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16. Abstract

Under this project, researchers investigated the impact performance of molded plastic mailboxes through full-scale crash testing. TxDOT has been receiving an increasing number of requests to use these molded plastic mailboxes in lieu of the Department's standard mailbox support and mailbox connection hardware. These molded plastic mailboxes are available in a variety of styles and colors, which make them an aesthetic alternative to conventional mailbox installations.

Crash tests were conducted to evaluate the performance of molded plastic mailboxes on three different types of support posts: 4×4 wood, 2 lb/ft U-channel, and 3-in. diameter schedule 40 pipe. In all three tests, the molded plastic mailbox units satisfied *National Cooperative Highway Research Program (NCHRP) Report 350* evaluation criteria. However, some variations in performance associated with the different support posts were observed. From both a functional and impact performance standpoint, the 4×4 timber support post appears to be the best alternative from among the three support posts investigated. It is therefore recommended that these mailboxes be installed on a 4×4 wood support post per manufacturers' recommendations.

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TESTING AND EVALUATION OF MOLDED PLASTIC MAILBOXES

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Research Project Title: Roadside Safety Hardware
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DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data, and the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official view or policies of the Texas Department of Transportation (TxDOT), Federal Highway Administration (FHWA), the Texas A&M University System, or the Texas Transportation Institute. This report does not constitute a standard, specification, or regulation, and its contents are not intended for construction, bidding, or permit purposes. In addition, the above listed agencies assume no liability for its contents or use thereof. The use of names of specific products or manufacturers listed herein, such as Rubbermaid or the Step 2 Company, does not imply endorsement of those products or manufacturers. The engineer in charge was Roger P. Bligh, P.E. (Texas, #78550).

ACKNOWLEDGEMENTS

This research project was conducted under a cooperative program between the Texas Transportation Institute, the Texas Department of Transportation, and the U.S. Department of Transportation, Federal Highway Administration. The TxDOT project director for this research was Mr. Greg Brinkmeyer, Traffic Operations Division. His assistance is acknowledged and appreciated. The assistance of Mr. Ken Boehme, Maintenance Division, is also acknowledged and appreciated.

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CHAPTER 1. INTRODUCTION

BACKGROUND

Through their research program, the Texas Department of Transportation (TxDOT) continues to be proactive in their ongoing commitment to providing safer roadsides for the traveling public. TxDOT-sponsored research has resulted in the development of many satisfactory sign support and mailbox designs with demonstrated impact performance. The Department uses the results of in-service performance evaluations and feedback from field crews to continually assess the performance of these systems and identify areas in which design improvements can be realized in terms of cost, maintenance, or impact behavior.

As with other objects on the roadside, mailboxes can constitute a hazard to the motoring public when struck by an errant vehicle. For this reason, only crashworthy mailbox designs are permitted to be used on the state highway system. Recently, TxDOT has been receiving requests to use molded plastic mailboxes such as those manufactured by Step 2 and Rubbermaid in lieu of a standard mailbox, mailbox support, and mailbox connection hardware. These molded plastic mailboxes are available in a variety of styles and colors, which make them an aesthetic alternative to some conventional mailbox installations. However, before TxDOT can approve the use of these mailboxes on Texas highways, their crashworthiness must be evaluated through full-scale crash testing.

OBJECTIVES/SCOPE OF RESEARCH

The objective of this research project is to investigate the impact performance of molded plastic mailboxes and various methods of installing these mailboxes. The research approach and testing methodologies followed for this project are presented in Chapter 2. The results of full-scale crash testing are presented in Chapter 3. A summary of findings, conclusions, and implementation recommendations are presented in Chapter 4.

CHAPTER 2. STUDY APPROACH

TEST FACILITY

The test facilities at the Texas Transportation Institute's (TTI) Proving Ground consist of a 2000-acre complex of research and training facilities situated 10 mi northwest of the main campus of Texas A&M University. The site, formerly an Air Force base, has large expanses of concrete runways and parking aprons well suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, durability and efficacy of highway pavements, and safety evaluation of roadside safety hardware. The site selected for installation and testing of the molded plastic mailbox systems is the end of an out-of-service concrete apron. The apron consists of 12.5-ft. by 15-ft. blocks of unreinforced jointed concrete pavement that are nominally 8-12 in. deep. The aprons and runways are about 50 years old, and the joints have some displacement but are otherwise flat and level.

Crash tests were performed to evaluate the performance of molded plastic mailboxes on three different support posts. Figures 1 and 2 present details of the Step 2 mailbox mounted on 4×4 wood post. The Step 2 mailbox was also evaluated mounted on 2 lb/ft U-channel as shown in Figures 3 and 4. For the third test, a Rubbermaid mailbox mounted on 3-in. diameter steel pipe, as shown in Figures 5 and 6, was evaluated. All three installations were installed in National Cooperative Highway Research Program (*NCHRP) Report 350* standard soil. Chapter 3 provides complete descriptions of each installation under each respective test.

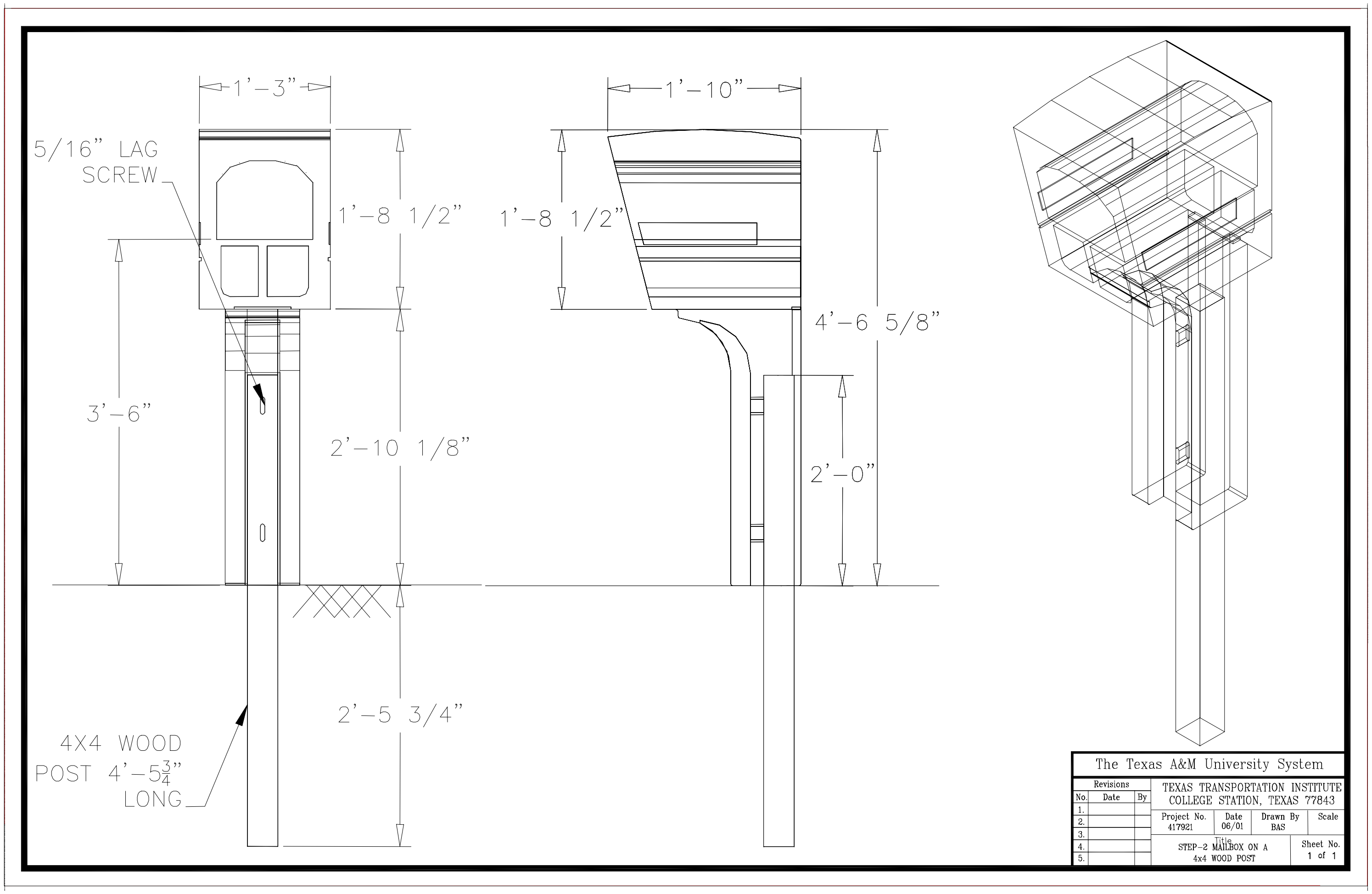


Figure 1. Details of the Step 2 Mailbox Mounted on 4×4 Timber Post.

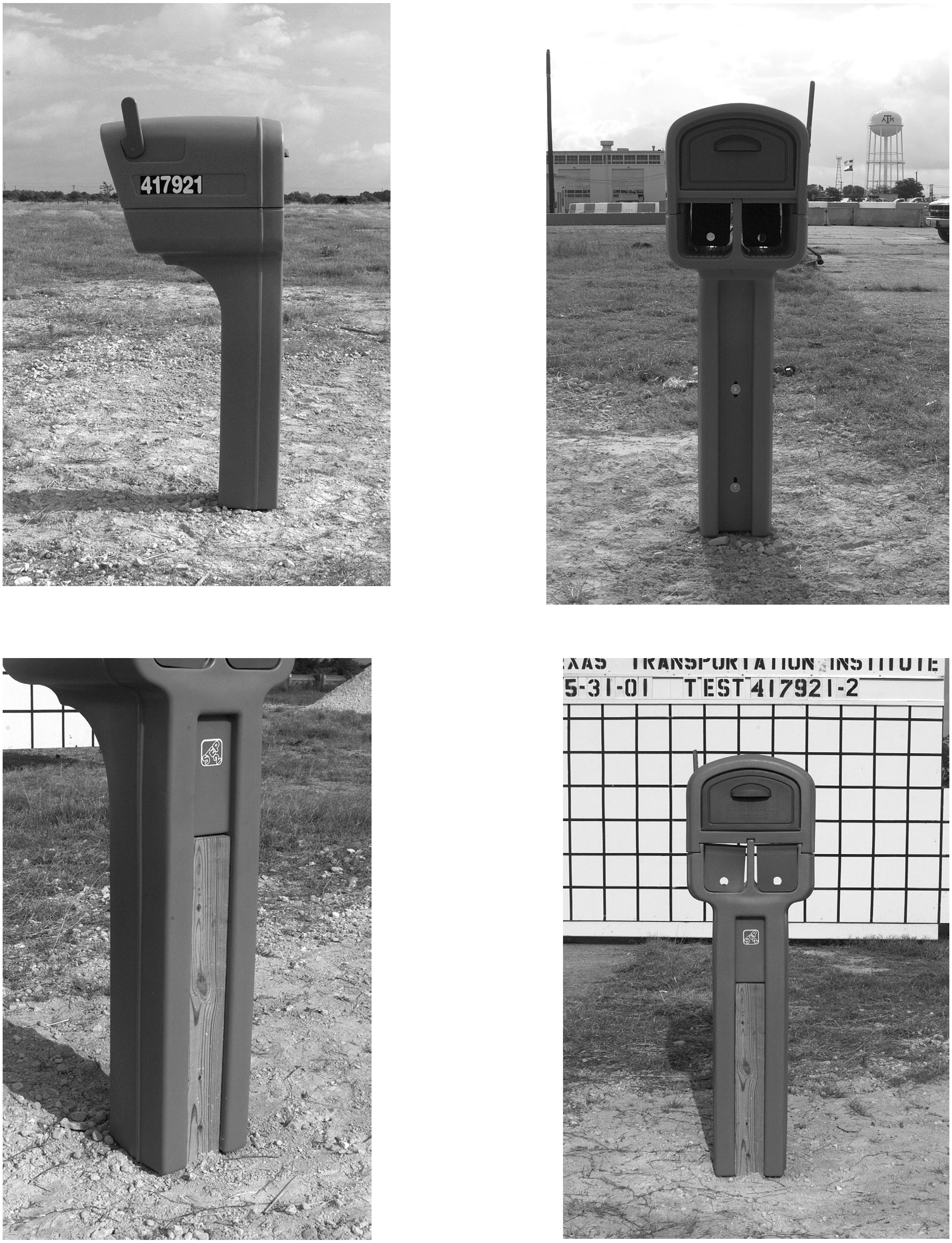


Figure 2. Step 2 Mailbox on Timber Post before Test 417921-2.

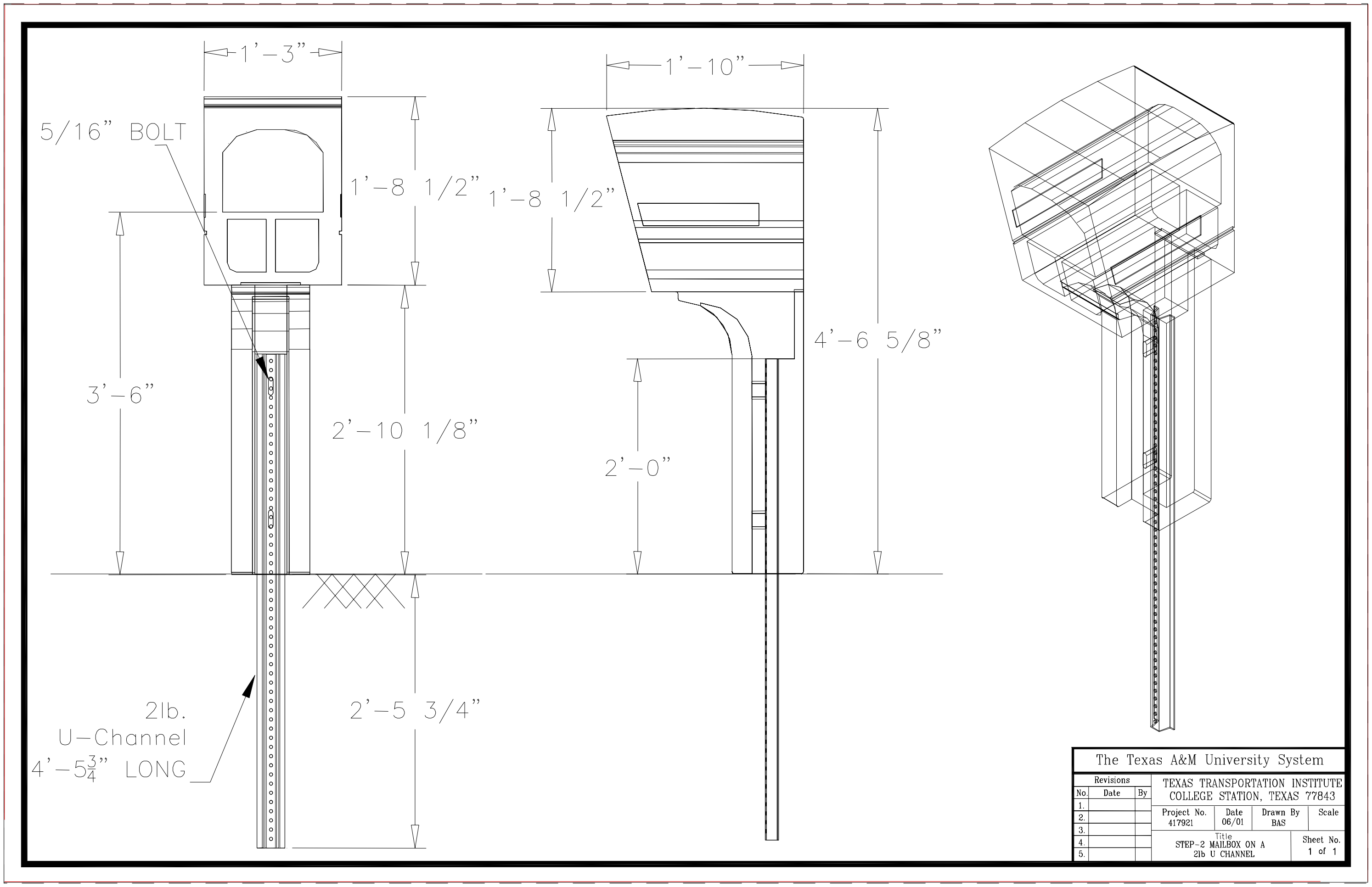


Figure 3. Details of the Step 2 Mailbox Mounted on Steel U-Channel.

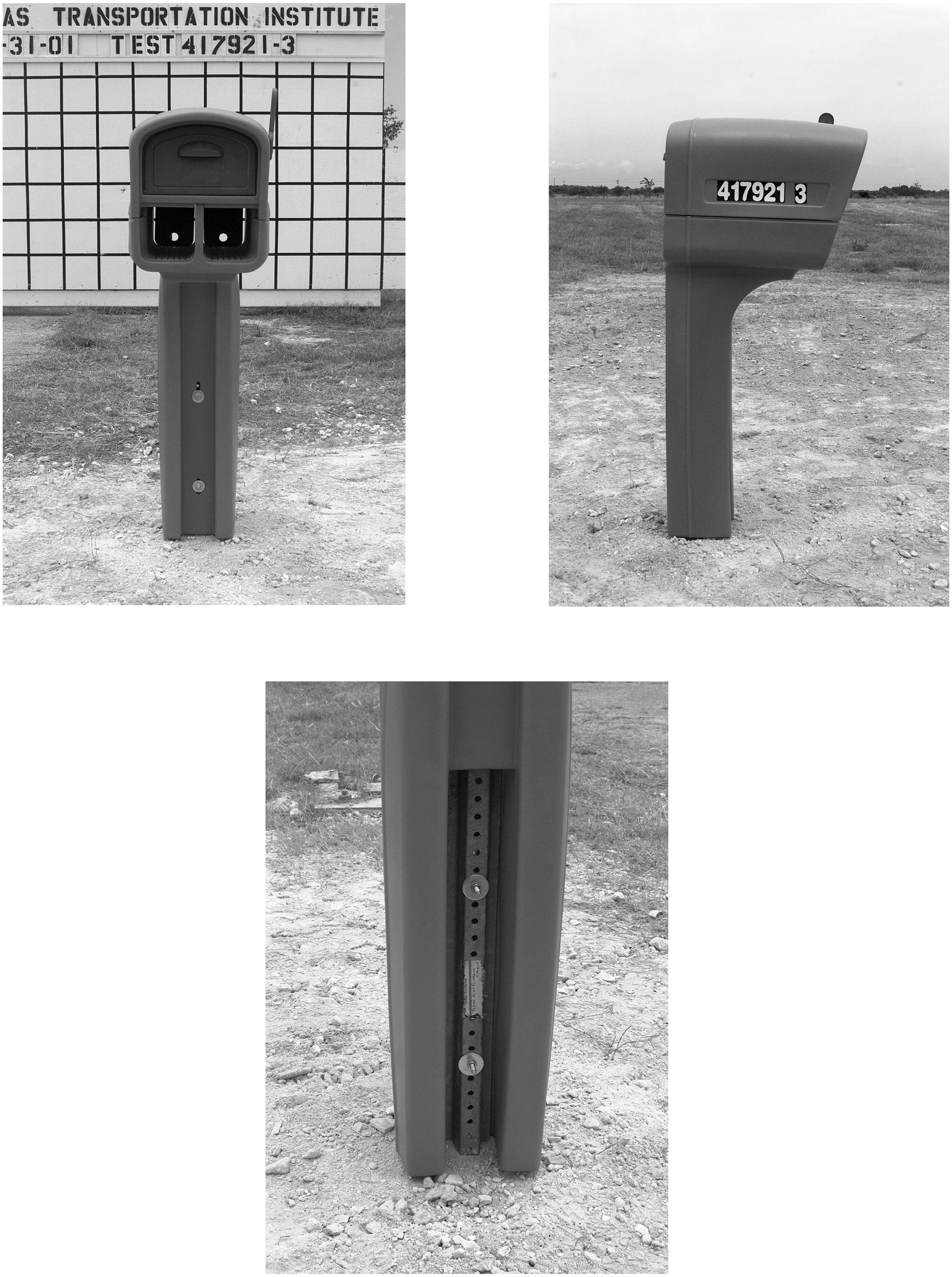


Figure 4. Step 2 Mailbox on Steel U-Channel before Test 417921-3.

