.0	22.6	Post 2 Split
4B1_005	14001G	5/12/2014	8" reduced embedment	144.2	5.3	95.7	143.7	5.1	93.0	5.8	4.2	2.8	11.7	20.1	19.0	23.2	Strut Bent
4B3_001	14001H	6/4/2014	1" slack in anchor cable	143.7	5.3	95.7	143.8	3.7	93.1	5.4	4.1	2.1	10.9	19.1	23.3	29.9	Post 2 Split Strut Bent
4B3_002	14001I	6/6/2014	2" slack in anchor cable	140.4	5.7	93.5	143.4	4.3	92.8	5.4	2.8	1.3	10.8	16.4	19.0	19.3	Post 2 Split Strut Bent
4B3_003	14001K	6/18/2014	3" slack in anchor cable	140.2	5.8	93.3	144.6	4.6	93.5	2.2	3.6	2.1	4.4	11.6	15.8	22.5	Post 2 Cracked
4B3_004	14001J	6/16/2014	4" slack in anchor cable	141.8	4.6	94.4	145.1	5.3	93.9	1.3	2.3	3.5	2.6	7.3	14.2	25.2	Post 2 Split Strut Bent

Summary Table (1 of 2)

Test No.	Test Date	Damage Mode	PRE-TEST MEASUREMENTS									POST-TEST RESULTS		
			Distance Post 2 to Soil Pit Front (in)	Distance Post 2 to Soil Pit Rear (in)	Distance Post 1 to Soil Pit Front (in)	Distance Post 1 to Soil Pit Rear (in)	Distance Center to Center Posts (in)	Height to Top of Rail (in)	Height to Load Point Top (in)	Height to Load Point Bottom (in)	Post Embedment Depth (in)	Distance Center to Center Posts (in)	Groundline Deflection Post #1 (in)	Groundline Deflection Post #2 (in)
13011B	12/16/2013	Baseline Test (used in Task 4A-2)												
14001E	4/18/2014	Undamaged System Test	88.0	16.0	43.0	30.0	75.5	28.5	25.5	17.5	57.0	74.0	5.8	4.0
14001D	4/16/2014	No groundline strut	86.0	18.0	45.0	28.0	74.0	-	-	-	-	70.0	4.3	< 0.125
14001L	5/20/2014	2" reduced embedment	88.5	17.8	42.0	30.5	75.3	29.5	26.5	18.5	55.0	75.0	8.0	7.0
14001F	5/6/2014	4" reduced embedment	85.8	18.3	41.3	31.8	74.5	31.5	28.5	17.3	53.0	73.3	4.8	4.0
14001L	6/20/2014	6" reduced embedment	87.0	19.3	42.0	30.5	76.5	34.5	31.5	23.5	51.0	73.3	9.0	6.5
14001G	5/12/2014	8" reduced embedment	85.5	18.5	44.5	28.5	75.0	31.0	28.0	20.0	49.0	71.5	4.5	3.0
14001H	6/4/2014	1" slack in anchor cable	87.5	18.3	41.5	25.0	75.3	26.0	23.0	16.0	57.0	69.0	9.5	3.0
14001I	6/6/2014	2" slack in anchor cable	86.8	19.5	40.8	31.8	75.5	26.5	22.8	15.0	57.0	69.5	9.8	5.0
14001K	6/18/2014	3" slack in anchor cable	87.0	19.3	42.0	30.5	75.0	29.0	26.0	18.0	57.0	72.8	8.0	6.5
14001J	6/16/2014	4" slack in anchor cable	86.8	19.5	40.8	31.8	76.3	27.3	24.3	17.0	57.0	68.8	9.5	3.0

Test Information

Project Case Number:	4B1_001
FOIL Test Number:	14001E
Test Date:	18-April-2014

System Properties

Rail Height (in):	28.5
Post Type:	BCT
Rail-to-Post 1:	Not Bolted
Rail-to-Post 2:	Bolted
Foundation Tube Type:	FMM02 (AASHTO-AGC-ARTB)
Embedment Depth (in):	57.0

Damage Type

Category:	Undamaged
Level:	0

Soil Properties

	@Post 1	@Post 2
Dry Density (pcf):	142.1	144.0
Wet Density (pcf):	151.1	150.6
Moisture Content (%):	6.4	4.6
Compaction (%):	94.6	93.2

Load Properties

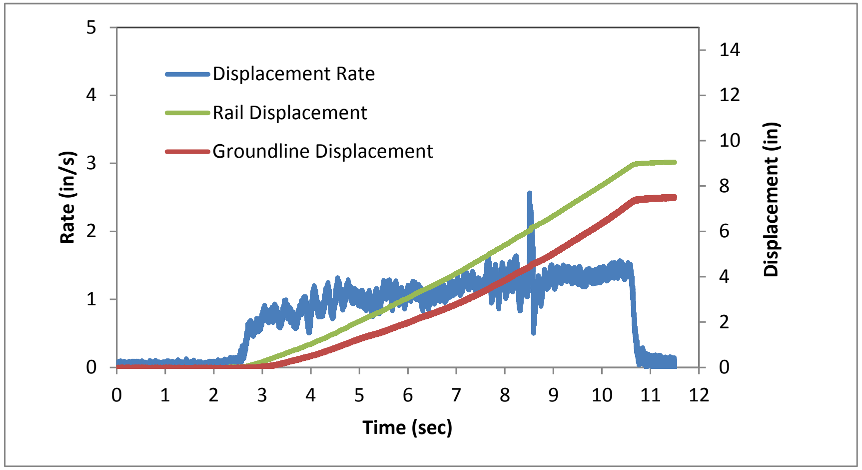
Quasi-Static Rate (in/s):	≈ 1.0
Method:	Winch & Cable
Load Point 1 (in):	25.5
Load Point 2 (in):	17.5

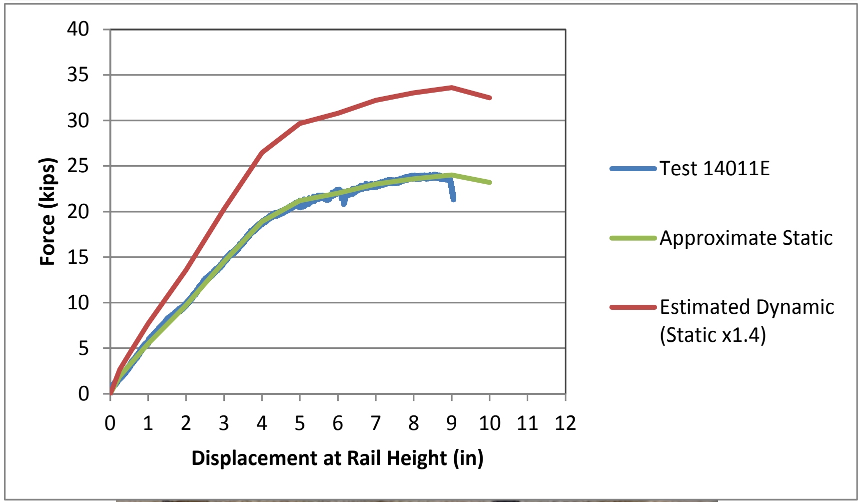
Result

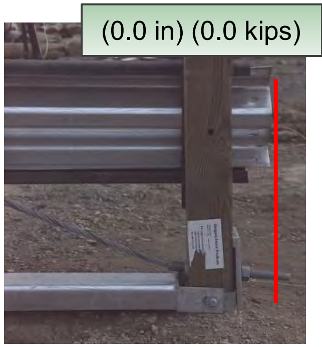
Anchor condition:	Soil Disp. Only
Max Load (kips):	22.0
Max Disp. at Max Load (in):	8.0

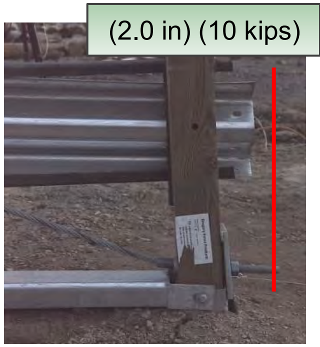
	@2 in.	@4 in.	@6 in.
Force (kip):	12.0	16.8	21
Stiffness (k/in):	4.9	4.5	1.7

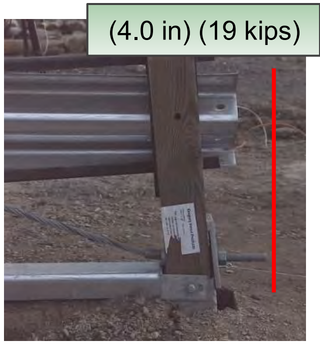
Post Test:	@Post 1	@Post 2
Groundline Displacement (in)	5.8	4.0

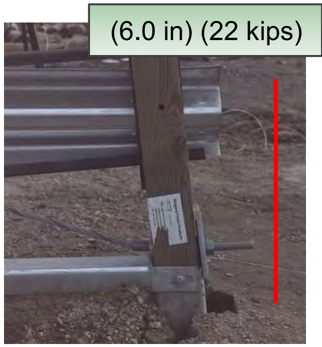




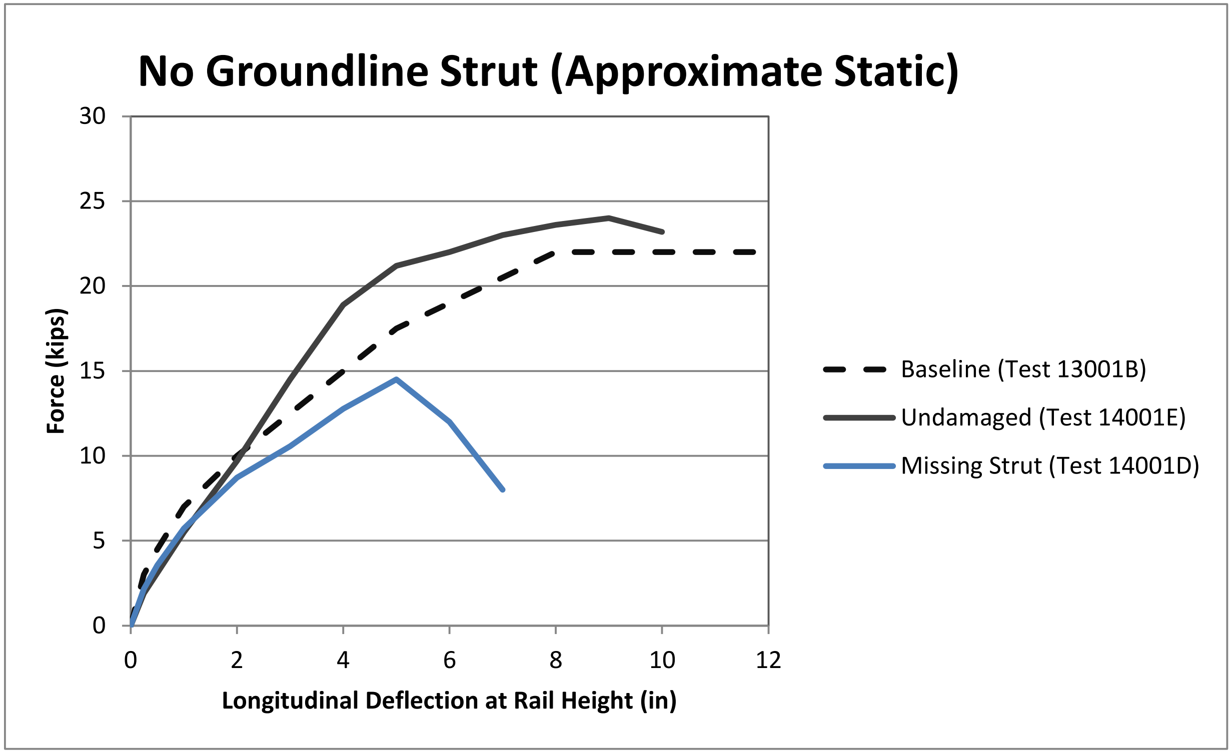








No Groundline Strut



Test Information

Project Case Number:	4B_001
FOIL Test Number:	14001D
Test Date:	16-April-2014

System Properties

Rail Height (in):	Not Measured
Post Type:	BCT
Rail-to-Post 1:	Not Bolted
Rail-to-Post 2:	Bolted
Foundation Tube Type:	FMM02 (AASHTO-AGC-ARTB)
Embedment Depth:	Not Measured

Damage Type

Category:	Groundline Strut
Level:	Missing

Soil Properties

	@Post 1	@Post 2
Dry Density (pcf):	143.4	143.5
Wet Density (pcf):	151.1	149.8
Moisture Content (%):	5.4	4.4
Compaction (%):	95.5	93.2

Load Properties

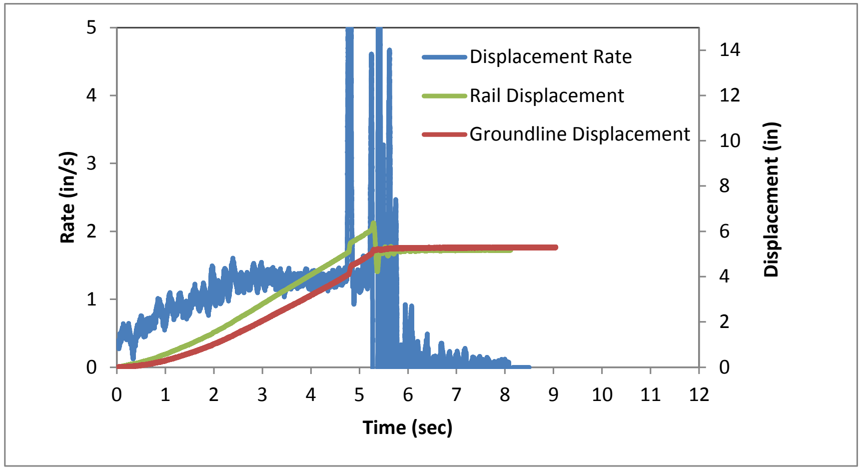
Quasi-Static Rate (in/s):	≈ 1.3
Method:	Winch & Cable
Load Point 1 (in):	Not Measured
Load Point 2 (in):	Not Measured

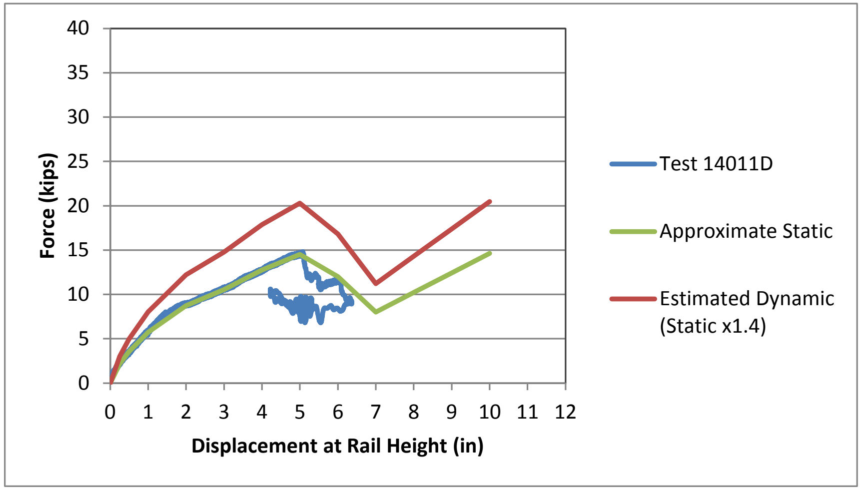
Result

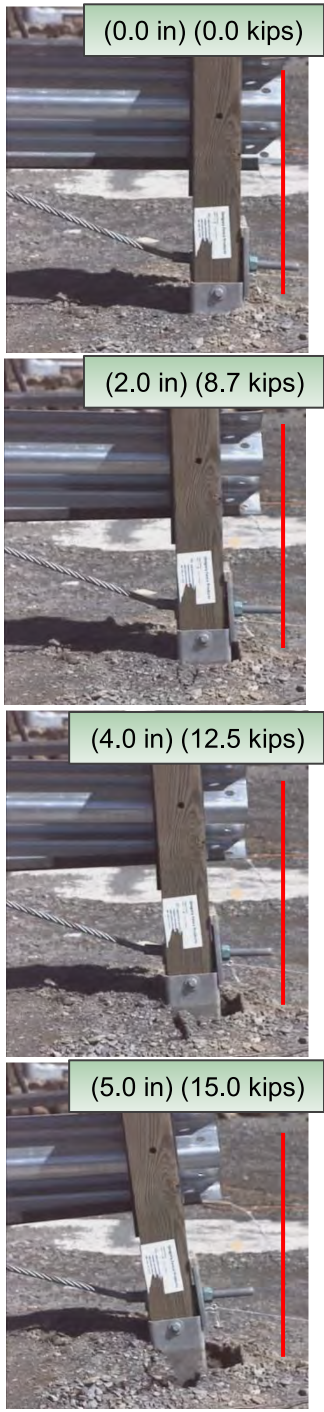
Anchor condition:	Post 2 Split @ 5" disp Soil Disp.
Max Load (kips):	14.8
Disp. at Peak Load (in):	5

