

*Midwest States Regional Pooled Fund Research Program
Fiscal Year 2002-2003 (Year 13)
Research Project Number SPR-3(017)
NDOR Sponsoring Agency Code RFPF-03-06*

DEVELOPMENT AND EVALUATION OF A TIE-DOWN SYSTEM FOR THE REDESIGNED F-SHAPE CONCRETE TEMPORARY BARRIER

Submitted by

Karla A. Polivka, M.S.M.E., E.I.T.
Research Associate Engineer

John R. Rohde, Ph.D., P.E.
Associate Professor

Bob W. Bielenberg, M.S.M.E., E.I.T.
Research Associate Engineer

Ronald K. Faller, Ph.D., P.E.
Research Assistant Professor

James C. Holloway, M.S.C.E., E.I.T.
Research Associate Engineer

Dean L. Sicking, Ph.D., P.E.
Professor and MwRSF Director

MIDWEST ROADSIDE SAFETY FACILITY

University of Nebraska-Lincoln
527 Nebraska Hall
Lincoln, Nebraska 68588-0529
(402) 472-6864

Submitted to

MIDWEST STATES REGIONAL POOLED FUND PROGRAM

Nebraska Department of Roads
1500 Nebraska Highway 2
Lincoln, Nebraska 68502

MwRSF Research Report No. TRP-03-134-03

August 22, 2003

Technical Report Documentation Page

| | | | |
|---|---|---|-----------|
| 1. Report No. RPFP-03-06 | 2. | 3. Recipient's Accession No. | |
| 4. Title and Subtitle Development and Evaluation of a Tie-Down System for the Redesigned F-Shape Concrete Temporary Barrier | | 5. Report Date August 22, 2003 | |
| | | 6. | |
| 7. Author(s) Polivka, K.A., Faller, R.K., Rohde, J.R., Holloway, J.C., Bielenberg, B.W., and Sicking, D.L. | | 8. Performing Organization Report No. TRP-03-134-03 | |
| 9. Performing Organization Name and Address Midwest Roadside Safety Facility (MwRSF) University of Nebraska-Lincoln 527 Nebraska Hall Lincoln, NE 68588-0529 | | 10. Project/Task/Work Unit No. | |
| | | 11. Contract © or Grant (G) No. SPR-3(017) | |
| 12. Sponsoring Organization Name and Address Midwest States Regional Pooled Fund Program Nebraska Department of Roads 1500 Nebraska Highway 2 Lincoln, Nebraska 68502 | | 13. Type of Report and Period Covered Final Report 2002-2003 | |
| | | 14. Sponsoring Agency Code RPFP-03-06 | |
| 15. Supplementary Notes Prepared in cooperation with U.S. Department of Transportation, Federal Highway Administration | | | |
| 16. Abstract (Limit: 200 words) <p>Often, temporary barriers are used in applications where it is desired that their deflection during vehicular impact be limited. One such application is in the installation of temporary barriers placed adjacent to the edge of a concrete bridge deck in order to maximize lane width. Acceptable tie-down systems for temporary barriers have previously been developed, but there are concerns when the barriers and tie-down systems are used on bridges that are reconstructed in stages and where very little tolerance in barrier deflection is allowable. Therefore, a rigid tie-down system was developed that minimizes barrier deflections. For this system, the original Kansas temporary barrier was redesigned in order to strengthen the barrier around the tie-down holes and to standardize the barriers for use in adjacent states and in various temporary and tied-down configurations. The tie-down anchor system fastened the traffic-side of the barriers to the concrete bridge deck with three 29-mm (1.125-in.) diameter ASTM A307 anchor bolts with heavy hex nuts and 76-mm (3-in.) x 76-mm (3-in.) x 13-mm (0.5-in.) thick washers.</p> <p>The research study included one full-scale vehicle crash test, using a ¾-ton pickup truck. The full-scale test, with an impact speed of 99.8 km/hr (62.0 mph) and an impact angle of 25.3 degrees, was conducted and reported in accordance with the requirements specified in the National Cooperative Highway Research Program (NCHRP) Report No. 350, <i>Recommended Procedures for the Safety Performance Evaluation of Highway Features</i>. The safety performance of the tie-down anchor system for use with concrete bridge decks and the redesigned F-shape temporary concrete barrier was determined to be acceptable according to the Test Level 3 (TL-3) evaluation criteria specified in NCHRP Report No. 350.</p> | | | |
| 17. Document Analysis/Descriptors Highway Safety, Temporary Barriers, Work Zones, Longitudinal Barriers, Concrete Barriers, Concrete Bridge Decks, Roadside Appurtenances, Crash Test, Compliance Test | | 18. Availability Statement No restrictions. Document available from: National Technical Information Services, Springfield, Virginia 22161 | |
| 19. Security Class (this report) Unclassified | 20. Security Class (this page) Unclassified | 21. No. of Pages 97 | 22. Price |

DISCLAIMER STATEMENT

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views nor policies of the State Highway Departments participating in the Midwest States Regional Pooled Fund Research Program nor the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

ACKNOWLEDGMENTS

The authors wish to acknowledge several sources that made a contribution to this project: (1) the Midwest States Regional Pooled Fund Program funded by the Connecticut Department of Transportation, Iowa Department of Transportation, Kansas Department of Transportation, Minnesota Department of Transportation, Missouri Department of Transportation, Montana Department of Transportation, Nebraska Department of Roads, Ohio Department of Transportation, South Dakota Department of Transportation, Texas Department of Transportation, and Wisconsin Department of Transportation for sponsoring this project; (2) the Kansas Department of Transportation for supplying the barriers; and (3) MwRSF personnel for constructing the barrier and conducting the crash test.

A special thanks is also given to the following individuals who made a contribution to the completion of this research project.

Midwest Roadside Safety Facility

J.D. Reid, Ph.D., Associate Professor
A.T. Russell, Laboratory Mechanic II
M.L. Hanau, Laboratory Mechanic I
G.L. Schmutte, Laboratory Mechanic I
Undergraduate and Graduate Assistants

Connecticut Department of Transportation

Dionysia Oliveira, Transportation Engineer 3

Iowa Department of Transportation

David Little, P.E., Assistant District Engineer
Will Stein, P.E., Design Methods Engineer

Kansas Department of Transportation

Ron Seitz, P.E., Assistant Bureau Chief
Rod Lacy, P.E., Road Design Leader

Minnesota Department of Transportation

Jim Klessig, Implementation Liaison
Mohammad Dehdashti, P.E., Design Standards Engineer
Ron Cassellius, Former Research Program Coordinator
Andrew Halverson, P.E., Former Assistant Design Standards Engineer

Missouri Department of Transportation

Daniel Smith, P.E., Research and Development Engineer

Montana Department of Transportation

Susan Sillick, Research Bureau Chief

Nebraska Department of Roads

Amy Starr, Research Engineer
Phil Tenhulzen, P.E., Design Standards Engineer
Leona Kolbet, former Research Coordinator

Ohio Department of Transportation

Monique Evans, P.E., Administrator
Dean Focke, Standards Engineer

South Dakota Department of Transportation

David Huft, Research Engineer
Bernie Clocksin, Lead Project Engineer

Texas Department of Transportation

Mark Bloschock, P.E., Supervising Design Engineer
Mark Marek, P.E., Design Engineer

Wisconsin Department of Transportation

Peter Amakobe, Standards Development Engineer
Beth Cannestra, P.E., Chief in Roadway Development

Federal Highway Administration

John Perry, P.E., Nebraska Division Office
Danny Briggs, Nebraska Division Office

Dunlap Photography

James Dunlap, President and Owner

TABLE OF CONTENTS

| | Page |
|---|------|
| TECHNICAL REPORT DOCUMENTATION PAGE | i |
| DISCLAIMER STATEMENT | ii |
| ACKNOWLEDGMENTS | iii |
| TABLE OF CONTENTS | vi |
| List of Figures | viii |
| List of Tables | x |
| 1 INTRODUCTION | 1 |
| 1.1 Problem Statement | 1 |
| 1.2 Objective | 1 |
| 1.3 Scope | 2 |
| 2 LITERATURE REVIEW | 3 |
| 2.1 Temporary Concrete Barriers | 3 |
| 2.2 Tie-Down Systems | 3 |
| 3 TEST REQUIREMENTS AND EVALUATION CRITERIA | 6 |
| 3.1 Test Requirements | 6 |
| 3.2 Evaluation Criteria | 7 |
| 4 DESIGN DETAILS | 9 |
| 4.1 Desired Design Changes | 9 |
| 4.2 Design Details | 10 |
| 5 TEST CONDITIONS | 24 |
| 5.1 Test Facility | 24 |
| 5.2 Vehicle Tow and Guidance System | 24 |
| 5.3 Test Vehicles | 24 |
| 5.4 Data Acquisition Systems | 27 |
| 5.4.1 Accelerometers | 27 |
| 5.4.2 Rate Transducers | 29 |
| 5.4.3 High-Speed Photography | 29 |
| 5.4.4 Pressure Tape Switches | 30 |
| 6 CRASH TEST NO. 1 | 32 |
| 6.1 Test KTB-1 | 32 |
| 6.2 Test Description | 32 |
| 6.3 Barrier Damage | 33 |

| | |
|--|----|
| 6.4 Vehicle Damage | 34 |
| 6.5 Occupant Risk Values | 36 |
| 6.6 Discussion | 36 |
| 7 SUMMARY AND CONCLUSIONS | 57 |
| 8 RECOMMENDATIONS | 59 |
| 9 REFERENCES | 63 |
| 10 APPENDICES | 65 |
| APPENDIX A - System Drawings in English Units | 66 |
| APPENDIX B - State Plans of the Redesigned Temporary Barrier Details | 73 |
| APPENDIX C - Epoxy Specifications used with the Tie-Down Anchors | 76 |
| APPENDIX D - Test Summary Sheet in English Units, Test KTB-1 | 79 |
| APPENDIX E - Concrete Damage Sketches, Test KTB-1 | 81 |
| APPENDIX F - Occupant Compartment Deformation Data, Test KTB-1 | 86 |
| APPENDIX G - Accelerometer Data Analysis, Test KTB-1 | 88 |
| APPENDIX H - Roll and Yaw Data Analysis, Test KTB-1 | 95 |

List of Figures

| | Page |
|---|------|
| 1. Temporary Barrier Details | 13 |
| 2. Temporary Barrier Profile and Tie-Down Details | 14 |
| 3. Temporary Barrier Connection and Lifting Slot Details | 15 |
| 4. Temporary Barrier Bill of Bars | 16 |
| 5. Connection to Iowa Temporary Barrier Details | 17 |
| 6. Distances Between Temporary Barriers | 18 |
| 7. Barrier System | 19 |
| 8. Barrier System | 20 |
| 9. Barrier Connection Joints | 21 |
| 10. Barrier Tie-Down System | 22 |
| 11. Barrier Tie-Down Installation | 23 |
| 12. Test Vehicle, Test KTB-1 | 25 |
| 13. Vehicle Dimensions, Test KTB-1 | 26 |
| 14. Vehicle Target Locations, Test KTB-1 | 28 |
| 15. Location of High-Speed Cameras, Test KTB-1 | 31 |
| 16. Summary of Test Results and Sequential Photographs, Test KTB-1 | 38 |
| 17. Additional Sequential Photographs, Test KTB-1 | 39 |
| 18. Additional Sequential Photographs, Test KTB-1 | 40 |
| 19. Additional Sequential Photographs, Test KTB-1 | 41 |
| 20. Documentary Photographs, Test KTB-1 | 42 |
| 21. Documentary Photographs, Test KTB-1 | 43 |
| 22. Impact Location, Test KTB-1 | 44 |
| 23. Vehicle Final Position and Trajectory Marks, Test KTB-1 | 45 |
| 24. System Damage, Test KTB-1 | 46 |
| 25. System Damage, Test KTB-1 | 47 |
| 26. Barrier Nos. 8 and 9 Damage, Test KTB-1 | 48 |
| 27. Barrier Nos. 8 and 9 Concrete Damage , Test KTB-1 | 49 |
| 28. Barrier No. 8 Tie-Down Anchor Damage, Test KTB-1 | 50 |
| 29. Barrier No. 9 Tie-Down Anchor Damage, Test KTB-1 | 51 |
| 30. Vehicle Damage, Test KTB-1 | 52 |
| 31. Vehicle Damage, Test KTB-1 | 53 |
| 32. Right-Side Tire Damage, Test KTB-1 | 54 |
| 33. Vehicle Undercarriage Damage, Test KTB-1 | 55 |
| 34. Occupant Compartment Damage, Test KTB-1 | 56 |
| 35. Treatment at Bridge Deck Thermal Expansion Joints | 61 |
| 36. Staked Down Installation into an Asphalt Road Surface (Transitioning to Free-Standing Sections at the End of a Bridge) | 62 |
| A-1. Temporary Barrier Details (English) | 67 |
| A-2. Temporary Barrier Profile and Tie-Down Details (English) | 68 |
| A-3. Temporary Barrier Connection and Lifting Slot Details (English) | 69 |
| A-4. Temporary Barrier Bill of Bars (English) | 70 |

| | |
|---|----|
| A-5. Connection to Iowa Temporary Barrier Details (English) | 71 |
| A-6. Distances Between Temporary Barriers (English) | 72 |
| B-1. Kansas State Plans (Metric) | 74 |
| B-2. Kansas State Plans (English) | 75 |
| C-1. Type of Epoxy | 77 |
| C-2. Epoxy Specifications | 78 |
| D-1. Summary of Test Results and Sequential Photographs (English), Test KTB-1 | 80 |
| E-1. Concrete Damage – Front Face Barrier No. 8, Test KTB-1 | 82 |
| E-2. Concrete Damage – Back Face Barrier No. 8, Test KTB-1 | 83 |
| E-3. Concrete Damage – Front Face Barrier No. 9, Test KTB-1 | 84 |
| E-4. Concrete Damage – Back Face Barrier No. 9, Test KTB-1 | 85 |
| F-1. Occupant Compartment Deformation Data, Test KTB-1 | 87 |
| G-1. Graph of Longitudinal Deceleration Test KTB-1 | 89 |
| G-2. Graph of Longitudinal Occupant Impact Velocity, Test KTB-1 | 90 |
| G-3. Graph of Longitudinal Occupant Displacement, Test KTB-1 | 91 |
| G-4. Graph of Lateral Deceleration, Test KTB-1 | 92 |
| G-5. Graph of Lateral Occupant Impact Velocity, Test KTB-1 | 93 |
| G-6. Graph of Lateral Occupant Displacement, Test KTB-1 | 94 |
| H-1. Graph of Roll Angular Displacements, Test KTB-1 | 96 |
| H-2. Graph of Yaw Angular Displacements, Test KTB-1 | 97 |

List of Tables

Page

1. NCHRP Report No. 350 Test Level 3 Crash Test Conditions 7
2. NCHRP Report No. 350 Evaluation Criteria for Crash Tests 8
3. Summary of Safety Performance Evaluation Results 58

1 INTRODUCTION

1.1 Problem Statement

Roadway construction or work zones are found along almost all Federal, State, and local highways in the United States. In most cases, these roadways often require the redirection of vehicular traffic around or through the construction zone. Typically, some form of temporary barrier is used to separate the flow of traffic within the construction area. In general, temporary barriers are segmented units which are attached end-to-end by a load bearing connection. The segmentation of the barriers allows them to be easily installed, repositioned, and removed from the work-zone area. The barrier system is designed to protect equipment and workers in the work zone, to prevent errant vehicles from leaving the traveled way, and to safely redirect those vehicles impacting the barrier.

Often, temporary barriers are used in applications where it is desired that their deflection during vehicular impact be limited. One such application is the installation of temporary barriers placed adjacent to the edge of a bridge deck in order to provide adequate lane width. However, freestanding barrier installations placed close to the deck edge pose a major safety hazard to errant vehicles as there is a significant risk for the barrier segments to be propelled off of the bridge. Thus, large dynamic deflections, in conjunction with narrow gaps behind the barriers, may prove sufficient to push the barriers off of the deck along with the impacting vehicle.

1.2 Objective

The objective of the research project was to redesign and standardize the F-shape concrete barrier previously developed for the Midwest States Regional Pooled Fund Program and develop and evaluate a tie-down system for use with these barriers on concrete bridge decks where deflections are restricted. The tie-down temporary barrier was to be evaluated according to the Test

Level 3 (TL-3) safety performance criteria set forth in the National Cooperative Highway Research Program (NCHRP) Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* (1).