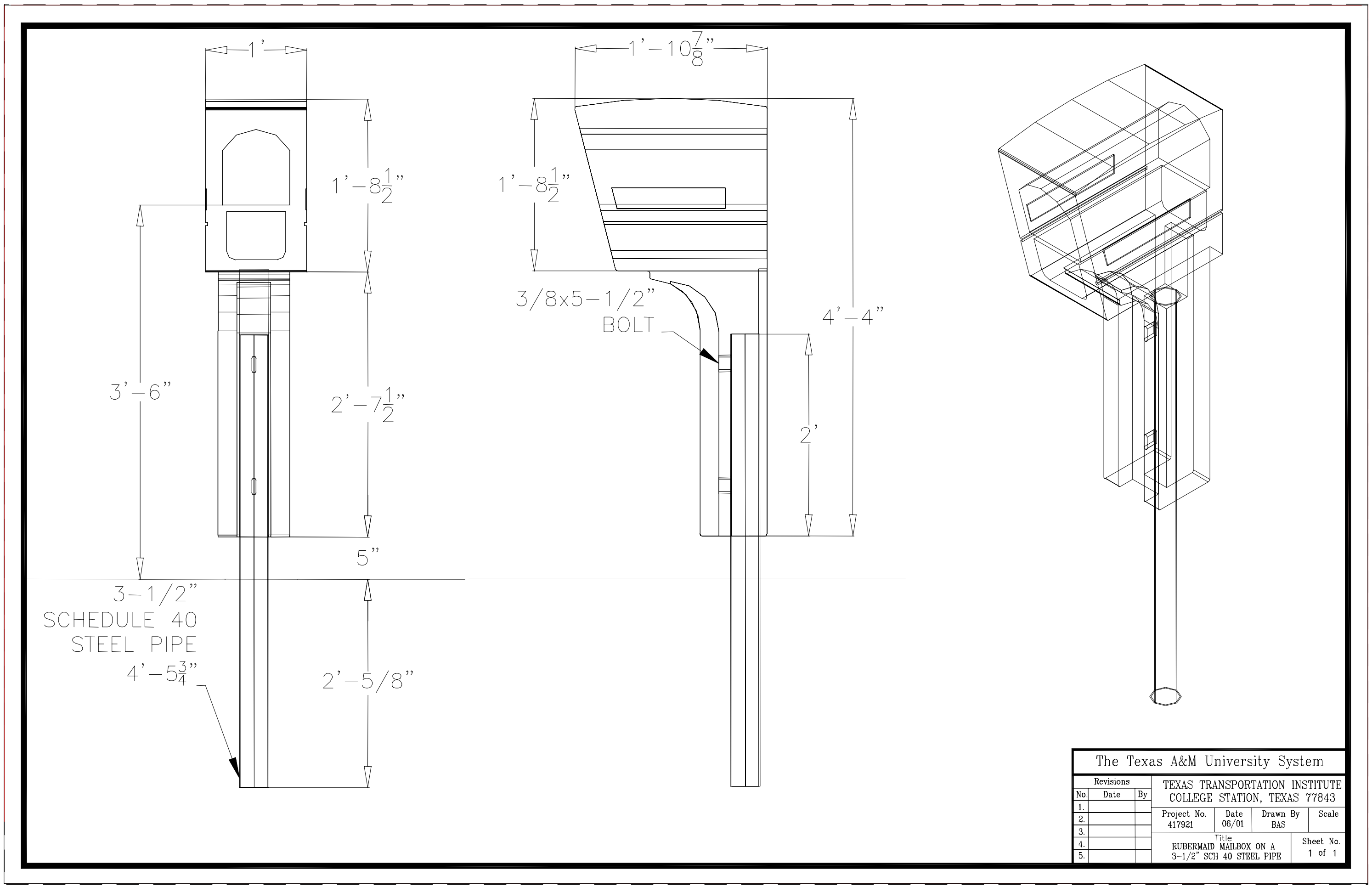


Figure 5. Details of the Rubbermaid Mailbox Mounted on Steel Pipe Post.

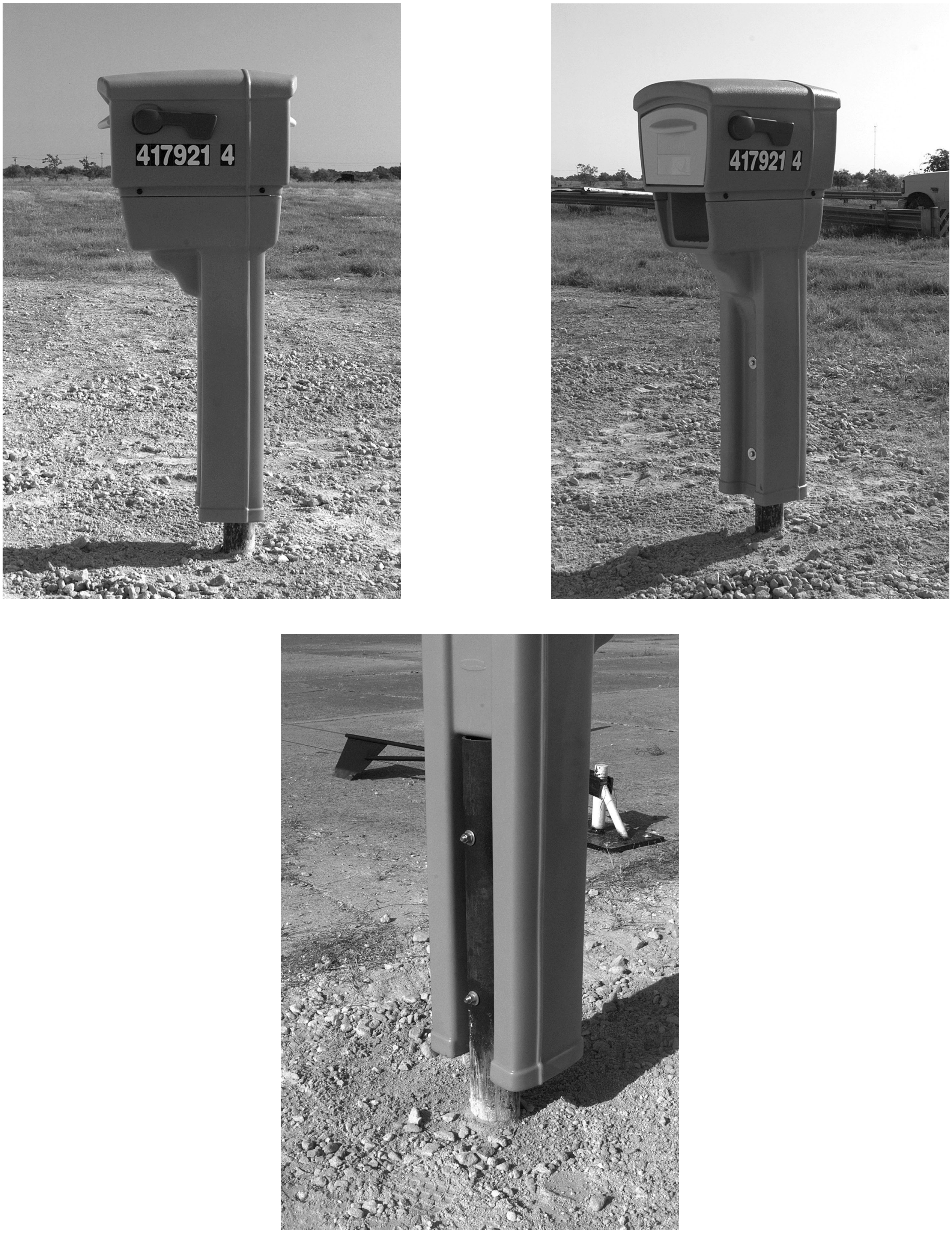


Figure 6. Rubbermaid Mailbox on Steel Pipe Post before Test 417921-4.

CRASH TEST CONDITIONS

NCHRP Report 350 requires two tests for test level 3 evaluation of breakaway support structures such as mailboxes. The impact conditions and objective of each test is summarized below:

> ***NCHRP Report 350*** **test designation 3-60**: This test involves an 1806-lb passenger vehicle (820C) impacting the support structure at a nominal speed of 21.7 mi/h and an angle ranging from 0-20 degrees. The purpose of this test is to evaluate the breakaway, fracture, or yielding mechanism of the support, as well as occupant risk.

> ***NCHRP Report 350*** **test designation 3-61**: This test involves an 1806-lb passenger vehicle (820C) impacting the support structure at a nominal speed of 62.1 mi/h and an angle ranging from 0-20 degrees. The test is intended to evaluate vehicle and test article trajectory and occupant risk.

The results of all the tests reported herein correspond to *NCHRP Report 350* test designation 3-61. Researchers considered this high-speed test to be the best condition for evaluating the impact performance of the molded plastic mailboxes. At the higher speed, there is more propensity for the mailbox to cause occupant compartment intrusion due to secondary contact of the mailbox with the windshield of the impacting vehicle.

The crash test and data analysis procedures followed for the tests reported herein were in accordance with guidelines presented in *NCHRP Report 350*. Appendix A presents a brief description of these procedures.

EVALUATION CRITERIA

The crash tests on the molded plastic mailbox units were evaluated in accordance with *NCHRP Report 350*. As stated in *NCHRP Report 350*, "Safety performance of a highway appurtenance cannot be measured directly but can be judged on the basis of three factors: structural adequacy, occupant risk, and vehicle trajectory after collision." Accordingly, researchers used the safety evaluation criteria from Table 5.1 of *NCHRP Report 350* to evaluate the crash tests reported herein.

CHAPTER 3. CRASH TEST RESULTS

STEP 2 MAILMASTER DELUXE MAILBOX ON TIMBER SUPPORT POST (TEST NO. 417921-2)

Test Article

The Step 2 Company manufactures molded plastic mailboxes in a variety of styles and colors. The researchers selected the MailMaster Deluxe (Model No. 5403) for testing because it is the heaviest model in the MailMaster line, which makes it most critical in terms of impact performance and the potential for occupant compartment intrusion. The MailMaster Deluxe model weighs 24 lb. It is molded in two separate sections that are attached to one another with four #8 × 1 ½-in. long sheet metal screws that pass through a lap joint between the two sections from the inside of the mailbox. The upper molded section contains the mailbox, which has access doors from both the front and rear. The lower molded section incorporates two newspaper compartments and the post housing. A cutout is molded into the back of the plastic post housing so that the mailbox unit can slide onto the mailbox support post. The manufacturer recommends that users install the mailbox over a 4×4 wood post. The mailbox unit is then secured to the wood post using two 5/16-in. diameter × 3-in. long lag screws through prefabricated holes in the front face of the plastic post housing.

For the first crash test, the MailMaster Deluxe mailbox was attached to a 4×4 wood support post per manufacturer's recommendations using the manufacturer-supplied hardware. The 4×4 wood support post was embedded in *NCHRP Report 350* standard soil to a depth of 30 in. The U.S. Post Office requires the height of the bottom of the mailbox door be between 40 and 44 in. with 42 in. as the target value. With the plastic housing of the MailMaster Deluxe placed directly on the ground, the height to the bottom of the mailbox door is approximately 42 in. Since the test site was flat and level, no further adjustment of the mailbox height was necessary. The 4×4 wood support post extended 24 in. above ground. This placed the bottom of the plastic mailbox housing flush with the ground. Details of the tested mailbox configuration are shown in Figure 1.

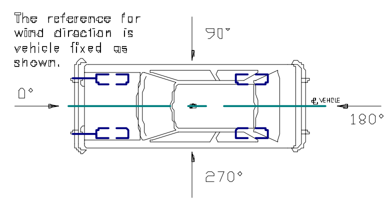
The MailMaster Deluxe mailbox with 4×4 wood support post was tested in an empty configuration without any added ballast in the mailbox or newspaper compartments. The mailbox was oriented perpendicular to the direction of the vehicle so that the front of the vehicle would impact the side of the mailbox in a manner similar to what would be expected to occur on the roadside. Photographs of the completed test installation are shown in Figure 2.

Test Vehicle

A 1996 Geo Metro, shown in Figures 7 and 8, was used for the crash test. Test inertia weight of the vehicle was 1806 lb, and its gross static weight was 1974 lb. The height to the lower edge of the vehicle bumper was 15.75 in., and the height to the upper edge of the vehicle bumper was 20.67 in. Figure 28 in Appendix B provides additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

Soil and Weather Conditions

The test was performed the morning of May 31, 2001. Six days prior to the test, 0.85 in. of rainfall was recorded. No other rainfall occurred within 10 days prior to the test. Moisture content of the *NCHRP Report 350* soil in which the 4×4 timber mailbox support was installed was 6.0 percent. Weather conditions at the time of testing were as follows: wind speed: 10 mi/h; wind direction: 180 degrees with respect to the vehicle (vehicle was traveling in a northerly direction); temperature: 80 °F; relative humidity: 80 percent.



Test Description

The vehicle, traveling at 60.8 mi/h, contacted the MailMaster Deluxe mailbox with timber support post at an impact angle of 0 degree with the right quarter point of the vehicle aligned with the centerline of the timber post. Shortly after impact, the support section of the mailbox began to deflect, and at 0.005 s the upper molded portion of the unit containing the

Figure 7. Vehicle/Installation Geometrics for Test 417921-2.

Figure 8. Vehicle before Test 417921-2.

mailbox began to separate from the lower base portion. At 0.010 s, the timber support post began to fracture at ground level. At 0.015 s, the upper end of the lower base portion of the mailbox contacted the hood of the vehicle. The upper molded portion containing the mailbox was completely separated from the lower base portion of the unit by 0.020 s. This upper section subsequently contacted the rear of the hood and lower part of the windshield at 0.032 s. The lower base portion and wood support post lost contact with the vehicle bumper at 0.052 s, and the upper section lost contact with the windshield at 0.077 s. Speed of the vehicle at loss of contact was 59.5 mi/h. The vehicle traveled forward in a straight path, and brakes were remotely applied at 1.3 s. The vehicle subsequently came to rest 263 ft downstream of impact. Sequential photographs of the test period are shown in Appendix C, Figure 30.

Damage to Test Installation

Figures 9 and 10 show damage to the test installation. The 4×4 timber support pulled out of the ground 3.5 in. before fracturing flush with ground level. The mailbox separated into several pieces, the heaviest of which weighed 12 lb-2 oz. The debris pattern extended 77.5 ft downstream, 20.0 ft to the left, and 25 ft to the right of the point of impact.

Vehicle Damage

As shown in Figure 11, damage to the vehicle was minimal. The windshield was cracked (Case 4 of the Federal Highway Administration (FHWA) Windshield Damage Guidance) due to contact with the upper portion of the mailbox unit. However, there were no holes in the windshield nor any deformation of the windshield into the passenger compartment, and visibility was not restricted. No other occupant compartment deformation was noted. The hood was deformed over an area 16 in. long × 19.68 in. wide × 0.40 in. deep. Photographs of the interior of the vehicle are shown in Figure 12. Exterior crush measurements and occupant compartment measurements are provided in Appendix B, Tables 4 and 5.

Occupant Risk Factors

Data from the tri-axial accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact

Figure 9. After Impact Trajectory for Test 417921-2.

Figure 10. Step 2 Mailbox on Timber Post after Test 417921-2.

Figure 11. Vehicle after Test 417921-2.

Before Test

After Test

Figure 12. Interior of Vehicle for Test 417921-2.

velocity was 2.0 ft/s at 0.791 s, the highest 0.010-s occupant ridedown acceleration was -1.4 g's from 1.456 to 1.466 s, and the maximum 0.050-s average acceleration was -1.0 g's between 0.020 and 0.070 s. In the lateral direction, the occupant impact velocity was 5.2 ft/s at 0.791 s, the highest 0.010-s occupant ridedown acceleration was −1.1 g's from 1.552 to 1.562 s, and the maximum 0.050-s average was 0.7 g's between 0.561 and 0.611 s. These data and other pertinent information from the test are summarized in Figure 13. Vehicle angular displacements are presented in Appendix D, Figure 33. Vehicle acceleration versus time traces are presented in Figures 36 through 38.

Assessment of Test Results

An assessment of the test based on the applicable *NCHRP Report 350* safety evaluation criteria is provided below.

- **Structural Adequacy**

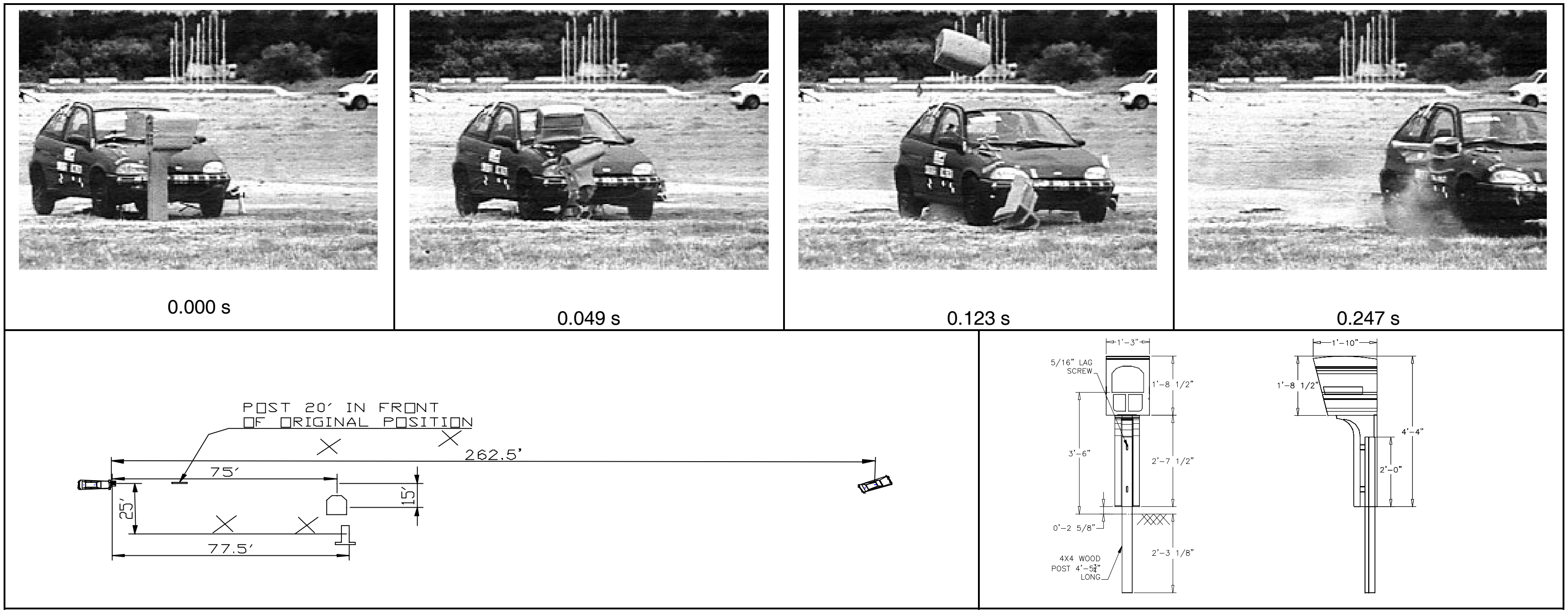
  B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.

  Results: The 4×4 timber post on which the Step 2 mailbox was mounted fractured at ground level. *(pass)*

- **Occupant Risk**

  C. 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. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.

  Results: The timber post fractured at ground level, and the mailbox separated into several pieces. The largest, heaviest piece was the lower base portion of the mailbox attached to the upper section of the fractured wooden support post, which had a combined weight of 12 lb-2 oz. However, neither this piece nor any of the



General Information
- Test Agency .... Texas Transportation Institute
- Test No. 417921-2
- Date 05/31/01

Test Article
- Type .... Mailbox
- Name .... Step-2 Mailbox on a 4x4 wood post
- Installation Length (ft) .... 4 ft 4 in
- Material or Key Elements .... Plastic mailbox mounted on a 4x4 wood post

Soil Type and Condition .... Standard Soil, dry

Test Vehicle
- Type .... Production
- Designation 820C
- Model .... 1996 Geo Metro
- Mass (lb) Curb 1781
  - Test Inertial 1806
  - Dummy 168
  - Gross Static 1974

Impact Conditions
- Speed (mi/h) 60.8
- Angle (deg) 0

Exit Conditions
- Speed (mi/h) 59.5
- Angle (deg) 0

Occupant Risk Values
- Impact Velocity (ft/s)
  - x-direction 2.0
  - y-direction 5.2
- THIV (mi/h) 4
- Ridedown Accelerations (g's)
  - x-direction .... -1.4
  - y-direction .... -1.1
- PHD (g's) 1.4
- ASI 0.15
- Max. 0.050-s Average (g's)
  - x-direction .... -1.0
  - y-direction 0.7
  - z-direction .... -1.3

Test Article Scatter (ft)
- Longitudinal 77.5
- Lateral 25.0
- Working Width .... N/A

Vehicle Damage
- Exterior
  - VDS 12FD2
  - CDC .... N/A
- Maximum Exterior
  - Vehicle Crush (in) .... nil
- Interior
  - OCDI FS0000000
- Max. Occ. Compart.
  - Deformation (in) .... nil

Post-Impact Behavior
- (during 1.0 s after impact)
- Max. Yaw Angle (deg) 10
- Max. Pitch Angle (deg) 8
- Max. Roll Angle (deg) 4

Figure 13. Summary of Results for Test 417921-2, *NCHRP Report 350* Test 3-61.

other smaller pieces of the molded plastic mailbox penetrated nor showed potential for penetrating the occupant compartment. Further, since this debris was not considered to present undue hazard to others in the area as it remained relatively close to the vehicle as it traveled through the test site. The windshield was cracked, but there were no deformations or intrusions into the occupant compartment. *(pass)*

F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.