	@2 in.	@4 in.	@6 in.
Force (kip):	8.7	12.8	12.0
Stiffness (k/in):	4.5	1.9	1.8

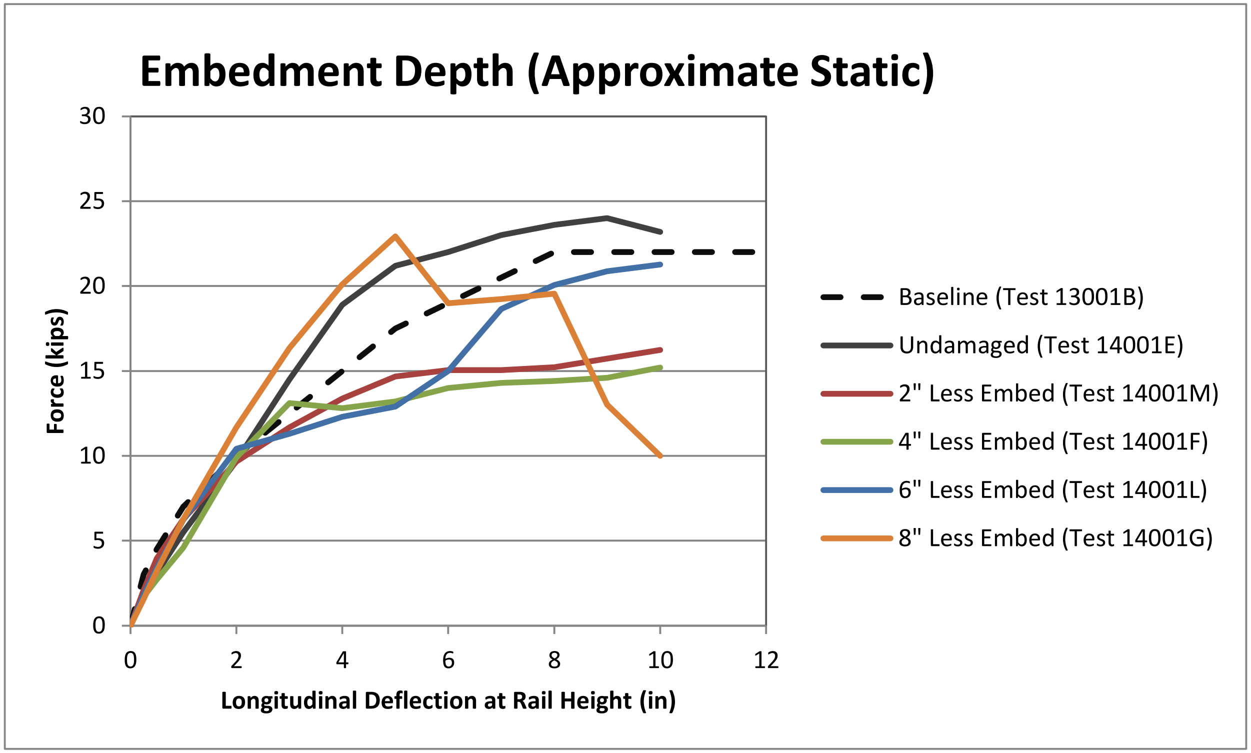
Post test:	@Post 1	@Post 2
Groundline Displacement (in)	4.3	0.0







Reduced Embedment Depth



Test Information

Project Case Number:	4B1_002
FOIL Test Number:	14001M
Test Date:	23-June-2014

System Properties

Rail Height (in):	29.5
Post Type:	BCT
Rail-to-Post 1:	Not Bolted
Rail-to-Post 2:	Bolted
Foundation Tube Type:	FMM02 (AASHTO-AGC-ARTB)
Embedment Depth:	55.0

Damage Type

Category:	Reduced Embed. Depth
Level:	2 inches

Soil Properties

	@Post 1	@Post 2
Dry Density (pcf):	138.8	140.3
Wet Density (pcf):	146.2	146.1
Moisture Content (%):	5.3	4.1
Compaction (%):	92.5	90.8

Load Properties

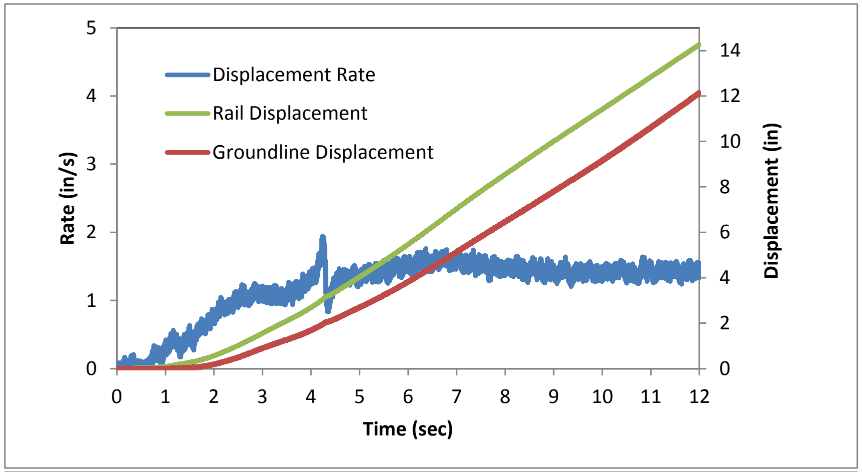
Quasi-Static Rate (in/s):	≈ 1.0-1.3
Method:	Winch & Cable
Load Point 1 (in):	26.5
Load Point 2 (in):	18.5

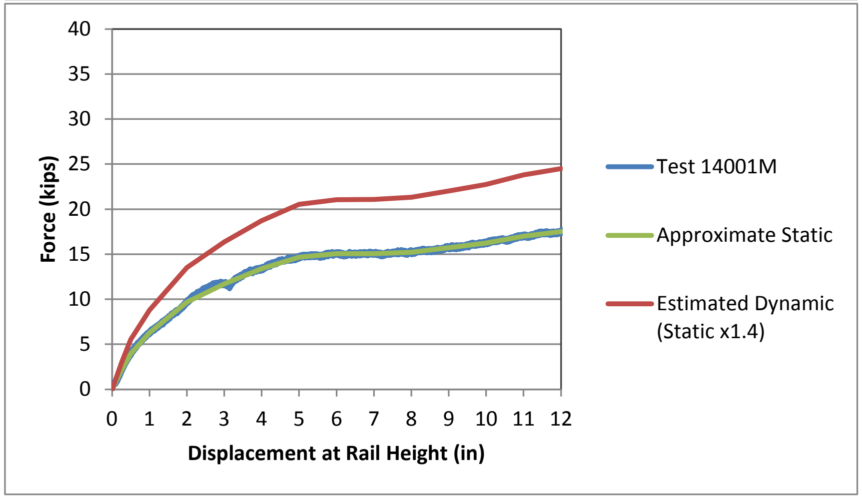
Result

Anchor condition:	Post 1 full extraction at > 12 inches rail deflec. Soil Disp.
Max Load (kips):	18.4
Disp. at Peak Load (in):	16.0

	@2 in.	@4 in.	@6 in.
Force (kip):	9.7	13.4	15.0
Stiffness (k/in):	4.8	1.9	0.8

Post Test:	@Post 1	@Post 2
Groundline Displacement (in)	8.0	7.0





(0.0 in) (0.0 kips)

(2.0 in) (9.6 kips)

(4.0 in) (13.4 kips)

(6.0 in) (15.0 kips)

Test Information

Project Case Number:	4B1_003
FOIL Test Number:	14001F
Test Date:	5-May-2014

System Properties

Rail Height (in):	31.5
Post Type:	BCT
Rail-to-Post 1:	Not Bolted
Rail-to-Post 2:	Bolted
Foundation Tube Type:	FMM02 (AASHTO-AGC-ARTB)
Embedment Depth:	53.0

Damage Type

Category:	Reduced Embed. Depth
Level:	4 inches

Soil Properties

	@Post 1	@Post 2
Dry Density (pcf):	145.2	143.4
Wet Density (pcf):	153.5	149.1
Moisture Content (%):	5.7	4.0
Compaction (%):	96.6	92.8

Load Properties

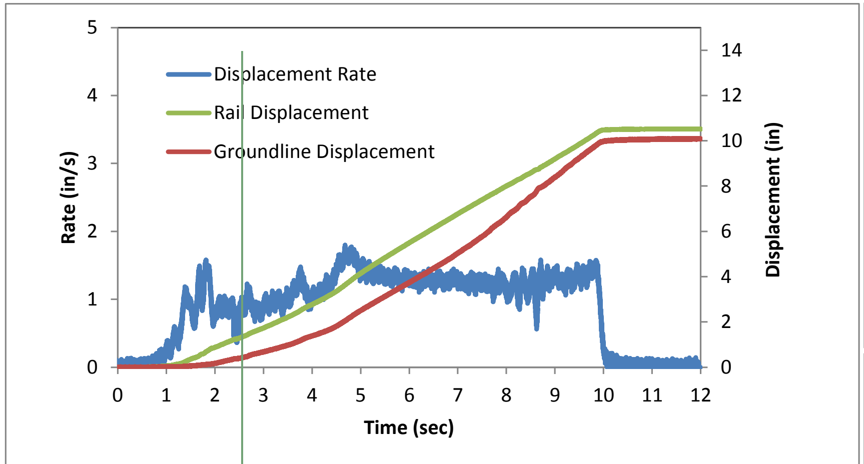
Quasi-Static Rate (in/s):	≈ 1.0-1.3
Method:	Winch & Cable
Load Point 1 (in):	28.5
Load Point 2 (in):	17.3

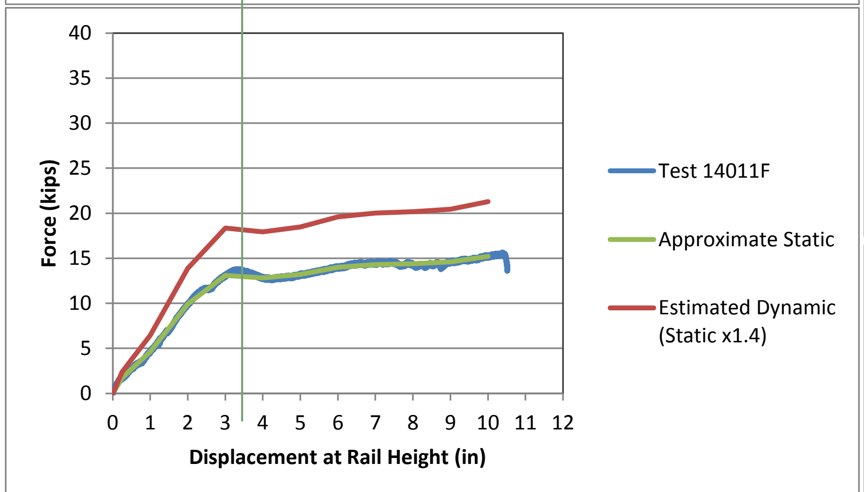
Result

Anchor condition:	Post 1 Partial Extraction Soil Disp.
Max Load (kips):	15.7
Max Disp. at Max Load (in):	10.5

	@2 in.	@4 in.	@6 in.
Force (kip):	9.9	12.8	14.0
Stiffness (k/in):	5.0	1.5	0.6

Post Test:	@Post 1	@Post 2
Groundline Displacement (in)	4.8	4.0





(0.0 in) (0.0 kips)

Photo not Available

(2.0 in) (9.9 kips)

Photo not Available

(4.0 in) (12.8 kips)

Photo not Available

(6.0 in) (14.0 kips)

Photo not Available

Test Information

Project Case Number:	4B1_004	
FOIL Test Number:	14001L	
Test Date:	20-June-2014	

System Properties

Rail Height (in):	34.5	
Post Type:	BCT	
Rail-to-Post 1:	Not Bolted	
Rail-to-Post 2:	Bolted	
Foundation Tube Type:	FMM02 (AASHTO-AGC-ARTB)	
Embedment Depth:	51.0	

Damage Type

Category:	Reduced Embed. Depth	
Level:	6 inches	

Soil Properties

	@Post 1	@Post 2
Dry Density (pcf):	141.3	142.8
Wet Density (pcf):	148.5	149.3
Moisture Content (%):	5.1	4.5
Compaction (%):	94.1	92.4

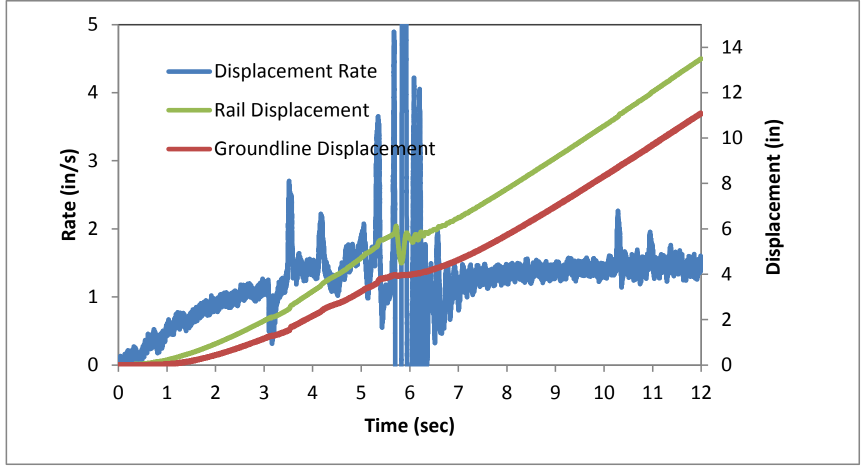
Load Properties

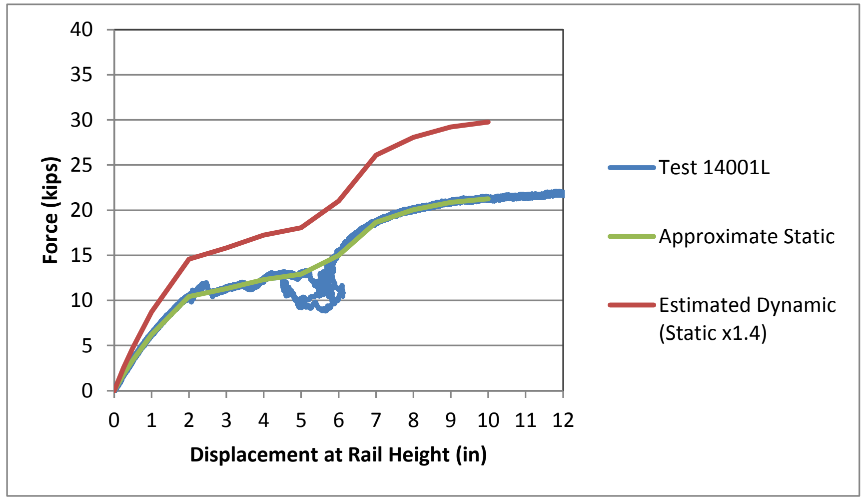
Quasi-Static Rate (in/s):	≈ 0.5 - 1.4	
Method:	Winch & Cable	
Load Point 1 (in):	31.5	
Load Point 2 (in):	23.5	

Result

Anchor condition:		Post 2 Split @ 5.1” disp. Soil Disp.	
Max Load (kips):		22.6	
Max Disp. at Max Load (in):		12	
	@2 in.	@4 in.	@6 in.
Force (kip):	10.4	12.3	15.0
Stiffness (k/in):	5.2	0.9	1.3

Post Test:	@Post 1	@Post 2
Groundline Displacement (in)	6.5	4.0





(0.0 in) (0.0 kips)

(2.0 in) (10.4 kips)

(5.0 in) (12.8 kips)

(9.0 in) (20.9 kips)

Test Information

Project Case Number:	4B1_005
FOIL Test Number:	14001G
Test Date:	12-May-2014

System Properties

Rail Height (in):	31
Post Type:	BCT
Rail-to-Post 1:	Not Bolted
Rail-to-Post 2:	Bolted
Foundation Tube Type:	FMM02 (AASHTO-AGC-ARTB)
Embedment Depth:	