1.3 Scope

The research objective was achieved by performing several tasks. First, a literature review was performed on previously crash tested tie-down systems. Next, a design phase was conducted to redesign and standardize the existing F-shape barrier and to develop a rigid tie-down system for use on concrete bridge decks that minimizes barrier deflections. After the final design and fabrication of the system, a full-scale vehicle crash test was performed, using a ¾-ton pickup truck weighing approximately 2,000 kg (4,409 lbs), with a target impact speed and angle of 100.0 km/hr (62.1 mph) and 25 degrees, respectively. Finally, the test results were analyzed, evaluated, and documented. Conclusions and recommendations were then made that pertain to the safety performance of the tie-down system for temporary barriers on concrete bridge decks.

2 LITERATURE REVIEW

2.1 Temporary Concrete Barriers

Temporary concrete barriers are a common safety device used in work zone and construction areas throughout the country. Currently, there are many temporary concrete barrier designs in use, but these designs vary widely in terms of steel reinforcement, joint connection, and segment length. The most common barriers in use are the New Jersey safety shape and the more recently developed F-shape and single-slope barriers. Currently, most of the Midwest states employ the NCHRP Report No. 350 compliant F-shape temporary concrete barrier developed by the Midwest Roadside Safety Facility (MwRSF) (2-3).

2.2 Tie-Down Systems

In 1993, the Texas Transportation Institute (TTI) developed and tested a tie-down system for portable concrete barriers that was compliant with the NCHRP Report No. 350 safety criteria for longitudinal barriers (4). The TTI system consisted of 9.1-m (30-ft) long barrier segments that were constrained by a set of four 31.8-mm (1.25-in.) diameter by 521-mm (20.5-in.) long steel pins that passed through 35-mm (1.375-in.) diameter holes drilled into the front of the barrier and into the concrete slab to a depth of 127 mm (5 in.). The holes were drilled at an angle of 40.1 degrees in order to maximize the constraint on the barrier while keeping the depth of the pins to a minimum. The maximum permanent set and dynamic deflections measured during the test of the system were found to be 200 mm (7.875 in.) and 400 mm (15.75 in.), respectively.

In 1999, the California Department of Transportation (CALTRANS) successfully developed and tested a K-rail system according to the NCHRP Report No. 350 evaluation criteria (5). The K-rail system consisted of 6.1-m (20-ft) long segments of New Jersey safety shape barrier connected

by a pin and loop connection. Each barrier was constrained by a set of four 25-mm (1-in.) diameter by 610-mm (24-in.) long steel stakes that were driven into the asphalt road surface to a depth of 420 mm (16.5 in.) through cast holes near the corners of the barrier. The system limited the permanent set and dynamic deflections to 70 mm (2.75 in.) and 254 mm (10 in.), respectively.

In 2001, MwRSF developed a double tie-down system for use with temporary barriers and successfully tested the system according to the NCHRP Report No. 350 evaluation criteria (6-7). The tie-down system consisted of 3.81-m (12.5-ft) long segments of Iowa F-shape barriers connected by a pin and loop connection and double steel straps to constrain the motion of the barrier joints. The steel strap consisted of a 76-mm (3-in.) wide x 6.4-mm (0.25-in.) thick x 914-mm (36-in.) long piece of ASTM A36 steel that was bent at four points along the strap to form a trapezoidal shape. A 22-mm (0.875-in.) diameter hole, punched 51 mm (2 in.) from each end of the plate, was used to accommodate the two Red Head 19-mm (0.75-in.) diameter drop-in anchors and the 19-mm (0.75-in.) diameter x 57-mm (2.25-in.) long ISO Class 8.8 bolts which constrained the strap. In addition, 76-mm (3-in.) wide x 6.4-mm (0.25-in.) thick x 83-mm (3.25-in.) long steel plates with identically sized holes were welded to the strap at the hole locations in order to reinforce the strap. A third 35-mm (1.375-in.) diameter hole was also punched in the center of the strap to accommodate the vertical pin used to connect the barrier segments. The center hole in the plate was reinforced by a 76-mm (3-in.) wide x 12.7-mm (0.5-in.) thick x 83-mm (3.25-in.) long ASTM A36 steel plate. The maximum permanent set and dynamic deflections measured during the test of the double tie-down system were found to be 850 mm (33.5 in.) and 960 mm (37.75 in.), respectively.

In 2002, MwRSF developed a tie-down system for rigidly attaching steel H-section temporary barriers to a concrete bridge deck. The system was successfully tested according to the

NCHRP Report No. 350 evaluation criteria (6-7). The tie-down system consisted of 6.1-m (20-ft) long segments of Iowa H-section temporary barriers connected by two drop pins and two steel shear plates to allow 4.0 and 2.4 degrees of rotation about the transverse and vertical axes, respectively (6). The original Iowa H-section barrier rails were also retrofitted with a series of steel angle brackets that were used as tie-downs to constrain the barrier motion. Four 102-mm x 152-mm x 12.7-mm (4-in. x 6-in. x 0.5-in.) thick by 152-mm (6-in.) long ASTM A36 steel angle brackets were welded to the base of each side of the steel barrier and placed at 381 mm (15 in.) and 762 mm (30 in.) from each end. The base of each angle bracket was drilled with a 32-mm (1.25-in.) diameter hole. The brackets were fastened to the concrete bridge deck using 19-mm (0.75-in.) Red Head drop-in anchors with 19-mm (0.75-in.) diameter by 57-mm (2.25-in.) long ASTM A307 bolts and using 64-mm (2.5-in.) wide x 64-mm (2.5-in.) long x 4.8-mm (0.1875-in.) thick steel plate washers. The maximum permanent set and dynamic deflections measured during the test of the H-section barrier tie-down system were found to be 241 mm (9.5 in.) and 314 mm (12.4 in.), respectively.

3 TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1 Test Requirements

Longitudinal barriers, such as temporary concrete barriers, must satisfy the requirements provided in NCHRP Report No. 350 to be accepted for use on National Highway System (NHS) construction projects or as a replacement for existing systems not meeting current safety standards. According to TL-3 of NCHRP Report No. 350, the longitudinal barriers must be subjected to two full-scale vehicle crash tests. The two crash tests are as follows:

1. Test Designation 3-10. An 820-kg (1,808-lb) small car impacting the bridge rail system at a nominal speed and angle of 100.0 km/hr (62.1 mph) and 20 degrees, respectively.
2. Test Designation 3-11. A 2,000-kg (4,409-lb) pickup truck impacting the bridge rail system at a nominal speed and angle of 100.0 km/hr (62.1 mph) and 25 degrees, respectively.

However, vertical shaped barriers are safer than safety shaped barriers which have also shown acceptable safety performance. For example, a rigid, F-shape bridge rail impacted by a small car was successfully tested to current safety performance standards (8). In the same manner, rigid New Jersey safety shape barriers struck by small cars have also been shown to meet safety performance standards (9-10). Furthermore, temporary New Jersey safety shape concrete median barriers have encountered only slight barrier deflections when impacted by small cars (11). Thus, since impacts with vertical barriers are less severe than those with safety shapes which typically result in an increased propensity for vehicle climbing, the 820-kg (1,808-lb) small car test was deemed unnecessary for this project. The test conditions for TL-3 longitudinal barriers are summarized in Table 1.

3.2 Evaluation Criteria

Evaluation criteria for full-scale vehicle crash testing are based on three appraisal areas: (1) structural adequacy; (2) occupant risk; and (3) vehicle trajectory after collision. Criteria for structural adequacy are intended to evaluate the ability of the barrier to contain, redirect, or allow controlled vehicle penetration in a predictable manner. Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle. Vehicle trajectory after collision is a measure of the potential for the post-impact trajectory of the vehicle to cause subsequent multi-vehicle accidents. This criterion also indicates the potential safety hazard for the occupants of other vehicles or the occupants of the impacting vehicle when subjected to secondary collisions with other fixed objects. These three evaluation criteria are defined in Table 2. The full-scale vehicle crash test was conducted and reported in accordance with the procedures provided in NCHRP Report No. 350.

Table 1. NCHRP Report No. 350 Test Level 3 Crash Test Conditions

| Test Article | Test Designation | Test Vehicle | Impact Conditions | | | Evaluation Criteria ¹ |
|----------------------|------------------|--------------|-------------------|-------|-----------------|----------------------------------|
| | | | Speed | | Angle (degrees) | |
| | | | (km/hr) | (mph) | | |
| Longitudinal Barrier | 3-10 | 820C | 100 | 62.1 | 20 | A,D,F,H,I,K,M |
| | 3-11 | 2000P | 100 | 62.1 | 25 | A,D,F,K,L,M |

¹ Evaluation criteria explained in Table 2.

Table 2. NCHRP Report No. 350 Evaluation Criteria for Crash Tests (1)

| | |
|---------------------|--|
| Structural Adequacy | A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underide, or override the installation although controlled lateral deflection of the test article is acceptable. |
| 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. |
| | F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable. |
| | G. It is preferable, although not essential, that the vehicle remain upright during and after collision. |
| | H. Longitudinal and lateral occupant impact velocities should fall below the preferred value of 9 m/s (29.53 ft/s), or at least below the maximum allowable value of 12 m/s (39.37 ft/s). |
| | I. Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15 g's, or at least below the maximum allowable value of 20 g's. |
| Vehicle Trajectory | K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes. |
| | L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/sec (39.37 ft/sec), and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 G's. |
| | M. The exit angle from the test article preferably should be less than 60 percent of test impact angle measured at time of vehicle loss of contact with test device. |

4 DESIGN DETAILS

4.1 Desired Design Changes

The bridge division of the Kansas Department of Transportation (KsDOT) desired to develop a more positive connection on concrete bridge decks as compared to the strap design previously developed for the Iowa Barrier as part of the Pooled Fund efforts (6). This need existed primarily for bridges that were reconstructed in stages and where very little tolerance in barrier deflection was allowable. In addition, it was desired to develop one barrier that could be used in adjacent states and in the various temporary and tied-down configurations (i.e., deformable tie-down strap at the joints and the bolt-through detail). Consequently, the redesign of the original temporary barrier developed by MwRSF was to include important features from the Kansas, Iowa, Nebraska, and Missouri DOT standard plans and the previously-approved Oregon temporary barrier, as well as incorporate a bolt-through tie-down option.

One modification to the temporary barrier was the redesign of the barrier-to-barrier connection. Modifying this connection to resemble the three loop connection detail found in the Oregon design provides double shear at two locations on each pin and consequently allows for the elimination of the retainer bolt at the bottom of the vertical pin. This modification required adjustment of the loop spacing to allow for the connection of the new barrier with the original temporary barriers constructed with either the single loop bars or those with three bars per loop. The modified barrier that resulted is compatible with both ends of the Iowa barrier constructed with single bar loops and one end of these barriers constructed with triple bars per loop.

In order to develop a tie-down system that utilizes a bolt-through detail, vertical holes would need to be positioned on both sides of the barrier in order to allow bolts to penetrate the barrier and

allow its attachment to the rigid concrete pavement. Three vertical holes were added on each side of the KsDOT barrier detail. Steel reinforcement was required to provide sufficient reaction to the retainer bolts. In addition, it was necessary to shift the lower longitudinal bars inward to accommodate for the addition of the vertical holes. This inward shift will slightly reduced the barrier's moment capacity about the vertical axis, but not significantly to compromise the barrier's performance.

Finally, it was recommended that the through bolts be placed on only the traffic-side face of the barrier. This would allow the barrier to be placed closer to the deck edge. In addition, bolts placed on the back side of the barrier could potentially degrade performance, causing the barrier to rotate about this connection and increase barrier rotation. This action could increase the propensity for impacting vehicles to climb the barrier face and vault over the top. If bolts were used on only the front face and exhibited a tendency to shear, the barriers would likely only translate backward with reduced barrier roll.

4.2 Design Details

The test installation consisted of 62.23 m (204 ft) of temporary concrete barriers attached to a concrete bridge deck, as shown in Figures 1 through 6. The corresponding drawings in English units are shown in Appendix A. The KDOT's state plans are shown in Appendix B. Photographs of the test installation are shown in Figures 7 through 11.

The concrete used for the barriers consisted of Iowa's Barrier Mix, with a minimum 28-day concrete compressive strength of 34.5 MPa (5,000 psi). The actual 28-day concrete compressive strength for the barriers, as determined from concrete cylinder testing, was found to be approximately 31.2 MPa (4,521 psi). A minimum concrete cover varied at different positions of

rebar in the barrier. A minimum concrete cover of 51 mm (2 in.) was used along the top of the vertical stirrup rebar and the bottom longitudinal rebar. Minimum concrete covers of 44 mm (1.75 in.) and 25 mm (1 in.) were used along the sides of the vertical stirrup rebar and at the rebar around the anchor bolt block, respectively. All of the steel reinforcement in the barrier was ASTM A615 Grade 60 rebar, except for the loop bars which were ASTM A706 Grade 60 rebar. The barrier reinforcement details are shown in Figures 1 through 4.

Barrier reinforcement consisted of three No. 5 and two No. 4 longitudinal bars, twelve No. 4 bars for the vertical stirrups, and six No. 6 bars for the anchor bolt block reinforcement loops. Each of the five longitudinal rebar was 3.71-m (12-ft 2-in.) long. The vertical spacings of the lower, middle, and upper longitudinal bars were 165 mm (6.5 in.), 368 mm (14.5 in.), and 780 mm (29.125 in.) from the ground to their centers, respectively. The vertical stirrups were 1,829-mm (72-in.) long and were bent into the shape of the barrier. Their spacings varied longitudinally, as shown in Figure 1. The anchor bolt block loops were 889-mm (35-in.) long and were bent into a U-shape and were used to reinforce the anchor bolt area, as shown in Figures 1 and 4.

The barriers used a pin and loop type connection comprised of two sets of rebar loops on each barrier interconnection. Each loop assembly was configured with three ASTM A706 Grade 60 No. 6 bars that were bent into a loop shape, as shown in Figure 4. The vertical pin used in the connection consisted of a 32-mm (1.25-in.) diameter x 711-mm (28-in.) long round bar composed of ASTM A36 steel, as shown in Figure 3. The pin was held in place using one 64-mm (2.5-in.) wide x 102-mm (4-in.) long x 13-mm (0.5-in.) thick ASTM A36 steel plate with a 35-mm (1.375-in.) diameter hole center on it. The plate was welded 64 mm (2.5 in.) below the top of the pin.

The barriers were fastened to the concrete bridge deck with a 29-mm (1.125-in.) diameter

ASTM A307 anchor bolt with heavy hex nut and a 76-mm (3-in.) x 76-mm (3-in.) x 13-mm (0.5-in.) thick washer at each of the anchor bolt blockout positions, as shown in Figures 2 and 10. Each anchor bolt was epoxied into the concrete to an embedment depth of approximately 305 mm (12 in.), as shown in Figure 11. The epoxy's specifications are shown in Appendix C. Note that the bolt-through tie-down system was only used on the traffic side of the barrier in order to reduce the propensity for barrier tipping and subsequent vehicle climbing and vaulting.