Results: The vehicle remained upright during and after the test period. *(pass)*

H. Occupant impact velocities should satisfy the following:

Longitudinal Occupant Impact Velocity – m/s

Preferred	*Maximum*
3 [9.8 ft/s]	*5* [16.4 ft.s]

Results: Longitudinal occupant impact velocity was 2.0 m/s. *(pass)*

I. Occupant ridedown accelerations should satisfy the following:

Longitudinal and Lateral Occupant Ridedown Accelerations – g's

Preferred	*Maximum*
15	*20*

Results: Longitudinal occupant ridedown acceleration was –1.4 g's and lateral occupant ridedown was –1.1 g's. *(pass)*

- **Vehicle Trajectory**

K. After collision, it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.

Results: The vehicle did not intrude into adjacent traffic lanes. *(pass)*

N. Vehicle trajectory behind the test article is acceptable.

Results: The vehicle came to rest behind the initial location of the mailbox. *(pass)*

In addition, the 1994 American Association of State Highway and Transportation Officials (AASHTO) Specification states:

> *"Satisfactory dynamic performance is indicated when the maximum change in velocity for a standard 1800 pound [816.5 kg] vehicle, or its equivalent, striking a breakaway support at speeds of 20 mph to 60 mph [32 kmph to 97 kmph] does not exceed 16 fps [4.87 mps], but preferably does not exceed 10 fps [3.05 mps]. . .*
>
> *To avoid vehicle undercarriage snagging, any substantial remains of a breakaway support, when it is broken away, should not project more than four inches (0.102 m) above a 60-inch (1.524 m) chord aligned radially to the centerline of the highway and connecting any point, within the length of the chord, on the ground surface on one side of the support to a point on the ground surface on the other side."*

Results: The change in velocity was 4.25 ft/s. The timber post fractured at ground level leaving only splinters projecting upward. *(pass)*

The following supplemental evaluation factors and terminology, as presented in the FHWA memo entitled "Action: Identifying Acceptable Highway Safety Features," were used for visual assessment of test results:

- ♦ **Passenger Compartment Intrusion**
  1. Windshield Intrusion
     - a. No windshield contact
     - b. Windshield contact, no damage
     - c. Windshield contact, no intrusion
     - d. Device embedded in windshield, no significant intrusion
     - e. Complete intrusion into passenger compartment
     - f. Partial intrusion into passenger compartment
  2. Body Panel Intrusion — yes or no

- **Loss of Vehicle Control**
  1. Physical loss of control
  2. Loss of windshield visibility
  3. Perceived threat to other vehicles
  4. Debris on pavement

- **Physical Threat to Workers or Other Vehicles**
  1. Harmful debris that could injure workers or others in the area
  2. Harmful debris that could injure occupants in other vehicles

  If yes, Size: 8 in. × 6 in. × 24 in. long Speed: high or low
  Mass: 12 lb-2 oz Trajectory: ht: 3 ft
  direction: 5 deg

  Note: This piece and smaller pieces remained near the vehicle path.

- **Vehicle and Device Condition**
  1. Vehicle Damage
     a. None
     b. Minor scrapes, scratches, or dents
     c. Significant cosmetic dents
     d. Major dents to grill and body panels
     e. Major structural damage
  2. Windshield Damage
     a. None
     b. Minor chip or crack
     c. Broken, no interference with visibility
     d. Broken and shattered, visibility restricted but remained intact
     e. Shattered, remained intact but partially dislodged
     f. Large portion removed
     g. Completely removed
  3. Device Damage
     a. None
     b. Superficial
     c. Substantial, but can be straightened
     d. Substantial, replacement parts needed for repair
     e. Cannot be repaired

STEP 2 MAILMASTER DELUXE MAILBOX ON STEEL U-CHANNEL SUPPORT (TEST NO. 417921-3)

Test Article

This test evaluated the MailMaster Deluxe (Model No. 5403) mailbox mounted on a 2 lb/ft steel U-channel support post. The 2 lb/ft U-channel is the standard mailbox support used by TxDOT. The molded plastic mailbox was similar to that used in the previous test. The mailbox unit was attached to the 2 lb/ft U-channel support post using two 5/16-in. diameter × 3 ½-in. long bolts that passed through prefabricated holes in the front fact of the plastic post housing and the U-channel. The U-channel support post was embedded in *NCHRP Report 350* standard soil to a depth of 30 in. The length of the U-channel support post was adjusted to place the bottom of the mailbox door at a height of 42 in. Since the test site was flat and level, this mailbox height placed the bottom of the plastic mailbox housing flush with the ground. Details of the tested mailbox configuration are shown in Chapter 2, Figure 3.

The MailMaster Deluxe mailbox with U-channel support post was tested in an empty configuration without any added ballast in the mailbox or newspaper compartments. The mailbox was oriented perpendicular to the direction of the vehicle so that the front of the vehicle would impact the side of the mailbox in a manner similar to what would be expected to occur on the roadside. Photographs of the completed test installation are shown in Chapter 2, Figure 4.

Test Vehicle

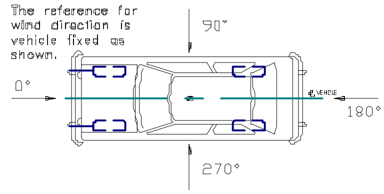
The crash test used a 1996 Geo Metro, shown in Figures 14 and 15. Test inertia weight of the vehicle was 1806 lb, and its gross static weight was 1974 lb. The height to the lower edge of the vehicle bumper was 15.75 in., and the height to the upper edge of the vehicle bumper was 20.67 in. Additional dimensions and information on the vehicle are given in Appendix B, Figure 29. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

Figure 14. Vehicle/Installation Geometrics for Test 417921-3.

Figure 15. Vehicle before Test 417921-3.

Soil and Weather Conditions

The test was performed the afternoon of May 31, 2001. Six days prior to the test 0.85 in. of rainfall was recorded. No other rainfall occurred within 10 days prior to the test. Moisture content of the *NCHRP Report 350* soil in which the U-channel mailbox support was installed was 6.0 percent. Weather conditions at the time of testing were as follows: wind speed: 4 mi/h; wind direction: 120 degrees with respect to the vehicle (vehicle was traveling in a northerly direction); temperature: 86 °F; relative humidity: 67 percent.



Test Description

The vehicle, traveling at 60.7 mi/h, impacted the MailMaster Deluxe mailbox on a 2 lb-ft U-channel support post at 0 degree with the vehicle left quarter point aligned with the centerline of the mailbox support. Shortly after impact, the mailbox began to deflect, and at 0.017 s the upper section of the mailbox separated from the lower base section. The U-channel fractured at ground level at 0.025 s with the lower molded plastic base section attached. The upper section of the mailbox contacted the hood at 0.030 s and then contacted the windshield at 0.040 s. At 0.089 s the vehicle lost contact with the upper section of the mailbox, and at 0.149 s the vehicle lost contact with the U-channel support post. Speed of the vehicle at loss of contact was 59.0 mi/h. Brakes on the vehicle were remotely applied 1.8 s after impact. The vehicle traveled on a straight path through the test site and subsequently came to rest 272.5 ft downstream of the point of impact. Sequential photographs of the test period are shown in Appendix C, Figure 31.

Damage to Test Installation

Damage to the test installation is shown in Figures 16 and 17. The impact caused the upper portion of the mailbox unit to separate from the lower base portion. The steel U-channel fractured at ground level with the lower molded plastic base portion still attached. The ground stub remaining from the U-channel projected 1.75 in. above ground level. The molded plastic mailbox separated into several pieces, the heaviest of which weighed 13 lb-8 oz. The debris pattern extended 80.0 ft downstream and 15.0 ft to the left of the point of impact.

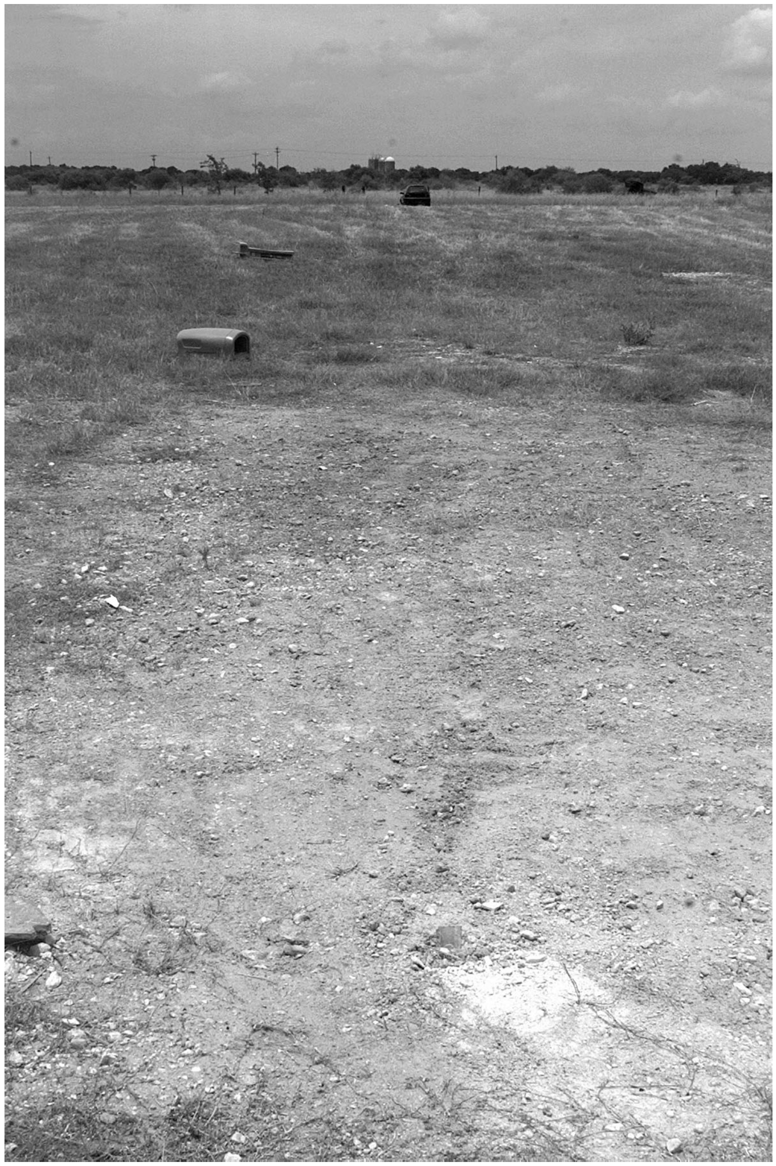


Figure 16. After Impact Trajectory for Test 417921-3.

Figure 17. Step 2 Mailbox on Steel U-Channel after Test 417921-3.

Vehicle Damage

As shown in Figure 18, damage to the vehicle was minimal. The windshield was cracked and deformed inward 1.5 in. (Case 4 of the FHWA Windshield Damage Guidance), but there was no hole and visibility was not restricted. No other occupant compartment deformation was noted. The hood was deformed over an area 13.00 in. long × 20.87 in. wide × 0.20 in. deep. Photographs of the interior of the vehicle are shown in Figure 19. Exterior crush measurements and occupant compartment measurements are detailed in Appendix B, Tables 6 and 7.

Occupant Risk Factors

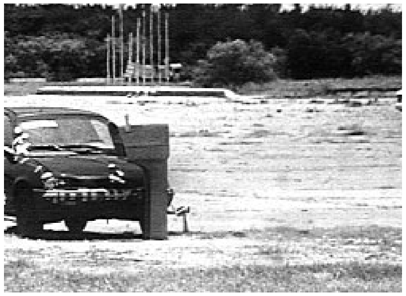
Data from the tri-axial accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity was 3.0 ft/s at 0.938 s, the highest 0.010-s occupant ridedown acceleration was −1.1 g's from 1.714 to 1.724 s, and the maximum 0.050-s average acceleration was −0.9 g's between 0.004 and 0.054 s. In the lateral direction, the occupant impact velocity was 0.3 ft/s at 0.938 s, the highest 0.010-s occupant ridedown acceleration was −0.3 g's from 1.698 to 1.708 s, and the maximum 0.050-s average was 0.3 g's between 0.009 and 0.059 s. These data and other pertinent information from the test are summarized in Figure 20. Vehicle angular displacements are presented in Appendix D, Figure 34. Vehicle accelerations versus time traces are presented in Figures 39 through 41.

Figure 18. Vehicle after Test 417921-3.

Before Test

After Test

Figure 19. Interior of Vehicle for Test 417921-3.

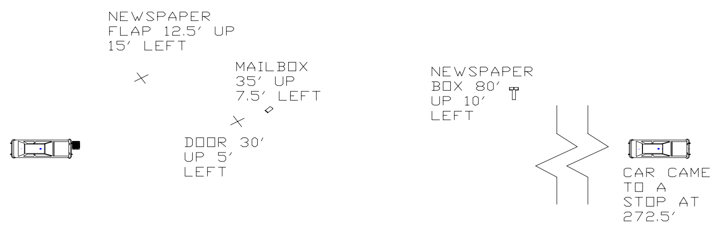


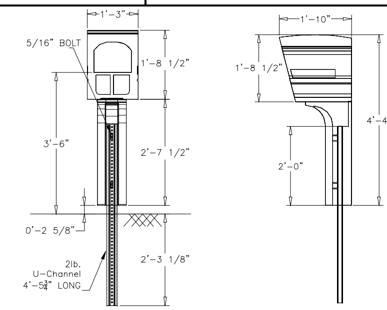
0.000 s

0.050 s

0.124 s

0.248 s





General Information
- Test Agency .... Texas Transportation Institute
- Test No. 417921-3
- Date 05/31/01

Test Article
- Type .... Mailbox
- Name .... Step 2 Mailbox on a 2 lb U channel
- Installation Length (ft) .... 4 ft 4 in
- Material or Key Elements .... Mailbox mounted on a 2 lb U channel

Soil Type and Condition .... Standard Soil, dry

Test Vehicle
- Type .... Production
- Designation 820C
- Model .... 1996 Geo Metro
- Mass (lb) Curb 1775
  - Test Inertial 1806
  - Dummy 168
  - Gross Static 1974

Impact Conditions
- Speed (mi/h) 60.7
- Angle (deg) 0

Exit Conditions
- Speed (mi/h) 59.0
- Angle (deg) 0

Occupant Risk Values
- Impact Velocity (ft/s)
  - x-direction 3.0
  - y-direction 0.3
- THIV (mi/h) 2
- Ridedown Accelerations (g's)
  - x-direction .... -1.1
  - y-direction .... -0.3
- PHD (g's) 1.1
- ASI 0.11
- Max. 0.050-s Average (g's)
  - x-direction .... -0.9
  - y-direction 0.3
  - z-direction .... -1.1

Test Article Scatter (ft)
- Longitudinal 80.0
- Lateral 15.0
- Working Width .... N/A

Vehicle Damage
- Exterior
  - VDS 12FD2
  - CDC .... N/A
- Maximum Exterior
  - Vehicle Crush (in) .... nil
- Interior
  - OCDI FS0000000
- Max. Occ. Compart.
  - Deformation (in) .... nil

Post-Impact Behavior
- (during 1.0 s after impact)
- Max. Yaw Angle (deg) 5
- Max. Pitch Angle (deg) 9
- Max. Roll Angle (deg) 2

Figure 20. Summary of Results for Test 417921-3, *NCHRP Report 350* Test 3-61.

Assessment of Test Results

An assessment of the test based on the applicable *NCHRP Report 350* safety evaluation criteria is provided below.

- **Structural Adequacy**

B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.

Results: The steel U-channel on which the MailMaster Deluxe mailbox was mounted fractured at ground level. *(pass)*

- **Occupant Risk**

C. 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. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.

Results: The upper portion of the mailbox separated from the lower base section upon impact. The lower base section remained attached to the U-channel support post and had a combined weight of 13 lb-8 oz. However, this piece and several smaller pieces of the mailbox did not penetrate nor show potential for penetrating the occupant compartment. Further, these pieces remained near the vehicle path and did not present undue hazard to others in the area. Maximum occupant compartment deformation was 1.5 in. in the windshield area. *(pass)*

F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.

Results: The vehicle remained upright during and after the collision period. *(pass)*

H. *Occupant impact velocities should satisfy the following:*

Longitudinal Occupant Impact Velocity – m/s

Preferred	*Maximum*
3 [9.8 ft/s]	*5* [16.4 ft/s]

Results: Longitudinal occupant impact velocity was 3.0 ft/s. *(pass)*

I. *Occupant ridedown accelerations should satisfy the following:*

Longitudinal and Lateral Occupant Ridedown Accelerations – g's

Preferred	*Maximum*
15	*20*

Results: Longitudinal occupant ridedown acceleration was −1.1 g's and lateral occupant ridedown acceleration was −0.3 g's. *(pass)*

- **Vehicle Trajectory**

K. *After collision, it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.*

Results: The vehicle did not intrude into adjacent traffic lanes. *(pass)*

N. *Vehicle trajectory behind the test article is acceptable.*

Results: The vehicle came to rest behind the initial position of the mailbox. *(pass)*

In addition, the 1994 AASHTO Specification states:

"Satisfactory dynamic performance is indicated when the maximum change in velocity for a standard 1800 pound [816.5 kg] vehicle, or its equivalent, striking a

breakaway support at speeds of 20 mph to 60 mph [32 kmph to 97 kmph] does not exceed 16 fps [4.87 mps], but preferably does not exceed 10 fps [3.05 mps]. . .

To avoid vehicle undercarriage snagging, any substantial remains of a breakaway support, when it is broken away, should not project more than four inches (0.102 m) above a 60-inch (1.524 m) chord aligned radially to the centerline of the highway and connecting any point, within the length of the chord, on the ground surface on one side of the support to a point on the ground surface on the other side."

Results: The change in velocity was 2.49 ft/s. The stub remaining from the U-channel support post projected 1.75 in. above ground level. *(pass)*

The following supplemental evaluation factors and terminology, as presented in the FHWA memo entitled "Action: Identifying Acceptable Highway Safety Features," were used for visual assessment of test results:

♦ **Passenger Compartment Intrusion**

1. Windshield Intrusion
   a. No windshield contact
   b. Windshield contact, no damage
   c. Windshield contact, no intrusion
   d. Device embedded in windshield, no significant intrusion
   e. Complete intrusion into passenger compartment
   f. Partial intrusion into passenger compartment
2. Body Panel Intrusion — yes or no

♦ **Loss of Vehicle Control**

1. Physical loss of control
2. Loss of windshield visibility
3. Perceived threat to other vehicles
4. Debris on pavement

♦ **Physical Threat to Workers or Other Vehicles**

1. Harmful debris that could injure workers or others in the area
2. Harmful debris that could injure occupants in other vehicles

If yes, Size: 6 in. × 8 in. × 24 in. Speed: high or low
Mass: 13 lb-2 oz Trajectory: ht: 3 ft
direction: 5 deg

Note: This piece and smaller pieces remained near the vehicle path.

♦ **Vehicle and Device Condition**

1. Vehicle Damage
   a. None
   d. Major dents to grill and

b. Minor scrapes, scratches or dents
c. Significant cosmetic dents body panels
e. Major structural damage

2. Windshield Damage
   a. None
   b. Minor chip or crack
   c. Broken, no interference with visibility
   d. Broken and shattered, visibility restricted but remained intact
   e. Shattered, remained intact but partially dislodged
   f. Large portion removed
   g. Completely removed
3. Device Damage
   a. None
   b. Superficial
   c. Substantial, but can be straightened
   d. Substantial, replacement parts needed for repair
   e. Cannot be repaired

RUBBERMAID DELUXE MAILBOX ON STEEL PIPE SUPPORT (TEST NO. 417921-4)

Test Article

Rubbermaid manufactures a molded plastic mailbox with an integral post housing similar to those manufactured by the Step 2 Company. The Rubbermaid Deluxe (Model No. 7276) weighs 25.8 lb. It is molded in two separate sections that are attached to one another with four 5/16-in. diameter × 1 ½-in. long plastic pins that pass through a lap joint between the two molded sections. The upper molded section contains the mailbox, which has access doors from both the front and rear. The lower molded section incorporates a newspaper compartment and post housing. The plastic housing has a cutout that permits the mailbox to slide onto the support post. The manufacturer recommends that the mailbox be installed over a 4×4 wood post. The mailbox unit is then secured to the wood post using two 5/16-in. diameter × 3-in. long lag screws through prefabricated holes in the front face of the plastic post housing.