Damage Type

Category:	Reduced Embed. Depth
Level:	8 inches

Soil Properties

	@Post 1	@Post 2
Dry Density (pcf):	144.2	143.7
Wet Density (pcf):	152.1	151.1
Moisture Content (%):	5.3	5.1
Compaction (%):	95.7	93.0

Load Properties

Quasi-Static Rate (in/s):	≈ 0.5 - 1.3
Method:	Winch & Cable
Load Point 1 (in):	28.0
Load Point 2 (in):	20.0

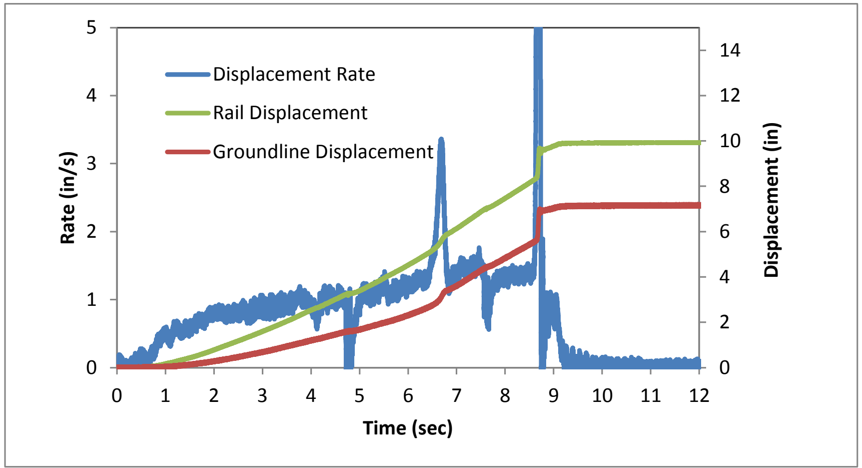
Result

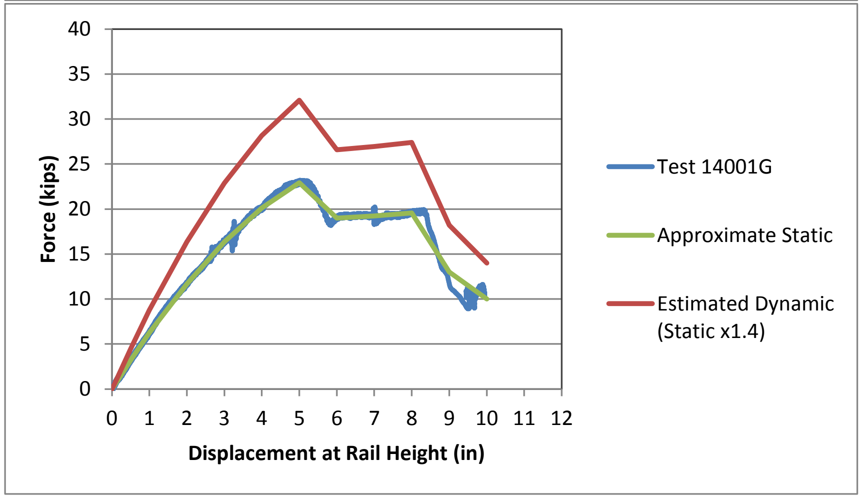
Anchor condition: Post 1 Partial Extraction at 5.1 in deflec. Strut Buckled @ 8 in. Soil Disp.

Max Load (kips):	23.2
Max Disp. at Max Load (in):	5.0

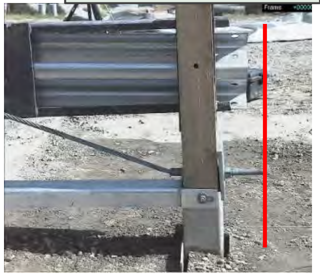
	@2 in.	@4 in.	@6 in.
Force (kip):	11.7	20.1	19.0
Stiffness (k/in):	5.8	4.2	2.8

Post Test:	@Post 1	@Post 2
Groundline Displacement (in):	4.5	3.0





(0.0 in) (0.0 kips)

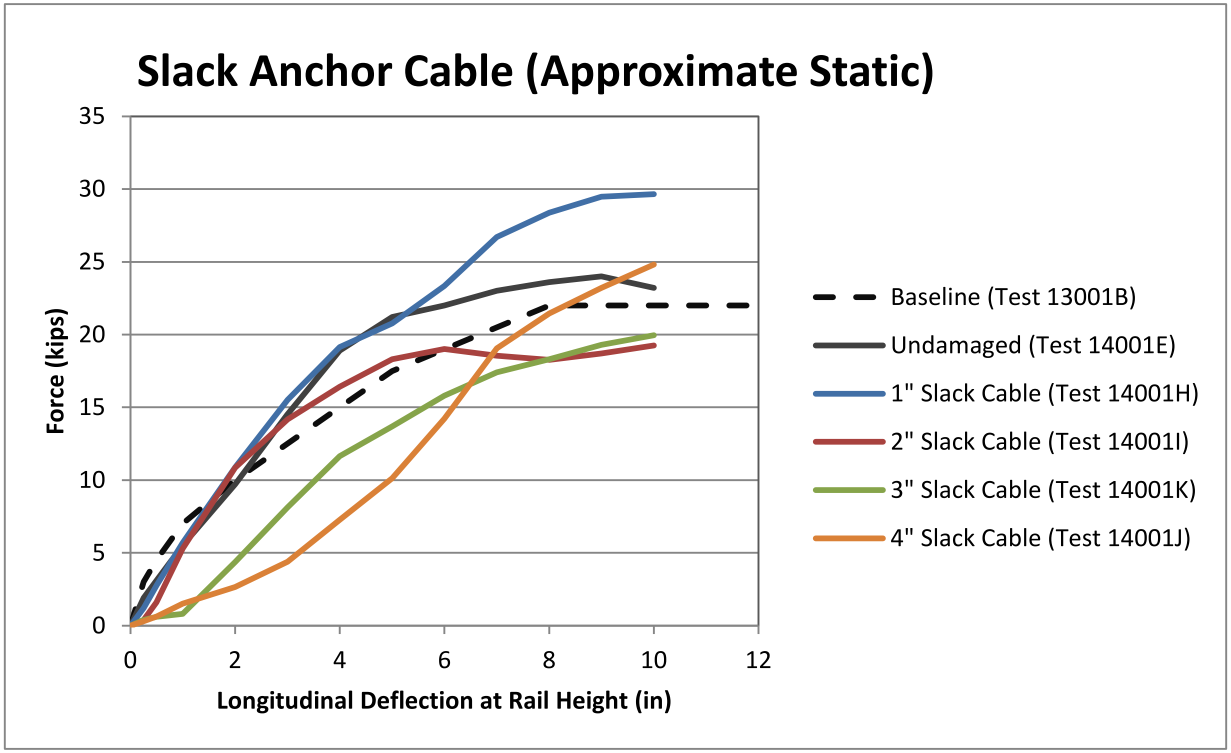


(2.0 in) (11.6 kips)

(5.0 in) (23.2 kips)

(9.0 in) (13.0 kips)

Slack Anchor Cable



Test Information

Project Case Number:	4B3_001
FOIL Test Number:	14001H
Test Date:	4-June-2014

System Properties

Rail Height (in):	26.0
Post Type:	BCT
Rail-to-Post 1:	Not Bolted
Rail-to-Post 2:	Bolted
Foundation Tube Type:	FMM02 (AASHTO-AGC-ARTB)
Embedment Depth (in):	57

Damage Type

Category:	Slack Cable
Level:	1”

Soil Properties

	@Post 1	@Post 2
Dry Density (pcf):	143.7	143.8
Wet Density (pcf):	151.3	149.1
Moisture Content (%):	5.3	3.7
Compaction (%):	95.7	93.1

Load Properties

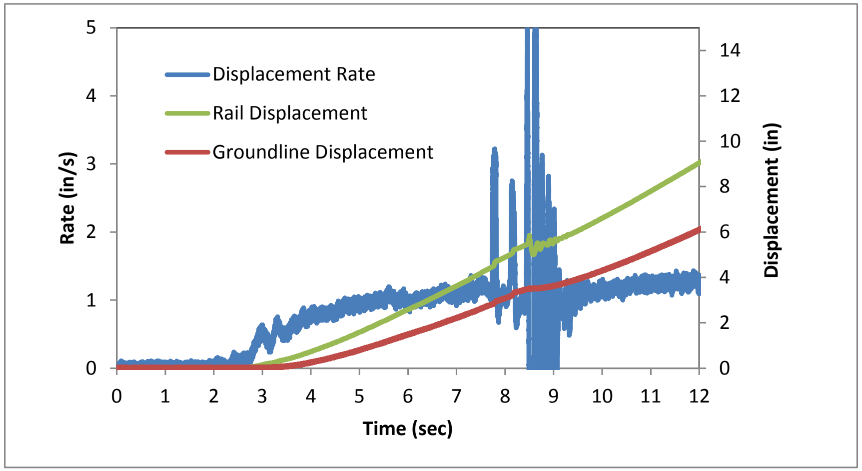
Quasi-Static Rate (in/s):	≈ 1.0
Method:	Winch & Cable
Load Point 1 (in):	23.0
Load Point 2 (in):	16.0

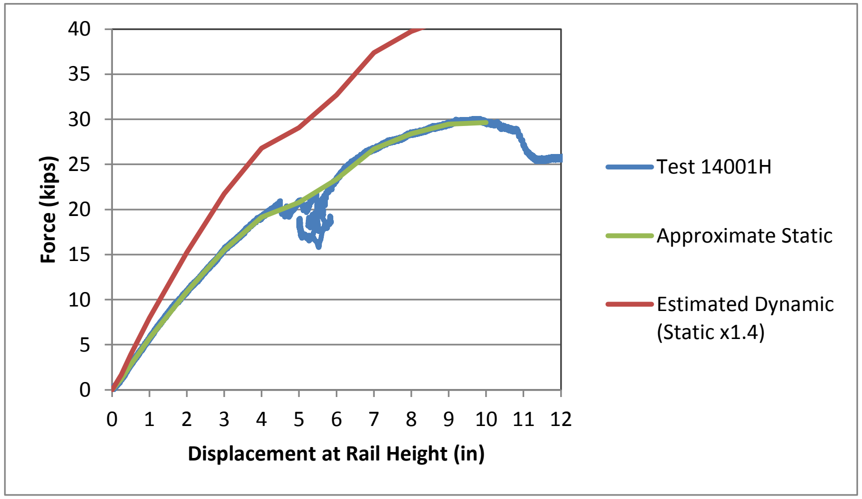
Result

Anchor condition:	Post 2 Split @ 4” disp. Strut Bent @ > 10” disp. Soil Disp.
Max Load (kips):	29.9
Max Disp. at Max Load (in):	10

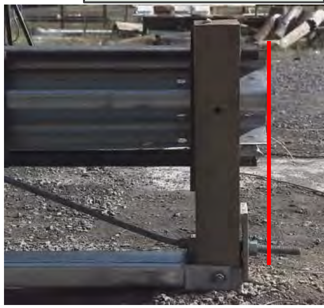
	@2 in.	@4 in.	@6 in.
Force (kip):	10.9	19.1	23.3
Stiffness (k/in):	5.4	4.1	2.1

Post Test:	@Post 1	@Post 2
Groundline Displacement (in)	9.5	3.0

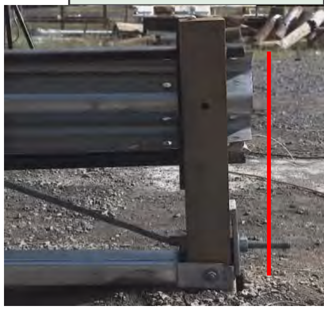




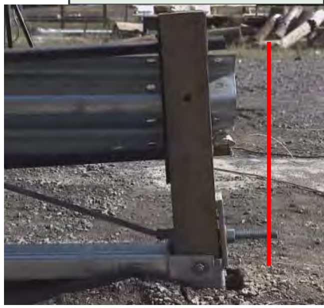
(0.0 in) (0.0 kips)



(2.0 in) (10.9 kips)



(4.0 in) (19.1 kips)



(6.0 in) (23.3 kips)

Test Information

Project Case Number:	4B3_002
FOIL Test Number:	14001I
Test Date:	6-June-2014

System Properties

Rail Height (in):	26.5
Post Type:	BCT
Rail-to-Post 1:	Not Bolted
Rail-to-Post 2:	Bolted
Foundation Tube Type:	FMM02 (AASHTO-AGC-ARTB)
Embedment Depth (in):	57

Damage Type

Category:	Slack Cable
Level:	2”

Soil Properties

	@Post 1	@Post 2
Dry Density (pcf):	140.4	143.4
Wet Density (pcf):	148.4	149.5
Moisture Content (%):	5.7	4.3
Compaction (%):	93.5	92.8

Load Properties

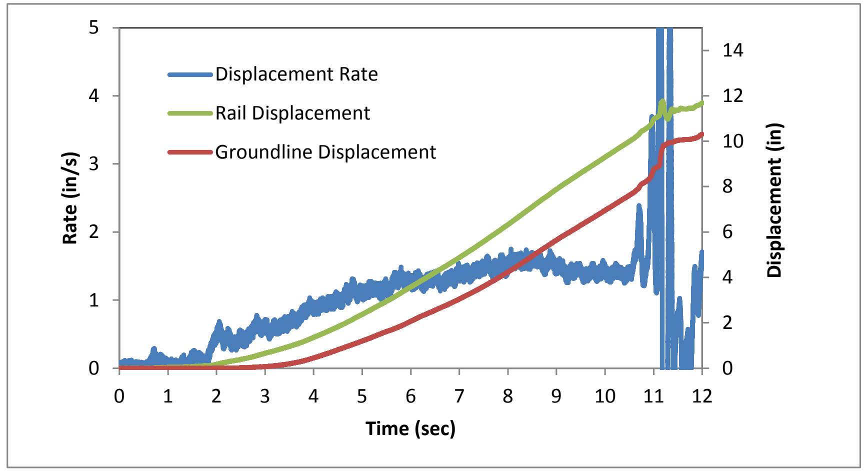
Quasi-Static Rate (in/s):	≈ 1.3
Method:	Winch & Cable
Load Point 1 (in):	22.75
Load Point 2 (in):	15.0

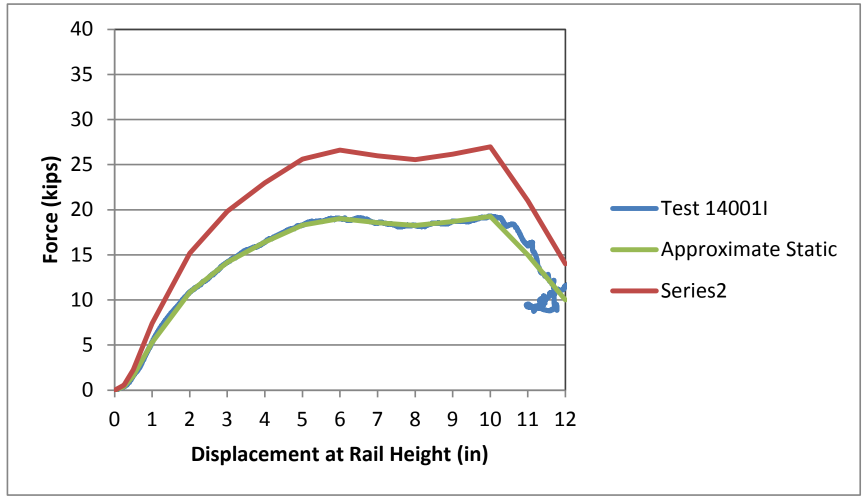
Result

Mode of failure:	Post 2 Split @ 11” disp.
Anchor condition:	Strut Bent @ 10.6” disp. Soil Disp.
Max Load (kips):	19.3
Max Disp. at Max Load (in):	10

	@2 in.	@4 in.	@6 in.
Force (kip):	10.8	16.4	19.0
Stiffness (k/in):	5.4	2.8	1.3

Post Test:	@Post 1	@Post 2
Groundline Displacement (in)	9.8	5.0





Pre-test measurements for cable slack

(0.0 in) (0.0 kips)

(2.0 in) (10.8 kips)

(4.0 in) (16.4 kips)

(6.0 in) (19.0 kips)

Test Information

Project Case Number:	4B3_003
FOIL Test Number:	14001K
Test Date:	18-June-2014

System Properties

Rail Height (in):	29.0
Post Type:	BCT
Rail-to-Post 1:	Not Bolted
Rail-to-Post 2:	Bolted
Foundation Tube Type:	FMM02 (AASHTO-AGC-ARTB)
Embedment Depth (in):	57

Damage Type

Category:	Slack Cable
Level:	3”