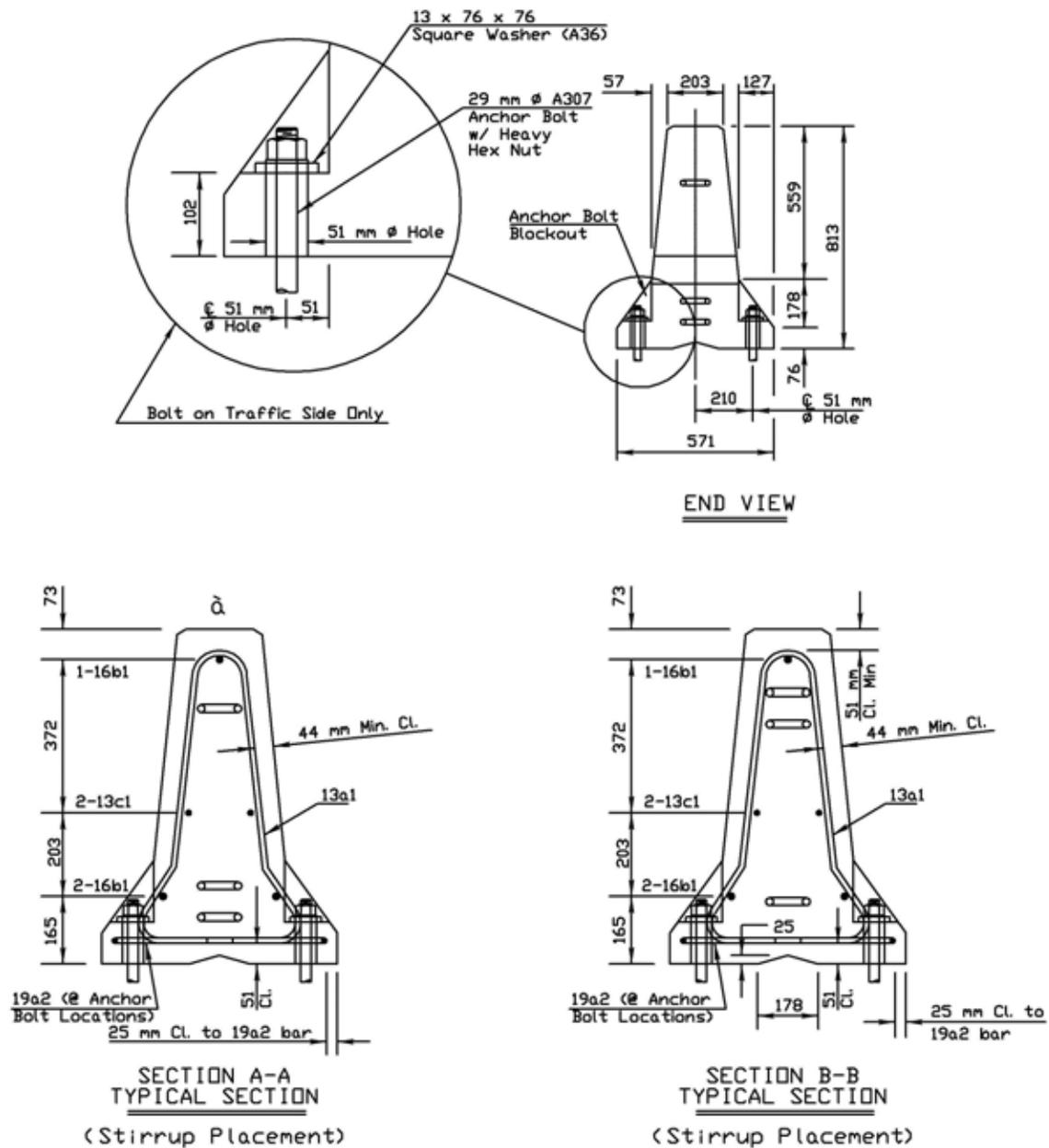
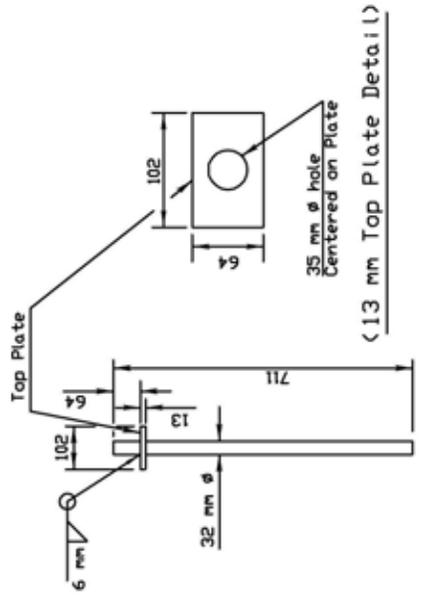
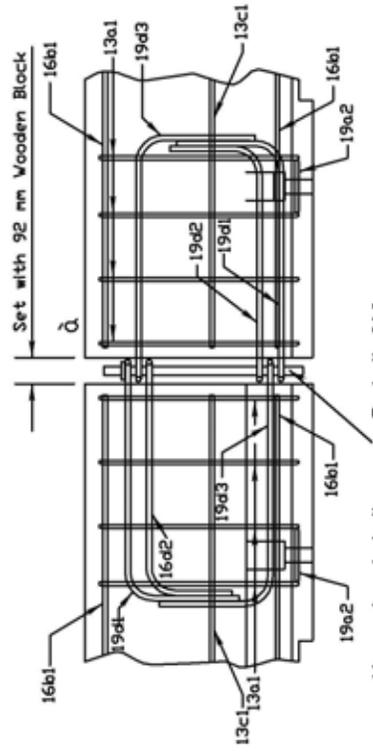


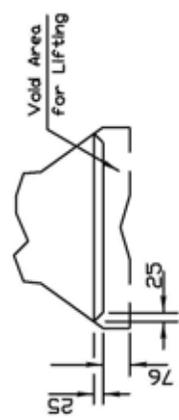
Figure 2. Temporary Barrier Profile and Tie-Down Details



DETAIL A
CONNECTION PIN
(A36 Steel)
4.9 kg each



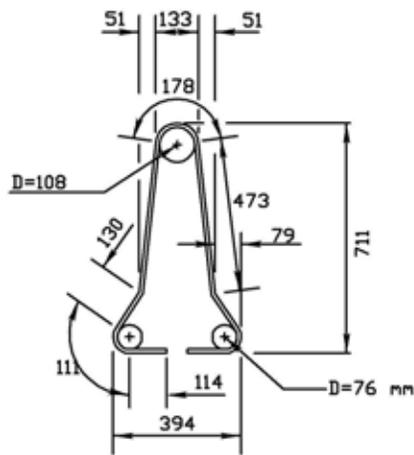
For connection pin details see Detail 'A'
DETAILS OF BARRIER CONNECTION



DETAIL 'B'
LIFTING SLOT DETAIL
(25 mm Chamfer to prevent spalling)

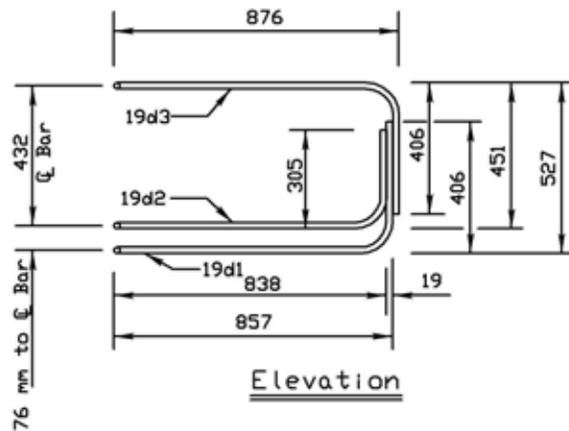
- Note: a - Marked End
- See table for rebar definitions
 - Dimensions are out to out of bars unless otherwise noted.

Figure 3. Temporary Barrier Connection and Lifting Slot Details

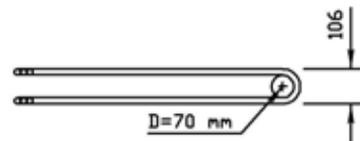


13a1

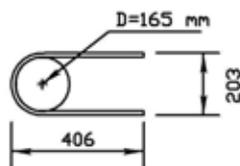
Vertical Stirrups



Elevation



Plan



19a2

LOOP BAR ASSEMBLY

(Marked end shown, invert for other end)
(A706 Steel)

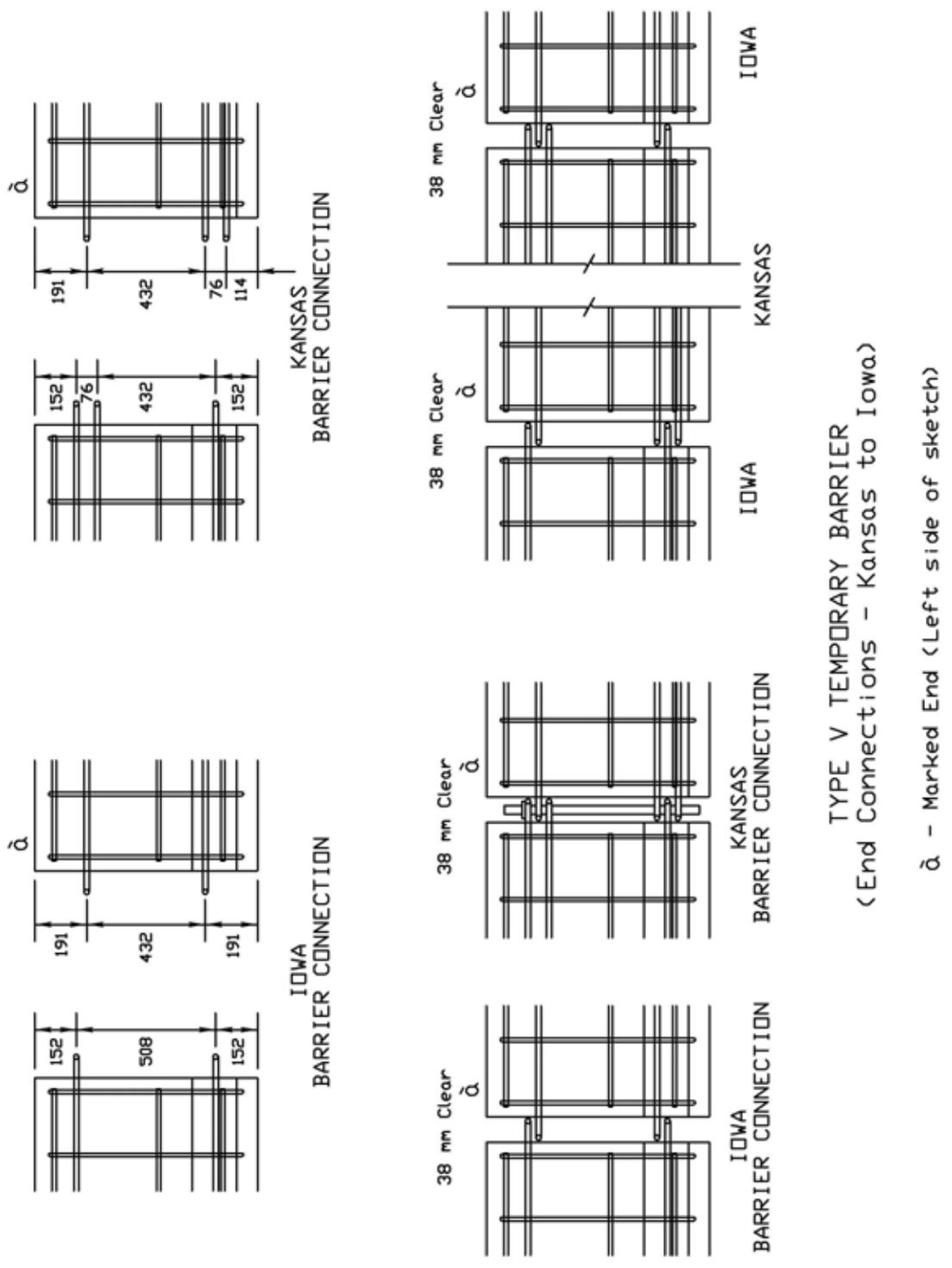
Dimensions are out to out of bars unless otherwise noted.

Per 3810 mm Barrier Section

| REINFORCING A615 Gr. 60 | | | | | |
|---------------------------|----------|-------|-------------|-----------|-----------|
| Bar | Bar Size | Shape | No. of Bars | Length mm | Weight kg |
| 13a1 | 13 | ∧ | 12 | 1834 | 21.9 |
| 19a2 | 19 | ⊂ | 6 | 898 | 12.0 |
| 16b1 | 16 | — | 3 | 3708 | 17.3 |
| 13c1 | 13 | — | 2 | 3708 | 7.4 |
| LOOP ASSEMBLY A706 Gr. 60 | | | | | |
| 19d1 | 19 | ┌ | 2 | 2565 | 11.5 |
| 19d2 | 19 | ┌ | 2 | 2311 | 10.3 |
| 19d3 | 19 | ┌ | 2 | 2591 | 11.6 |

Concrete Quantity = 1.0 cubic meters

Figure 4. Temporary Barrier Bill of Bars



TYPE V TEMPORARY BARRIER
 (End Connections - Kansas to Iowa)

Figure 5. Connection to Iowa Temporary Barrier Details

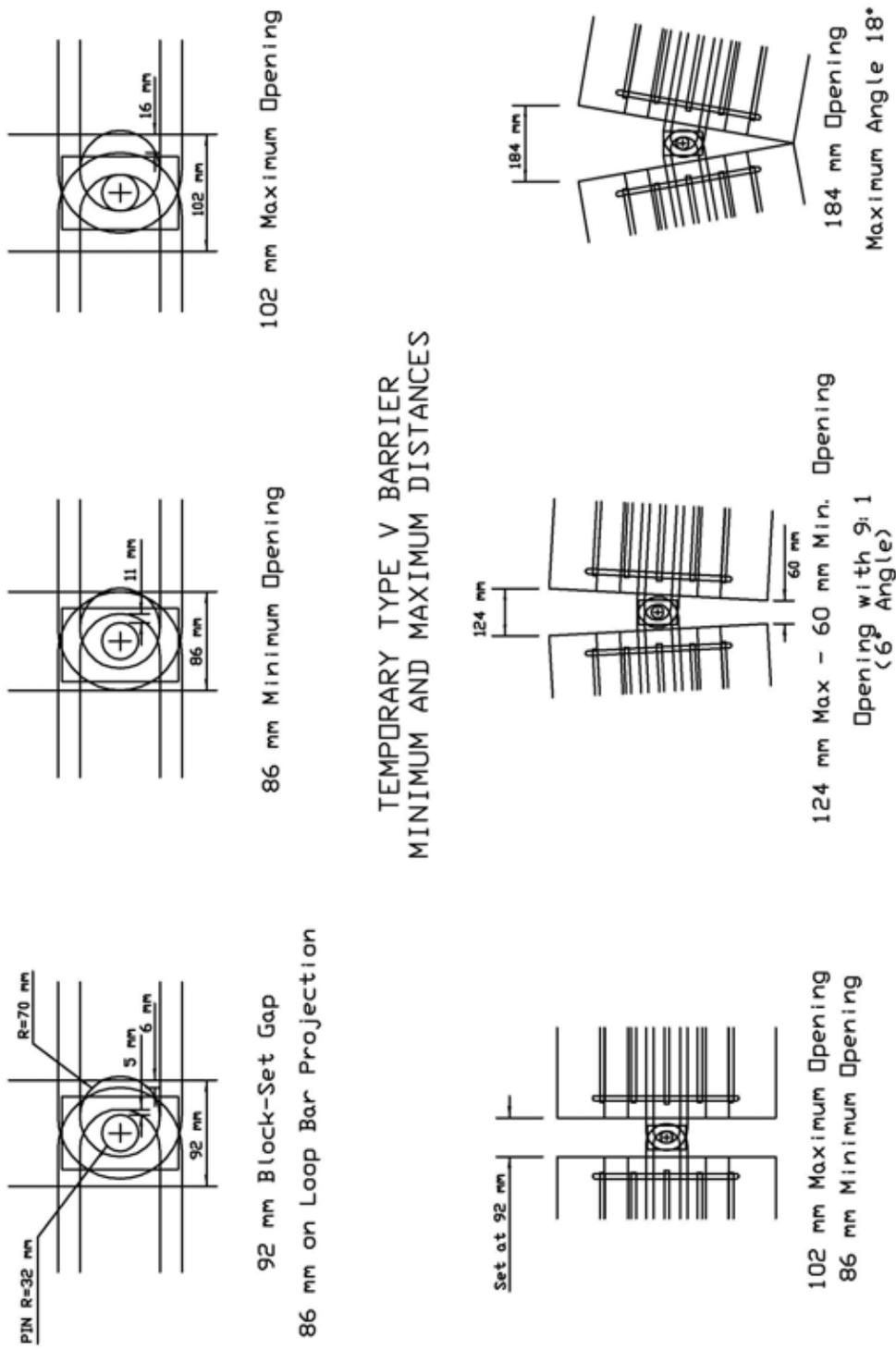


Figure 6. Distances Between Temporary Barriers

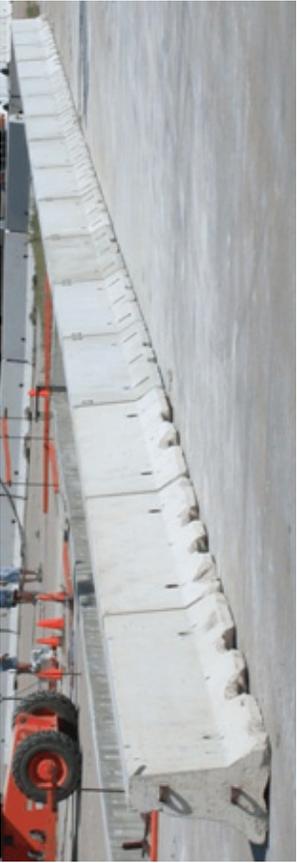
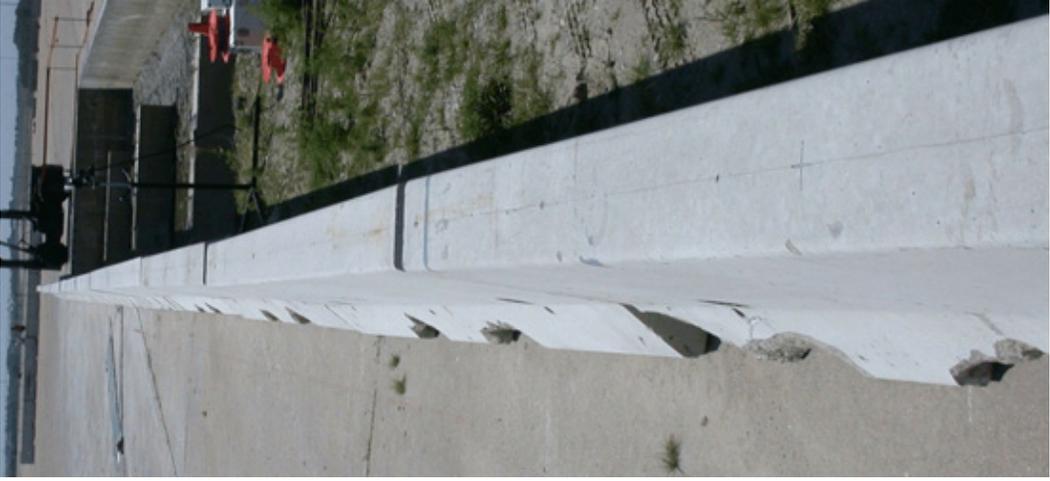


Figure 7. Barrier System



Figure 8. Barrier System



Figure 9. Barrier Connection Joints



Figure 10. Barrier Tie-Down System



Figure 11. Barrier Tie-Down Installation

5 TEST CONDITIONS

5.1 Test Facility

The testing facility is located at the Lincoln Air-Park on the northwest (NW) side of the Lincoln Municipal Airport and is approximately 8.0 km (5 mi.) NW of the University of Nebraska-Lincoln.