For the crash test, the Rubbermaid Deluxe mailbox was attached to a 3-in. diameter schedule 40 steel pipe support. The purpose of the test was to evaluate the molded plastic style mailbox units on a pipe support. The mailbox unit was attached to the 3-in. pipe using two 3/8-in. diameter × 5 ½-in. long bolts that passed through prefabricated holes in the front face of the plastic post housing and pipe support. The 3-in. diameter steel support pipe was embedded in *NCHRP Report 350* standard soil to a depth of 30 in. With the plastic housing of the MailMaster Deluxe placed directly on the ground, the height to the bottom of the mailbox door is approximately 36 in. Presumably, this permits these mailboxes to be installed in residential areas with 4-8 in. curbs and still be within the height range accepted by the post office. For the crash test, the length of the pipe support was adjusted to place the bottom of the mailbox door at a height of 42 in. Since the test site was flat and level with no curb and gutter section, this placed the bottom of the plastic housing of the mailbox approximately 6 in. above ground level.

The length of the pipe was selected to place the bottom of the mailbox door at a height of 42 in. Since the test site was flat and level with no curb and gutter section, this placed the bottom of the plastic housing of the mailbox approximately 6 in. above ground level. Details of the tested mailbox configuration are shown in Chapter 2 in Figure 5.

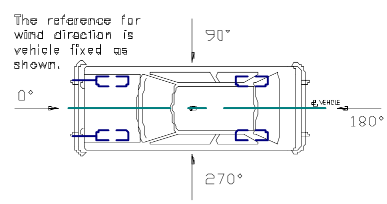
The Rubbermaid Deluxe mailbox with 3-in. diameter steel support pipe was tested in an empty configuration without any added ballast in the mailbox or newspaper compartments. The mailbox was oriented perpendicular to the direction of the vehicle so that the front of the vehicle would impact the side of the mailbox in a manner similar to what would be expected to occur on the roadside. Photographs of the completed test installation are shown in Chapter 2, Figure 6.

Test Vehicle

A 1996 Geo Metro, shown in Figures 21 and 22, was used for the crash test. Test inertia weight of the vehicle was 1806 lb, and its gross static weight was 1974 lb. The height to the lower edge of the vehicle bumper was 15.75 in., and the height to the upper edge of the vehicle bumper was 20.67 in. Additional dimensions and information on the vehicle are given in Appendix B, Figure 29. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

Soil and Weather Conditions

The test was performed the morning of June 1, 2001. Seven days prior to the test 0.85 in. of rainfall was recorded. No other rainfall occurred within 10 days prior to the test. Moisture content of the *NCHRP Report 350* soil in which the devices was installed was 6.0 percent. Weather conditions at the time of testing were as follows: wind speed: 2 mi/h; wind direction: 80 degrees with respect to the vehicle (vehicle was traveling in a northerly direction); temperature: 85 °F; relative humidity: 61 percent.



Test Description

The vehicle, traveling at 62.0 mi/h, impacted the Rubbermaid Deluxe mailbox at 0 degree with the right quarter point of the vehicle aligned with the centerline of the steel pipe support. Shortly after impact the upper section of the mailbox separated from the lower base section, and at 0.044 s the separated upper section contacted the windshield. The steel pipe support yielded and bent near ground level, and the top of the steel pipe support contacted the ground at 0.050 s. The vehicle lost contact with the support at 0.189 s while traveling at a speed of 56.7 mi/h. Brakes on the vehicle were remotely applied 1.55 s after impact. The vehicle traveled on a straight path through the test site and subsequently came to rest 232.5 ft

Figure 21. Vehicle/Installation Geometrics for Test 417921-4.

Figure 22. Vehicle before Test 417921-4.

downstream and 25.0 ft left of the point of impact. Sequential photographs of the test period are shown in Appendix C, Figure 32.

Damage to Test Installation

Damage to the test installation is shown in Figures 23 and 24. The steel pipe support yielded and bent near ground level. As the vehicle rode over the pipe support, most of the lower molded plastic base section of the mailbox was pulled off the support post. The upper portion of the deformed steel pipe had a maximum height of 5.1 in. above ground level. The mailbox separated into several pieces, none of which was considered heavy enough to cause physical threat. The debris pattern extended 45.0 ft downstream, 18 ft left, and 10 ft right of the point of impact.

Vehicle Damage

Damage to the vehicle is shown in Figure 25. A 0.5-in. long tear was noted in the windshield, and the windshield was deformed inward 2.75 in (Case 1 of the FHWA Windshield Damage Guidance). Visibility was not restricted. No other occupant compartment deformation was noted. The right motor mount and radiator support were damaged and there was a dent in the oil pan. Also damaged were the front bumper, hood, radiator, compressor, and condenser. Maximum exterior crush to the vehicle was 9.8 in. at the right front quarter point. Photographs of the interior of the vehicle are shown in Figure 26. Exterior crush measurements and occupant compartment measurements are detailed in Appendix B, Tables 7 and 8.

Occupant Risk Factors

Data from the tri-axial accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity was 5.6 ft/s at 0.403 s, the highest 0.010-s occupant ridedown acceleration was -1.0 g's from 1.612 to 1.622 s, and the maximum 0.050-s average acceleration was −3.1 g's between 0.022 and 0.072 s. In the lateral direction, the occupant impact velocity was 2.3 ft/s at 0.403 s, the highest 0.010-s occupant ridedown acceleration was −1.3 g's from 1.328 to 1.338 s, and the

Figure 23. After Impact Trajectory for Test 417921-4.

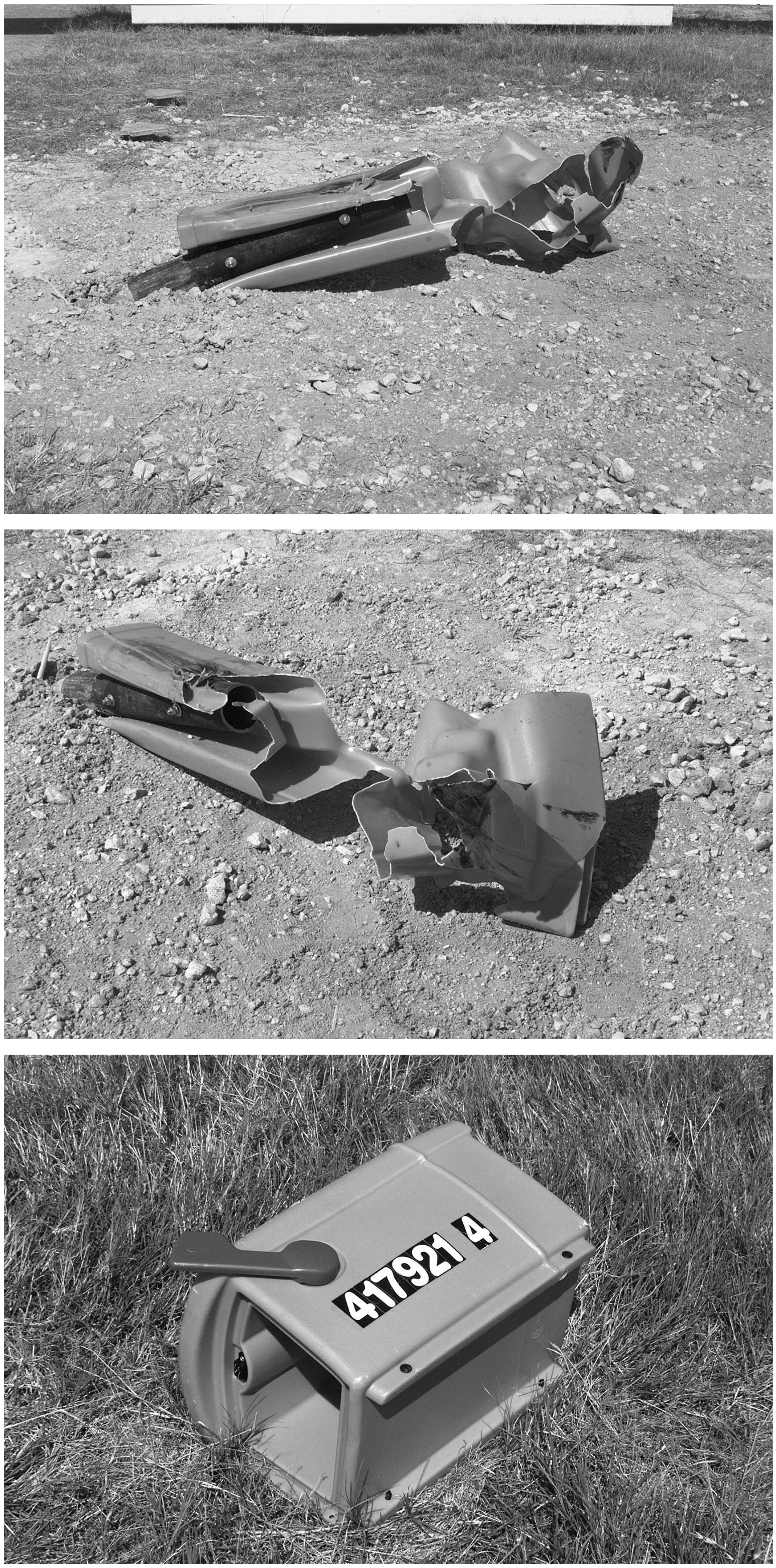


Figure 24. Rubbermaid Mailbox on Steel Pipe after Test 417921-4.

Figure 25. Vehicle after Test 417921-4.

Before Test

After Test

Figure 26. Interior of Vehicle for Test 417921-4.

maximum 0.050-s average was 0.9 g's between 0.027 and 0.077 s. These data and other pertinent information from the test are summarized in Figure 27. Vehicle angular displacements are presented in Appendix D, Figure 35. Vehicle acceleration versus time traces are presented in Figures 42 through 44.

Assessment of Test Results

An assessment of the test based on the applicable *NCHRP Report 350* safety evaluation criteria is provided below.

- **Structural Adequacy**

    B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.

    Results: The steel pipe support on which the Rubbermaid Deluxe mailbox was mounted yielded at ground level and allowed the vehicle to pass over the mailbox and support in a controlled manner. *(pass)*

- **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. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.

    Results: The upper portion of the mailbox separated from the lower base section and contacted the windshield. This contact caused the windshield to deform inward 2.75 in. and induced a small tear (0.5 in. long) in the windshield. No other deformation of the occupant compartment was noted. None of the pieces of debris from the mailbox were considered heavy enough to cause physical threat. *(marginal)*

    F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.

Results: The vehicle remained upright during and after the collision period. *(pass)*

H. *Occupant impact velocities should satisfy the following:*

Longitudinal Occupant Impact Velocity – m/s

Preferred	*Maximum*
3 [9.8 ft/s]	*5* [16.5 ft/s]

Results: Longitudinal occupant impact velocity was 5.6 ft/s. *(pass)*

I. *Occupant ridedown accelerations should satisfy the following:*

Longitudinal and Lateral Occupant Ridedown Accelerations – g's

Preferred	*Maximum*
15	*20*

Results: Longitudinal occupant ridedown acceleration was –1.0 g's and lateral occupant ridedown acceleration was –1.3 g's. *(pass)*

- **Vehicle Trajectory**

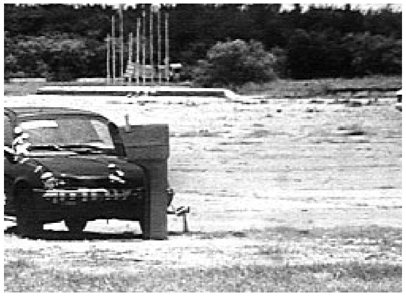
K. *After collision, it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.*

Results: The vehicle did not intrude into adjacent traffic lanes. *(pass)*

N. *Vehicle trajectory behind the test article is acceptable.*

Results: The vehicle came to rest behind the initial position of the mailbox. *(pass)*

In addition, the 1994 AASHTO Specification states:

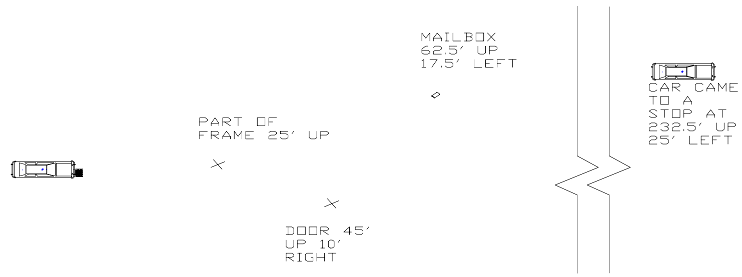


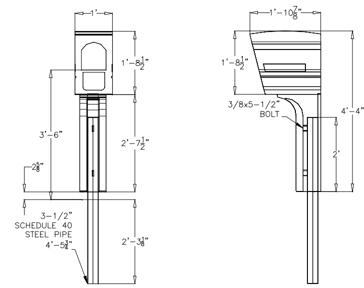
0.000 s

0.041 s

0.104 s

0.207 s





General Information
Test Agency........................... Texas Transportation Institute
Test No................................. 417921-4
Date...................................... 06/01/01
Test Article
Type .... Mailbox
Name.................................... Rubbermaid Mailbox on a 3-1/2" pipe
Installation Length (ft) .... 4 ft 4 in
Material or Key Elements....... Rubbermaid Mailbox on a 3-1/2" Schedule 40 steel pipe
Soil Type and Condition.......... Standard Soil, dry
Test Vehicle
Type .... Production
Designation........................... 820C
Model .... 1996 Geo Metro
Mass (lb) Curb 1775
Test Inertial 1806
Dummy 168
Gross Static 1974

Impact Conditions
Speed (mi/h)................................. 62.0
Angle (deg) 0
Exit Conditions
Speed (mi/h)................................. 56.7
Angle (deg) 0
Occupant Risk Values
Impact Velocity (ft/s)
x-direction................................. 5.6
y-direction................................. 2.3
THIV (mi/h) 4
Ridedown Accelerations (g's)
x-direction................................. -1.0
y-direction................................. -1.3
PHD (g's) 1.3
ASI 0.35
Max. 0.050-s Average (g's)
x-direction................................. -3.1
y-direction................................. 0.9
z-direction................................. -2.6

Test Article Scatter (ft)
Longitudinal............................. 45
Lateral 18
Working Width .... N/A
Vehicle Damage
Exterior
VDS.................................... 12FD2
CDC .... N/A
Maximum Exterior
Vehicle Crush (in)................ 9.8
Interior
OCDI FS0000000
Max. Occ. Compart.
Deformation (in).................. nil
Post-Impact Behavior
(during 1.0 s after impact)
Max. Yaw Angle (deg) .... -22
Max. Pitch Angle (deg) 2
Max. Roll Angle (deg) 6

Figure 27. Summary of Results for Test 417921-4, *NCHRP Report 350* Test 3-61.

"Satisfactory dynamic performance is indicated when the maximum change in velocity for a standard 1800 pound [816.5 kg] vehicle, or its equivalent, striking a breakaway support at speeds of 20 mph to 60 mph [32 kmph to 97 kmph] does not exceed 16 fps [4.87 mps], but preferably does not exceed 10 fps [3.05 mps]. . .

To avoid vehicle undercarriage snagging, any substantial remains of a breakaway support, when it is broken away, should not project more than four inches (0.102 m) above a 60-inch (1.524 m) chord aligned radially to the centerline of the highway and connecting any point, within the length of the chord, on the ground surface on one side of the support to a point on the ground surface on the other side."

<u>Results</u>: The change in velocity was 7.72 ft/s. The steel pipe yielded and laid over as the vehicle rode over it. The pipe remained laid over at a maximum height of 5.1 in. at the upper end of the pipe. Because the pipe laid over in the direction of vehicle travel, it did not constitute a snagging hazard for the vehicle undercarriage. However, if the damaged pipe was subsequently hit by another vehicle from the opposite direction before it could be repaired, it could potentially snag on the vehicle undercarriage. *(marginal)*

The following supplemental evaluation factors and terminology, as presented in the FHWA memo entitled "Action: Identifying Acceptable Highway Safety Features," were used for visual assessment of test results:

- ♦ **Passenger Compartment Intrusion**
  1. Windshield Intrusion
     - a. No windshield contact
     - b. Windshield contact, no damage
     - c. Windshield contact, no intrusion
     - d. Device embedded in windshield, no significant intrusion
     - e. Complete intrusion into passenger compartment
     - <u>f. Partial intrusion into passenger compartment</u>
  2. Body Panel Intrusion — yes or <u>no</u>

- ♦ **Loss of Vehicle Control**
  1. Physical loss of control
  2. Loss of windshield visibility
  3. Perceived threat to other vehicles
  4. <u>Debris on pavement</u>

- **Physical Threat to Workers or Other Vehicles**
  1. Harmful debris that could injure workers or others in the area
  2. Harmful debris that could injure occupants in other vehicles

  <u>None of the debris was judged to be a physical threat.</u>

- **Vehicle and Device Condition**
  1. Vehicle Damage
     a. None
     b. Minor scrapes, scratches or dents
     c. Significant cosmetic dents
     d. Major dents to grill and body panels
     <u>e. Major structural damage</u>
  2. Windshield Damage
     a. None
     b. Minor chip or crack
     <u>c. Broken, no interference with visibility</u>
     d. Broken and shattered, visibility restricted but remained intact
     e. Shattered, remained intact but partially dislodged
     f. Large portion removed
     g. Completely removed
  3. Device Damage
     a. None
     b. Superficial
     c. Substantial, but can be straightened
     d. Substantial, replacement parts needed for repair
     <u>e. Cannot be repaired</u>

CHAPTER 4. CONCLUSIONS

Recently, TxDOT has been receiving requests to use molded plastic mailboxes such as those manufactured by Step 2 and Rubbermaid in lieu of the Department's standard mailbox support and mailbox connection hardware. These molded plastic mailboxes are available in a variety of styles and colors, which make them an aesthetic alternative to some conventional mailbox installations. However, before TxDOT can permit the use of these mailboxes on Texas highways, their crashworthiness had to be evaluated through full-scale crash testing.

As summarized in Table 1, Table 2, and Table 3, all three tests conducted on the molded plastic mailbox units satisfied *NCHRP Report 350* evaluation criteria. In each test, the upper molded portion of the mailbox separated from the lower base unit resulting in secondary contact with the hood and windshield of the impacting vehicle. However, beyond the deformation of the windshield, there was no penetration of any mailbox components into the occupant compartment. In each test, the 820C test vehicle remained upright and stable during and after the collision, and occupant risk factors were within the preferred limits specified in *NCHRP Report 350*.

Although each mailbox configuration met *NCHRP Report 350* guidelines, variations in performance associated with the different support posts were observed. From a functional standpoint, the 4×4 timber support post appears to be the best alternative from among the three support posts investigated. The 4×4 timber post is the manufacturers' recommended support post for both the MailMaster Deluxe and Rubbermaid Deluxe mailboxes. The plastic housing of these mailboxes is molded to snugly fit the 4×4 wood post, which limits rotation of the mailbox on the support. Further, the 4×4 wood post has sufficient stiffness to limit deflections of the mailbox under service loads. The 2 lb/ft steel U-channel support post permitted swaying motion of the mailbox, and the 3-in. diameter schedule 40 pipe support permitted some rotational movement of the mailbox. From an impact performance standpoint, the 4×4 timber support post also appears to be the best alternative. In the test of the MailMaster Deluxe mounted on the 4×4 timber support, the windshield of the test vehicle was cracked, but there was no deformation of the windshield into the occupant compartment. A greater degree of windshield damage and deformation was observed in the mailbox tests with the other supports. For the 2 lb/ft steel

Table 1. Performance Evaluation Summary for Test on Step 2 Mailbox on 4×4 Timber Post.

Test Agency: Texas Transportation Institute | Test No.: 417921-2 | Test Date: 05/31/01

NCHRP Report 350 **Evaluation Criteria for Test 3-61**	**Test Results**	**Assessment**
Structural Adequacy B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The timber post on which the MailMaster Deluxe mailbox was mounted fractured at ground level.	Pass
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. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	Detached pieces did not penetrate nor show potential for penetrating the occupant compartment, nor present undue hazard to others in the area as these pieces remained relatively close to the vehicle as it traveled through the test site. The windshield was cracked but there were no deformations or intrusions into the occupant compartment.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.	The vehicle remained upright during and after the collision period.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Velocity Limits (m/s) Component | Preferred | Maximum Longitudinal | 3 [9.8 ft/s] | 5 [16.4 ft/s]	Longitudinal occupant impact velocity was 2.0 ft/s.	Pass
I. Occupant ridedown accelerations should satisfy the following: Occupant Ridedown Acceleration Limits (g's) Component | Preferred | Maximum Longitudinal and lateral | 15 | 20	Longitudinal occupant ridedown acceleration was −1.4 g's and lateral occupant ridedown acceleration was −1.1 g's.	Pass
Vehicle Trajectory K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle did not intrude into adjacent traffic lanes.	Pass
N. Vehicle trajectory behind the test article is acceptable.	The vehicle came to rest behind the mailbox.	Pass

Table 2. Performance Evaluation Summary for Test on Step 2 Mailbox on Steel U-Channel.