Soil Properties

	@Post 1	@Post 2
Dry Density (pcf):	140.2	144.6
Wet Density (pcf):	148.3	151.2
Moisture Content (%):	5.8	4.6
Compaction (%):	93.3	93.5

Load Properties

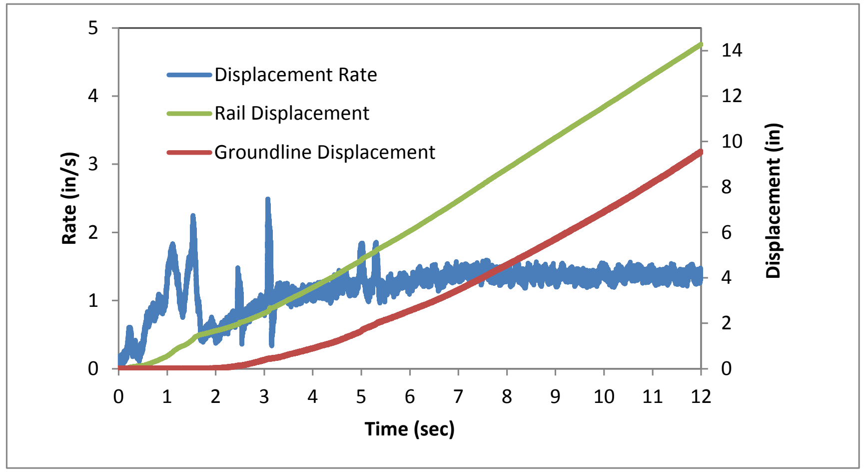
Quasi-Static Rate (in/s):	≈ 1-1.4
Method:	Winch & Cable
Load Point 1 (in):	26.0
Load Point 2 (in):	18.0

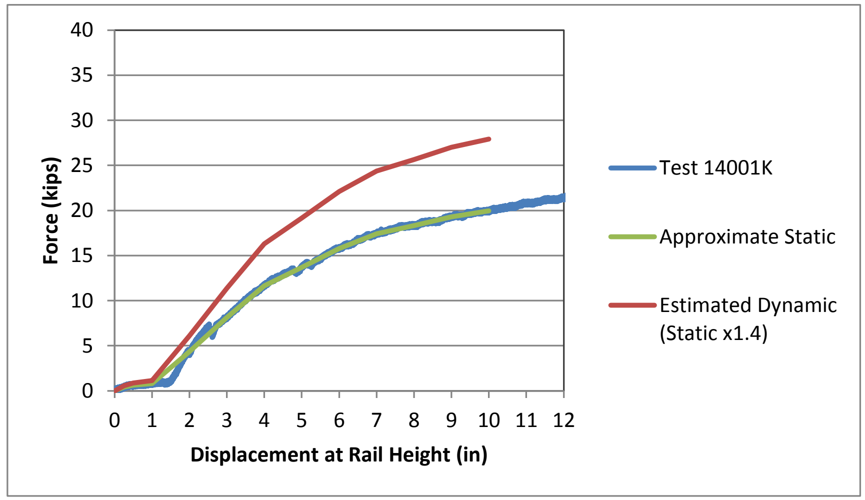
Result

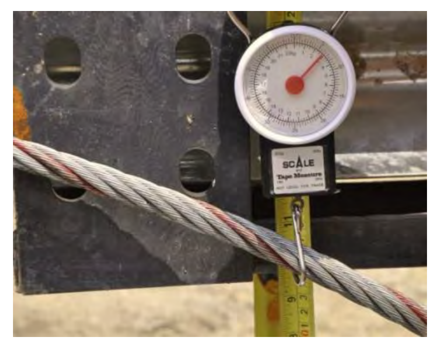
Anchor condition:	Post 2 Crack @ 6.8” disp Soil Disp.
Max Load (kips):	22.5
Max Disp. at Max Load (in):	12

	@2 in.	@4 in.	@6 in.
Force (kip):	4.4	11.6	15.8
Stiffness (k/in):	2.2	3.6	2.1

Post Test:	@Post 1	@Post 2
Groundline Displacement (in)	8.0	3.0





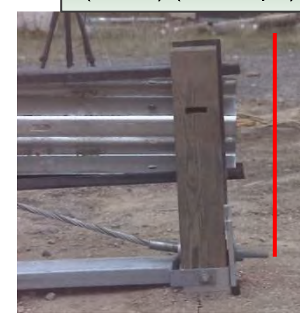


Pre-test measurements for cable slack

(0.0 in) (0.0 kips)

(2.0 in) (4.4 kips)

(4.0 in) (11.7 kips)



(6.0 in) (15.8 kips)

Test Information

Project Case Number:	4B3_004
FOIL Test Number:	14001J
Test Date:	16-June-2014

System Properties

Rail Height (in):	27.25
Post Type:	BCT
Rail-to-Post 1:	Not Bolted
Rail-to-Post 2:	Bolted
Foundation Tube Type:	FMM02 (AASHTO-AGC-ARTB)
Embedment Depth (in):	57

Damage Type

Category:	Slack Cable
Level:	4”

Soil Properties

	@Post 1	@Post 2
Dry Density (pcf):	141.8	145.1
Wet Density (pcf):	148.4	152.8
Moisture Content (%):	4.6	5.3
Compaction (%):	94.4	93.9

Load Properties

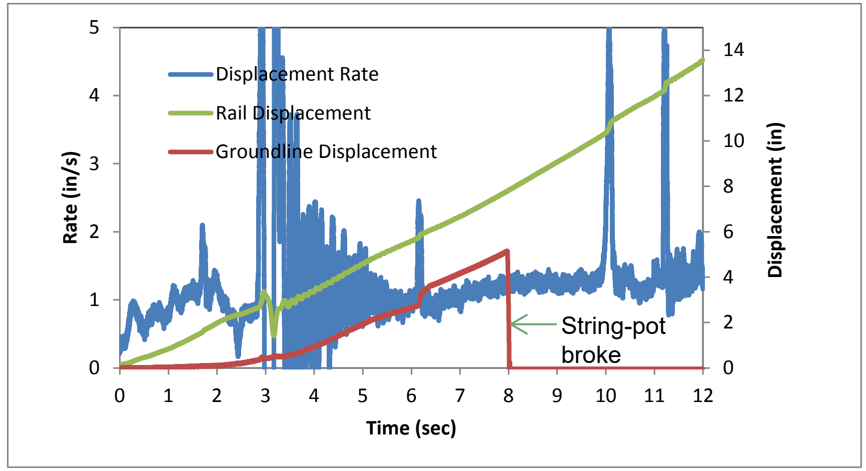
Quasi-Static Rate (in/s):	≈ 0.92
Method:	Winch & Cable
Load Point 1 (in):	24.25
Load Point 2 (in):	17.0

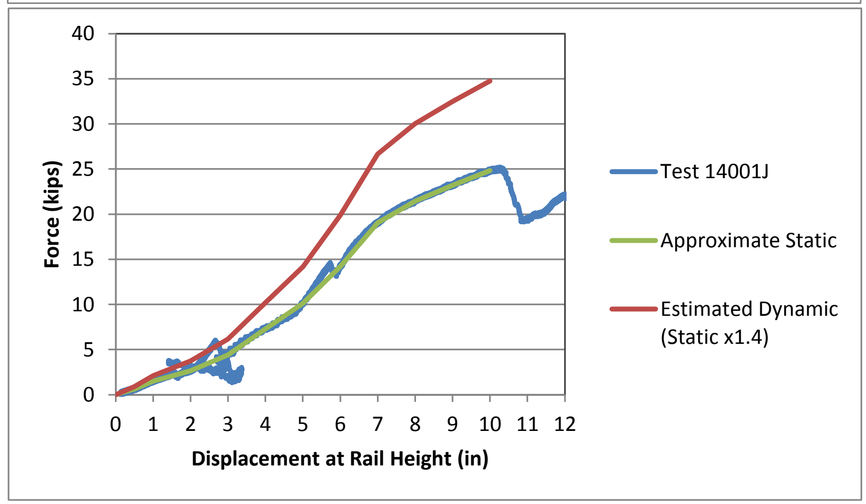
Result

Anchor condition:	Post 2 Split @ 3.3” disp. Strut Bent @ 10.8” disp. Soil Disp.
Max Load (kips):	25.2
Max Disp. at Max Load (in):	10

	@2 in.	@4 in.	@6 in.
Force (kip):	2.6	7.3	14.2
Stiffness (k/in):	1.3	2.3	3.5

Post Test:	@Post 1	@Post 2
Groundline Displacement (in)	8.0	6.5





Pre-test measurements for cable slack

(0.0 in) (0.0 kips)

(2.0 in) (2.6 kips)

(4.0 in) (7.3 kips)

(6.0 in) (14.2 kips)

APPENDIX R

Visual Inspection of Crash-Damaged Splice Specimens – Damage Summary Sheets

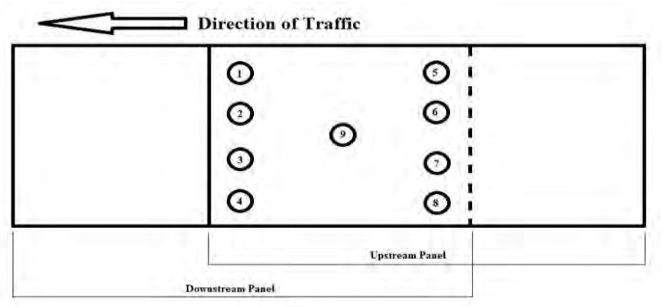
Task 4A-5: Quantify Effects of W-Beam Splice Damage on Capacity of Railing

By: Chuck Plaxico and Archie Ray

June 25, 2014

Date: 6/3/2014
Specimen #: 4A5_ME001
Specimen ID: 108_A
Specimen ID 2: panel 1-2
Pendulum Test No. : 14004F
Comment:

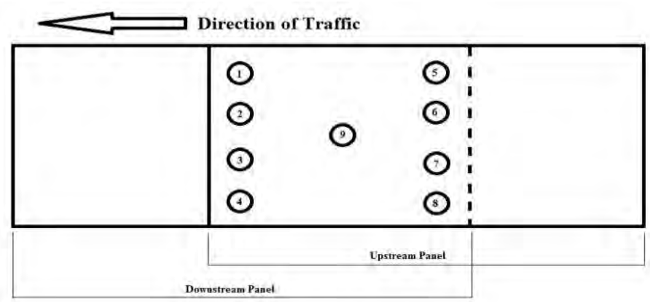
Other Damages Noted:



Location	Rail separation			Splice Bolts	Visible Hole Condition		Rail Flattening		Horizontal Tear		Verticle tear	
	Max Slip (Long.)	Traffic Face (Lat.)	Back Face (Lat.)	Condition	Upstream Panel	Downstream Panel	Upstream End	Downstream End	Upstream Panel	Downstream Panel	Upstream Panel	Downstream Panel
1	0.20											
2												
3				Loose								
4		0.125										
5												
6												
7				Loose								
8				Loose								
9						H-Tear						
Top section							8.5	8.5				
Bottom section							6.25	5.25				
Middle section												
Top edge												
Bottom edge												
Downstream edge												
Upstream edge												

Date: 6/3/2014
Specimen #: 4A5_ME002
Specimen ID: 108_A
Specimen ID 2: panel 2-3
Pendulum Test No. :
Comment: Splice was disassembled prior to damage assessment

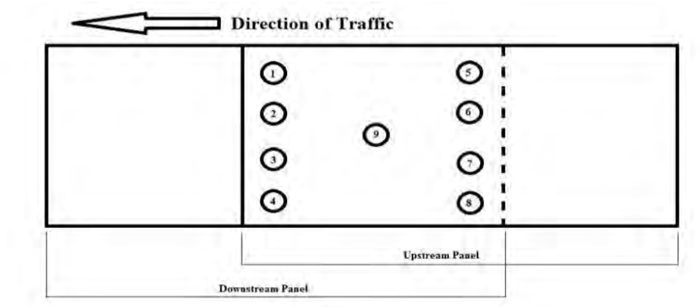
Other Damages Noted:



Location	Rail separation			Splice Bolts	Visible Hole Condition		Rail Flattening		Horizontal Tear		Verticle tear	
	Max Slip (Long.)	Traffic Face (Lat.)	Back Face (Lat.)	Condition	Upstream Panel	Downstream Panel	Upstream End	Downstream End	Upstream Panel	Downstream Panel	Upstream Panel	Downstream Panel
1	N.A.	N.A.		N.A.								
2	N.A.	N.A.		N.A.								
3	N.A.	N.A.		N.A.								
4	N.A.	N.A.		N.A.	Torn							
5			N.A.	N.A.								
6			N.A.	N.A.								
7			N.A.	N.A.								
8			N.A.	N.A.								
9												
Top section							7	6.25				
Bottom section							6.25	7.5	5			
Middle section												
Top edge												
Bottom edge												
Downstream edge												
Upstream edge												

Date: 6/3/2014
Specimen #: 4A5_ME003
Specimen ID: 108_B
Specimen ID 2:
Pendulum Test No. : 14004A
Comment:

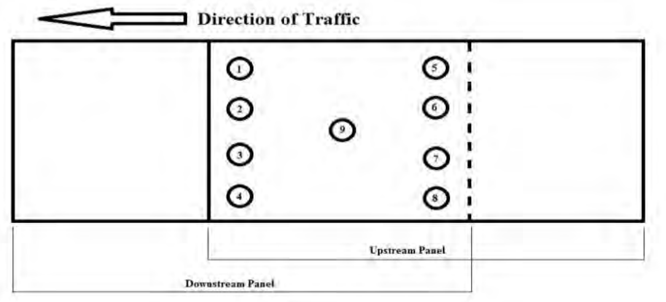
<u>Other Damages Noted:</u>
Rail Fold at top, downstream corner.



Location	Rail separation			Splice Bolts	Visible Hole Condition		Rail Flattening		Horizontal Tear		Verticle tear	
	Max Slip (Long.)	Traffic Face (Lat.)	Back Face (Lat.)	Condition	Upstream Panel	Downstream Panel	Upstream End	Downstream End	Upstream Panel	Downstream Panel	Upstream Panel	Downstream Panel
1		0.25										
2												
3												
4												
5			0.25									
6												
7												
8												
9												
Top section							8.25	7				
Bottom section							6.5	6				
Middle section												
Top edge											1	
Bottom edge												
Downstream edge												
Upstream edge												

Date: 6/3/2014
Specimen #: 4A5_ME004
Specimen ID: 108_C
Specimen ID 2:
Pendulum Test No. : **14004J**
Comment:

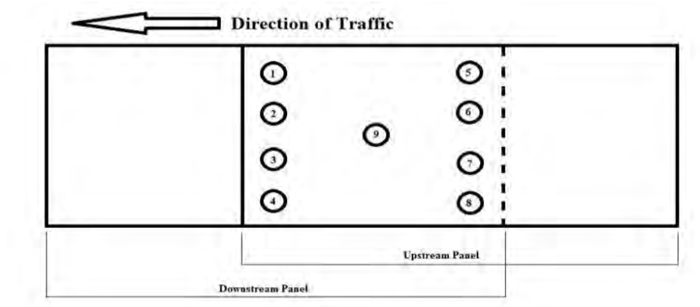
Other Damages Noted:



Location	Rail separation			Splice Bolts	Visible Hole Condition		Rail Flattening		Horizontal Tear		Verticle tear	
	Max Slip (Long.)	Traffic Face (Lat.)	Back Face (Lat.)	Condition	Upstream Panel	Downstream Panel	Upstream End	Downstream End	Upstream Panel	Downstream Panel	Upstream Panel	Downstream Panel
1		0.25										
2												
3												
4												
5												
6												
7												
8												
9												
Top section							4.5	4.25				
Bottom section							4.25	6.25				
Middle section												
Top edge												
Bottom edge												
Downstream edge												
Upstream edge												

Date: 6/3/2014
Specimen #: 4A5_ME005
Specimen ID: 108_D
Specimen ID 2:
Pendulum Test No. : 14004B and 14004D
Comment:

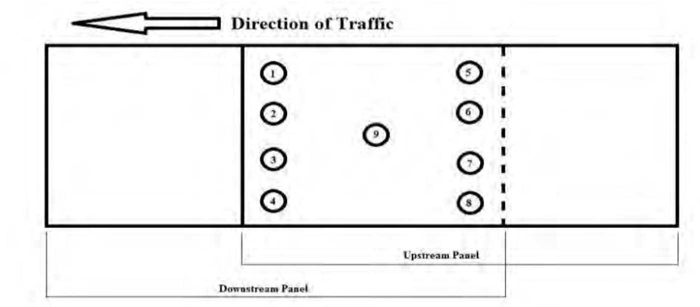
Other Damages Noted:
Tear intersected upstream edge of downstream panel.