5.2 Vehicle Tow and Guidance System

A reverse cable tow system with a 1:2 mechanical advantage was used to propel the test vehicle. The distance traveled and the speed of the tow vehicle were one-half that of the test vehicle. The test vehicle was released from the tow cable before impact with the guardrail system. A digital speedometer was located on the tow vehicle to increase the accuracy of the test vehicle impact speed.

A vehicle guidance system developed by Hinch (13) was used to steer the test vehicle. A guide-flag, attached to the front-right wheel and the guide cable, was sheared off before impact with the guardrail system. The 9.5-mm (0.375-in.) diameter guide cable was tensioned to approximately 15.6 kN (3,500 lbf), and supported laterally and vertically every 30.48 m (100 ft) by hinged stanchions. The hinged stanchions stood upright while holding up the guide cable, but as the vehicle was towed down the line, the guide-flag struck and knocked each stanchion to the ground. For test KTB-1, the vehicle guidance system was approximately 305-m (1000-ft) long.

5.3 Test Vehicles

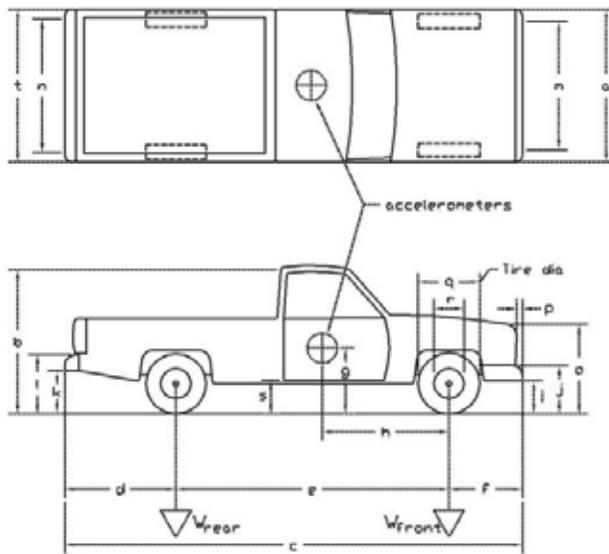
For test KTB-1, a 1997 Chevrolet 2500 ³/₄-ton pickup truck was used as the test vehicle. The test inertial and gross static weights were 2,018 kg (4,448 lbs). The test vehicle is shown in Figure 12, and vehicle dimensions are shown in Figure 13.



Figure 12. Test Vehicle, Test KTB-1

Date: 7/31/02 Test Number: KTB-1 Model: 2000P
 Make: Chevrolet Vehicle I.D.#: 1GAGC24RXVZ536852
 Tire Size: 245/75 R16 Year: 1997 Odometer: 284108

*(All Measurements Refer to Impacting Side)



Vehicle Geometry - mm (in.)

a 1880 (74.0) b 1861 (73.25)
 c 5537 (218.0) d 1308 (51.5)
 e 3353 (132.0) f 876 (34.5)
 g 667 (26.25) h 1401 (55.15)
 i 454 (17.875) j 660 (26.0)
 k 584 (23.0) l 826 (32.5)
 m 1594 (62.75) n 1613 (63.5)
 o 1035 (40.75) p 89 (3.5)
 q 749 (29.5) r 445 (17.5)
 s 483 (19.0) t 1854 (73.0)
 Wheel Center Height Front 362 (14.25)
 Wheel Center Height Rear 368 (14.5)
 Wheel Well Clearance (FR) 902 (35.5)
 Wheel Well Clearance (RR) 962 (37.875)

| Weights kg (lbs) | Curb | Test Inertial | Gross Static |
|---------------------|--------------------|--------------------|--------------------|
| W_{front} | <u>1146 (2527)</u> | <u>1181 (2604)</u> | <u>1181 (2604)</u> |
| W_{rear} | <u>845 (1863)</u> | <u>836 (1844)</u> | <u>836 (1844)</u> |
| W_{total} | <u>1991 (4390)</u> | <u>2018 (4448)</u> | <u>2018 (4448)</u> |

Engine Type 8 CYL. GAS
 Engine Size 5.7 L 350 CID
 Transmission Type:
 Automatic or Manual
 FWD or RWD or 4WD

Note any damage prior to test: Minor dents: left door & box fender

Figure 13. Vehicle Dimensions, Test KTB-1

The longitudinal component of the center of gravity was determined using the measured axle weights. The location of the final centers of gravity are shown in Figures 12 and 13.

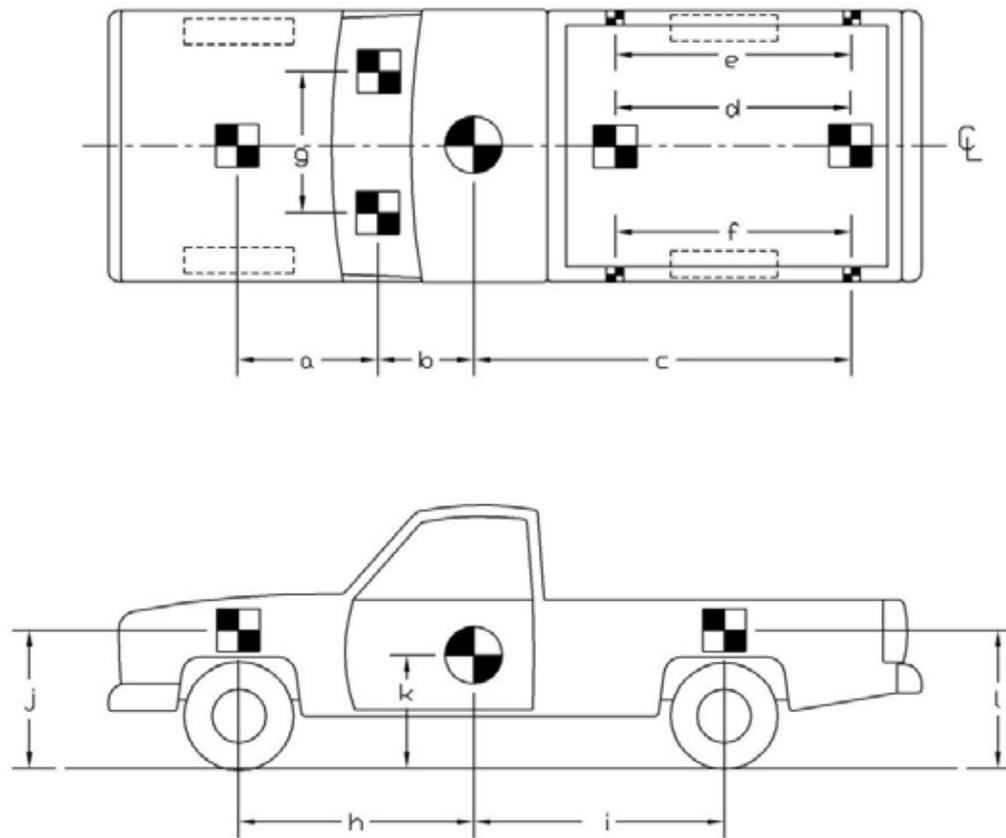
Square black and white-checked targets were placed on the vehicle to aid in the analysis of the high-speed film and E/cam video, as shown in Figure 14. Round, checked targets were placed on the center of gravity, on the driver's side door, on the passenger's side door, and on the roof of the vehicle. The remaining targets were located for reference so that they could be viewed from the high-speed cameras for film analysis.

The front wheels of the test vehicle were aligned for camber, caster, and toe-in values of zero so that the vehicle would track properly along the guide cable. Two 5B flash bulbs were mounted on both the hood and roof of the vehicle to pinpoint the time of impact with the bridge rail on the high-speed film and E/cam video. The flash bulbs were fired by a pressure tape switch mounted on the front face of the bumper. A remote-controlled brake system was installed in the test vehicle so the vehicle could be brought safely to a stop after the test.

5.4 Data Acquisition Systems

5.4.1 Accelerometers

One triaxial piezoresistive accelerometer system with a range of ± 200 G's was used to measure the acceleration in the longitudinal, lateral, and vertical directions at a sample rate of 10,000 Hz. The environmental shock and vibration sensor/recorder system, Model EDR-4M6, was developed by Instrumented Sensor Technology (IST) of Okemos, Michigan and includes three differential channels as well as three single-ended channels. The EDR-4 was configured with 6 Mb of RAM memory and a 1,500 Hz lowpass filter. Computer software, "DynaMax 1 (DM-1)" and "DADiSP", was used to analyze and plot the accelerometer data.



| TEST #: <u>KTB-1</u> | | | | | | | |
|-----------------------------|----------------------|---|---------------------|---|----------------------|---|---------------------|
| TARGET GEOMETRY -- mm (in.) | | | | | | | |
| a | <u>1575 (62.0)</u> | d | <u>1962 (77.25)</u> | g | <u>1143 (45.0)</u> | j | <u>1003 (39.5)</u> |
| b | <u>NA</u> | e | <u>2153 (84.75)</u> | h | <u>1400 (55.125)</u> | k | <u>667 (26.25)</u> |
| c | <u>2775 (109.25)</u> | f | <u>2153 (84.75)</u> | i | <u>1975 (77.75)</u> | l | <u>1073 (42.25)</u> |

Figure 14. Vehicle Target Locations, Test KTB-1

A backup triaxial piezoresistive accelerometer system with a range of ± 200 G's was also used to measure the acceleration in the longitudinal, lateral, and vertical directions at a sample rate of 3,200 Hz. The environmental shock and vibration sensor/recorder system, Model EDR-3, was developed by Instrumental Sensor Technology (IST) of Okemos, Michigan. The EDR-3 was configured with 256 Kb of RAM memory and a 1,120 Hz lowpass filter. Computer software, "DynaMax 1 (DM-1)" and "DADiSP", was used to analyze and plot the accelerometer data.

5.4.2 Rate Transducers

A Humphrey 3-axis rate transducer with a range of 360 deg/sec in each of the three directions (pitch, roll, and yaw) was used to measure the rates of motion of the test vehicle. The rate transducer was rigidly attached to the vehicle near the center of gravity of the test vehicle. Rate transducer signals, excited by a 28-volt DC power source, were received through the three single-ended channels located externally on the EDR-4M6 and stored in the internal memory. The raw data measurements were then downloaded for analysis and plotted. Computer software, "DynaMax 1 (DM-1)" and "DADiSP", was used to analyze and plot the rate transducer data.

5.4.3 High-Speed Photography

For test KTB-1, two high-speed 16-mm Red Lake Locam cameras, with operating speeds of approximately 500 frames/sec, were used to film the crash test. Five high-speed Red Lake E/cam video cameras, with operating speeds of 500 frames/sec, were also used to film the crash test. Six Canon digital video cameras, with a standard operating speed of 29.97 frames/sec, were also used to film the crash test. A Locam, with a wide-angle 12.5-mm lens, and two high-speed E/cam video cameras were placed above the test installation to provide a field of view perpendicular to the ground. A Locam and a Canon digital video camera were placed downstream from the impact point

and had a field of view parallel to the barrier. A high-speed E/cam video camera and a Canon digital video camera were placed downstream from the impact point and behind the barrier. Two Canon digital video cameras were placed downstream from the impact point and above the barrier. A high-speed E/cam video camera and a Canon digital video camera were placed upstream from the impact point and had a field of view parallel to the barrier. A high-speed E/cam video camera was placed upstream from the point of impact and behind the barrier. A Canon digital video camera, with a panning view, was placed on the traffic side of the barrier and had a field of view perpendicular to the barrier. A schematic of all thirteen camera locations for test KTB-1 is shown in Figure 15.

The Locam films and E/cam videos were analyzed using the Vanguard Motion Analyzer and the Redlake Motion Scope software, respectively. Actual camera speed and camera divergence factors were considered in the analysis of the high-speed film.

5.4.4 Pressure Tape Switches

For test KTB-1, five pressure-activated tape switches, spaced at 2-m (6.56-ft) intervals, were used to determine the speed of the vehicle before impact. Each tape switch fired a strobe light which sent an electronic timing signal to the data acquisition system as the right-front tire of the test vehicle passed over it. Test vehicle speed was determined from electronic timing mark data recorded using the "Test Point" software. Strobe lights and high-speed film analysis are used only as a backup in the event that vehicle speed cannot be determined from the electronic data.

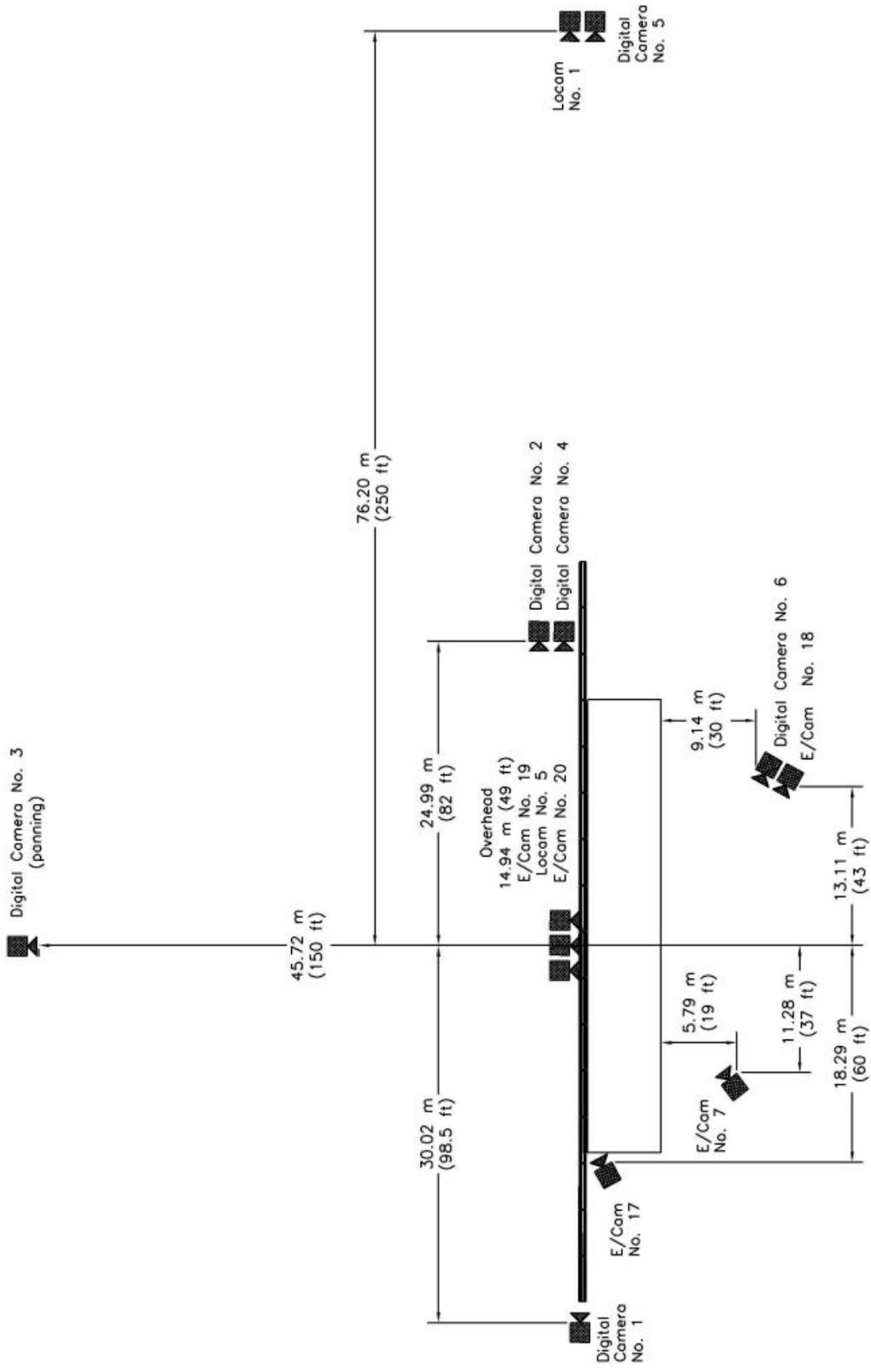


Figure 15. Location of High-Speed Cameras, Test KTB-1

6 CRASH TEST NO. 1

6.1 Test KTB-1

The 2,018-kg (4,448-lb) pickup truck impacted the temporary barrier tie-down system at a speed of 99.8 km/hr (62.0 mph) and at an angle of 25.3 degrees. A summary of the test results and the sequential photographs are shown in Figure 16. The summary of the test results and sequential photographs in English units is shown in Appendix D. Additional sequential photographs are shown in Figures 17 through 19. Documentary photographs of the crash test are shown in Figures 20 and 21.