Test Agency: Texas Transportation Institute | Test No.: 417921-3 | Test Date: 05/31/01

<table>
<tr><th>NCHRP Report 350 Evaluation Criteria for Test 3-61</th><th>Test Results</th><th>Assessment</th></tr>
<tr><td><u>Structural Adequacy</u>
B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.</td><td>The steel U-channel post on which the MailMaster Deluxe mailbox was mounted fractured at ground level.</td><td>Pass</td></tr>
<tr><td><u>Occupant Risk</u>
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. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.</td><td>The detached pieces of the mailbox did not penetrate nor show potential for penetrating the occupant compartment. These pieces remained near the vehicle path and did not present undue hazard to others in the area. Maximum occupant compartment deformation was 1.5 in. in the windshield glass area.</td><td>Pass</td></tr>
<tr><td>F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.</td><td>The vehicle remained upright during and after the collision period.</td><td>Pass</td></tr>
<tr><td>H. Occupant impact velocities should satisfy the following:<table><tr><th colspan="3">Occupant Velocity Limits (m/s)</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal</td><td>3 [9.8 ft/s]</td><td>5 [16.4 ft/s]</td></tr></table></td><td>Longitudinal occupant impact velocity was 3.0 ft/s.</td><td>Pass</td></tr>
<tr><td>I. 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>Longitudinal occupant ridedown acceleration was −1.1 g's and lateral occupant ridedown acceleration was –0.3 g's.</td><td>Pass</td></tr>
<tr><td><u>Vehicle Trajectory</u>
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.</td><td>The vehicle did not intrude into adjacent traffic lanes.</td><td>Pass</td></tr>
<tr><td>N. Vehicle trajectory behind the test article is acceptable.</td><td>The vehicle came to rest behind the mailbox.</td><td>Pass</td></tr>
</table>

Table 3. Performance Evaluation Summary for Test on Rubbermaid Mailbox on Steel Pipe.

Test Agency: Texas Transportation Institute — Test No.: 417921-4 — Test Date: 06/01/01

NCHRP Report 350 Evaluation Criteria for Test 3-61	Test Results	Assessment
Structural Adequacy B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The steel pipe on which the Rubbermaid Deluxe mailbox was mounted yielded at ground level.	Pass
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. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	The upper portion of the mailbox contacted the windshield causing a small tear (0.5 in. long). Inward deformation of the windshield was 2.75 in. However, there was no direct penetration of the occupant compartment, and the debris was not considered to present undue hazard to others in the area.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.	The vehicle remained upright during and after the collision period.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Velocity Limits (m/s) Component: Longitudinal — Preferred: 3 [9.8 ft/s] — Maximum: 5 [16.4 ft/s]	Longitudinal occupant impact velocity was 5.6 ft/s.	Pass
I. Occupant ridedown accelerations should satisfy the following: Occupant Ridedown Acceleration Limits (g's) Component: Longitudinal and lateral — Preferred: 15 — Maximum: 20	Longitudinal occupant ridedown acceleration was –1.1 g's and lateral occupant ridedown acceleration was –1.3 g's.	Pass
Vehicle Trajectory K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle did not intrude into adjacent traffic lanes.	Pass
N. Vehicle trajectory behind the test article is acceptable.	The vehicle came to rest behind the mailbox.	Pass

U-channel, the separated upper section of the mailbox deformed the windshield inward a distance of 1.5 in. The 3-in. diameter schedule 40 pipe support caused the most vehicle damage of the three support types evaluated and also induced the highest change in vehicle velocity. In this test, the separated upper section of the mailbox support deforme d the windshield inward a distance of 2.75 in. and caused a 0.5-in. long tear in the windshield. There may also be some concern with the steel pipe support regarding stub height. Although the steel pipe support yielded and laid down as the vehicle rode over it, the end of the pipe was 5.1 in. above ground after the test. This was not a concern for the test vehicle, because the pipe laid over in the direction of travel, thus preventing any snagging with the vehicle undercarriage. However, if the damaged pipe was subsequently hit by another vehicle from the opposite direction before it could be repaired, it could potentially snag on the vehicle undercarriage.

CHAPTER 5. IMPLEMENTATION STATEMENT

Under this study, the impact performance of molded plastic mailboxes was investigated through full-scale crash testing. TxDOT has been receiving an increasing number of requests to use these molded plastic mailboxes in lieu of the Department's standard mailbox support and mailbox connection hardware. These molded plastic mailboxes are available in a variety of styles and colors, which make them an aesthetic alternative to conventional mailbox installations.

Crash tests were conducted to evaluate the performance of molded plastic mailboxes on three different types of support posts: 4×4 wood, 2 lb/ft U-channel, and 3-in. diameter schedule 40 pipe. In all three tests, the molded plastic mailbox units satisfied *NCHRP Report 350* evaluation criteria. However, some variations in performance associated with the different support posts were observed. From both a functional and impact performance standpoint, the 4×4 timber support post appears to be the best alternative from among the three support posts investigated. The 4×4 timber post is the manufacturers' recommended support post for both the Step 2 MailMaster Deluxe and Rubbermaid Deluxe mailboxes. The plastic housing of these mailboxes is molded to snugly fit the 4×4 wood post, which limits rotation of the mailbox on the support. Further, the 4×4 wood post has sufficient stiffness to limit deflections of the mailbox under service loads. In terms of crashworthiness, the mailbox installation mounted on the 4×4 timber support post resulted in the least amount of windshield damage to the test vehicle.

Based on the results of the testing and evaluation reported herein, the molded plastic mailboxes are considered suitable for implementation as an alternative to other conventional mailbox supports. It is recommended that these mailboxes be installed on a 4×4 wood support post per manufacturers' recommendations.

BIBLIOGRAPHY

1. H. E. Ross, Jr., D. L. Sicking, R. A. Zimmer and J. D. Michie, *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, National Cooperative Highway Research Program Report 350, Transportation Research Board, National Research Council, Washington, D.C., 1993.

2. *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*, American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., 1994.

APPENDIX A. CRASH TEST PROCEDURES AND DATA ANALYSIS

The crash test and data analysis procedures were in accordance with guidelines presented in *NCHRP Report 350*. Brief descriptions of these procedures are presented as follows.

ELECTRONIC INSTRUMENTATION AND DATA PROCESSING

The test vehicle was instrumented with three solid-state angular rate transducers to measure roll, pitch, and yaw rates; a triaxial accelerometer near the vehicle center of gravity (c.g.) to measure longitudinal, lateral, and vertical acceleration levels; and a back-up biaxial accelerometer in the rear of the vehicle to measure longitudinal and later acceleration levels. These accelerometers were ENDEVCO Model 2262CA, piezoresistive accelerometers with a ±100 g range.

The accelerometers are strain gage type with a linear millivolt output proportional to acceleration. Angular rate transducers are solid state, gas flow units designed for high-“g” service. Signal conditioners and amplifiers in the test vehicle increase the low level signals to a ±2.5 volt maximum level. The signal conditioners also provide the capability of an R-Cal or shunt calibration for the accelerometers and a precision voltage calibration for the rate transducers. The electronic signals from the accelerometers and rate transducers are transmitted to a base station by means of a 15-channel, constant bandwidth, Inter-Range Instrumentation Group (I.R.I.G.), FM/FM telemetry link for recording on magnetic tape and for display on a real-time strip chart. Calibration signals from the test vehicle are recorded before the test and immediately afterward. A crystal-controlled time reference signal is simultaneously recorded with the data. Wooden dowels actuate pressure-sensitive switches on the bumper of the impacting vehicle prior to impact by wooden dowels to indicate the elapsed time over a known distance to provide a measurement of impact velocity. The initial contact also produces an “event” mark on the data record to establish the instant of contact with the installation.

The multiplex of data channels, transmitted on one radio frequency, is received and demultiplexed onto separate tracks of a 28-track, I.R.I.G. tape recorder. After the test, the data are played back from the tape machine and digitized. A proprietary software program (WinDigit) converts the analog data from each transducer into engineering units using the R-cal and pre-zero values at 10,000 samples per second per channel. WinDigit also provides Society of Automotive Engineers (SAE) J211 class 180 phaseless digital filtering and vehicle impact velocity.

All accelerometers are calibrated annually according to SAE J211 *4.6.1* by means of an ENDEVCO 2901, precision primary vibration standard. This device and its support instruments are returned to the factory annually for a National Institute of Standards Technology (NIST) traceable calibration. The subsystems of each data channel are also evaluated annually, using instruments with current NIST traceability, and the results are factored into the accuracy of the total data channel, per SAE J211. Calibrations and evaluations are made any time data are suspect.

The Test Risk Assessment Program (TRAP) uses the data from WinDigit to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and the highest 10-ms average ridedown acceleration. WinDigit calculates change in vehicle velocity at the end of a given impulse period. In addition, maximum average accelerations over 50-ms intervals in each of the three directions are computed. For reporting purposes, analysis filters the data from the vehicle-mounted accelerometers using a 60-Hz digital filter, and plots acceleration versus time curves for the longitudinal, lateral, and vertical directions using TRAP.

TRAP uses the data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.0001-s intervals and then plots: yaw, pitch, and roll versus time. These displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate system being initial impact.

ANTHROPOMORPHIC DUMMY INSTRUMENTATION

An Alderson Research Laboratories Hybrid II, 50th percentile male anthropomorphic dummy, restrained with lap and shoulder belts, was placed in the driver's position of the 820C vehicle. The dummy was uninstrumented.

PHOTOGRAPHIC INSTRUMENTATION AND DATA PROCESSING

Photographic coverage of the test included two high-speed cameras: one placed behind the installation at a 45-degree angle to the mailbox/vehicle path; and a second placed to have a field of view perpendicular to the mailbox/vehicle path. A flash bulb activated by pressure sensitive tape switches was positioned on the impacting vehicle to indicate the instant of contact with the installation and was visible from each camera. The films from these high-speed cameras were analyzed on a computer-linked Motion Analyzer to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A BetaCam, a VHS-format video camera and recorder, and still cameras were used to record and document conditions of the test vehicle and installation before and after the test.

TEST VEHICLE PROPULSION AND GUIDANCE

The test vehicle was towed into the test installation using a steel cable guidance and reverse tow system. A steel cable for guiding the test vehicle was tensioned along the path, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle. An additional steel cable was connected to the test vehicle, passed around a pulley near the impact point, through a pulley on the tow vehicle, and then anchored to the ground such that the tow vehicle moved away from the test site. A two-to-one speed ratio between the test and tow vehicle existed with this system. Just prior to impact with the installation, the test vehicle was released to be free-wheeling and unrestrained. The vehicle remained free-wheeling, i.e., no steering or braking inputs, until the vehicle cleared the immediate area of the test site, at which time brakes on the vehicle were activated to bring it to a safe and controlled stop.

APPENDIX B. TEST VEHICLE PROPERTIES AND INFORMATION

DATE: 05/31/01 TEST NO.: 417921–2 VIN NO.: 2C1MR2265T6717166

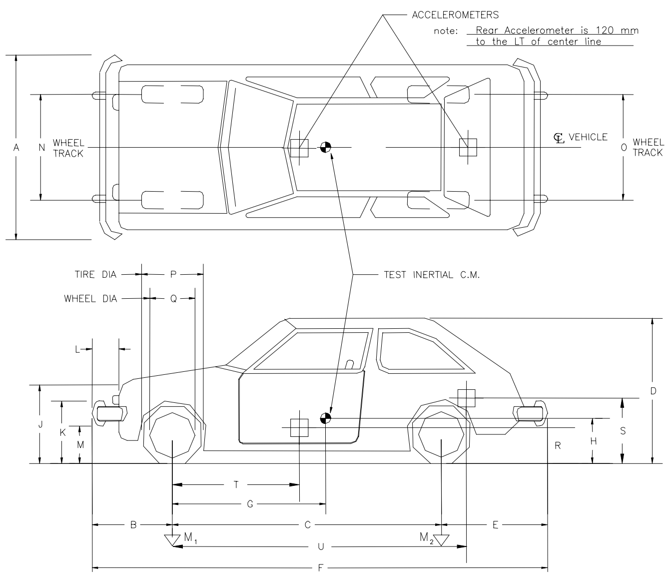
YEAR: 1996 MAKE: Geo MODEL: Metro

TIRE INFLATION PRESSURE: ODOMETER: 61980 TIRE SIZE: 155 80R13

1st Use: 2nd or More Use: Minor Damage Charged to Project:

MASS DISTRIBUTION (kg) LF 262 RF 244 LR 164 RR 150

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 3 CYL.

ENGINE CID: 1.0L

TRANSMISSION TYPE:

__ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th percentile male

MASS: 76 kg

SEAT POSITION: Driver

GEOMETRY – (mm)

A	1470	E	560	J	610	N	1380	R	400
B	770	F	3695	K	525	O	1365	S	570
C	2365	G	905.6	L	160	P	570	T	955
D	1430	H		M	400	Q	365	U	2525

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	500	506	542
M_2	308	314	354
M_T	808	820	896

Figure 28. Vehicle Properties for Tests 417921-2.

DATE: 05/31/01 & 6/1/01 TEST NO.: 417921-3 & 4 VIN NO.: 2C1MR2269T6748775

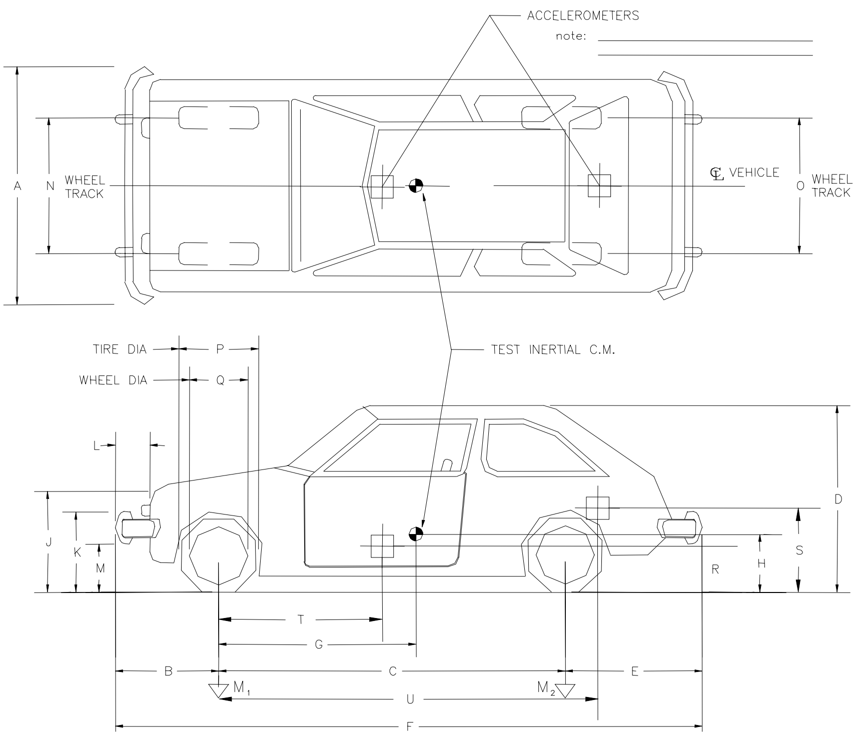
YEAR: 1996 MAKE: Geo MODEL: Metro

TIRE INFLATION PRESSURE: ______ ODOMETER: 140228 TIRE SIZE: 155 80R13

1st Use: ___ 2nd or More Use: ___ Minor Damage Charged to Project: ______

MASS DISTRIBUTION (kg) LF 261 RF 240 LR 163 RR 156

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 3 CYL.

ENGINE CID: 1.0L

TRANSMISSION TYPE:

__ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th percentile male

MASS: 76 kg

SEAT POSITION: Driver

GEOMETRY – (mm)

A	1470	E	560	J	610	N	1375	R	400
B	770	F	3695	K	525	O	1360	S	570
C	2365	G	920.0	L	160	P	570	T	950
D	1430	H		M	400	Q	365	U	2525

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	502	501	537
M_2	303	319	359
M_T	805	820	896

Figure 29. Vehicle Properties for Test 417921-3 and 417921-4.

Table 4. Exterior Crush Measurements for Test 417921-2.

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	Side Damage
Undeformed end width ___________ Corner shift: A1 ____ A2 _____ End shift at frame (CDC) (check one) < 4 inches ______ ≥ 4 inches ______	Bowing: B1 ___ X1 ___ B2 ___ X2 ___ Bowing constant $\frac{X1+X2}{2}$ = ______

Note: Measure C1 to C6 from Driver to Passenger side in Front or Rear impacts– Rear to Front in Side impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width ** (CDC)	Max*** Crush								
	Not measurable										

[1]Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

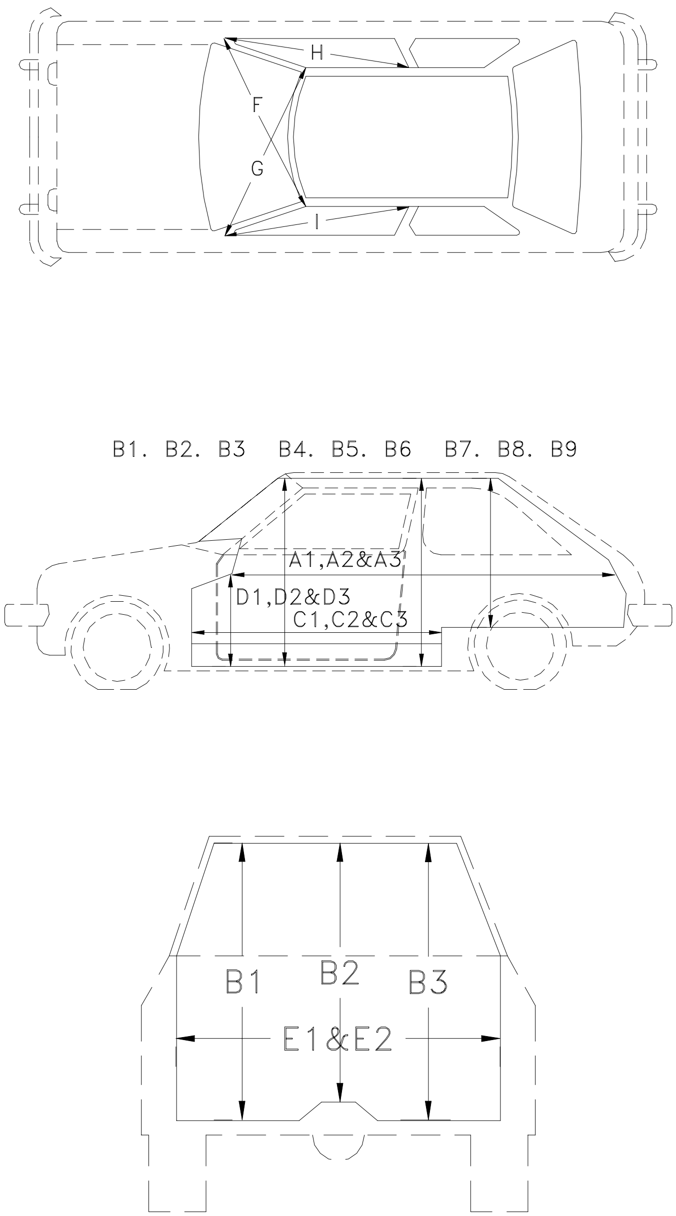
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

***Measure and document on the vehicle diagram the location of the maximum crush.
Note: Use as many lines/columns as necessary to describe each damage profile.

Table 5. Occupant Compartment Measurements for Test 417921-2.

Small Car

Occupant Compartment Deformation



	BEFORE	AFTER
A1	1435	1435
A2	2005	2005
A3	1440	1440
B1	965	965
B2	975	975
B3	960	960
B4	928	928
B5	905	905
B6	930	930
B7	----	----
B8	----	----
B9	----	----
C1	705	705
C2	705	705
C3	700	700
D1	245	245
D2	145	145
D3	245	245
E1	1220	1220
E2	1180	1180
F	1210	1210
G	1210	1210
H	1000	1000
I	1000	1000
J	1190	1190

Table 6. Exterior Crush Measurements for Test 417921-3.