Location	Rail separation			Splice Bolts	Visible Hole Condition		Rail Flattening		Horizontal Tear		Verticle tear	
	Max Slip (Long.)	Traffic Face (Lat.)	Back Face (Lat.)	Condition	Upstream Panel	Downstream Panel	Upstream End	Downstream End	Upstream Panel	Downstream Panel	Upstream Panel	Downstream Panel
1	0.08											
2	0.12											
3	0.12											
4		0.25										
5												
6												
7												
8												
9												
Top section							6.75	6.5				
Bottom section							8.5	7.25	4.5	3		
Middle section												
Top edge												
Bottom edge												
Downstream edge												
Upstream edge												

Date: 6/3/2014
Specimen #: 4A5_ME006
Specimen ID: 108_E
Specimen ID 2: Panel 1-2
Pendulum Test No. :
Comment: Splice was disassembled prior to damage assessment

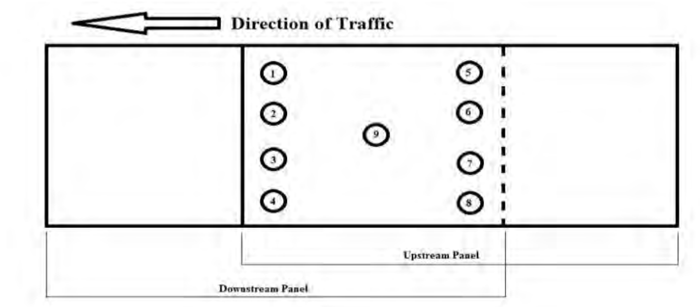
Other Damages Noted:



Location	Rail separation			Splice Bolts	Visible Hole Condition		Rail Flattening		Horizontal Tear		Verticle tear	
	Max Slip (Long.)	Traffic Face (Lat.)	Back Face (Lat.)	Condition	Upstream Panel	Downstream Panel	Upstream End	Downstream End	Upstream Panel	Downstream Panel	Upstream Panel	Downstream Panel
1	N.A.	N.A.		N.A.								
2	N.A.	N.A.		N.A.								
3	N.A.	N.A.		N.A.								
4	N.A.	N.A.		N.A.								
5			N.A.	N.A.								
6			N.A.	N.A.								
7			N.A.	N.A.								
8			N.A.	N.A.								
9												
Top section							9.25	9.5				
Bottom section							8.5	9				
Middle section												
Top edge												
Bottom edge												
Downstream edge												
Upstream edge												

Date: 6/3/2014
Specimen #: 4A5_ME007
Specimen ID: 108_E
Specimen ID 2: Panel 2-3
Pendulum Test No. : 14004L
Comment:

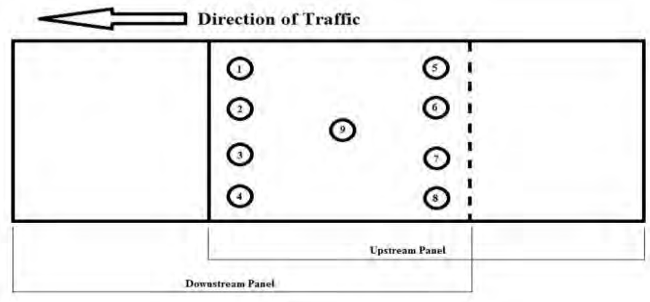
Other Damages Noted:
Visible bolt rotation at num. 2, 5 and 6.



Location	Rail separation			Splice Bolts	Visible Hole Condition		Rail Flattening		Horizontal Tear		Verticle tear	
	Max Slip (Long.)	Traffic Face (Lat.)	Back Face (Lat.)	Condition	Upstream Panel	Downstream Panel	Upstream End	Downstream End	Upstream Panel	Downstream Panel	Upstream Panel	Downstream Panel
1												
2		0.5		Gouging								
3		0.3125										
4		0.25										
5				Gouging								
6				Gouging								
7												
8												
9												
Top section							8.75	9				
Bottom section							8.25	8.25				
Middle section												
Top edge												
Bottom edge												
Downstream edge												
Upstream edge												

Date: 6/6/2014
Specimen #: 4A5_ME008
Specimen ID: Dixfield Garage
Specimen ID 2:
Pendulum Test No. : 14004C
Comment:

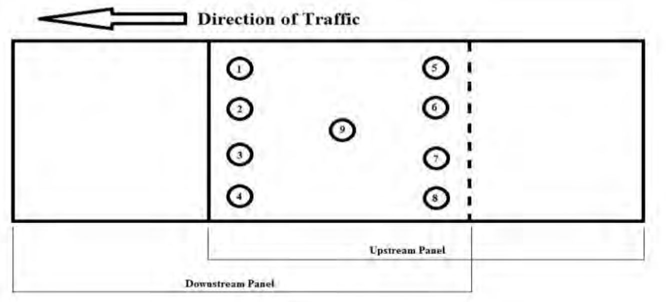
Other Damages Noted:



Location	Rail separation			Splice Bolts	Visible Hole Condition		Rail Flattening		Horizontal Tear		Verticle tear	
	Max Slip (Long.)	Traffic Face (Lat.)	Back Face (Lat.)	Condition	Upstream Panel	Downstream Panel	Upstream End	Downstream End	Upstream Panel	Downstream Panel	Upstream Panel	Downstream Panel
1	0.197	0.276										
2		0.118										
3												
4												
5												
6												
7												
8												
9												
Top section							9.125	8.75				
Bottom section							6.5	6.5				
Middle section												
Top edge												
Bottom edge												
Downstream edge												
Upstream edge												

Date: 6/6/2014
Specimen #: 4A5_ME010
Specimen ID: Dixfield Garage
Specimen ID 2:
Pendulum Test No. : 14004K
Comment: Very slight gouging at splice bolts 3 and 6

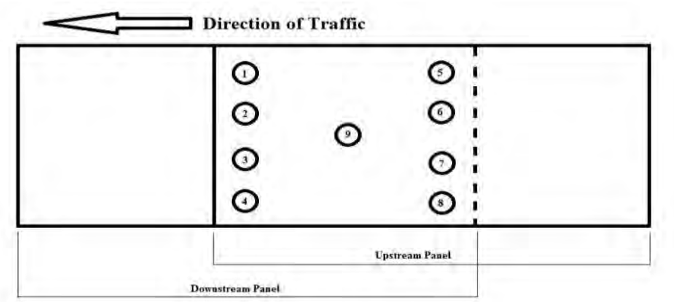
Other Damages Noted:



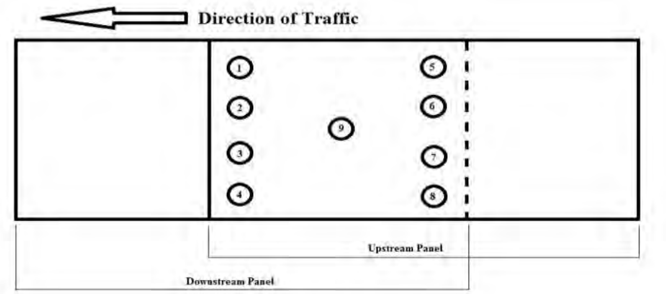
Location	Rail separation			Splice Bolts	Visible Hole Condition		Rail Flattening		Horizontal Tear		Verticle tear	
	Max Slip (Long.)	Traffic Face (Lat.)	Back Face (Lat.)	Condition	Upstream Panel	Downstream Panel	Upstream End	Downstream End	Upstream Panel	Downstream Panel	Upstream Panel	Downstream Panel
1	0.157	0.236										
2		0.551										
3		0.157		Gouging								
4	0.197											
5			0.118									
6				Gouging								
7												
8												
9												
Top section							9.5	9.125				
Bottom section							6	5.875				
Middle section												
Top edge												
Bottom edge												
Downstream edge												
Upstream edge												

Date: 6/6/2014
Specimen #: 4A5_ME011
Specimen ID: Dixfield Garage
Specimen ID 2:
Pendulum Test No. : 14004G
Comment: Disassembled prior to damage assessment

Other Damages Noted:



Location	Rail separation			Splice Bolts	Visible Hole Condition		Rail Flattening		Horizontal Tear		Verticle tear	
	Max Slip (Long.)	Traffic Face (Lat.)	Back Face (Lat.)	Condition	Upstream Panel	Downstream Panel	Upstream End	Downstream End	Upstream Panel	Downstream Panel	Upstream Panel	Downstream Panel
1	N.A.	N.A.		N.A.		Stretched						
2	N.A.	N.A.		N.A.		Stretched						
3	N.A.	N.A.		N.A.	Stretched							
4	N.A.	N.A.		N.A.								
5			N.A.	N.A.								
6			N.A.	N.A.		Stretched						
7			N.A.	N.A.								
8			N.A.	N.A.								
9												
Top section							9	8.5				
Bottom section							6.5	6.75				
Middle section												
Top edge												
Bottom edge												
Downstream edge												
Upstream edge												



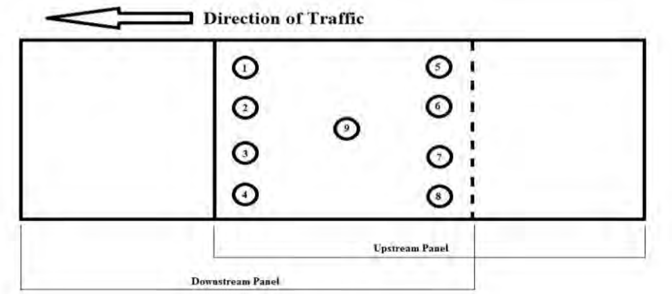
Date: 7/17/2014
Specimen #: 4A5_ME13
Specimen ID: Jay Garage
Specimen ID 2:
Pendulum Test No. : 14004M
Comment: Slip was estimated from the apparent initial position of the rails
Horizontal tear was on the upstream edge of the downstream panel

Other Damages Noted:

Location	Rail separation			Splice Bolts	Visible Hole Condition		Rail Flattening		Horizontal Tear		Verticle tear	
	Max Slip (Long.)	Traffic Face (Lat.)	Back Face (Lat.)	Condition	Upstream Panel	Downstream Panel	Upstream End	Downstream End	Upstream Panel	Downstream Panel	Upstream Panel	Downstream Panel
1	0.197	0.276		Gouging	Stretched	Stretched						
2	0.118	0.354		Gouging		Stretched						
3												
4												
5			0.157	Gouging	Stretched	Stretched						
6				Gouging	Stretched							
7					Stretched							
8												
9												
Top section							9.375	9.25				
Bottom section							6.25	6.25				
Middle section									11.81	1.77		
Top edge												
Bottom edge												
Downstream edge												
Upstream edge												

Date: 7/17/2014
Specimen #: 4A5_ME14
Specimen ID: Jay Garage
Specimen ID 2:
Pendulum Test No. : 14004H
Comment: Bolt #4 was partially pulled through about 30%

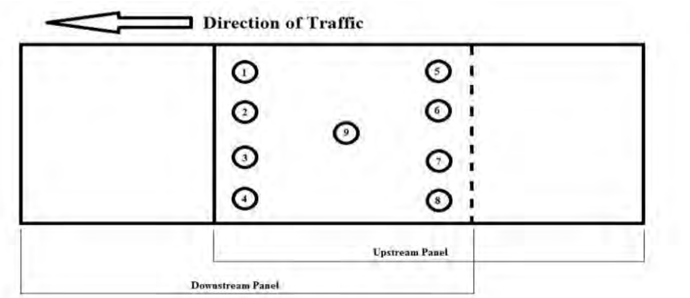
Other Damages Noted:
Impact was from a reverse hit.
The top and bottom corners of the upstream rail were folded over.



Location	Rail separation			Splice Bolts	Visible Hole Condition		Rail Flattening		Horizontal Tear		Verticle tear	
	Max Slip (Long.)	Traffic Face (Lat.)	Back Face (Lat.)	Condition	Upstream Panel	Downstream Panel	Upstream End	Downstream End	Upstream Panel	Downstream Panel	Upstream Panel	Downstream Panel
1	-											
2	0.276											
3	0.276											
4	-			Pulled Through	Stretched							
5												
6				Loose								
7												
8												
9												
Top section							7	7				
Bottom section							6.38	5.59				
Middle section												
Top edge												
Bottom edge												
Downstream edge												
Upstream edge												

Date: 7/17/2014
Specimen #: 4A5_ME15
Specimen ID: Hyw 2
Specimen ID 2: Field Measurment
Pendulum Test No. :
Comment: Impact was directly to the top of the post. The post bolt tore through blockout. Splice was essentially undamaged.

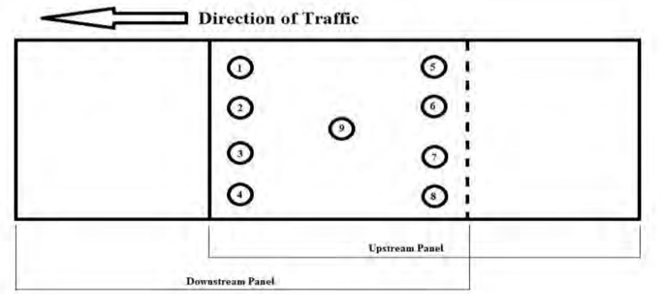
Other Damages Noted:



Location	Rail separation			Splice Bolts	Visible Hole Condition		Rail Flattening		Horizontal Tear		Verticle tear	
	Max Slip (Long.)	Traffic Face (Lat.)	Back Face (Lat.)	Condition	Upstream Panel	Downstream Panel	Upstream End	Downstream End	Upstream Panel	Downstream Panel	Upstream Panel	Downstream Panel
1												
2												
3												
4												
5												
6												
7				Loose								
8												
9												
Top section							6.125	6.125				
Bottom section							6.125	5.875				
Middle section												
Top edge												
Bottom edge												
Downstream edge												
Upstream edge												

Date:
Specimen #: 4A5_ME17
Specimen ID: Hyw 2
Specimen ID 2: Field Measurment
Pendulum Test No. : 14404I
Comment: This damged splice was adjacent to another damaged splice downstream. (See 4A5-ME018)

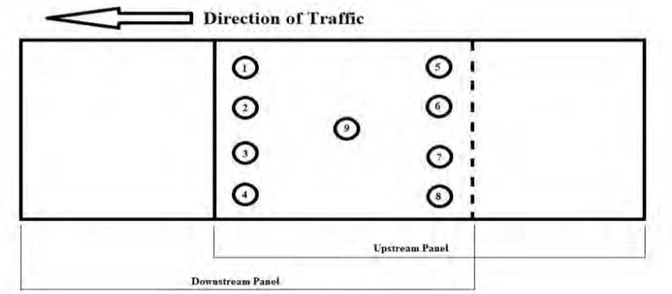
Other Damages Noted:
Post broke away from blockout.



Location	Rail separation			Splice Bolts	Visible Hole Condition		Rail Flattening		Horizontal Tear		Verticle tear	
	Max Slip (Long.)	Traffic Face (Lat.)	Back Face (Lat.)	Condition	Upstream Panel	Downstream Panel	Upstream End	Downstream End	Upstream Panel	Downstream Panel	Upstream Panel	Downstream Panel
1	0.25			Gouging								
2		0.25		Gouging								
3		0.25		Gouging								
4												
5				Gouging								
6				Gouging								
7			0.25									
8												
9												
Top section							7.25	7.75				
Bottom section							8.5	8.25				
Middle section										22.5		
Top edge												
Bottom edge												
Downstream edge												
Upstream edge												

Date:
Specimen #: 4A5_ME18
Specimen ID: Hyw 2
Specimen ID 2: Field Measurment
Pendulum Test No. :
Comment: This damged splice was adjacent to another damaged splice upstream. (See 4A5-ME017)

Other Damages Noted:



Location	Rail separation			Splice Bolts	Visible Hole Condition		Rail Flattening		Horizontal Tear		Verticle tear	
	Max Slip (Long.)	Traffic Face (Lat.)	Back Face (Lat.)	Condition	Upstream Panel	Downstream Panel	Upstream End	Downstream End	Upstream Panel	Downstream Panel	Upstream Panel	Downstream Panel
1	0.25			Gouging								
2		0.5		Missing								
3		0.5		Missing								
4												
5				Gouging								
6				Missing								
7												
8												
9												
Top section							7.75	7.5				
Bottom section							7.5	7.25				
Middle section												
Top edge												
Bottom edge												
Downstream edge												
Upstream edge												

APPENDIX S

Task 4A-5
Quantify Effects of W-Beam Splice Damage on Capacity of Railing

FOIL Tests 14004 Summary Sheets
Pendulum Impact study

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RoadSafe LLC
Canton, ME

Chris Story
Federal Outdoor Impact Laboratory
McLean, VA

October 31, 2014

Test Setup

- The test article was a 13-ft long section of w-beam rail with a w-beam splice located at 65 inches from the downstream end.
- Each end of the rail was constrained from longitudinal displacement using two 0.75-inch diameter cables (i.e., AASHTO-AGC-ARTBA FCA01) fastened onto the ends of the rail.
- On the downstream end, the cables were fastened to two standard cable anchor brackets (i.e., AASHTO-AGC-ARTBA FPA01). Each bracket was bolted onto the rail using eight ½-inch bolts and nuts with 1-1/16 inch diameter washers under the bolt heads and two 2.5 x 15 x ¼-inch steel bearing plates under the nuts.
- On the upstream end, the cables were fastened to the rail by welding three modified anchor cable brackets directly to the end of the w-beam, as shown in Figure 13. The two legs of each of the cable anchor brackets were removed and a continuous weld along the top and bottom side of each bracket was used to fasten the bracket to the rail.
- A W6x16 structural steel post was installed at the splice connection. The post was 72 inches long and was embedded 44 inches in the soil.
- The 6x8x12 inch routed wood blockout was used to separate the w-beam rail from the post, and a standard 10-inch long 5/8-inch diameter bolt and nut (i.e., AASHTO-AGC-ARTBA FBB03) was used to fasten the rail to the blockout and post.
- The post-bolt was positioned at the downstream end of the slotted hole in the w-beam to emulate the typical position of the bolt resulting from an impact upstream of the splice.
- The rail height was 28 inches measured from the ground to the top of the rail.