6.2 Test Description

Initial impact was to occur 1,295-mm (51-in.) upstream from the center of the gap between barrier nos. 8 and 9, as shown in Figure 22. Actual vehicle impact occurred 1,651-mm (65-in.) upstream from the center of the gap between barrier nos. 8 and 9. At 0.026 sec after impact, the right-front corner of the vehicle was positioned over the top of the barrier. At 0.044 sec, the right-front corner of the vehicle protruded over the barrier as the top of the right-side door became ajar. At this same time, barrier no. 8 began to deflect backward. At 0.050 sec, the right-front corner was crushed inward toward the engine compartment and the right-front corner of the hood was positioned at the joint between barrier nos. 8 and 9. At 0.058 sec, barrier no. 9 began to deflect as the top tipped backward. At 0.066 sec, the right-front corner continued to crush inward as the vehicle began to redirect. At 0.084 sec, the hood's right-front corner remained over the top of the barrier. At this same time, a crack formed at the midspan of barrier no. 9 on the top and back sides. At 0.101 sec, the right-front corner of the vehicle reached its maximum intrusion of 534 mm (21 in.) beyond the front face of the barrier which had deflected and tipped 203 mm (8 in.) by this time. At

0.126 sec, the left-front tire became airborne as the front of the vehicle began to pitch upward. At 0.136 sec, barrier no. 9 continued to deflect. At 0.162 sec, the vehicle began to roll counter-clockwise (CCW) away from the barrier as the front of the vehicle became airborne. At 0.199 sec, the right-front corner of the vehicle was positioned at the joint between barrier nos. 9 and 10. At this same time, barrier nos. 8 and 9 ceased movement. At 0.215 sec, the rear of the vehicle began to pitch upward as the right-front corner of the vehicle was positioned above the barrier. At 0.254 sec, the left-rear tire became airborne. At 0.257 sec, the vehicle became parallel to the barrier with a resultant velocity of 79.9 km/hr (49.6 mph). At 0.300 sec, the right-rear tire of the vehicle contacted the midspan of barrier no. 9 near the top of the barrier. At this same time, the vehicle continued to redirect off of the barrier. At 0.354 sec, the vehicle exited the barrier at a trajectory angle of 14.4 degrees and at a resultant velocity of 81.5 km/hr (50.6 mph). At 0.435 sec, the left-front tire contacted the ground as the vehicle continued to roll CCW. At 0.469 sec, the rear of the vehicle remained airborne as the vehicle encountered significant CCW roll away from the barrier. At 0.606 sec, the vehicle reached its maximum roll angle of 34.0 degrees away from barrier. At 0.671 sec, the front of the vehicle pitched downward to an extent where the left-front corner of the bumper almost contacted the ground. At 0.765 sec, the vehicle ceased its CCW rolling motion as the rear of the vehicle began to descend toward the ground. At 1.178 sec, the rear tires contacted the ground. At 1.317 sec, the vehicle yawed back toward the barrier. The vehicle came to rest 56.25-m (184.5-ft) downstream from impact and 12.80-m (42-ft) laterally behind a line projected parallel to the traffic-side face of the barrier, as shown in Figures 16 and 23.

6.3 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 24 through 29. Barrier damage

consisted of contact marks on the front concrete face, spalling of the concrete, and concrete cracking and failure. The length of vehicle contact along the barrier was approximately 5.6 m (18.4 ft) which spanned from 1,651 mm (65 in.) upstream from the center of the joint between barrier nos. 8 and 9 to the upstream end of barrier no. 10.

Tire marks were visible on the front face of barrier nos. 8 and 9 and the upstream edge of barrier no. 10. Concrete failure was found at all of the tie-down anchors of barrier nos. 8 and 9, as shown in Figures 28 and 29. A 152-mm (6-in.) wide x 152-mm (6-in.) long x 89-mm (3.5-in.) deep piece of concrete was removed from the downstream end of barrier no. 8. Major concrete failure was found 457-mm (18-in.) upstream from the center of barrier no. 9 due to torsional loading. In addition, two larger cracks were found downstream from the center of barrier no. 9. Detailed sketches of the concrete failure and cracking of barrier nos. 8 and 9 are shown in Appendix E. The anchor dowels at the middle and downstream end of barrier no. 8 and the upstream end of barrier no. 9 were deformed. No major concrete spalling was found on the front face of barrier no. 9. Concrete deck failure did not occur at any of the anchor locations. No noticeable deformations were found on the connection pins nor the loops.

The permanent set of the barrier system is shown in Figures 24 and 25. The maximum lateral permanent set barrier deflection was 89 mm (3.5 in.) at the downstream end of barrier no. 8 and the upstream end of barrier no. 9, as measured in the field. The maximum lateral dynamic barrier deflection, including barrier tipping of the top surface, was 287 mm (11.3 in.) at the upstream end of barrier no. 9, as determined from high-speed film analysis.

6.4 Vehicle Damage

Exterior vehicle damage was moderate, as shown in Figures 30 through 34. Damage was

concentrated on the right-front corner and right side of the vehicle where the impact occurred. The right-front corner of the vehicle was crushed inward and back, including the fender, bumper, and frame rail. A buckling point was found at the center of the front bumper with a minor tear near the right-front frame horn. Major frame damage was observed, including deformation to the right-side frame horn. The outer right-front tie-rod disengaged completely. The right-front tire disengaged from the rim, and the inner wall was torn. In addition, the right-front outer rim disengaged from the remainder of the hub and was severely deformed. Scuff marks were found on the right-rear wheel well, and the side wall of the right-rear tire encountered a 76-mm (3-in.) wide tear. The right-rear steel rim also received significant deformations and scrape marks. Minor scrapes and dents were also observed on the right-side door and the right side of the truck bed from the contact with the barriers. The top of the right-side door was jarred open with a 127 mm (5 in.) gap. Moreover, the door was jammed shut and could not be opened. The grill was broken and deformed around the right-side headlight assembly. The truck's box twisted and produced an inconsistent gap between the box and cab portions. The roof, the hood, the left side and rear of the vehicle, and all the window glass remained undamaged.

Moderate occupant compartment deformations occurred with deformations to the right-side floor pan and firewall, as shown in Figure 34. Occupant compartment deformations and the corresponding locations are provided in Appendix F. A maximum vertical deflection of 121 mm (4.75 in.) was found near the firewall at the center of the right side. Another significant vertical deflection of 76 mm (3 in.) was found near the center of the floor on the right side. Maximum longitudinal and lateral deflections of the floor pan were measured as 121 mm (4.75 in.) and 83 mm (3.25 in.), respectively. Maximum dash deflection was found to be approximately 25 mm (1 in.).

6.5 Occupant Risk Values

The longitudinal and lateral occupant impact velocities were determined to be 5.68 m/sec (18.63 ft/sec) and 7.01 m/sec (22.99 ft/sec), respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were 10.98 g's and 10.60 g's, respectively. It is noted that the occupant impact velocities (OIV's) and occupant ridedown decelerations (ORD's) were within the suggested limits provided in NCHRP Report No. 350. The results of the occupant risk, determined from the accelerometer data, are summarized in Figure 16. Results are shown graphically in Appendix G. Roll and yaw data were collected from film analysis and are shown graphically in Appendix H.

6.6 Discussion

The analysis of the test results for test KTB-1 showed that the tie-down system for use on concrete bridge decks and with the redesigned F-shape temporary barrier adequately contained and redirected the vehicle with controlled lateral displacements of the barrier system. There were no detached elements nor fragments which showed potential for penetrating the occupant compartment nor presented undue hazard to other traffic. Deformations of, or intrusion into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the concrete barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements were noted, but they were deemed acceptable because they did not adversely influence occupant risk safety criteria nor cause rollover. After collision, the vehicle's trajectory revealed minimum intrusion into adjacent traffic lanes. In addition, the vehicle's exit angle was less than 60 percent of the impact angle. Therefore, test KTB-1 conducted on the tie-

down system for use on concrete bridge decks and with the redesigned F-shape temporary barrier was determined to be acceptable according to the TL-3 safety performance criteria found in NCHRP Report No. 350.



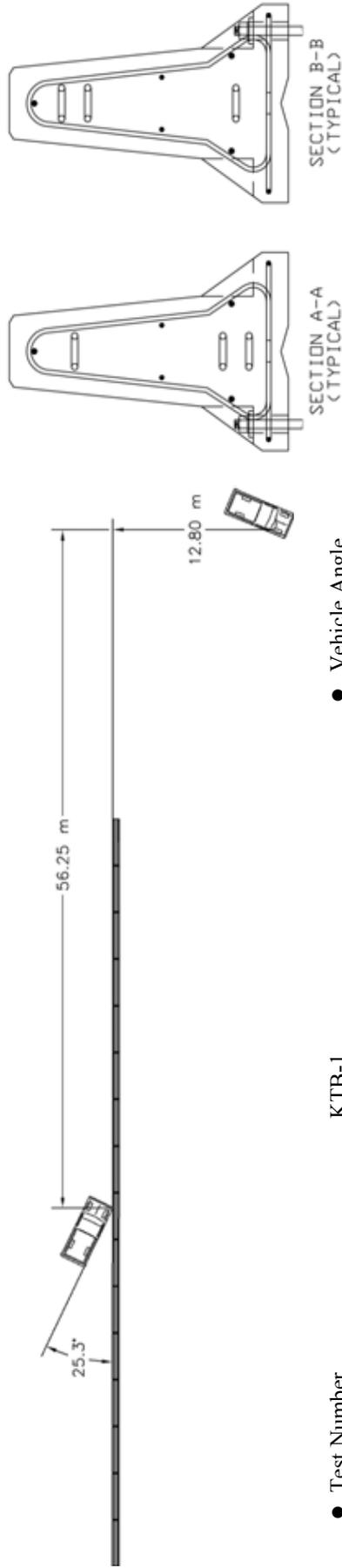
0.000 sec

0.044 sec

0.084 sec

0.231 sec

0.469 sec

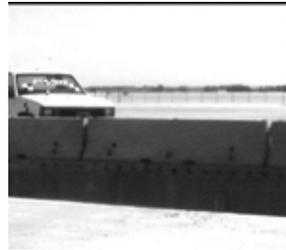


- Test Number KTB-1
- Date 7/31/02
- Appurtenance Kansas Temporary Barrier Tie Down System
- Total Length 62.23 m
- Placement 25 mm from concrete bridge deck edge
- Key Elements Nine 3,810-mm long Kansas Temporary Barriers
- Barrier Joint Pin Connections Seven 3,810-mm long Iowa F-Shape Temporary Barriers
- Tie-Down Anchors 32-mm diameter by 712-mm long A36 steel rod with 64x102x132-mm plate
- Number per Barrier 3
- Embedment into Concrete 305 mm
- Placement Traffic side only
- Vehicle Model 1997 Chevrolet 2500 ¾-ton pickup
- Curb 1,991 kg
- Test Inertial 2,018 kg
- Gross Static 2,018 kg
- Vehicle Speed
- Impact 99.8 km/hr
- Exit (resultant) 81.5 km/hr
- Vehicle Angle 25.3 deg
- Impact (orientation) 25.3 deg
- Exit (trajectory) 14.4 deg
- Vehicle Snagging None
- Vehicle Pocketing None
- Vehicle Stability Satisfactory
- Occupant Ridedown Deceleration (10 msec avg.)
- Longitudinal 10.98 G's < 20 G's
- Lateral (not required) 10.60 G's
- Occupant Impact Velocity
- Longitudinal 5.68 m/s < 12 m/s
- Lateral (not required) 7.01 m/s
- Vehicle Damage Moderate
- TAD¹⁴ 1-RFQ-3
- SAE¹⁵ 1-RFAW3
- Vehicle Stopping Distance 56.25 m downstream
- Barrier Damage 12.80 m laterally behind
- Maximum Rail Deflections
- Permanent Set Moderate
- Dynamic 89 mm
- Working Width 287 mm
- 534 mm