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	Side Damage
Undeformed end width ___________ Corner shift: A1 ____ A2 _____ End shift at frame (CDC) (check one) < 4 inches ______ ≥ 4 inches ______	Bowing: B1 ___ X1 ___ B2 ___ X2 ___ Bowing constant $\frac{X1+X2}{2}$ = ______

Note: Measure C1 to C6 from Driver to Passenger side in Front or Rear impacts–
Rear to Front in Side impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	. D
		Width ** (CDC)	Max*** Crush								
	Not measurable										

[1]Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

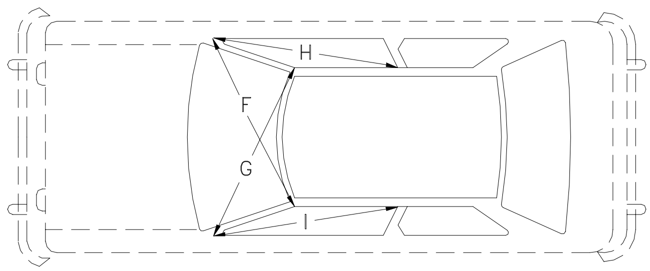
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

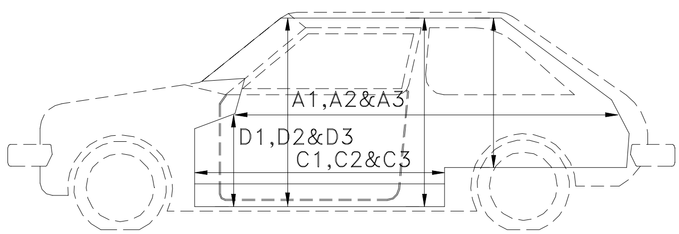
***Measure and document on the vehicle diagram the location of the maximum crush.
Note: Use as many lines/columns as necessary to describe each damage profile.

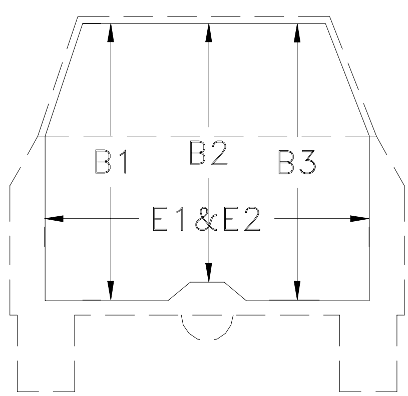
Table 7. Occupant Compartment Measurements for Tests 417921-3 and 4.

Small Car

Occupant Compartment Deformation







	BEFORE	AFTER
A1	1427	1427
A2	2005	2005
A3	1437	1437
B1	965	965
B2	973	973
B3	960	960
B4	928	928
B5	905	905
B6	930	930
B7	----	----
B8	----	----
B9	----	----
C1	706	706
C2	700	700
C3	705	705
D1	245	245
D2	145	145
D3	245	245
E1	1212	1212
E2	1170	1170
F	1210	1210
G	1210	1210
H	1000	1000
I	1000	1000
J	1185	1185

Table 8. Exterior Crush Measurements for Test 417921-4.

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	Side Damage
Undeformed end width ___________ Corner shift: A1 ____ A2 _____ End shift at frame (CDC) (check one) < 4 inches ______ ≥ 4 inches ______	Bowing: B1 ___ X1 ___ B2 ___ X2 ___ Bowing constant $\frac{X1+X2}{2}$ = ______

Note: Measure C1 to C6 from Driver to Passenger side in Front or Rear impacts–
Rear to Front in Side impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	D
		Width ** (CDC)	Max*** Crush								
1	At Inner Bumper	710	-250	1100	+20	-60	-160	210	250	+70	+60

[1]Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

***Measure and document on the vehicle diagram the location of the maximum crush.
Note: Use as many lines/columns as necessary to describe each damage profile.

APPENDIX C. SEQUENTIAL PHOTOGRAPHS

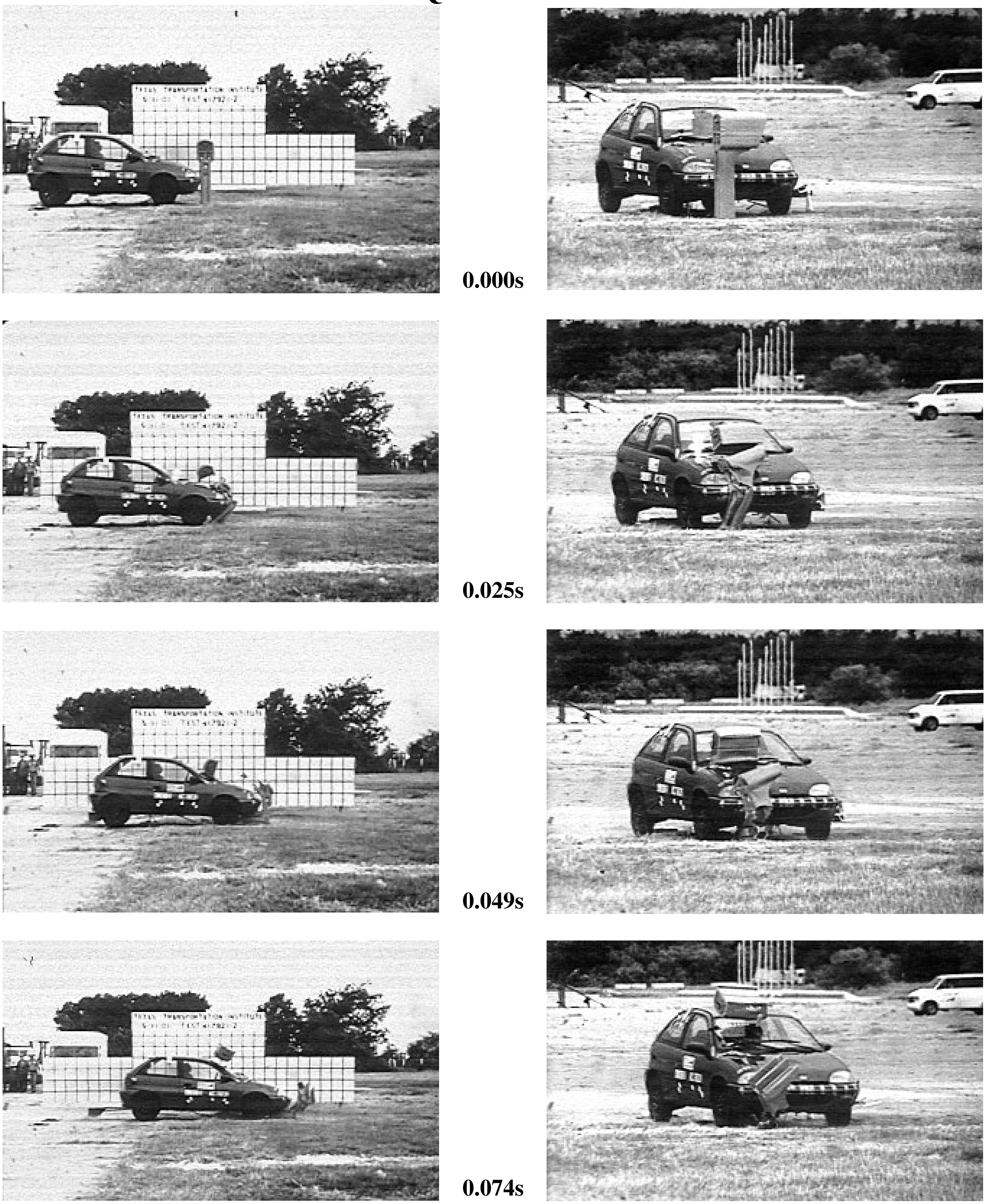


Figure 30. Sequential Photographs for Test 417921-2 (Perpendicular and Oblique Views).

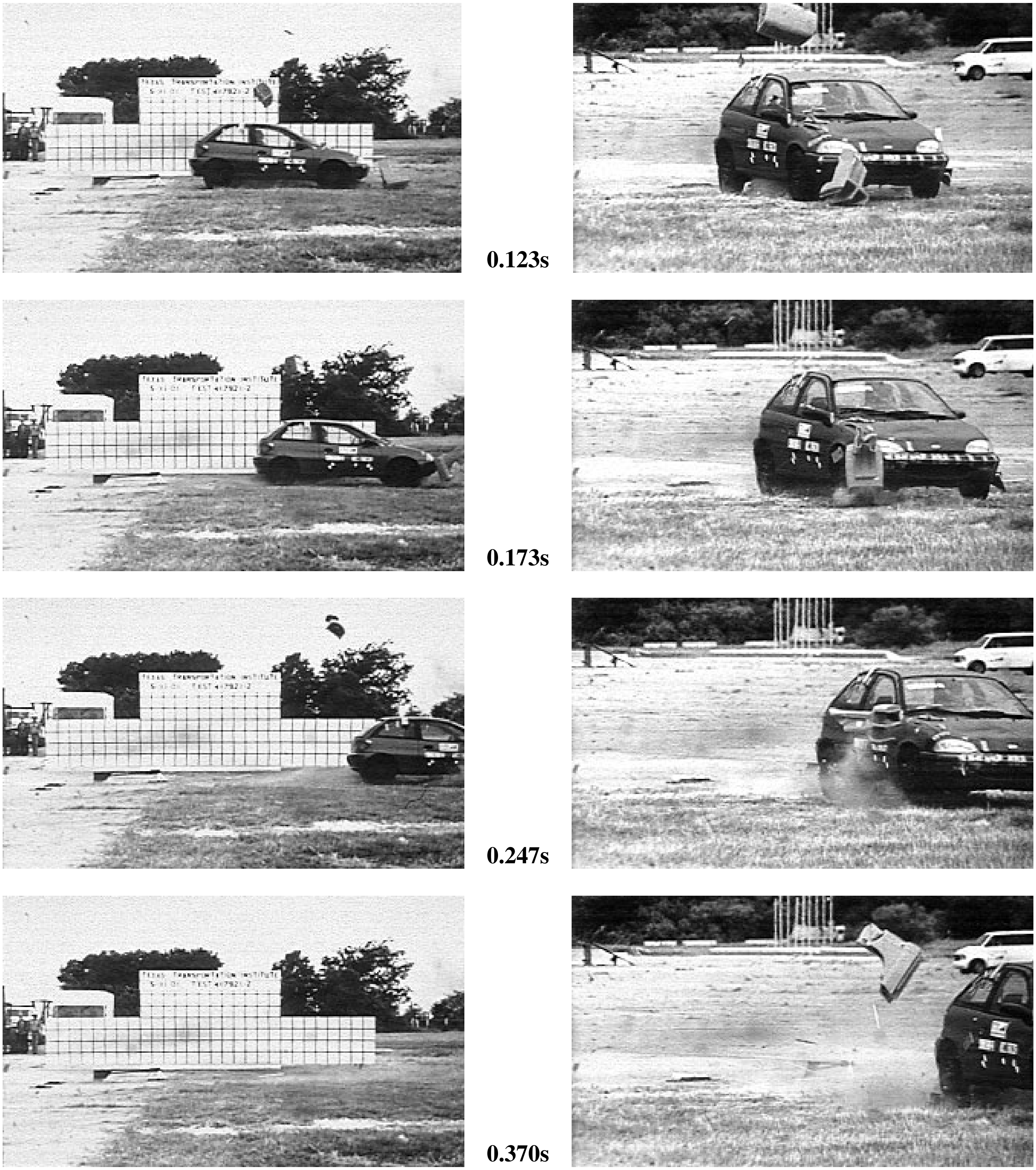


Figure 30. Sequential Photographs for Test 417921-2 (Perpendicular and Oblique Views) (Continued).

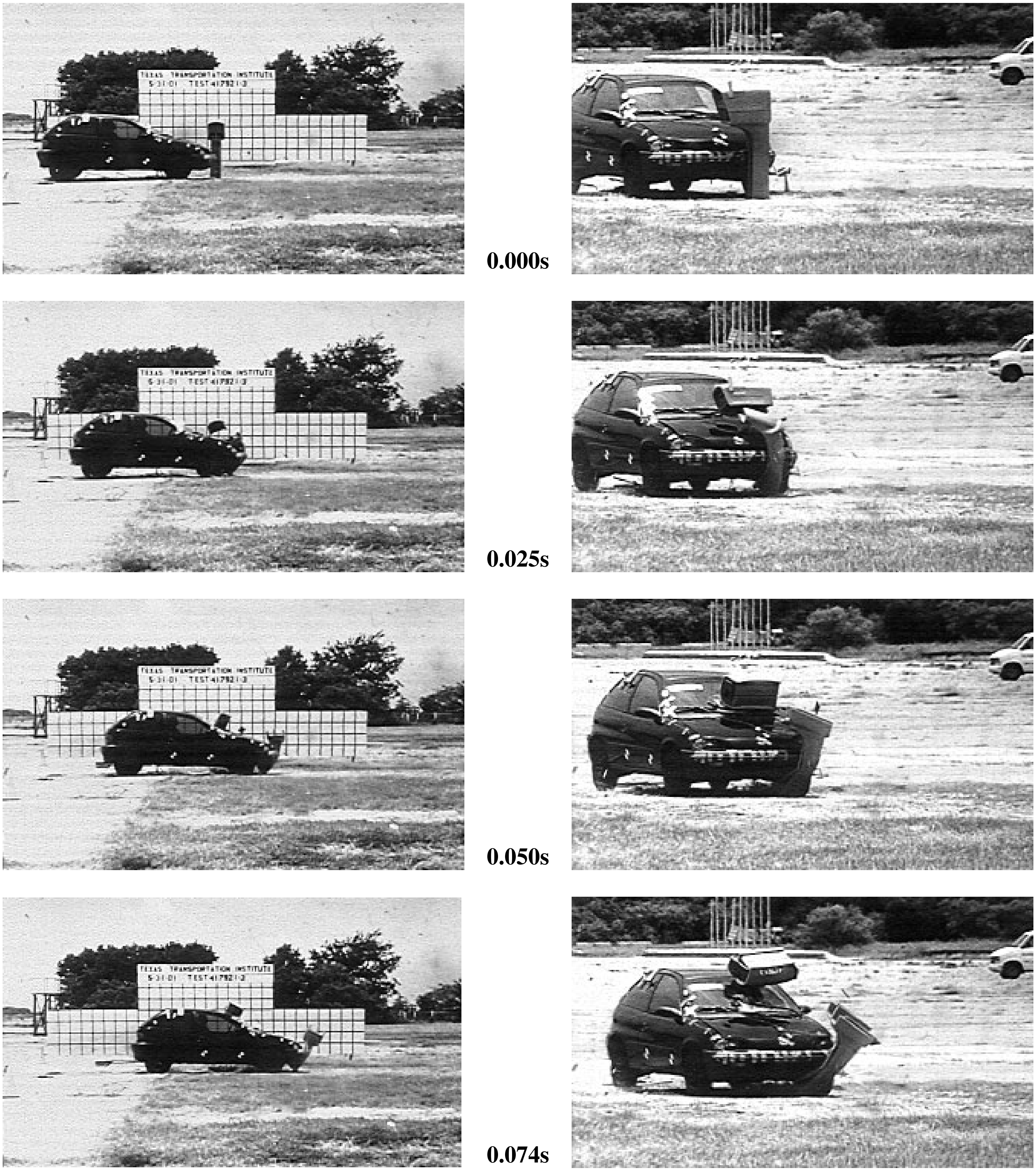
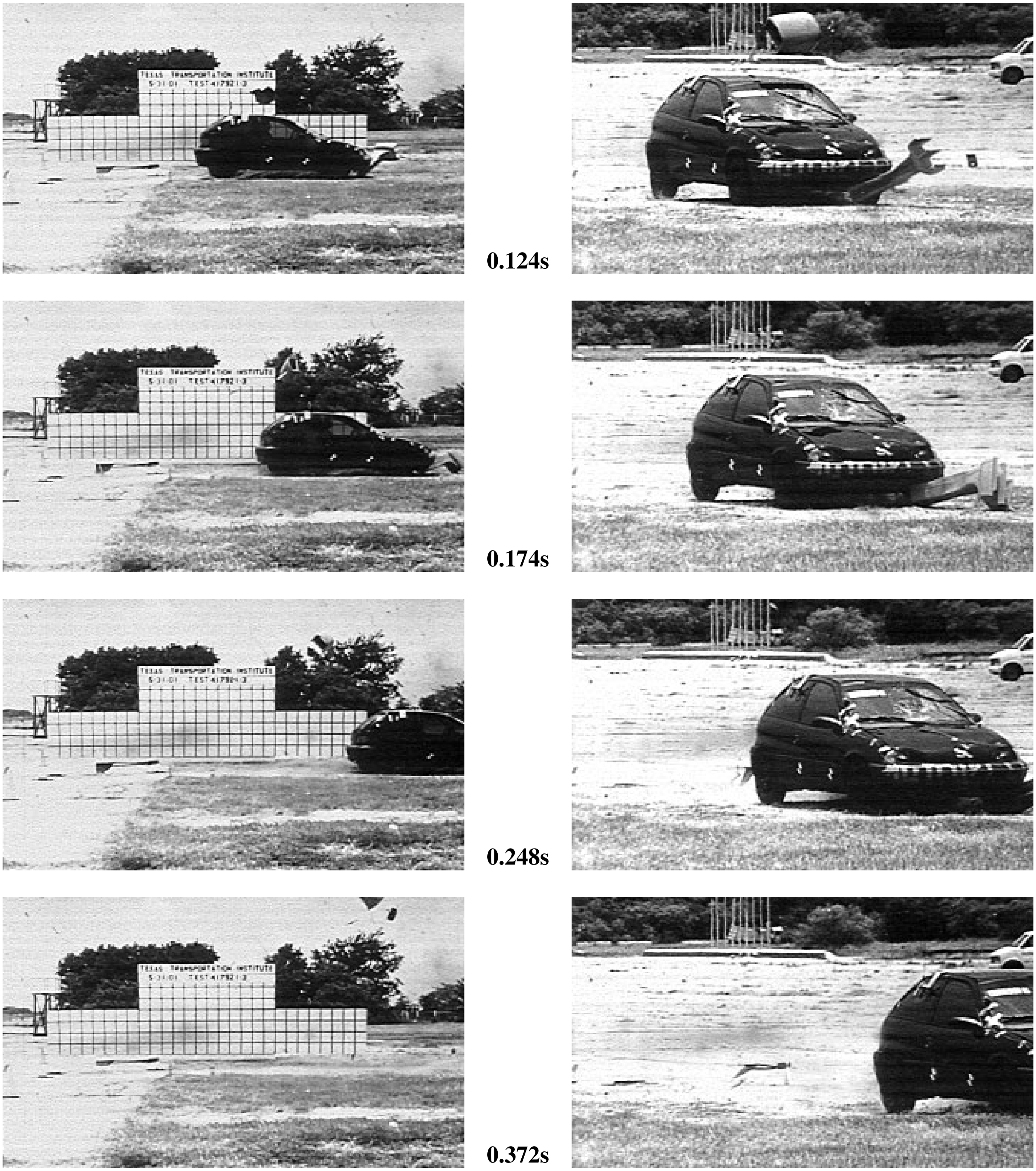


Figure 31. Sequential Photographs for Test 417921-3 (Perpendicular and Oblique Views).



0.124s

0.174s

0.248s

0.372s

Figure 31. Sequential Photographs for Test 417921-3 (Perpendicular and Oblique Views) (Continued).