Test Matrix

	Test #	Test Date	Specimen #	Damage Mode	Damage Level	Impact Velocity (mph)	Result	Max Force (kips)	Max Energy (kip/in)
Preliminary Tests	14004A	8/13/2014	4A5-ME003	Multiple	Minor	17.7	Boundary Failure	35.6	475
	14004B	8/1482014	4A5-ME005	Flat / Separ / Slip	68% / 0.25 / 0.12	20.2	Boundary Failure	54.2	662
	14004C	8/15/2014	4A5-ME008	Flat / Separ / Slip	86% / 0.28 / 0.2	18.6	Boundary Failure	48.7	605
	14004D	8/19/2014	4A5-ME005	Flat / Separ / Slip		18.9	Boundary Failure	37.9	624
	14004E	8/25/2014	New	Undamaged	-	20.6	Splice-Bolt Tear Out	40.4	425

Test #	Test Date	Specimen #	Damage Mode	Damage Level	Impact Velocity (mph)	Failure Mode	Max Force (kips)	Max Energy (kip/in)
14004F	9/17/2014	4A5-ME001	Rail Flattening / Crush	68% / 14%	20.4	Splice Tear	43.2	437
14004G	9/24/2014	4A5-ME011	Rail Flattening	83%	21.2	Splice-Bolt Tear -Out	45.4	550
14004H	9/29/2014	4A5-ME014	Long. Slip	0.28 inches	20.2	Splice-Bolt Tear -Out	41.7	443
14004I	10/1/2014	4A5-ME017	Long. Slip	0.25 inches	19.7	Boundary Failure	50.1	542
14004J	10/7/2014	4A5-ME004	Rail Crush	30.60%	20.3	Boundary Failure	52.1	561
14004K	10/9/2014	4A5-ME010	Splice Separation	0.55 inch	20.2	Splice-Bolt Tear -Out	39.5	501
14004L	10/17/2014	4A5-ME007	Splice Separation	0.5 inch	20.5	Splice-Bolt Tear -Out	54.6	512
14004M	10/23/2014	4A5-ME013	Splice Separation / Long. Slip / Flattening / Horz. Tear	0.35 inch / 0.2 inch /93.5% 11.81 in.	20.6	Splice-Bolt Tear -Out	48.2	503
14004N	10/24/2014	New	Undamaged	-	20.4	Splice-Bolt Tear -Out	49.9	573
14004O	10/30/2014	New	Undamaged	-	20.6	Splice-Bolt Tear -Out	46.1	520

Test Information

Project Case Number:	4A5_ME003
FOIL Test Number:	14004A
Test Date:	13-August-2014

System Properties

Rail Height:	27.25 inches
Post Type:	W6x16
Blockout Type:	6x8x10"Routed Wood
Foundation Type:	Grading B of AASHTO M147-95
Embedment Depth (in):	44

Damage Type

Category:	Pre-Test
Level:	N.A.

Soil Properties

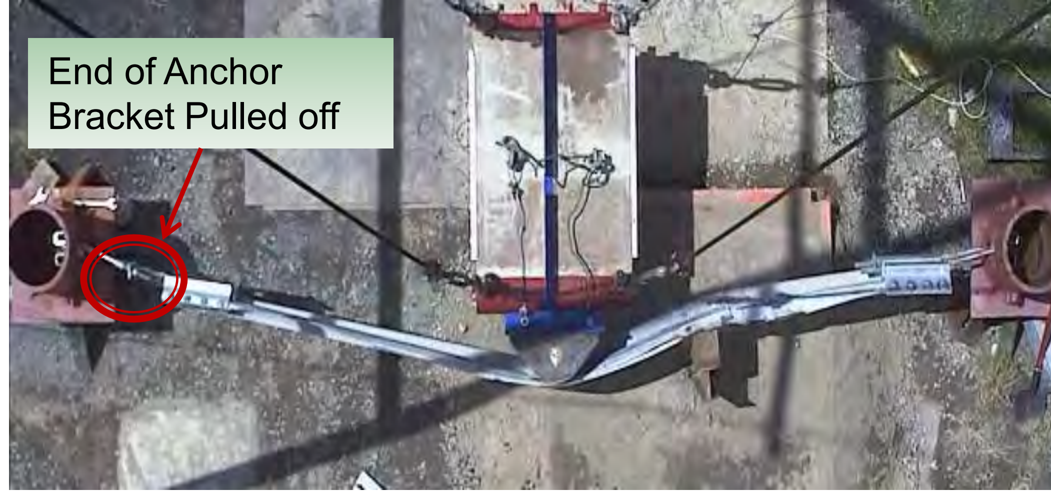
Dry Density :	x pcf
Wet Density :	x pcf
Moisture Content:	x %
Compaction:	x %

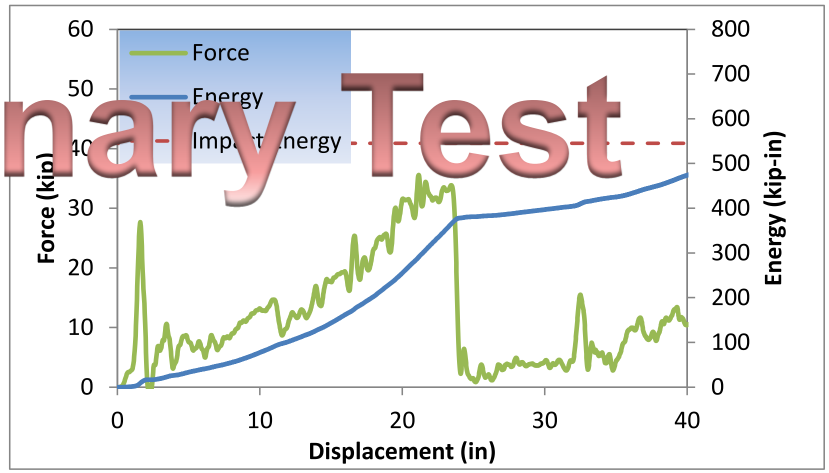
Impact Conditions

Pendulum Mass:	4,360 lb
Impact Velocity:	17.7 mph
Impact Energy:	545.0 kip-in
Load Point :	37.5 inches upstream of splice
Impact Orientation:	Perpendicular to rail

Result

Groundline Post Deflection	
Splice Slip	
Splice Rupture	
Rail Tear	
Boundary Failure	Cable bracket failure
Max Force	35.6 kip
Max Deflection	
Total Energy	475 kip-in





Pre-Test

Post-Test

Test Information

Project Case Number:	4A5_ME005
FOIL Test Number:	14004B
Test Date:	14-August-2014

System Properties

Rail Height:	27.25 inches
Post Type:	W6x16
Blockout Type:	6x8x10"Routed Wood
Foundation Type:	Grading B of AASHTO M147-95
Embedment Depth (in):	44

Damage Type

Category:	Pre-Test
Level:	N.A.

Soil Properties

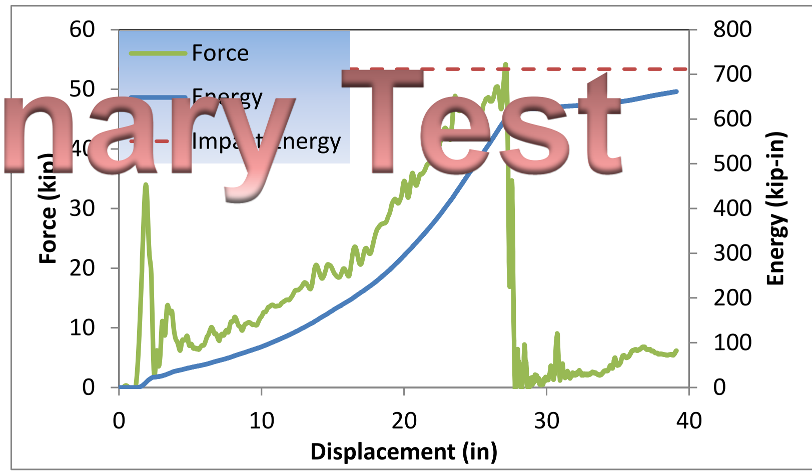
Dry Density :	x pcf
Wet Density :	x pcf
Moisture Content:	x %
Compaction:	x %

Impact Conditions

Pendulum Mass:	4,360 lb
Impact Velocity:	20.2 mph
Impact Energy:	711.7 kip-in
Load Point :	37.5 inches upstream of splice
Impact Orientation:	Perpendicular to rail

Result

Groundline Post Deflection	
Splice Slip	
Splice Rupture	
Rail Tear	
Boundary Failure	Cable rupture
Max Force	54.2 kip
Max Deflection	
Total Energy	661.6 kip-in



Pre-Test

Post-Test

Test Information

Project Case Number:	4A5_ME008
FOIL Test Number:	14004C
Test Date:	15-August-2014

System Properties

Rail Height:	27.25 inches
Post Type:	W6x16
Blockout Type:	6x8x10”Routed Wood
Foundation Type:	Grading B of AASHTO M147-95
Embedment Depth (in):	44

Damage Type

Category:	Pre-Test
Level:	N.A.

Soil Properties

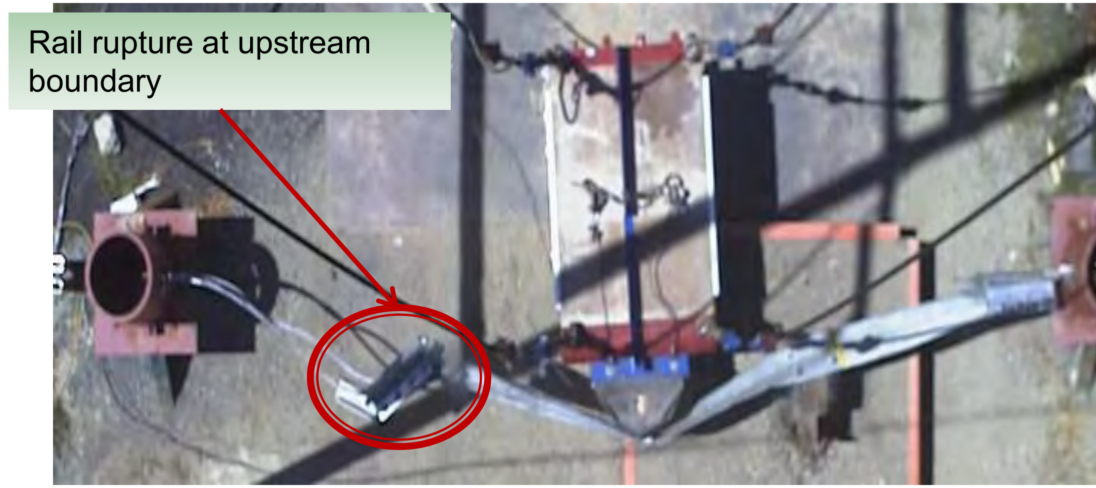
Dry Density :	x pcf
Wet Density :	x pcf
Moisture Content:	x %
Compaction:	x %

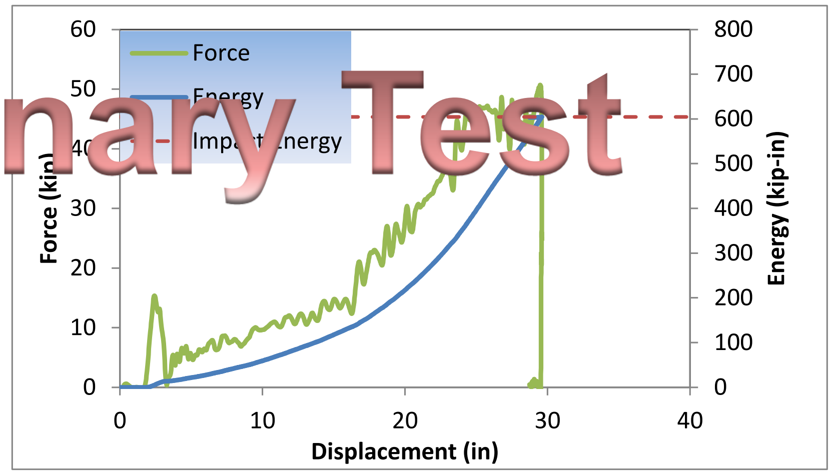
Impact Conditions

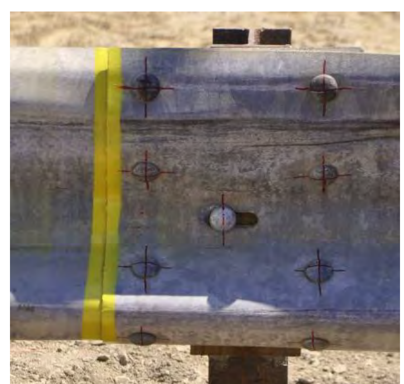
Pendulum Mass:	4,360 lb
Impact Velocity:	18.6 mph
Impact Energy:	604.6 kip-in
Load Point :	37.5 inches upstream of splice
Impact Orientation:	Perpendicular to rail

Result

Groundline Post Deflection	
Splice Slip	
Splice Rupture	
Rail Tear	Yes
Boundary Failure	Rail tear at upstream boundary
Max Force	48.7 kip
Max Deflection	
Total Energy	604.6 kip-in







Pre-Test

Post-Test

Test Information

Project Case Number:	4A5_ME005 – 2nd hit
FOIL Test Number:	14004D
Test Date:	19-August-2014

System Properties

Rail Height:	27.25 inches
Post Type:	W6x16
Blockout Type:	6x8x10"Routed Wood
Foundation Type:	Grading B of AASHTO M147-95
Embedment Depth (in):	44

Damage Type

Category:	Pre-Test
Level:	N.A.