Figure 16. Summary of Test Results and Sequential Photographs, Test KTB-1



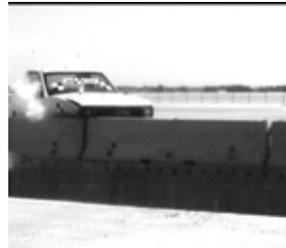
0.000 sec



0.000 sec



0.064 sec



0.050 sec



0.164 sec



0.096 sec



0.230 sec



0.140 sec



0.262 sec



0.304 sec

Figure 17. Additional Sequential Photographs, Test KTB-1



0.000 sec



0.000 sec



0.100 sec



0.100 sec



0.200 sec



0.234 sec



0.367 sec



0.400 sec



0.534 sec



1.702 sec



0.701 sec

Figure 18. Additional Sequential Photographs, Test KTB-1



0.000 sec



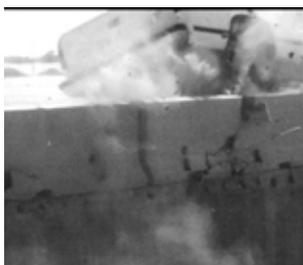
0.036 sec



0.082 sec



0.220 sec



0.326 sec



0.000 sec



0.133 sec



0.300 sec



0.534 sec



0.734 sec

Figure 19. Additional Sequential Photographs, Test KTB-1



Figure 20. Documentary Photographs, Test KTB-1



Figure 21. Documentary Photographs, Test KTB-1



Figure 22. Impact Location, Test KTB-1



Figure 23. Vehicle Final Position and Trajectory Marks, Test KTB-1



Figure 24. System Damage, Test KTB-1



Figure 25. System Damage, Test KTB-1

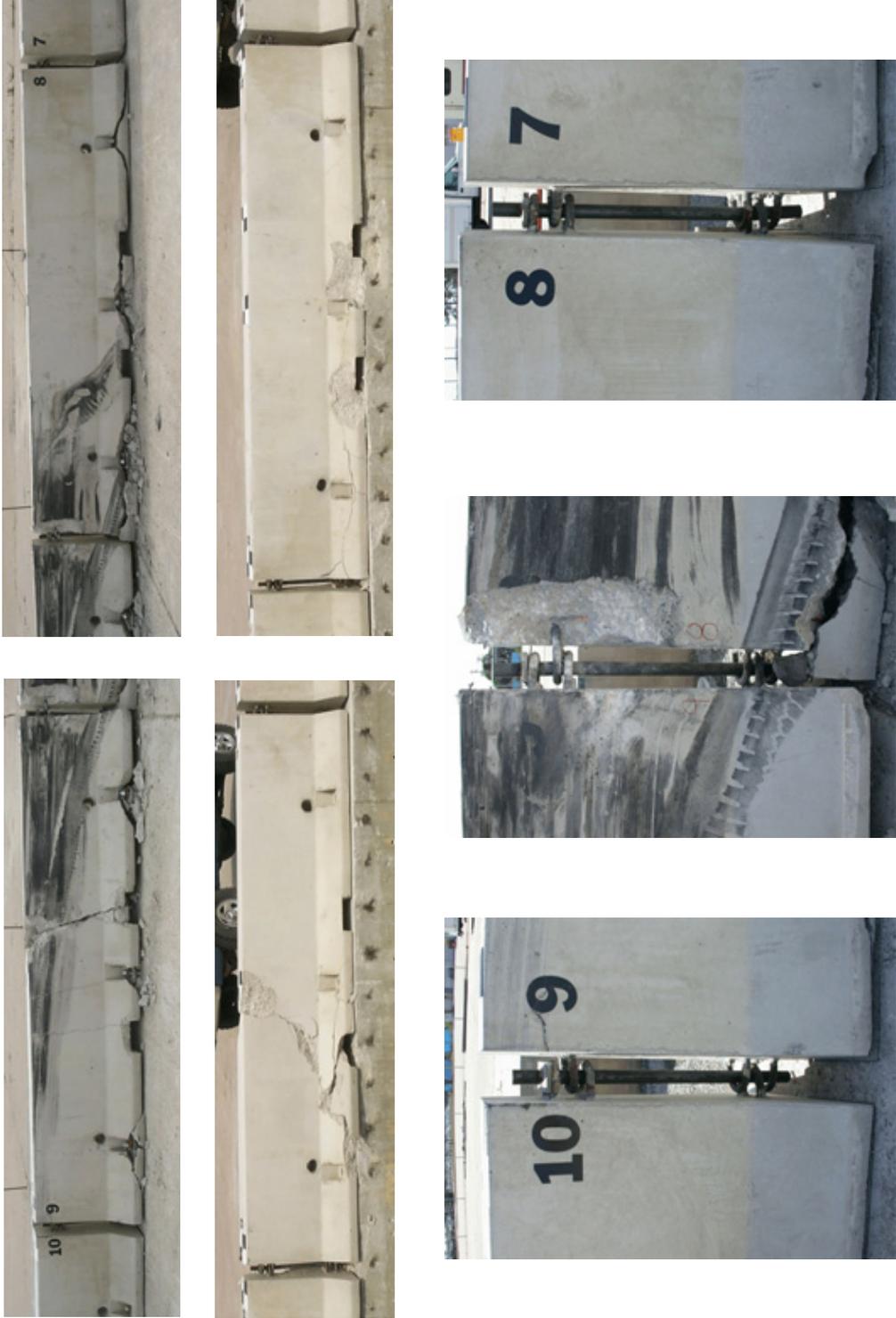


Figure 26. Barrier Nos. 8 and 9 Damage, Test KTB-1



Figure 27. Barrier Nos. 8 and 9 Concrete Damage , Test KTB-1



Figure 28. Barrier No. 8 Tie-Down Anchor Damage, Test KTB-1



Figure 29. Barrier No. 9 Tie-Down Anchor Damage, Test KTB-1



Figure 30. Vehicle Damage, Test KTB-1



Figure 31. Vehicle Damage, Test KTB-1



Front Tire



Rear Tire

Figure 32. Right-Side Tire Damage, Test KTB-1

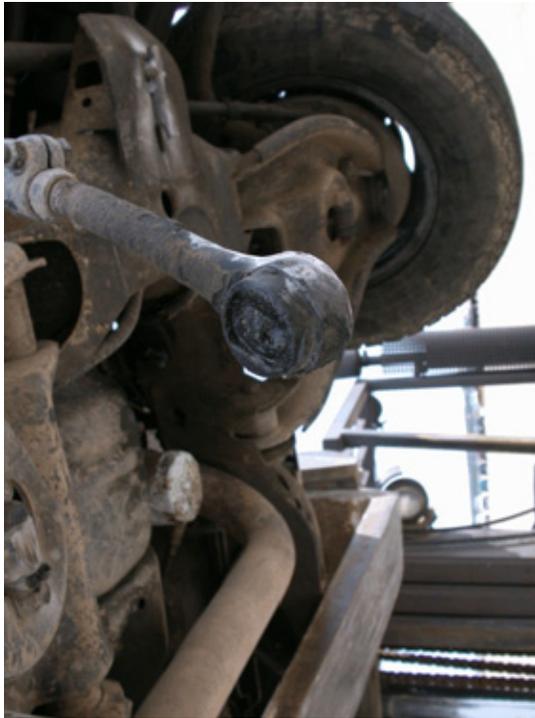


Figure 33. Vehicle Undercarriage Damage, Test KTB-1



Figure 34. Occupant Compartment Damage, Test KTB-1

7 SUMMARY AND CONCLUSIONS

A tie-down system for use on concrete bridge decks and with the redesigned F-shape temporary concrete barriers was developed and full-scale vehicle crash tested. The tie-down system consisted of three 28.575-mm (1.125-in.) diameter Grade 2 threaded dowel connections embedded approximately 305 mm (12 in.) into the concrete on the traffic side of each of the redesigned F-shape temporary concrete barriers. The barriers were placed 25.4 mm (1 in.) away from the edge of the concrete bridge deck. A full-scale vehicle crash test was performed with a $\frac{3}{4}$ -ton pickup truck on the barrier system and was determined to be acceptable according to the TL-3 safety performance criteria presented in NCHRP Report No. 350. The barrier safely redirected the pickup truck with minimal barrier deflections. A summary of the safety performance evaluation is provided in Table 3.

Table 3. Summary of Safety Performance Evaluation Results

| Evaluation Factors | Evaluation Criteria | Test KTB-1 |
|---------------------|--|------------|
| Structural Adequacy | A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable. | S |
| 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. | S |
| | F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable. | S |
| Vehicle Trajectory | K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes. | S |
| | L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/sec (39.37 ft/sec), and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 G's. | S |
| | M. The exit angle from the test article preferably should be less than 60 percent of test impact angle measured at time of vehicle loss of contact with test device. | S |

S - Satisfactory
M - Marginal
U - Unsatisfactory
NA - Not Available

8 RECOMMENDATIONS

A tie-down system for use on concrete bridge decks and with the redesigned F-shape temporary barriers, as described in this report, was developed and successfully crash tested according to the criteria found in NCHRP Report No. 350. The test results indicate that this design is suitable for use on Federal-aid highways. However, any significant modifications made to the tie-down design would require additional analysis and can only be verified through the use of full-scale crash testing.

It should be noted that the tie-down system developed within the scope of this project may be used as either a bolt-through system or as an adhesive-bonded system as long as the bolt capacity is developed. In addition, this tie-down system is not recommended for use on a bridge deck with an asphalt overlay. By placing the bolts through the overlay, high bending moments will be induced in the anchor bolts at the top of the concrete surface, causing them to bend at lower loads.

In some real-world applications, an expansion joint may fall between two anchor bolts within a single barrier unit. In this situation, omitting one anchor bolt is not believed to compromise the barrier performance. It is recommended that the one anchor bolt adjacent to the joint, as shown in Figure 35, should be left out of the barrier spanning the thermal expansion joint. It should be noted that the adjacent barrier units must each be installed with the standard three anchor bolts.

Since the anchored F-shape rail has substantially lower deflections than the free-standing section, it is recommended that a transition between bolted and free-standing barriers be made to reduce the propensity for vehicle pocketing. Therefore, it is suggested that the transition region always be placed in a tangent section of the barrier (that lies parallel to the roadway). In some situations, this transition section will occur on a structural slab or on a relatively thick concrete

section. In these cases, it is recommended that the first barrier adjacent to the bolted down section have two anchor bolts similar to the bolted down section and that the next barrier have one bolt placed in the end hole closest to the bolted down section.

In many situations, the bolted rail section will end adjacent to the end of the bridge, and the stiffness transitioning of the rail section will be accomplished over an asphalt paving surface. In this case, until further evaluation under a current study is completed, it is recommended to utilize the driven steel pin system of reinforcement similar to the one developed for the K-Rail by CALTRANS (5). It is recommended that the 32-mm (1.25-in.) diameter by 1,016-mm (40-in.) long steel stakes with stop plates, as detailed in Figure 36, driven into the asphalt road surface be utilized to stiffen the barriers upstream of the bolted down barrier sections. It is recommended that three stakes be utilized in the first barrier upstream of the bolted section, two stakes in the outer two locations in the second barrier upstream, and one stake in the downstream end in the third barrier upstream. Until a time when the currently funded study of this transition is completed, this recommended practice will serve as the best engineering assessment available.

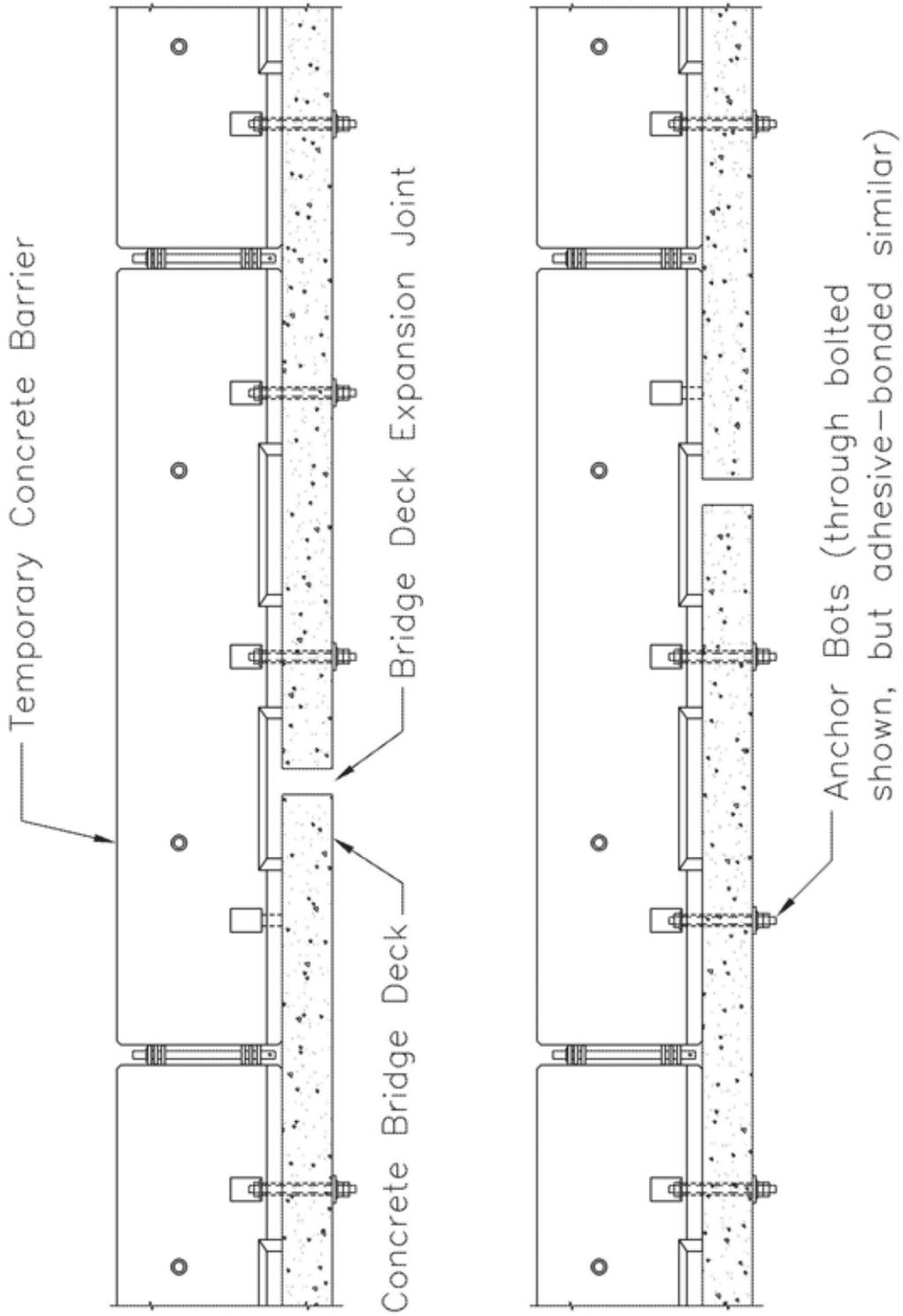


Figure 35. Treatment at Bridge Deck Thermal Expansion Joints

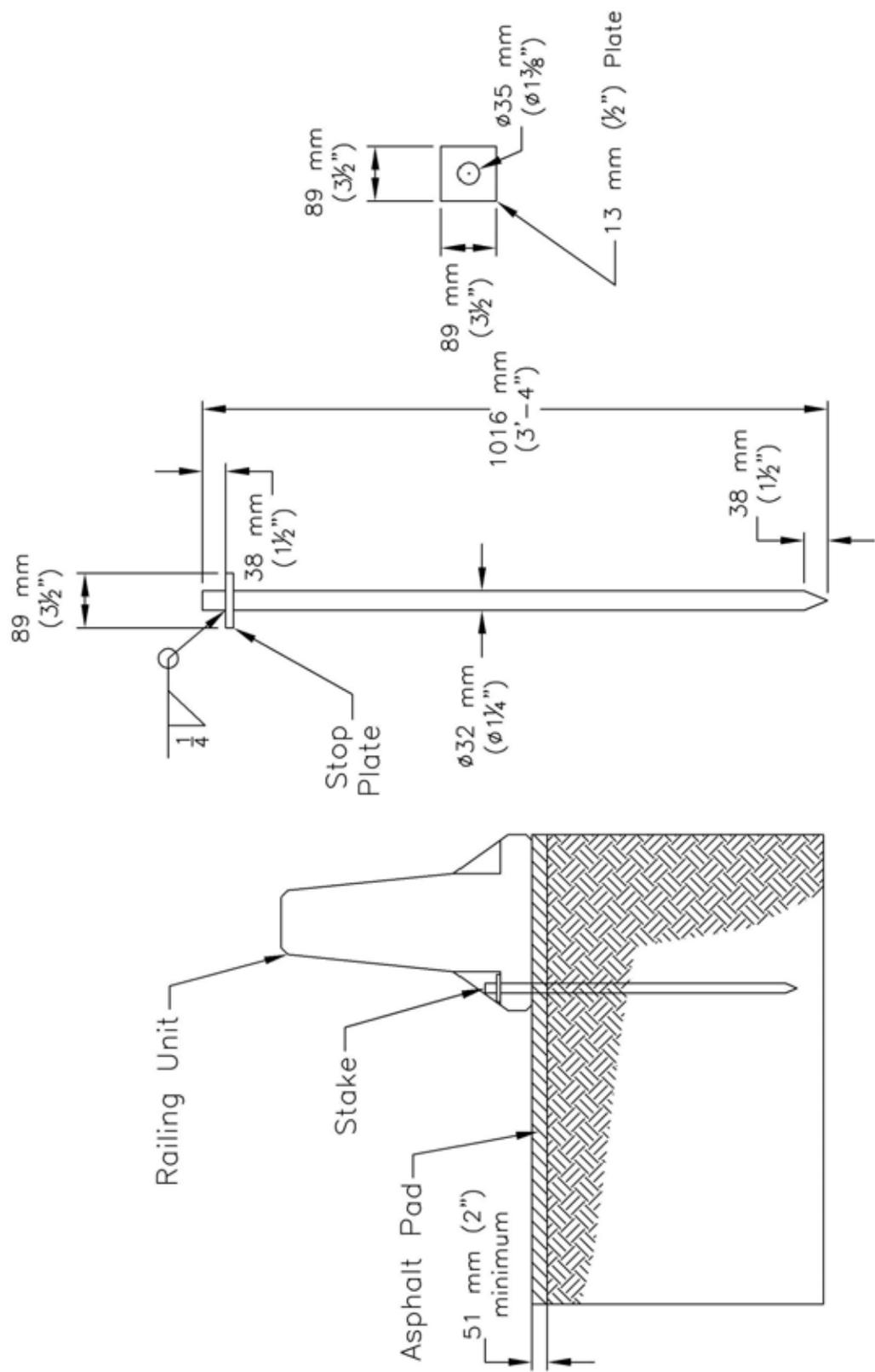


Figure 36. Staked Down Installation into an Asphalt Road Surface (Transitioning to Free-Standing Sections at the End of a Bridge)