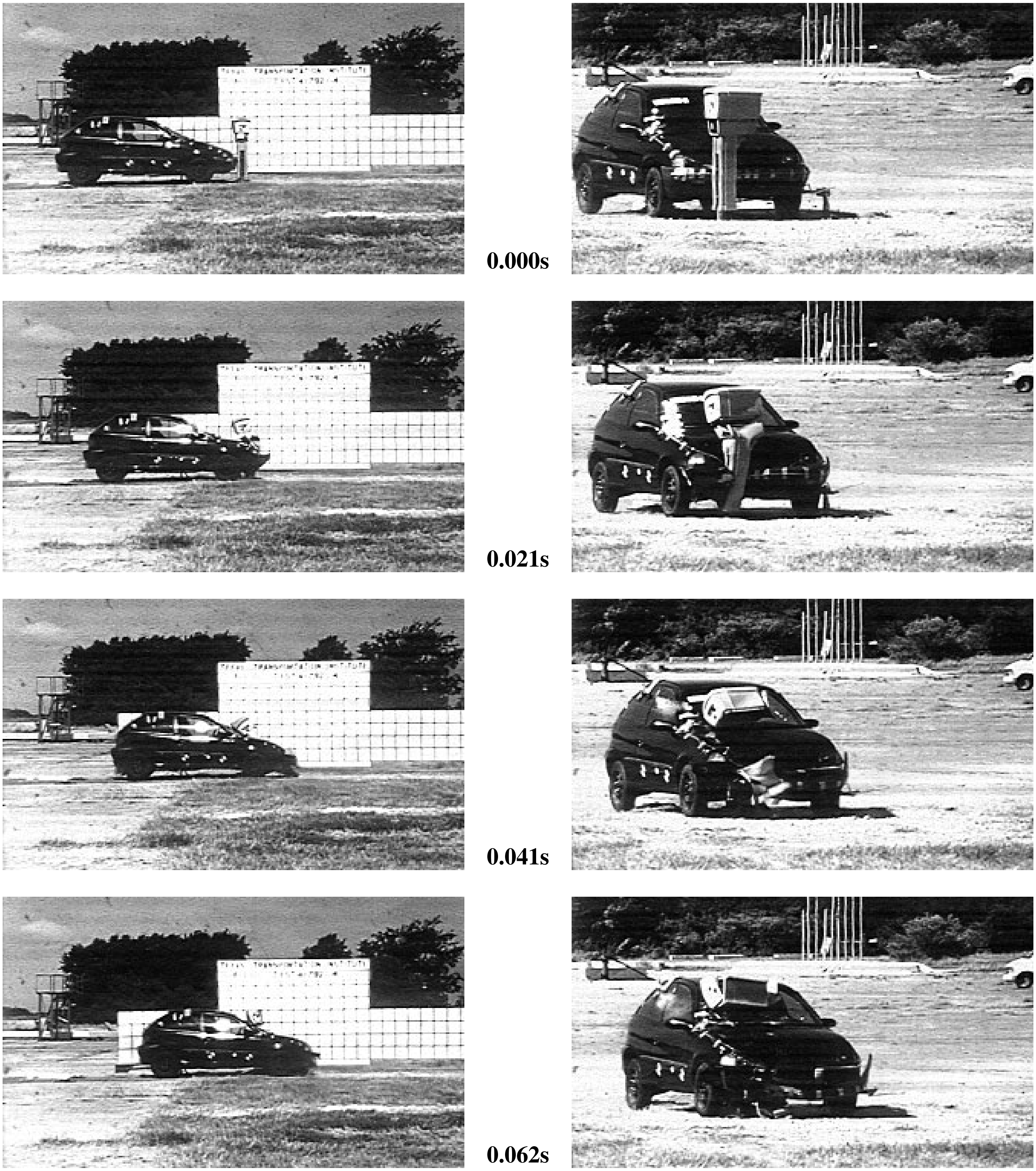


Figure 32. Sequential Photographs for Test 417921-4 (Perpendicular and Oblique Views).

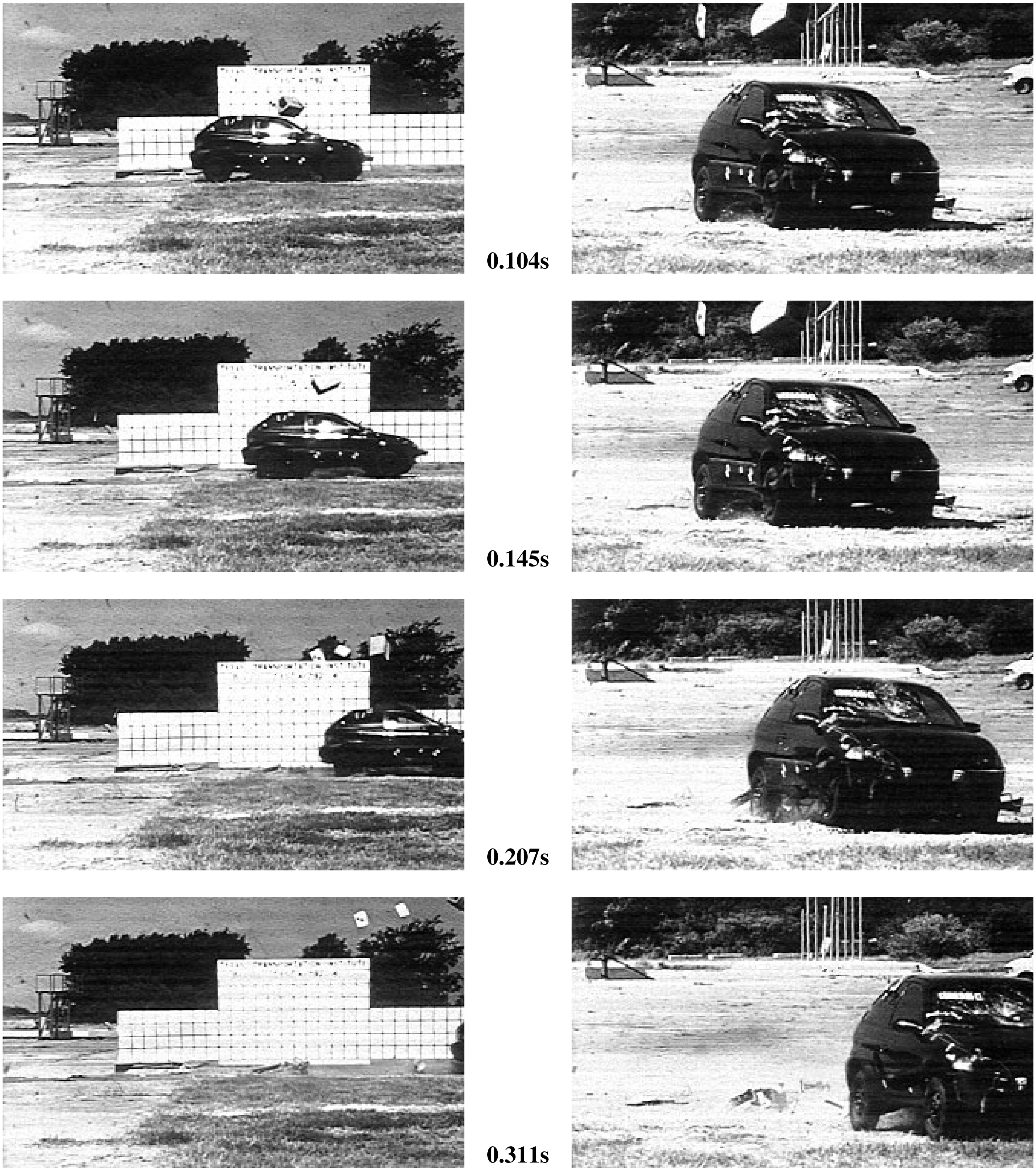


Figure 32. Sequential Photographs for Test 417921-4 (Perpendicular and Oblique Views) (Continued).

APPENDIX D. VEHICLE ANGULAR DISPLACEMENTS AND ACCELERATIONS

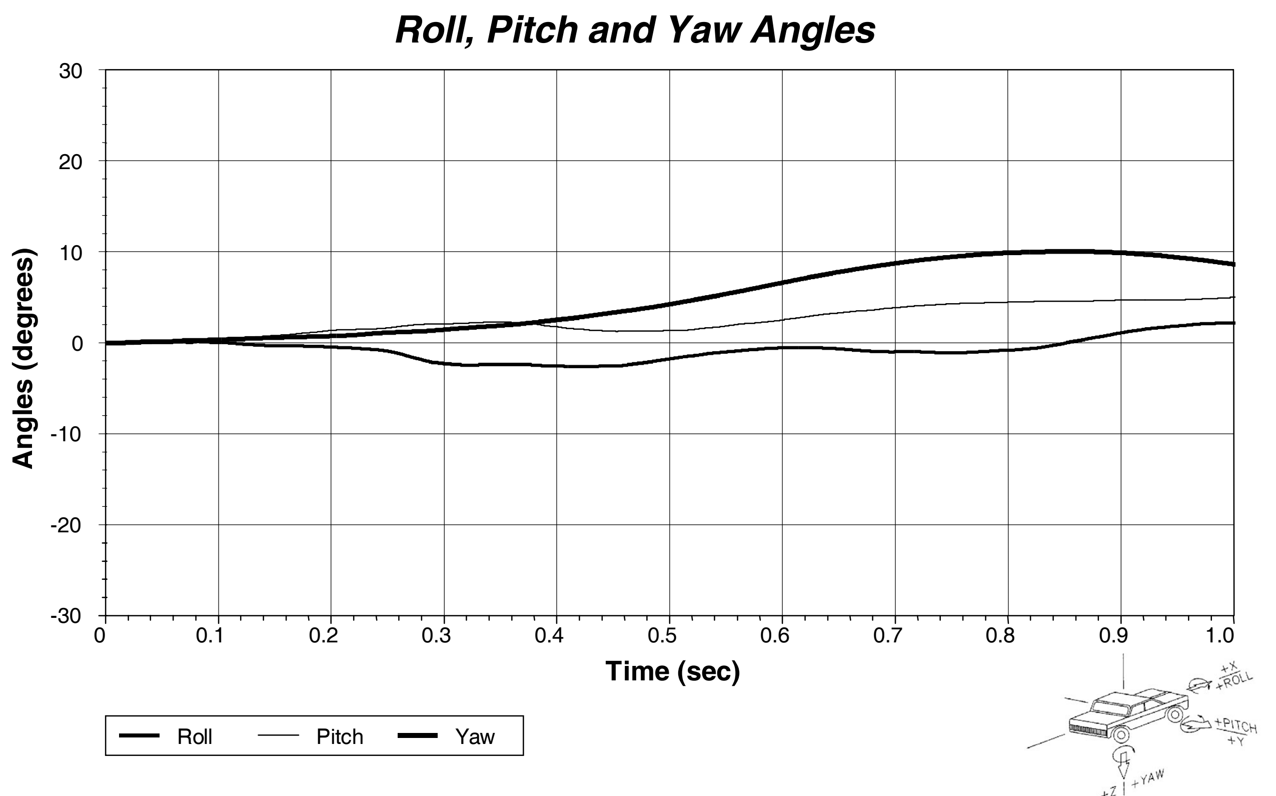


Figure 33. Vehicular Angular Displacements for Test 417921-2.

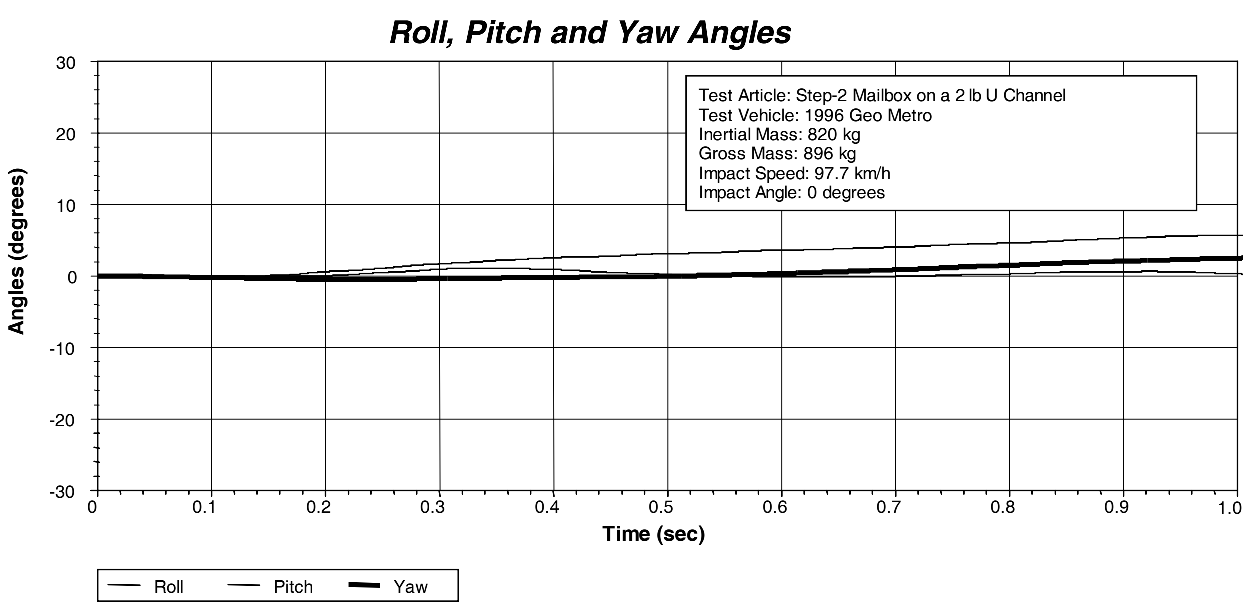


Figure 34. Vehicular Angular Displacements for Test 417921-3.

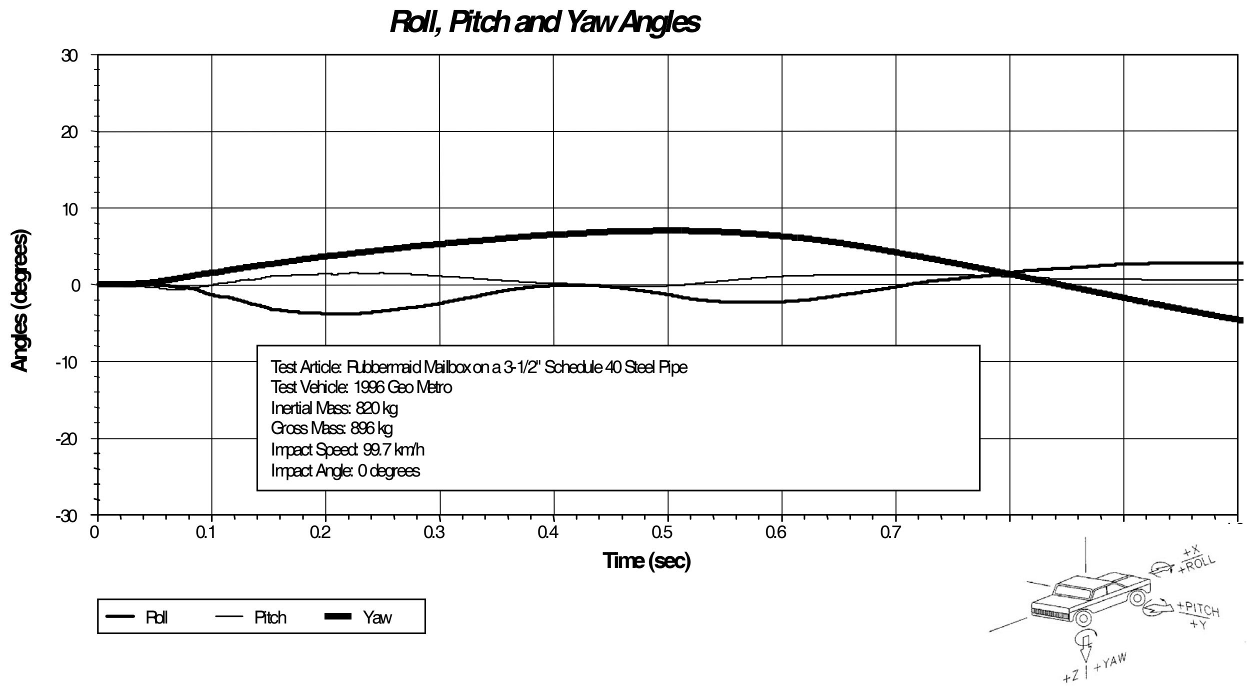


Figure 35. Vehicular Angular Displacements for Test 417921-4.

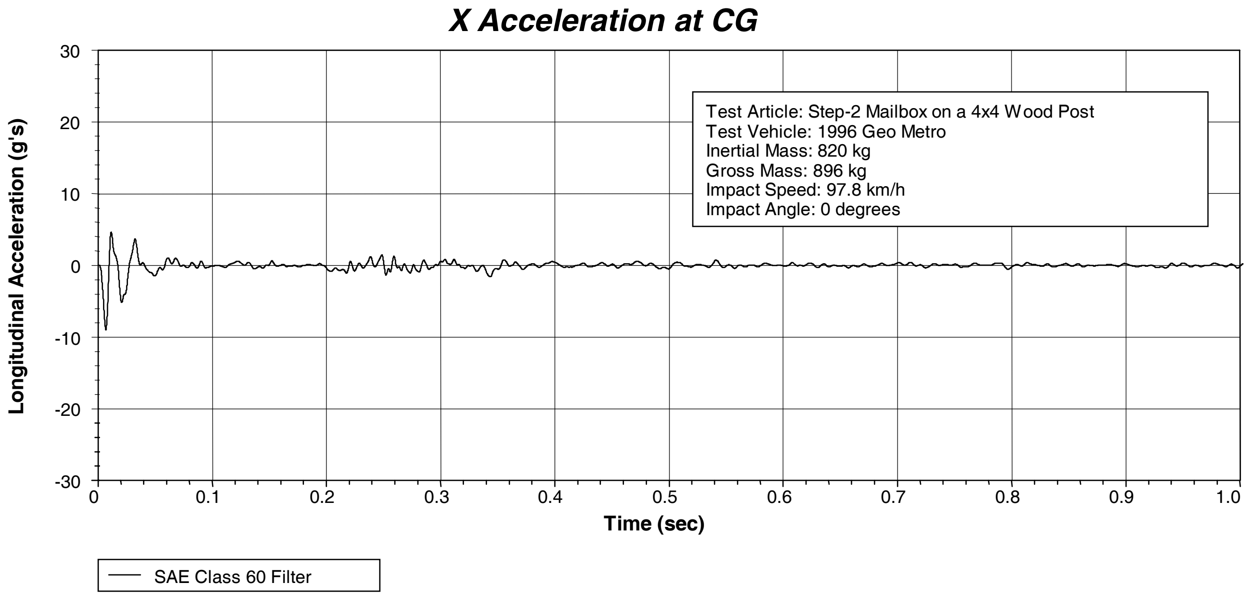


Figure 36. Vehicle Longitudinal Accelerometer Trace for Test 417921-2 (Accelerometer Located at Center of Gravity).

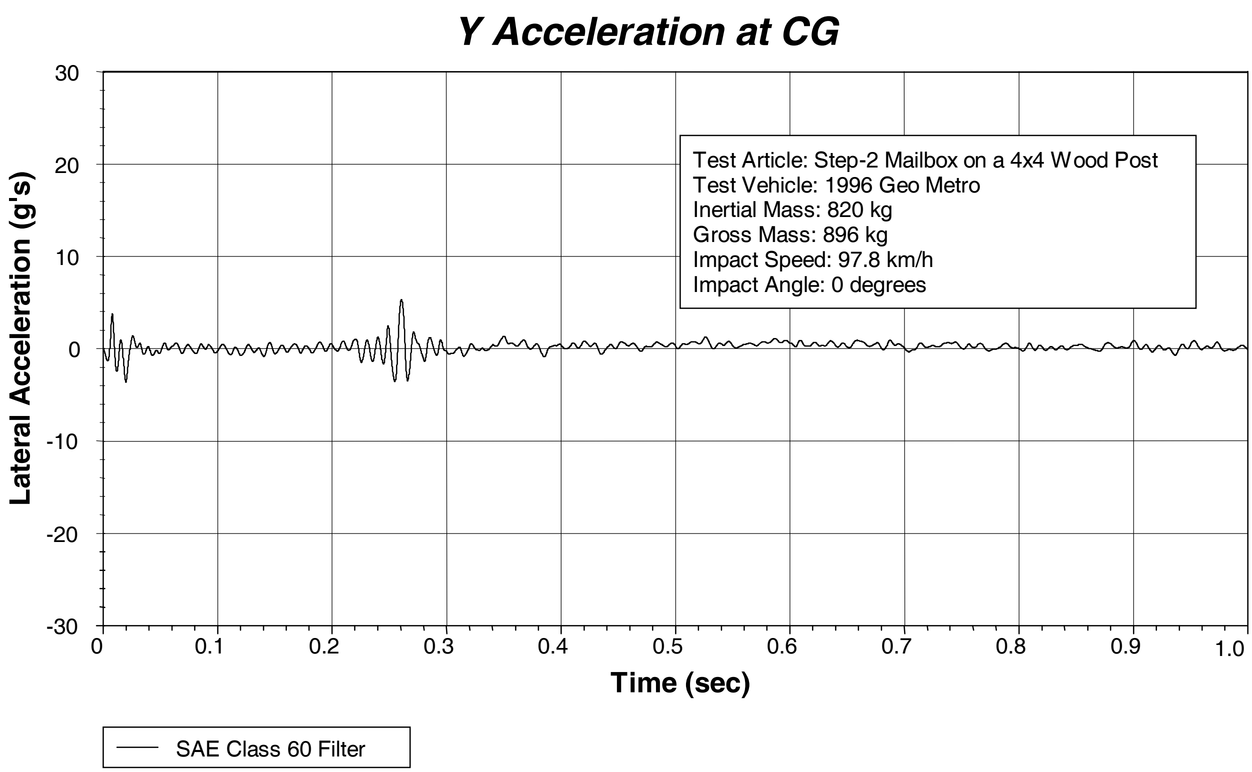


Figure 37. Vehicle Lateral Accelerometer Trace for Test 417921-2 (Accelerometer Located at Center of Gravity).