Soil Properties

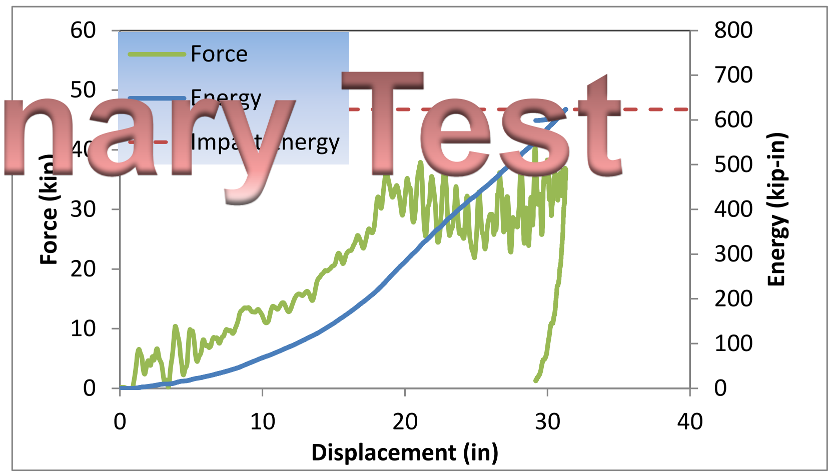
Dry Density :	x pcf
Wet Density :	x pcf
Moisture Content:	x %
Compaction:	x %

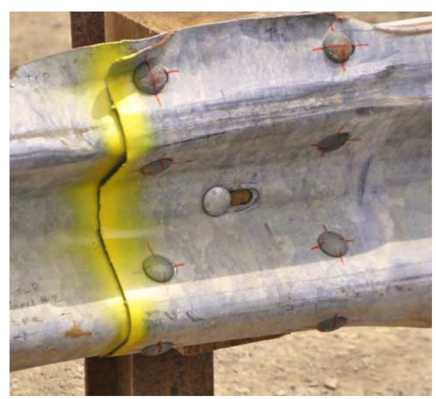
Impact Conditions

Pendulum Mass:	4,360 lb
Impact Velocity:	18.9 mph
Impact Energy:	623.6 kip-in
Load Point :	37.5 inches upstream of splice
Impact Orientation:	Perpendicular to rail

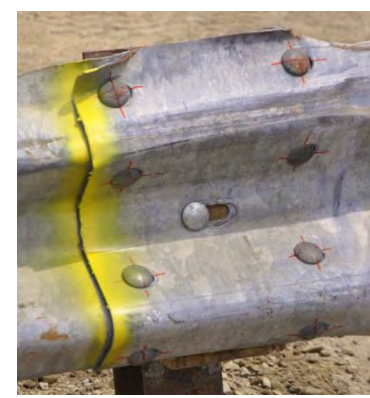
Result

Groundline Post Deflection	
Splice Slip	
Splice Rupture	
Rail Tear	
Boundary Failure	Friction slip of anchor cables
Max Force	37.9 kip
Max Deflection	
Total Energy	623.6 kip-in





Pre-Test



Post-Test

Test Information

Project Case Number:	4A5_NEW01
FOIL Test Number:	14004E
Test Date:	25-August-2014

System Properties

Rail Height:	27.25 inches
Post Type:	W6x16
Blockout Type:	6x8x10"Routed Wood
Foundation Type:	Grading B of AASHTO M147-95
Embedment Depth (in):	44

Damage Type

Category:	Undamaged Rail
Level:	N.A.

Soil Properties

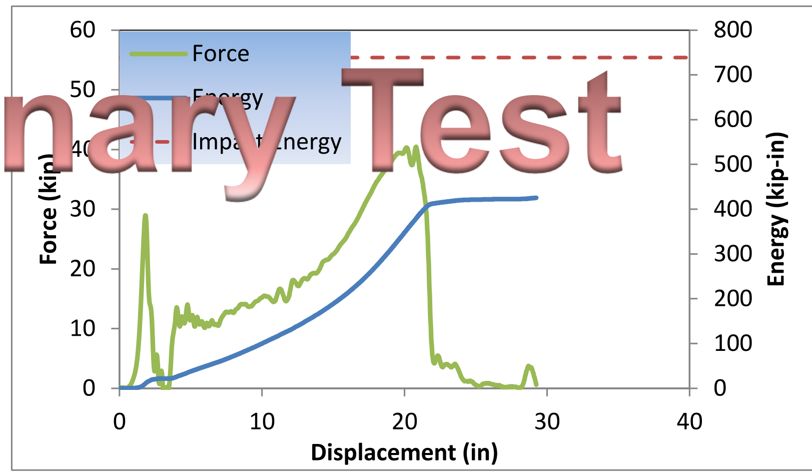
Dry Density :	1[illegible]6.9 pcf
Wet Density :	1[illegible].3 pcf
Moisture Content:	4.4%
Compaction:	97.8%

Impact Conditions

Pendulum Mass:	4,360 lb
Impact Velocity:	20.6 mph
Impact Energy:	738.7
Load Point :	37.5 inches upstream of splice
Impact Orientation:	Perpendicular to rail

Result

Groundline Post Deflection	
Splice Slip	
Splice Rupture	Bolt tear out
Rail Tear	
Boundary Failure	
Max Force	40.4 kip
Max Deflection	
Total Energy	425.2 kip-in



Pre-Test

Post-Test

Test Information

Project Case Number:	4A5_ME001
FOIL Test Number:	14004F
Test Date:	17-Sept-2014

System Properties

Rail Height:	27.25 inches
Post Type:	W6x16
Blockout Type:	6x8x10”Routed Wood
Foundation Type:	Grading B of AASHTO M147-95
Embedment Depth (in):	44

Damage Type

Category:	Flattening / Crush
Level:	68% / 14%

Soil Properties

Dry Density :	146.9 pcf
Wet Density :	153.3 pcf
Moisture Content:	4.4 %
Compaction:	97.8 %

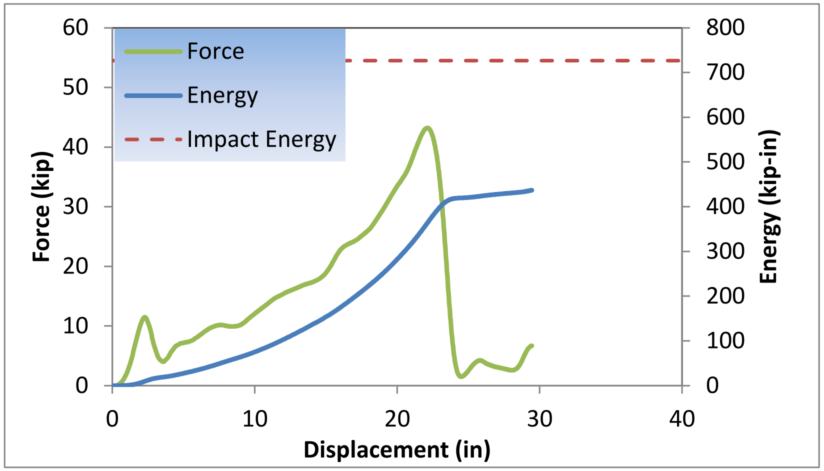
Impact Conditions

Pendulum Mass:	4,360 lb
Impact Velocity:	20.4 mph
Impact Energy:	726.6 kip-in
Load Point :	37.5 inches upstream of splice
Impact Orientation:	Perpendicular to rail

Result

Groundline Post Deflection	
Splice Slip	
Splice Rupture	Tear at downstream bolt-holes
Rail Tear	
Boundary Failure	
Max Force	43.2 kip
Max Deflection	
Total Energy	436.8 kip-in

Splice rupture



Pre-Test

Post-Test

Test Information

Project Case Number:	4A5_ME0011
FOIL Test Number:	14004G
Test Date:	24-Sept-2014

System Properties

Rail Height:	27.25 inches
Post Type:	W6x16
Blockout Type:	6x8x10"Routed Wood
Foundation Type:	Grading B of AASHTO M147-95
Embedment Depth (in):	44

Damage Type

Category:	Flattening / Crush
Level:	83% / 0%

Soil Properties

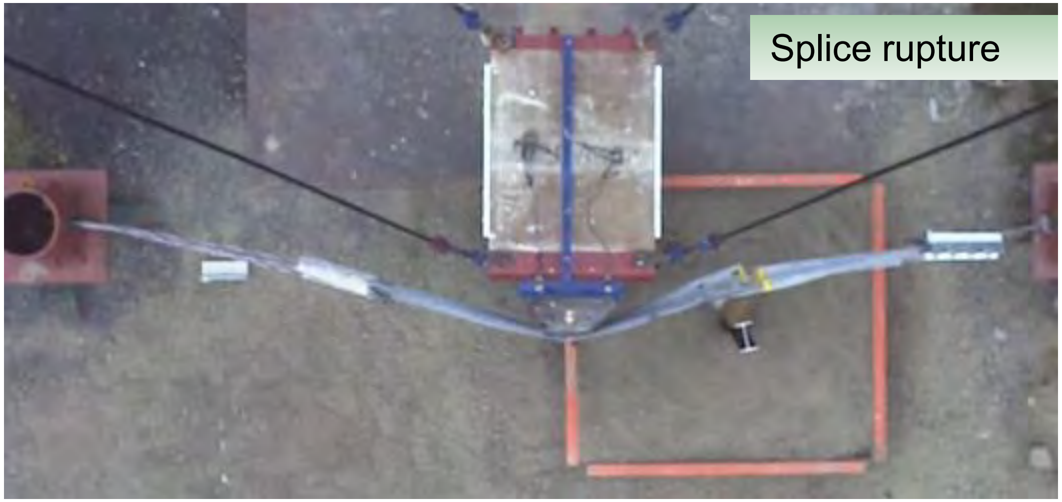
Dry Density :	pcf
Wet Density :	pcf
Moisture Content:	%
Compaction:	%

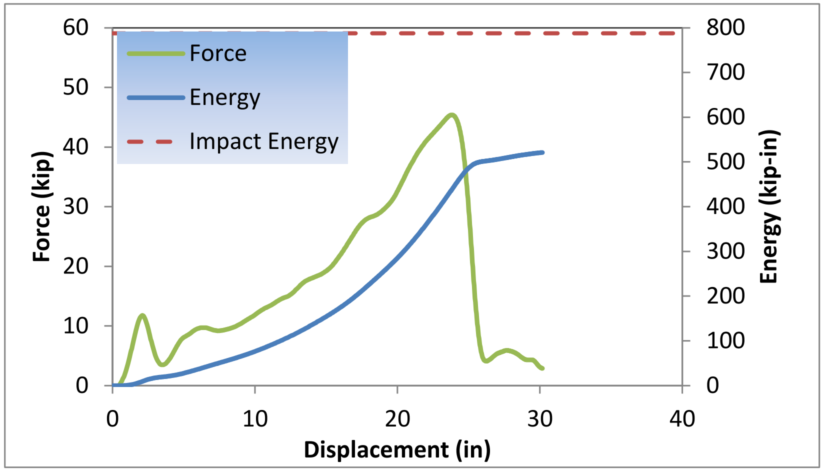
Impact Conditions

Pendulum Mass:	4,360 lb
Impact Velocity:	21.23 mph
Impact Energy:	787.7 kip-in
Load Point :	37.5 inches upstream of splice
Impact Orientation:	Perpendicular to rail

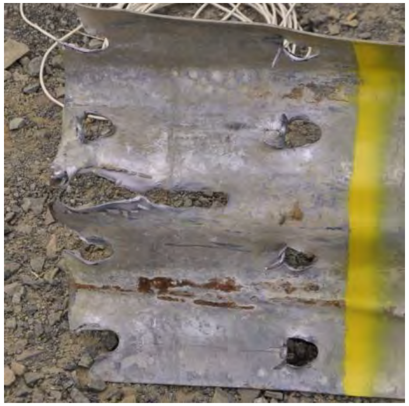
Result

Groundline Post Deflection	
Splice Slip	
Splice Rupture	Bolt tear out
Rail Tear	
Boundary Failure	
Max Force	45.4 kip
Max Deflection	
Total Energy	550.0 kip-in





Pre-Test



Post-Test

Test Information

Project Case Number:	4A5_ME0014
FOIL Test Number:	14004H
Test Date:	29-Sept-2014

System Properties

Rail Height:	27.25 inches
Post Type:	W6x16
Blockout Type:	6x8x10"Routed Wood
Foundation Type:	Grading B of AASHTO M147-95
Embedment Depth (in):	44

Damage Type

Category:	Longitudinal Slip
Level:	0.28 inches

Soil Properties

Dry Density :	147.7 pcf
Wet Density :	155.0 pcf
Moisture Content:	5.2%
Compaction:	98.1%

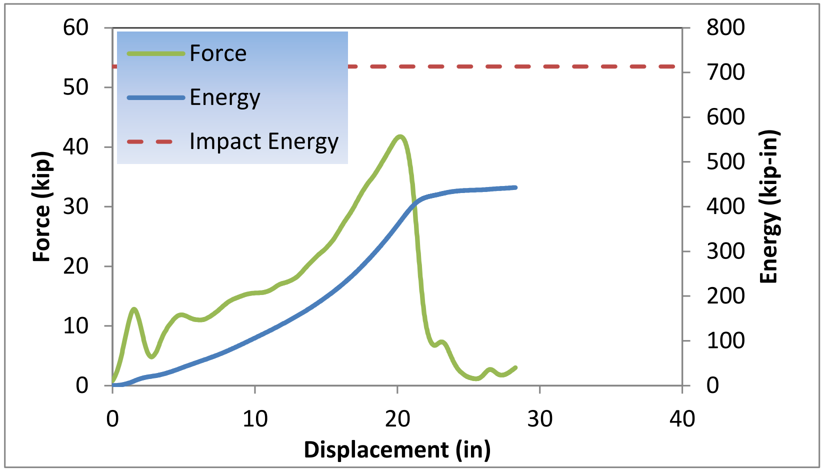
Impact Conditions

Pendulum Mass:	4,360 lb
Impact Velocity:	20.21 mph
Impact Energy:	713.1 kip-in
Load Point :	37.5 inches upstream of splice
Impact Orientation:	Perpendicular to rail

Result

Groundline Post Deflection	
Splice Slip	
Splice Rupture	Bolt tear out
Rail Tear	
Boundary Failure	
Max Force	41.7 kip
Max Deflection	
Total Energy	442.9 kip-in

Splice rupture



Pre-Test

Post-Test

Test Information

Project Case Number:	4A5_ME0017
FOIL Test Number:	140041
Test Date:	1-October-2014

System Properties

Rail Height:	27.25 inches
Post Type:	W6x16
Blockout Type:	6x8x10"Routed Wood
Foundation Type:	Grading B of AASHTO M147-95
Embedment Depth (in):	44

Damage Type

Category:	Longitudinal Slip
Level:	0.25 inches

Soil Properties

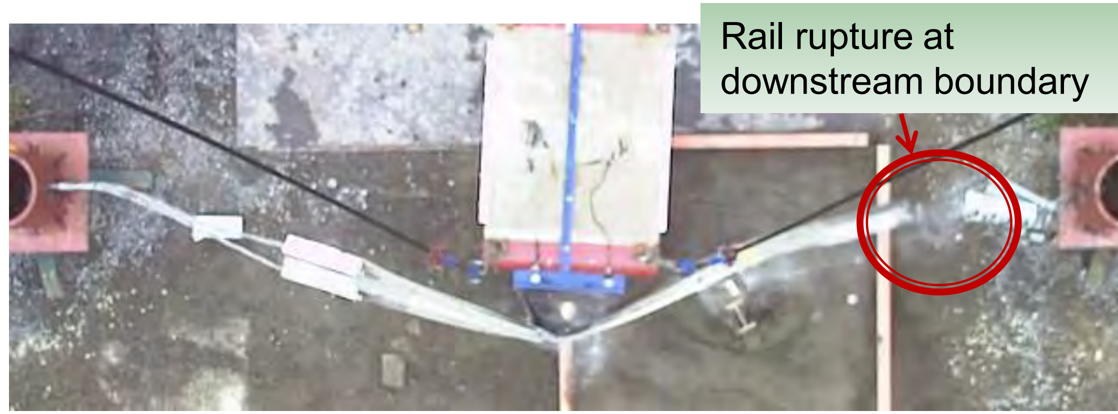
Dry Density :	148.4 pcf
Wet Density :	155.0 pcf
Moisture Content:	5.0%
Compaction:	98.8%

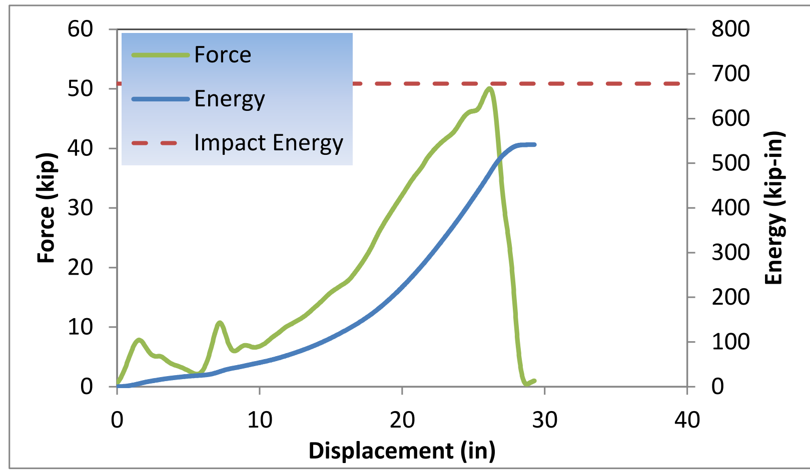
Impact Conditions

Pendulum Mass:	4,360 lb
Impact Velocity:	19.7 mph
Impact Energy:	678.2 kip-in
Load Point :	37.5 inches upstream of splice
Impact Orientation:	Perpendicular to rail

Result

Groundline Post Deflection	
Splice Slip	
Splice Rupture	
Rail Tear	Yes
Boundary Failure	Rail tear at downstream boundary
Max Force	50.1 kip
Max Deflection	
Total Energy	541.8 kip-in