9 REFERENCES

1. Ross, H.E., Sicking, D.L., Zimmer, R.A., and Michie, J.D., *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, National Cooperative Research Program (NCHRP) Report No. 350, Transportation Research Board, Washington, D.C., 1993.
2. Faller, R.K., Rohde, J.R., Rosson, B.T., Smith, R.P., and Addink, K.H., *Development of a TL-3 F-Shape Temporary Concrete Median Barrier*, Final Report to the Midwest States Regional Pooled Fund Program, Transportation Report No. TRP-03-64-96, Project No. SPR-3(017) - Fiscal Year 1995, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, NE, December 1996.
3. Faller, R.K., Rohde, J.R., Rosson, B.T., Smith, R.P., and Addink, K.H., *Development of a TL-3 F-Shape Temporary Concrete Median Barrier*, Transportation Research Board Paper No. 97-1207, December 9, 1996.
4. Beason, W.L. and Bullard, D.L., *Development of a Limited-Slip Portable Concrete Barrier Connection*, Report No. TX-94/1959-1, Texas Transportation Institute, Texas A&M University, College Station, TX, November 1993.
5. Jewel, J., Weldon, G., and Peter, R., *Compliance Crash Testing of K-Rail Used in Semi-Permanent Installations*, Report No. 59-680838, Division of Materials Engineering and Testing Services, CALTRANS, Sacramento, CA, October 1999.
6. Bielenberg, B.W., Faller, R.K., Reid, J.D., Holloway, J.C., Rohde, J.R., and Sicking, D.L., *Development of a Tie-Down System for Temporary Concrete Barriers*, Final Report to the Midwest States' Regional Pooled Fund Program, Transportation Report No. TRP-03-115-02, Project No. SPR-03(017)-Year 9, Sponsoring Agency Code RPPF-01-06, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, NE, August 16, 2002.
7. Bielenberg, B.W., Faller, R.K., Reid, J.D., Rohde, J.R., Sicking, D.L., *Design and Testing of Tie-Down Systems for Temporary Barriers*, Paper accepted for presentation at the 82nd Annual Meeting of the Transportation Research Board, Washington, D.C., Paper No. 03-3146, January 13-17, 2003.
8. Buth, C.E., Hirsch, T.J., and McDevitt, C.F., *Performance Level 2 Bridge Railings*, Transportation Research Record No. 1258, Transportation Research Board, National Research Council, Washington, D.C., 1990.
9. Bronstad, M.E., Calcote, L.R., and Kimball, C.E., Jr., *Concrete Median Barrier Research-Vol.2 Research Report*, Report No. FHWA-RD-77-4, Submitted to the Office of Research and Development, Federal Highway Administration, Performed by Southwest Research Institute, San Antonio, TX, March 1976.

10. Buth, C.E., Campise, W.L., Griffin III, L.I., Love, M.L., and Sicking, D.L., *Performance Limits of Longitudinal Barrier Systems-Volume I: Summary Report*, FHWA/RD-86/153, Final Report to the Federal Highway Administration, Office of Safety and Traffic Operations R&D, Performed by Texas Transportation Institute, Texas A&M University, College Station, TX, May 1986.
11. Fortuniewicz, J.S., Bryden, J.E., and Phillips, R.G., *Crash Tests of Portable Concrete Median Barrier for Maintenance Zones*, Report No. FHWA/NY/RR-82/102, Final Report to the Office of Research, Development, and Technology, Federal Highway Administration, Performed by the Engineering Research and Development Bureau, New York State Department of Transportation, December 1982.
12. Mak, K.K., and Sicking, D.L., *Rollover Caused by Concrete Safety Shape Barriers - Volume I: Technical Report and Volume II: Appendices*, Report Nos. FHWA-RD-88-219/220, Final Report to the Federal Highway Administration, Office of Safety and Traffic Operations R&D, Performed by Texas Transportation Institute, Texas A&M University, College Station, TX, January 1989.
13. Hinch, J., Yang, T.L., and Owings, R., *Guidance Systems for Vehicle Testing*, ENSCO, Inc., Springfield, VA, 1986.
14. *Vehicle Damage Scale for Traffic Investigators*, Second Edition, Technical Bulletin No. 1, Traffic Accident Data (TAD) Project, National Safety Council, Chicago, Illinois, 1971.
15. *Collision Deformation Classification - Recommended Practice J224 March 1980*, Handbook Volume 4, Society of Automotive Engineers (SAE), Warrendale, Pennsylvania, 1985.

10 APPENDICES

APPENDIX A

System Drawings in English Units

Figure A-1. Temporary Barrier Details (English)

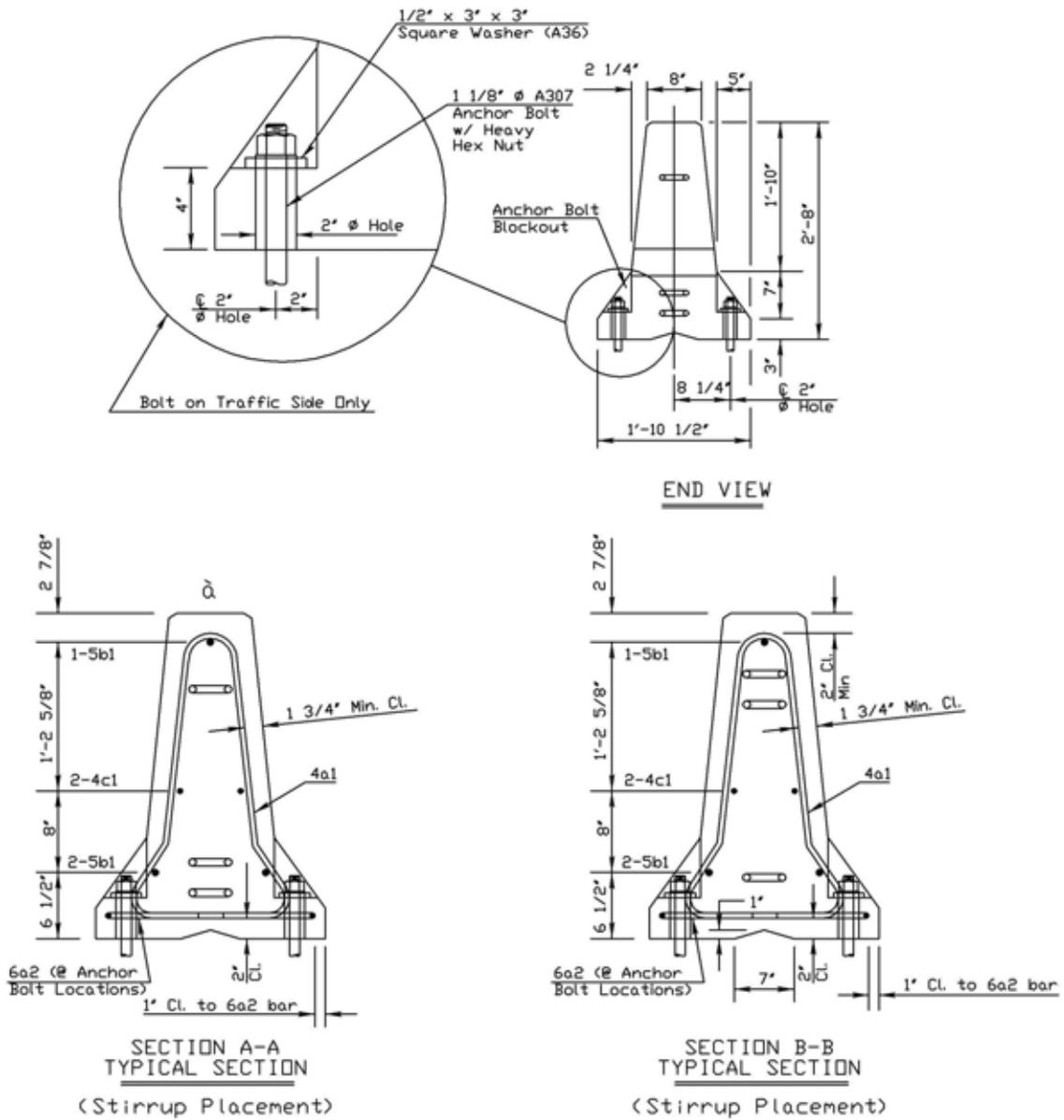
Figure A-2. Temporary Barrier Profile and Tie-Down Details (English)

Figure A-3. Temporary Barrier Connection and Lifting Slot Details (English)

Figure A-4. Temporary Barrier Bill of Bars (English)

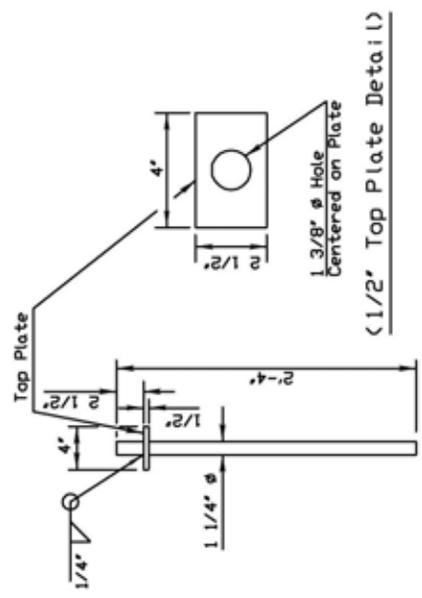
Figure A-5. Connection to Iowa Temporary Barrier Details (English)

Figure A-6. Distances Between Temporary Barriers (English)



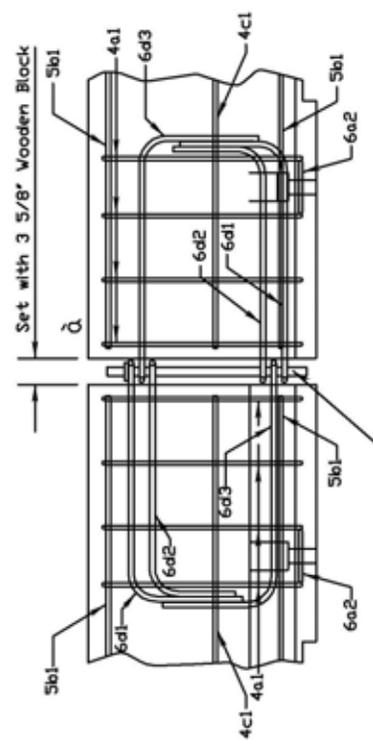
Note: $\hat{\alpha}$ - Marked End
 - See table for rebar definitions
 - Dimensions are out to out of bars unless otherwise noted.

Figure A-2. Temporary Barrier Profile and Tie-Down Details (English)



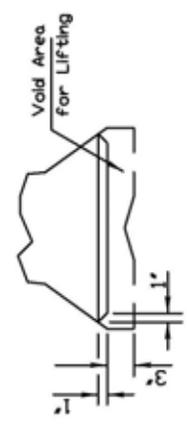
DETAIL A
CONNECTION PIN

< A36 Steel >
10.9 lbs. each



DETAILS OF BARRIER CONNECTION

For connection pin details see Detail 'A'

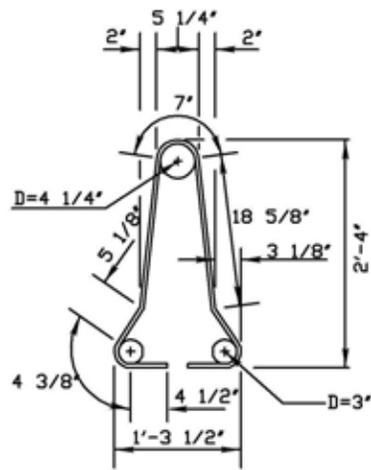


DETAIL 'B'
LIFTING SLOT DETAIL

< 1' Chamfer to prevent spalling >

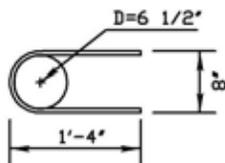
- Note: \bar{a} - Marked End
 - See table for rebar definitions
 - Dimensions are out to out of bars unless otherwise noted.

Figure A-3. Temporary Barrier Connection and Lifting Slot Details (English)

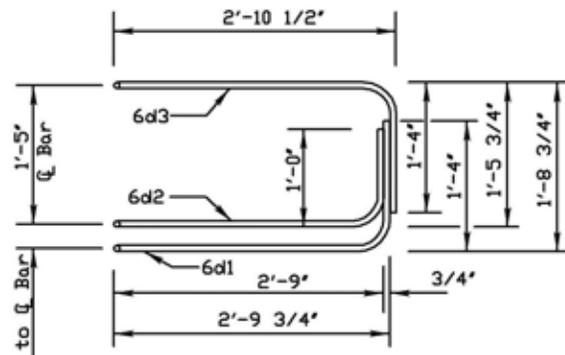


4a1

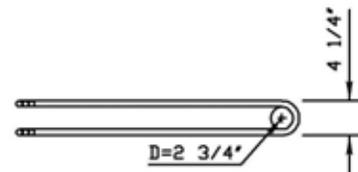
Vertical Stirrups



6a2



Elevation



Plan

LOOP BAR ASSEMBLY

(Marked end shown, invert for other end)
(A706 Steel)

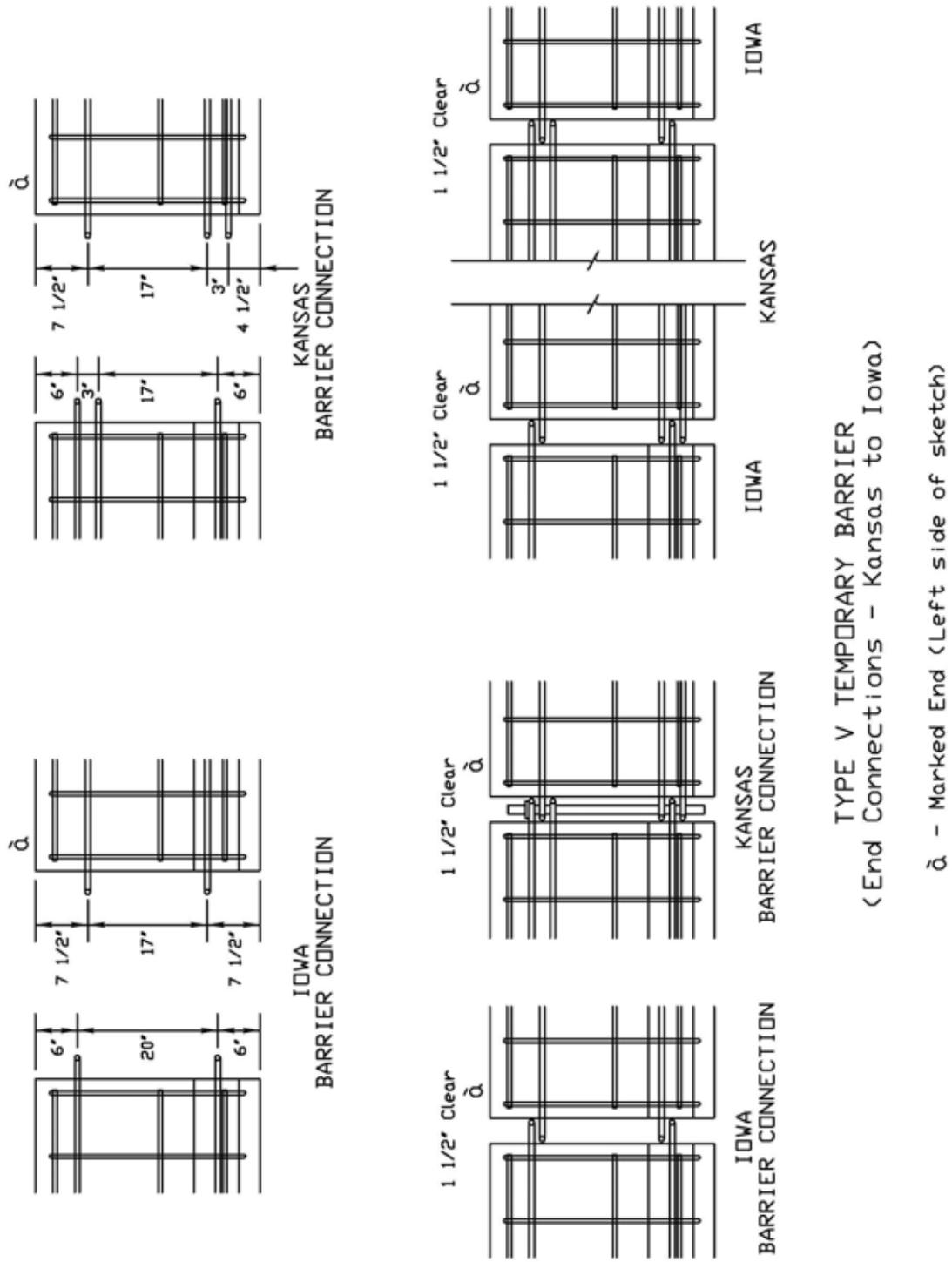
Dimensions are out to out of bars unless otherwise noted.