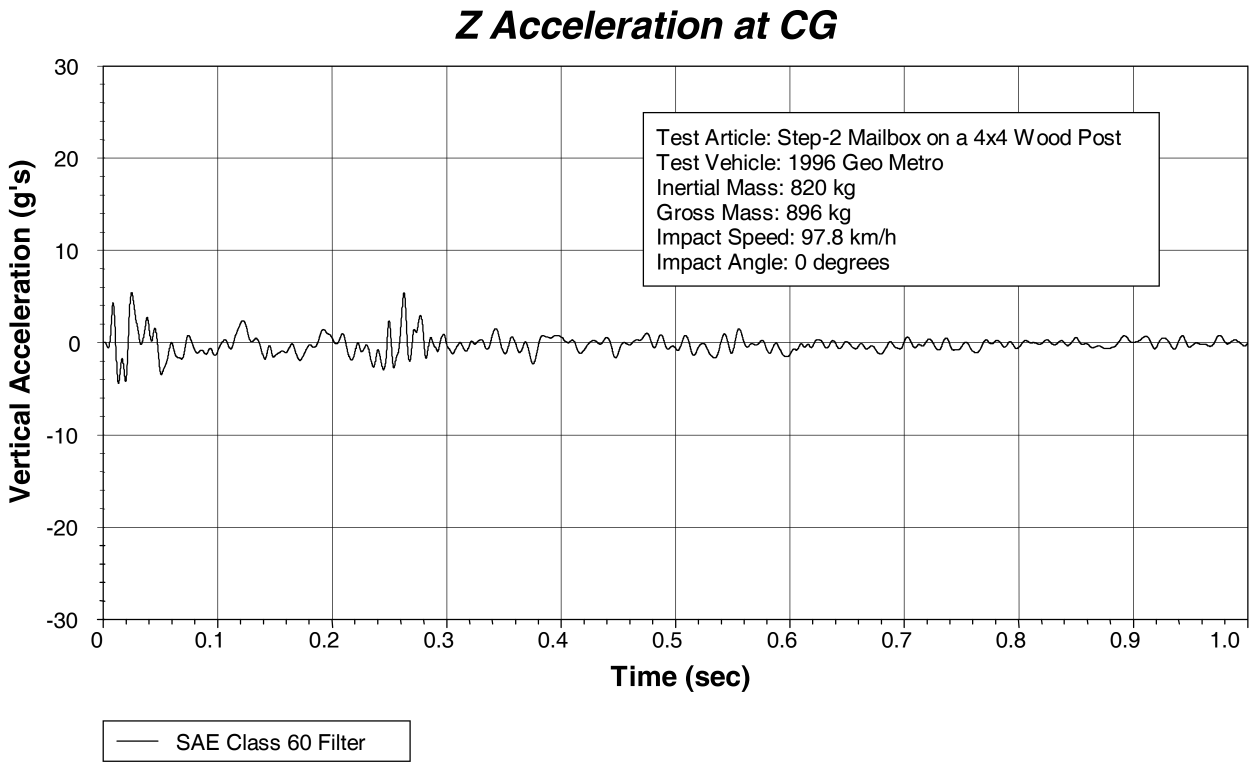


Figure 38. Vehicle Vertical Accelerometer Trace for Test 417921-2 (Accelerometer Located at Center of Gravity).

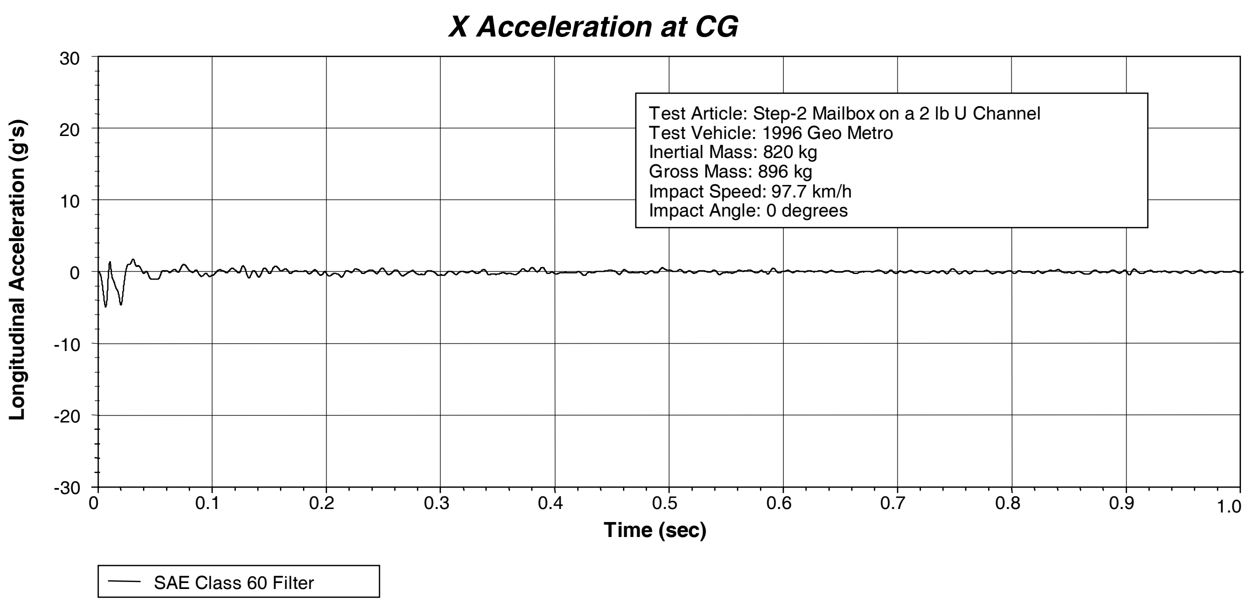


Figure 39. Vehicle Longitudinal Accelerometer Trace for Test 417921-3 (Accelerometer Located at Center of Gravity).

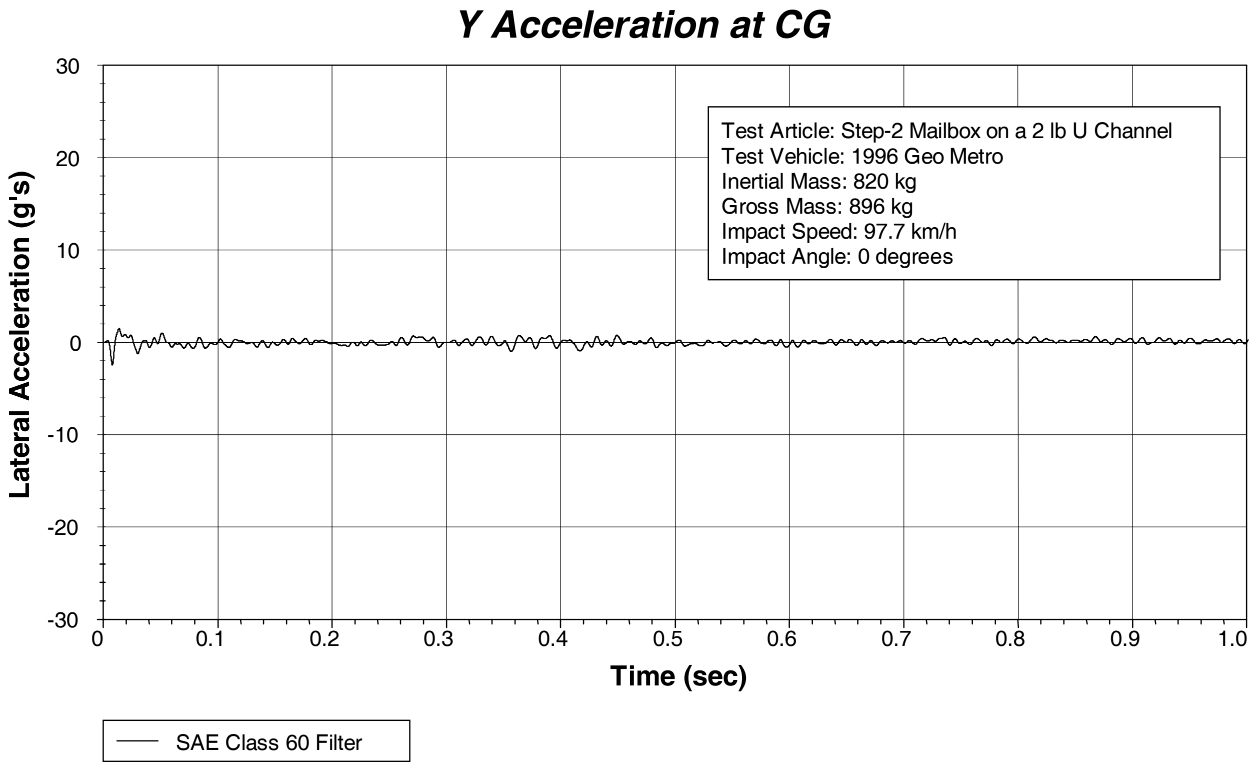


Figure 40. Vehicle Lateral Accelerometer Trace for Test 417921-3 (Accelerometer Located at Center of Gravity).

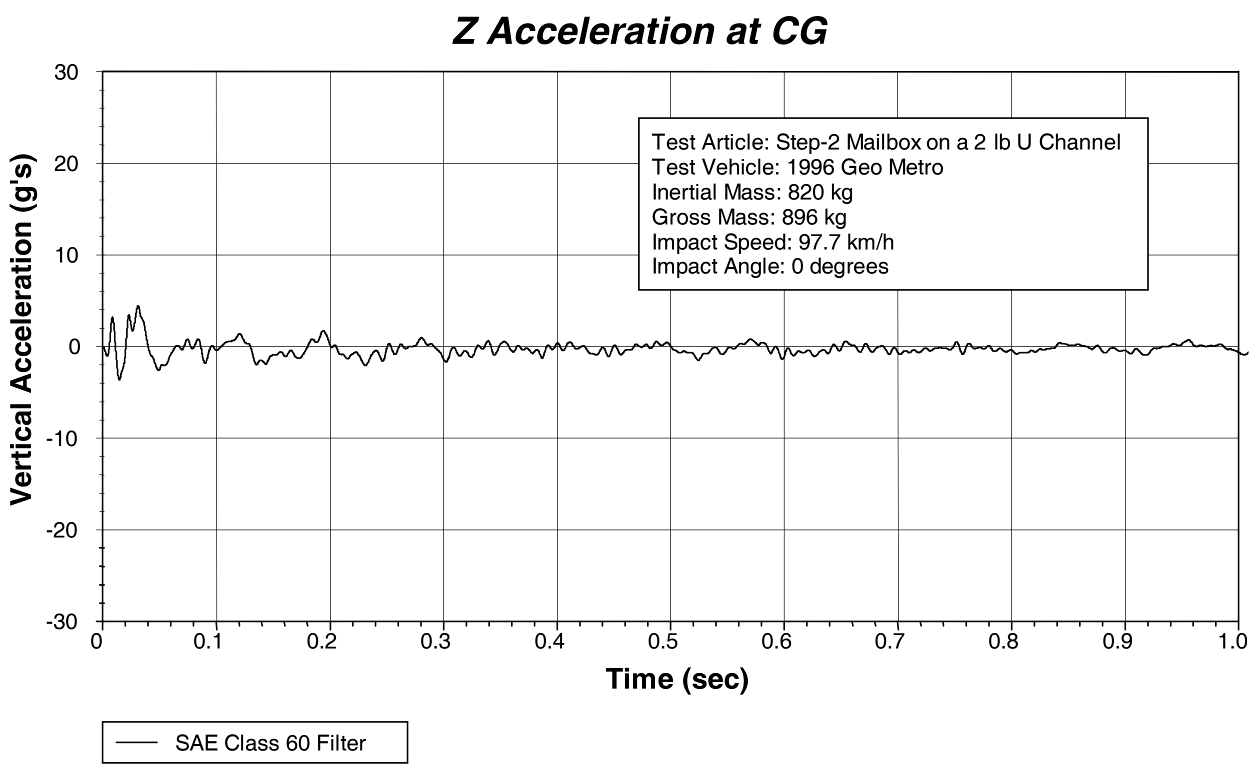


Figure 41. Vehicle Vertical Accelerometer Trace for Test 417921-3 (Accelerometer Located at Center of Gravity).

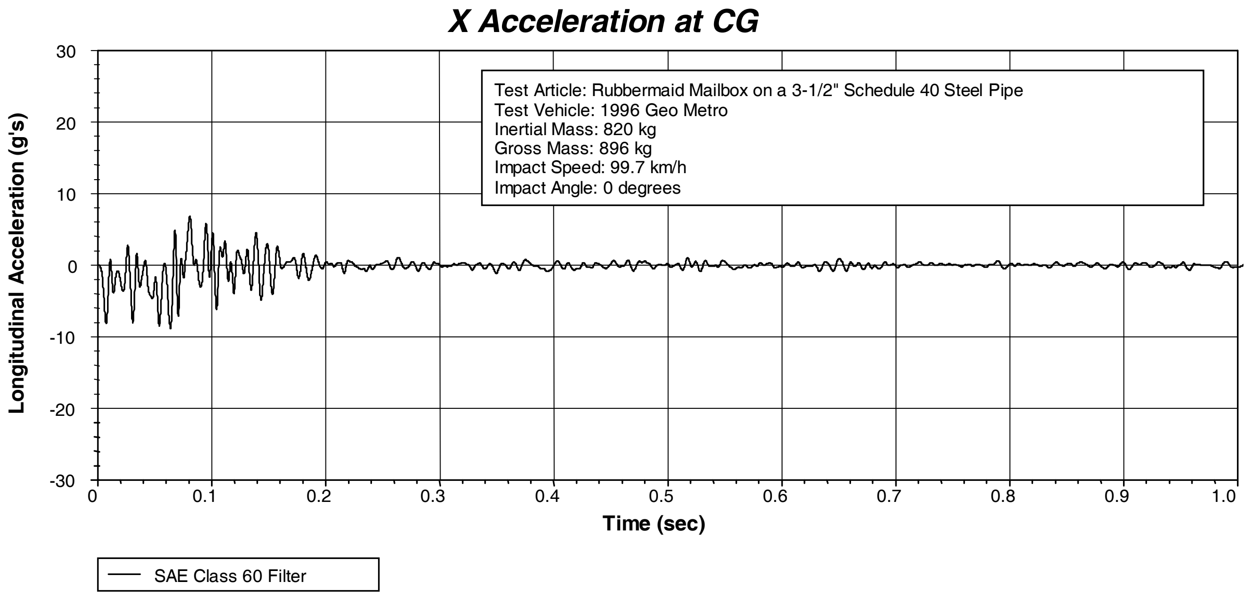


Figure 42. Vehicle Longitudinal Accelerometer Trace for Test 417921-4 (Accelerometer Located at Center of Gravity).

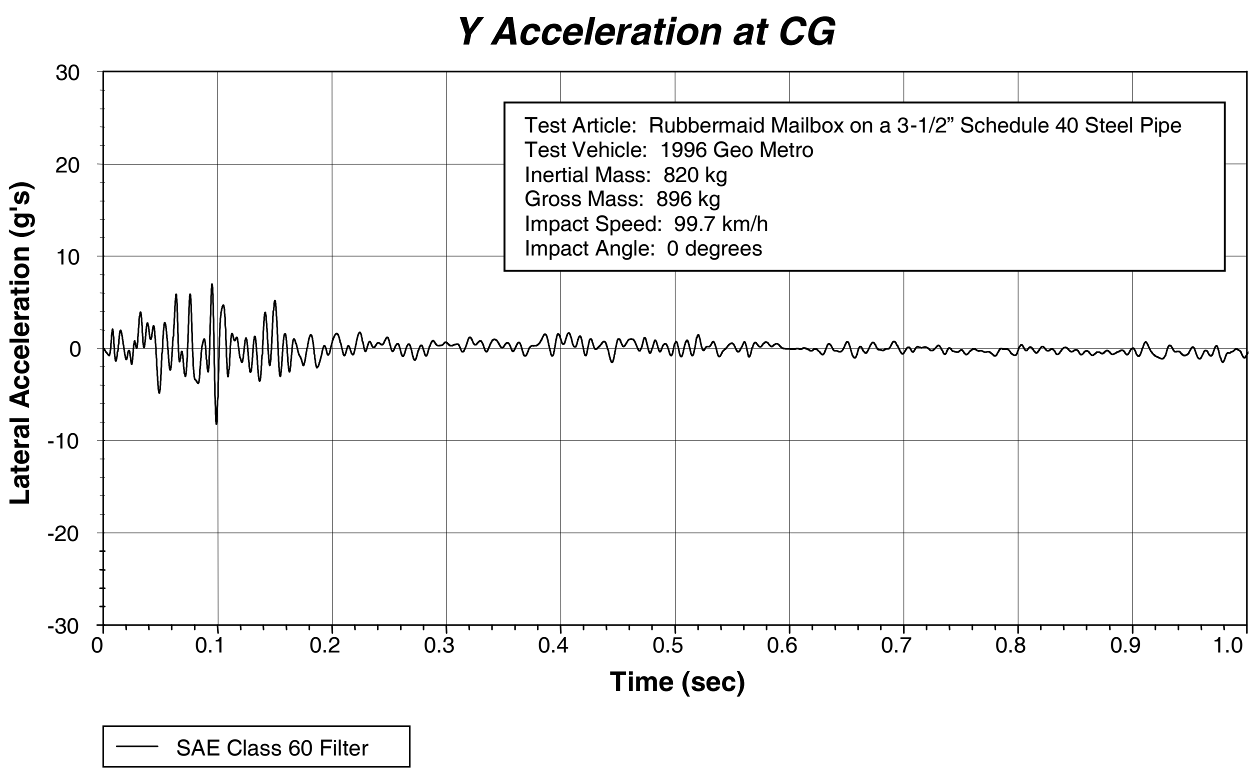


Figure 43. Vehicle Lateral Accelerometer Trace for Test 417921-4 (Accelerometer Located at Center of Gravity).

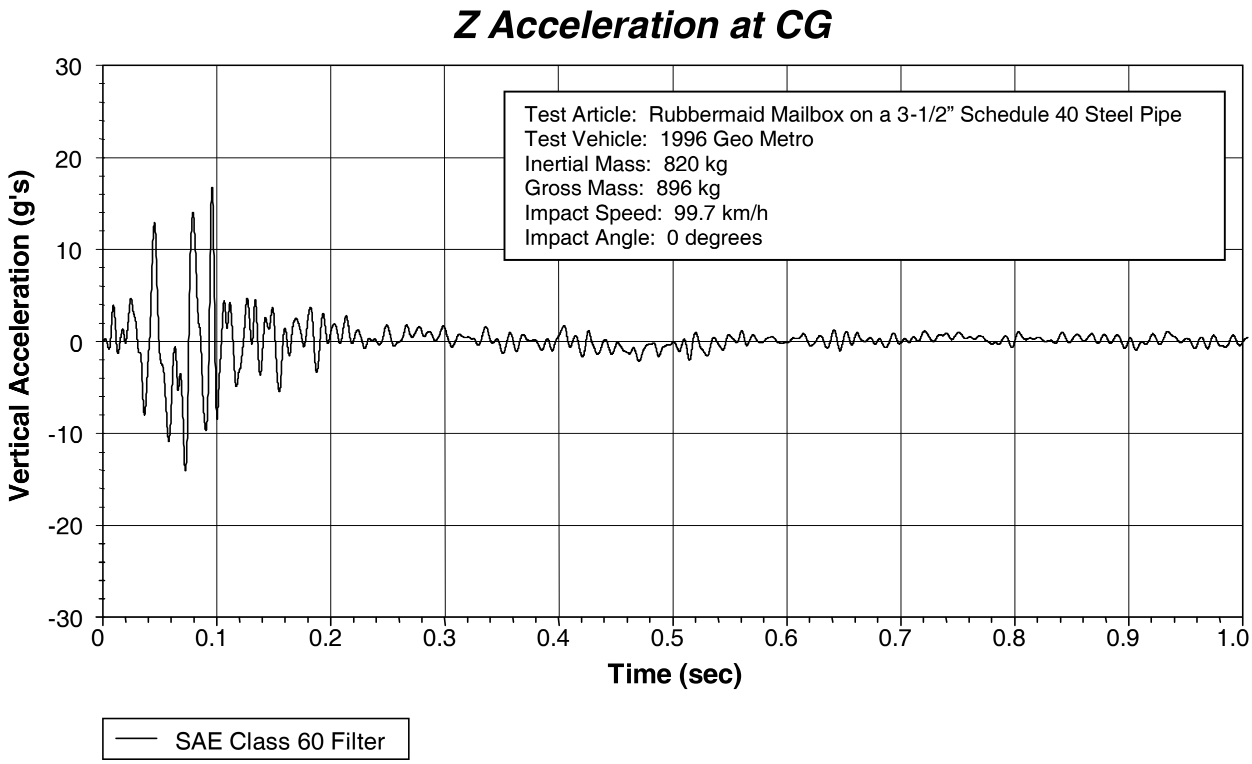


Figure 44. Vehicle Vertical Accelerometer Trace for Test 417921-4 (Accelerometer Located at Center of Gravity).