Pre-Test

Post-Test

Test Information

Project Case Number:	4A5_ME004
FOIL Test Number:	14004J
Test Date:	7-October-2014

System Properties

Rail Height:	27.25 inches
Post Type:	W6x16
Blockout Type:	6x8x10"Routed Wood
Foundation Type:	Grading B of AASHTO M147-95
Embedment Depth (in):	44

Damage Type

Category:	Rail Crush
Level:	30.6%

Soil Properties

Dry Density :	144.9 pcf
Wet Density :	150.4 pcf
Moisture Content:	3.8%
Compaction:	96.5%

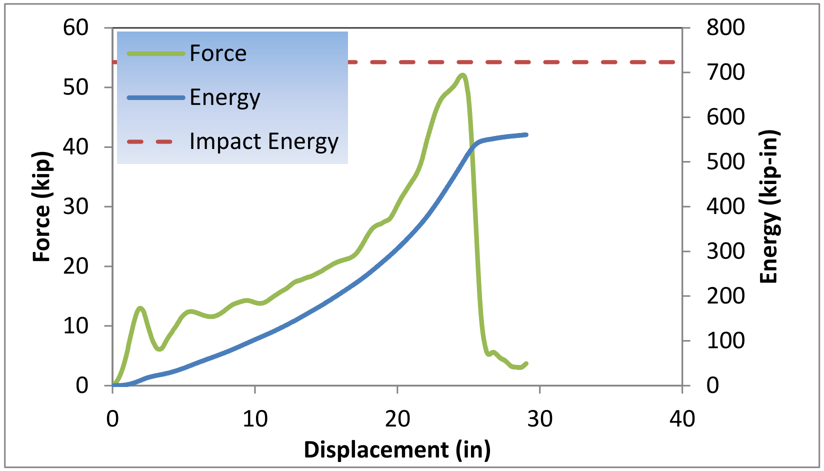
Impact Conditions

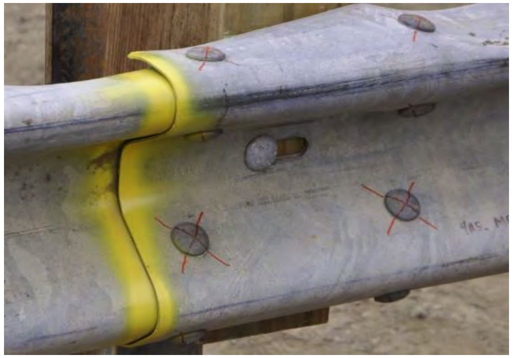
Pendulum Mass:	4,360 lb
Impact Velocity:	20.3 mph
Impact Energy:	723.0 kip-in
Load Point :	37.5 inches upstream of splice
Impact Orientation:	Perpendicular to rail

Result

Groundline Post Deflection	
Splice Slip	
Splice Rupture	
Rail Tear	
Boundary Failure	Cable rupture at downstream boundary
Max Force	52.1 kip
Max Deflection	
Total Energy	561.0 kip-in

Cable rupture at downstream boundary





Pre-Test

Post-Test

Test Information

Project Case Number:	4A5_ME010
FOIL Test Number:	14004K
Test Date:	9-October-2014

System Properties

Rail Height:	27.25 inches
Post Type:	W6x16
Blockout Type:	6x8x10"Routed Wood
Foundation Type:	Grading B of AASHTO M147-95
Embedment Depth (in):	44

Damage Type

Category:	Splice Lateral Separation
Level:	0.55 inches

Soil Properties

Dry Density :	149.9 pcf
Wet Density :	157.0 pcf
Moisture Content:	4.7%
Compaction:	99.9%

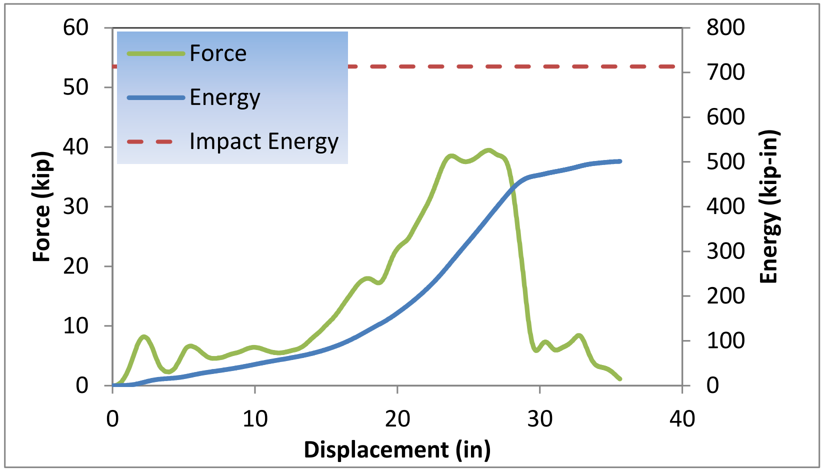
Impact Conditions

Pendulum Mass:	4,360 lb
Impact Velocity:	20.2 mph
Impact Energy:	713.1 kip-in
Load Point :	37.5 inches upstream of splice
Impact Orientation:	Perpendicular to rail

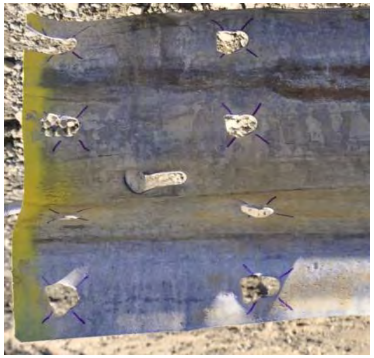
Result

Groundline Post Deflection	
Splice Slip	
Splice Rupture	Bolt teat out
Rail Tear	
Boundary Failure	
Max Force	39.5 kip
Max Deflection	
Total Energy	501.2 kip-in

Splice rupture



Downstream Panel



Upstream Panel

Pre-Test

Post-Test

Test Information

Project Case Number:	4A5_ME007
FOIL Test Number:	14004L
Test Date:	17-October-2014

System Properties

Rail Height:	27.25 inches
Post Type:	W6x16
Blockout Type:	6x8x10"Routed Wood
Foundation Type:	Grading B of AASHTO M147-95
Embedment Depth (in):	44

Damage Type

Category:	Splice Lateral Separation
Level:	0.50 inches

Soil Properties

Dry Density :	150.0 pcf
Wet Density :	157.5 pcf
Moisture Content:	5.0%
Compaction:	99.9%

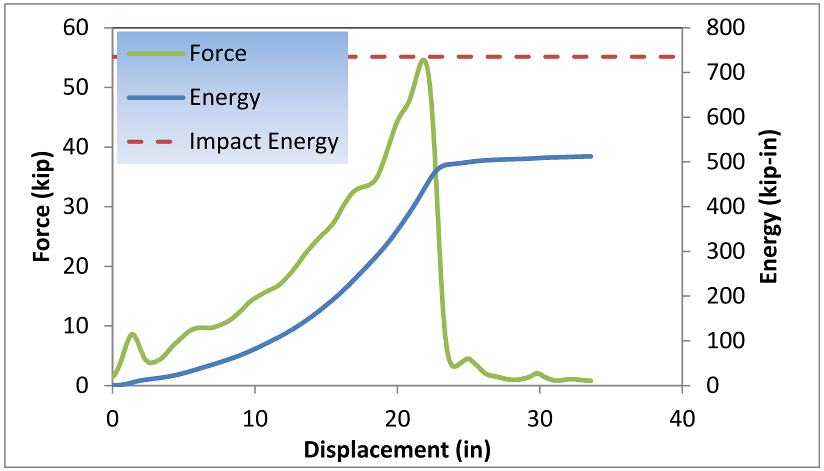
Impact Conditions

Pendulum Mass:	4,360 lb
Impact Velocity:	20.5 mph
Impact Energy:	735.2 kip-in
Load Point :	37.5 inches upstream of splice
Impact Orientation:	Perpendicular to rail

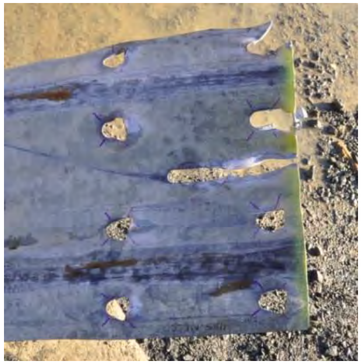
Result

Groundline Post Deflection	
Splice Slip	
Splice Rupture	Bolt teat out
Rail Tear	
Boundary Failure	
Max Force	54.6 kip
Max Deflection	
Total Energy	512.5 kip-in

Splice rupture



Downstream Panel



Upstream Panel

Pre-Test

Post-Test

Test Information

Project Case Number:	4A5_ME013
FOIL Test Number:	14004M
Test Date:	23-October-2014

System Properties

Rail Height:	27.25 inches
Post Type:	W6x16
Blockout Type:	6x8x10”Routed Wood
Foundation Type:	Grading B of AASHTO M147-95
Embedment Depth (in):	44

Damage Type

Category:	Splice Lateral Separation
Level:	0.50 inches

Soil Properties

Dry Density :	146.6 pcf
Wet Density :	153.4 pcf
Moisture Content:	4.6%
Compaction:	97.6%

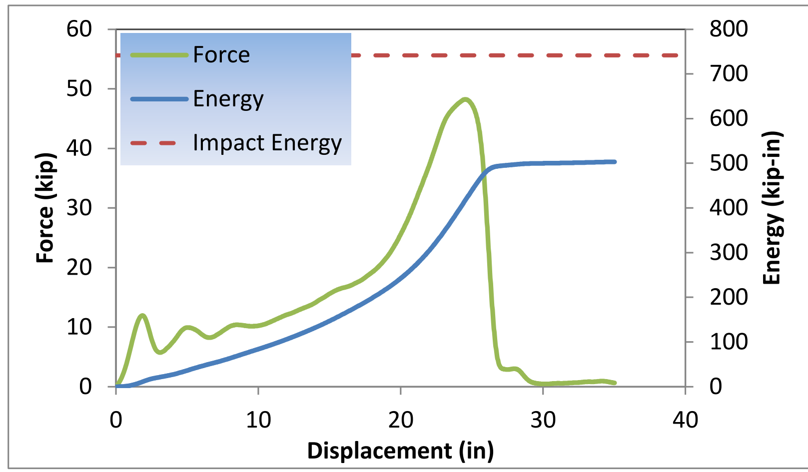
Impact Conditions

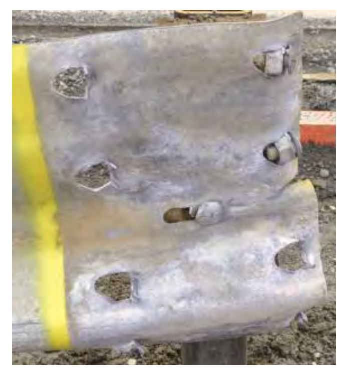
Pendulum Mass:	4,360 lb
Impact Velocity:	20.6 mph
Impact Energy:	741.6 kip-in
Load Point :	37.5 inches upstream of splice
Impact Orientation:	Perpendicular to rail

Result

Groundline Post Deflection	
Splice Slip	
Splice Rupture	Bolt teat out
Rail Tear	
Boundary Failure	
Max Force	48.2 kip
Max Deflection	
Total Energy	503.4 kip-in

Splice rupture





Downstream Panel

Upstream Panel

Pre-Test

Post-Test

Test Information

Project Case Number:	4A5_NEW02
FOIL Test Number:	14004N
Test Date:	24-October-2014

System Properties

Rail Height:	27.25 inches
Post Type:	W6x16
Blockout Type:	6x8x10”Routed Wood
Foundation Type:	Grading B of AASHTO M147-95
Embedment Depth (in):	44

Damage Type

Category:	Undamaged
Level:	N.A.

Soil Properties

Dry Density :	146.6 pcf
Wet Density :	154.9 pcf
Moisture Content:	5.6%
Compaction:	97.6%

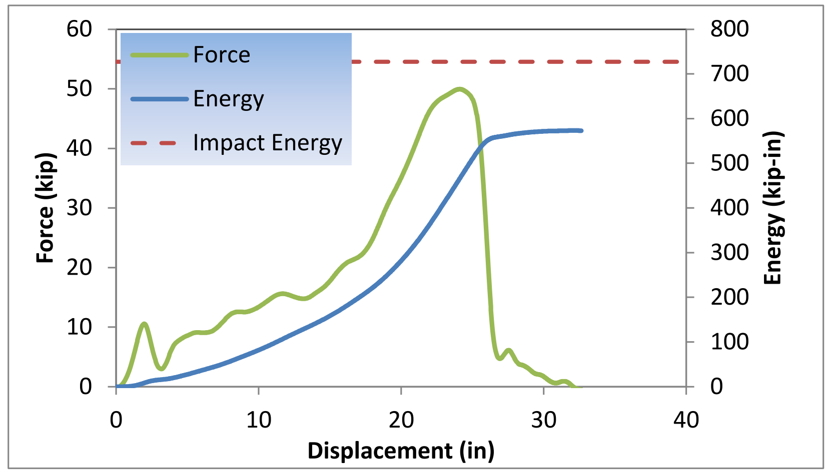
Impact Conditions

Pendulum Mass:	4,360 lb
Impact Velocity:	20.4 mph
Impact Energy:	727.3 kip-in
Load Point :	37.5 inches upstream of splice
Impact Orientation:	Perpendicular to rail

Result

Groundline Post Deflection	
Splice Slip	
Splice Rupture	Bolt teat out
Rail Tear	
Boundary Failure	
Max Force	49.9 kip
Max Deflection	
Total Energy	573.2 kip-in

Splice rupture



Downstream Panel

Upstream Panel

Pre-Test

Post-Test

Test Information

Project Case Number:	4A5_NEW03
FOIL Test Number:	14004O
Test Date:	30-October-2014

System Properties

Rail Height:	27.25 inches
Post Type:	W6x16
Blockout Type:	6x8x10"Routed Wood
Foundation Type:	Grading B of AASHTO M147-95
Embedment Depth (in):	44

Damage Type

Category:	Undamaged Rail
Level:	N.A.

Soil Properties

Dry Density :	147.5 pcf
Wet Density :	155.1 pcf
Moisture Content:	5.1%
Compaction:	98.2%

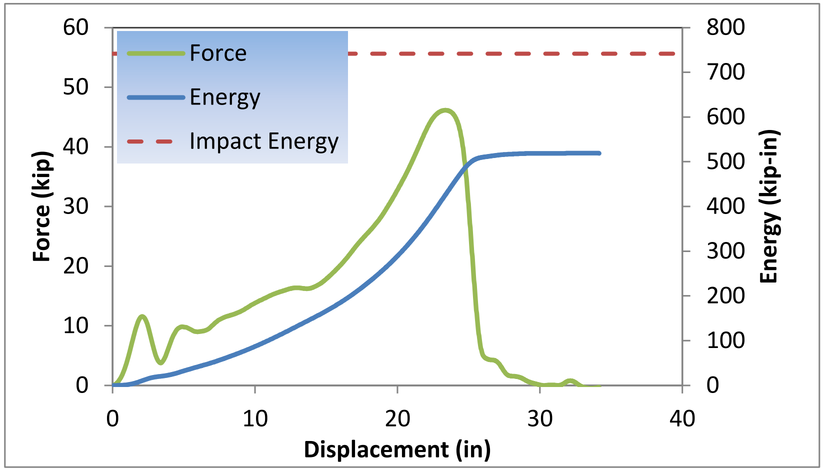
Impact Conditions

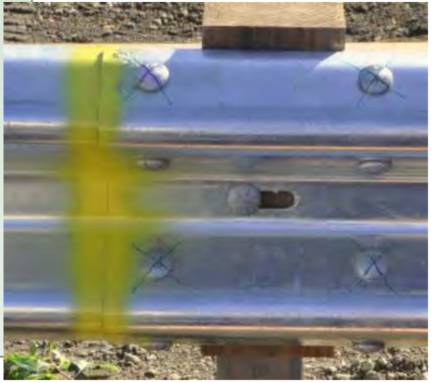
Pendulum Mass:	4,360 lb
Impact Velocity:	20.6 mph
Impact Energy:	741.6
Load Point :	37.5 inches upstream of splice
Impact Orientation:	Perpendicular to rail

Result

Groundline Post Deflection	
Splice Slip	
Splice Rupture	Bolt tear out
Rail Tear	
Boundary Failure	
Max Force	46.1 kip
Max Deflection	
Total Energy	519.5 kip-in

Splice rupture





Downstream Panel

Upstream Panel

Pre-Test

Post-Test