Per 12'-6" Barrier Section

| REINFORCING A615 Gr. 60 | | | | | |
|---------------------------|----------|-------|-------------|------------|-------------|
| Bar | Bar Size | Shape | No. of Bars | Length Ft. | Weight Lbs. |
| 4a1 | 4 | U | 12 | 6'-0" | 48.1 |
| 6a2 | 6 | C | 6 | 2'-11" | 26.3 |
| 5b1 | 5 | — | 3 | 12'-2" | 38.1 |
| 4c1 | 4 | — | 2 | 12'-2" | 16.3 |
| LOOP ASSEMBLY A706 Gr. 60 | | | | | |
| 6d1 | 6 | ┌ | 2 | 8'-5" | 25.3 |
| 6d2 | 6 | ┌ | 2 | 7'-7" | 22.8 |
| 6d3 | 6 | ┌ | 2 | 8'-6" | 25.5 |

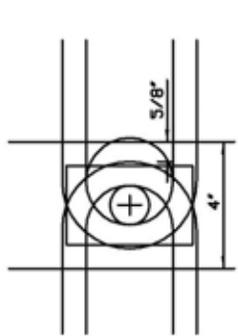
Concrete Quantity = 1.3 C.Y.

Figure A-4. Temporary Barrier Bill of Bars (English)

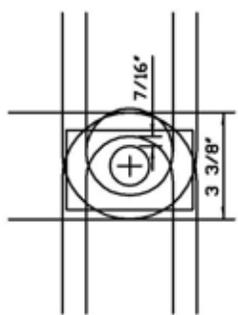


TYPE V TEMPORARY BARRIER
 (End Connections - Kansas to Iowa)

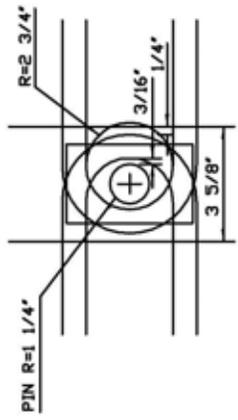
Figure A-5. Connection to Iowa Temporary Barrier Details (English)



4' Maximum Opening

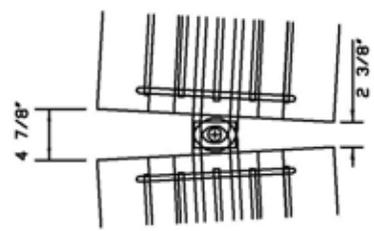


3 3/8' Minimum Opening

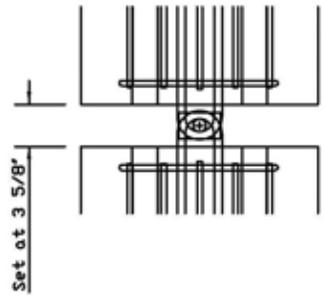


3 5/8' Block-Set Gap
3 3/8' on Loop Bar Projection

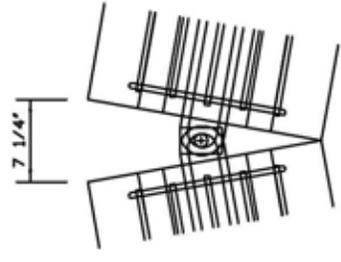
TEMPORARY TYPE V BARRIER
MINIMUM AND MAXIMUM DISTANCES



4 7/8' Max - 2 3/8' Min. Opening
Opening with 9:1
(6° Angle)



4' Maximum Opening
3 3/8' Minimum Opening



7 1/4' Opening
Maximum Angle 18°

Figure A-6. Distances Between Temporary Barriers (English)

APPENDIX B

State Plans of the Redesigned Temporary Barrier Details

Figure B-1. Kansas State Plans (Metric)

Figure B-2. Kansas State Plans (English)

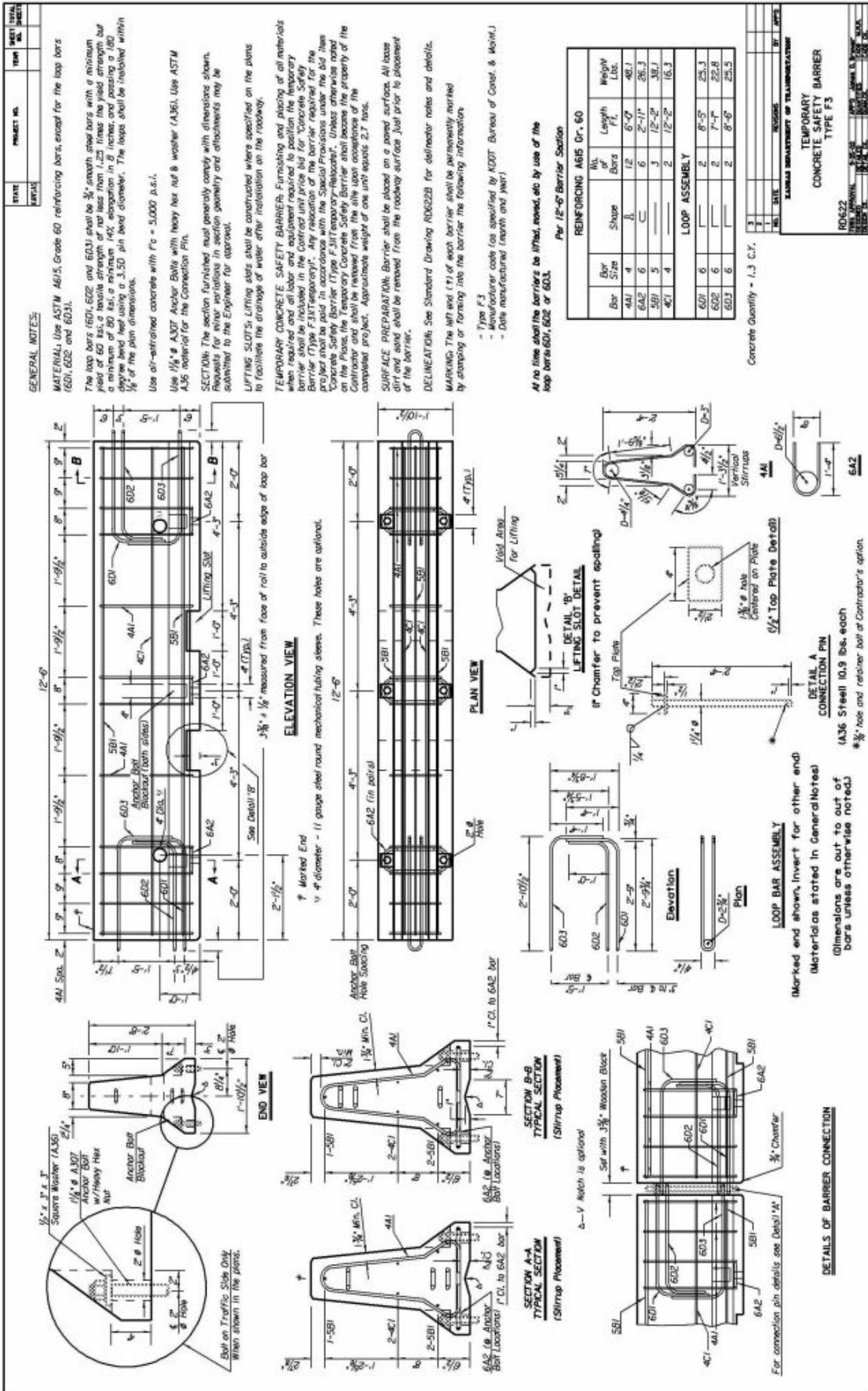


Figure B-2. Kansas State Plans (English)

APPENDIX C

Epoxy Specifications used with the Tie-Down Anchors

Figure C-1. Type of Epoxy

Figure C-2. Epoxy Specifications



Figure C-1. Type of Epoxy

| Base Material Temp. | | Maximum Gel Time (minutes) | | Minimum Gel Time (hours) | | Full Curing Time (hours) | |
|---------------------|------|----------------------------|----------|--------------------------|----------|--------------------------|----------|
| (F°) | (C°) | Fast Set | Std. Set | Fast Set | Std. Set | Fast Set | Std. Set |
| 40 | 4 | 30 | 60 | 8 | 16 | 36 | 48 |
| 60 | 15 | 20 | 45 | 3 | 7 | 24 | 36 |
| 75 | 24 | 15 | 35 | 2 | 6 | 24 | 24 |
| 90 | 32 | 10 | 20 | 1-1/2 | 4 | 16 | 24 |

| Anchor Size (Inches) | Drill Dia. (Inches) | INSTALLATION OF THREADED ANCHOR ROD IN SOLID BASE MATERIALS USING 24 FLUID OUNCES | | | | | | | | | | | | | | | |
|----------------------|---------------------|---|-------|-------|-------|-------|-------|------|------|------|------|------|------|------|------|------|-----|
| | | Hole Depth (Inches) | | | | | | | | | | | | | | | |
| | | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| 1/4 | 5/16 | 385.0 | 256.7 | 192.5 | 154.0 | 128.3 | 110.0 | 96.3 | 85.6 | 77.0 | 70.0 | 64.2 | 59.2 | 55.0 | 51.3 | 48.1 | 45 |
| 3/8 | 7/16 | 229.9 | 153.3 | 115.0 | 92.0 | 76.6 | 65.7 | 57.5 | 51.1 | 46.0 | 41.8 | 38.3 | 35.4 | 32.8 | 30.7 | 28.7 | 27 |
| 1/2 | 9/16 | 162.2 | 108.2 | 81.1 | 64.9 | 54.1 | 46.4 | 40.6 | 36.1 | 32.5 | 29.5 | 27 | 25.0 | 23.2 | 21.6 | 20.3 | 19 |
| 5/8 | 3/4 | 83.0 | 55.3 | 41.5 | 33.2 | 27.7 | 23.7 | 20.8 | 18.4 | 16.6 | 15.1 | 13.8 | 12.8 | 11.9 | 11.1 | 10.4 | 9 |
| 3/4 | 7/8 | 66.2 | 44.2 | 33.1 | 26.5 | 22.1 | 18.9 | 16.6 | 14.7 | 13.2 | 12.0 | 11.0 | 10.2 | 9.5 | 8.8 | 8.3 | 7.8 |
| 7/8 | 1 | 55.3 | 36.9 | 27.7 | 22.1 | 18.4 | 15.8 | 13.8 | 12.3 | 11.1 | 10.1 | 9.2 | 8.5 | 7.9 | 7.4 | 6.9 | 6.5 |
| 1 | 1-1/8 | 45.2 | 30.1 | 22.6 | 18.1 | 15.1 | 12.9 | 11.3 | 10.0 | 9.0 | 8.2 | 7.5 | 7.0 | 6.5 | 6.0 | 5.7 | 5.3 |
| 1-1/8 | 1-1/4 | 40.1 | 26.7 | 20.1 | 16.0 | 13.4 | 11.5 | 10.0 | 8.9 | 8.0 | 7.3 | 6.7 | 6.2 | 5.7 | 5.3 | 5.0 | 4.7 |
| 1-1/4 | 1-3/8 | 34.6 | 23.0 | 17.3 | 13.8 | 11.5 | 9.9 | 8.6 | 7.7 | 6.9 | 6.3 | 5.8 | 5.3 | 4.9 | 4.6 | 4.3 | 4.1 |
| 1-3/8 | 1-1/2 | 31.0 | 20.7 | 15.5 | 12.4 | 10.3 | 8.9 | 7.8 | 6.9 | 6.2 | 5.6 | 5.2 | 4.8 | 4.4 | 4.1 | 3.9 | 3.7 |
| 1-1/2 | 1-5/8 | 27.1 | 18.1 | 13.5 | 10.8 | 9.0 | 7.7 | 6.8 | 6.0 | 5.4 | 4.9 | 4.5 | 4.2 | 3.9 | 3.6 | 3.4 | 3.2 |

Figure C-2. Epoxy Specifications

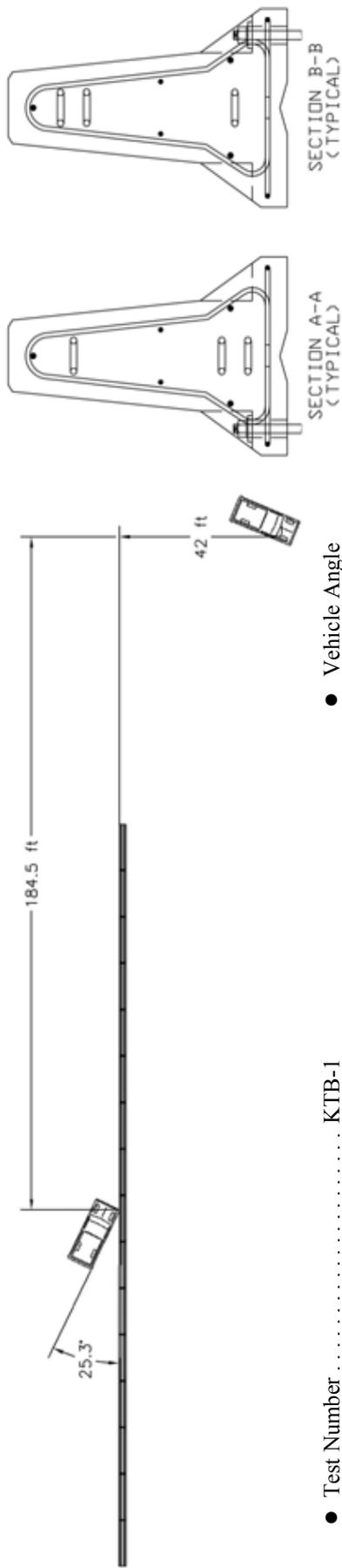
APPENDIX D

Test Summary Sheet in English Units, Test KTB-1

Figure D-1. Summary of Test Results and Sequential Photographs (English), Test KTB-1



0.000 sec 0.044 sec 0.084 sec 0.231 sec 0.469 sec



| | | | |
|---------------------------------|--|---|---|
| ● Test Number | KTB-1 | ● Vehicle Angle | 25.3 deg |
| ● Date | 7/31/02 | ● Impact (orientation) | 25.3 deg |
| ● Appurtenance | Kansas Temporary Barrier Tie Down System | ● Exit (trajectory) | 14.4 deg |
| ● Total Length | 204 ft | ● Vehicle Snagging | None |
| ● Placement | 1 in. from concrete bridge deck edge | ● Vehicle Pocketing | None |
| ● Key Elements | Nine 150-in. long Kansas Temporary Barriers | ● Vehicle Stability | Satisfactory |
| ● Barrier Joint Pin Connections | Seven 150-in. long Iowa F-Shape Temporary Barriers | ● Occupant Ridedown Deceleration (10 msec avg.) | Longitudinal 10.98 G's < 20 G's Lateral (not required) 10.60 G's |
| ● Tie-Down Anchors | 1.25-in. diameter by 28-in. long A36 steel rod with 2.5x4x0.5-in. plate | ● Occupant Impact Velocity | Longitudinal 18.63 ft/s < 39.37 ft/s Lateral (not required) 22.99 ft/s |
| ● Number per Barrier | 3 | ● Vehicle Damage | Moderate |
| ● Embedment into Concrete | 12 in. | ● TAD ¹⁴ | 1-RFQ-3 |
| ● Placement | Traffic side only | ● SAE ¹⁵ | 1-RFAW3 |
| ● Vehicle Model | 1997 Chevrolet 2500 ¾-ton pickup | ● Vehicle Stopping Distance | 184.5 ft downstream 42 ft laterally behind |
| ● Curb | 4,390 lbs | ● Barrier Damage | Moderate |
| ● Test Inertial | 4,448 lbs | ● Maximum Rail Deflections | Permanent Set 3.5 in. Dynamic 11.3 in. |
| ● Gross Static | 4,448 lbs | ● Working Width | 21.0 in. |
| ● Vehicle Speed | | | |
| ● Impact | 62.0 mph | | |
| ● Exit (resultant) | 50.6 mph | | |

Figure D-1. Summary of Test Results and Sequential Photographs (English), Test KTB-1

APPENDIX E

Concrete Damage Sketches, Test KTB-1

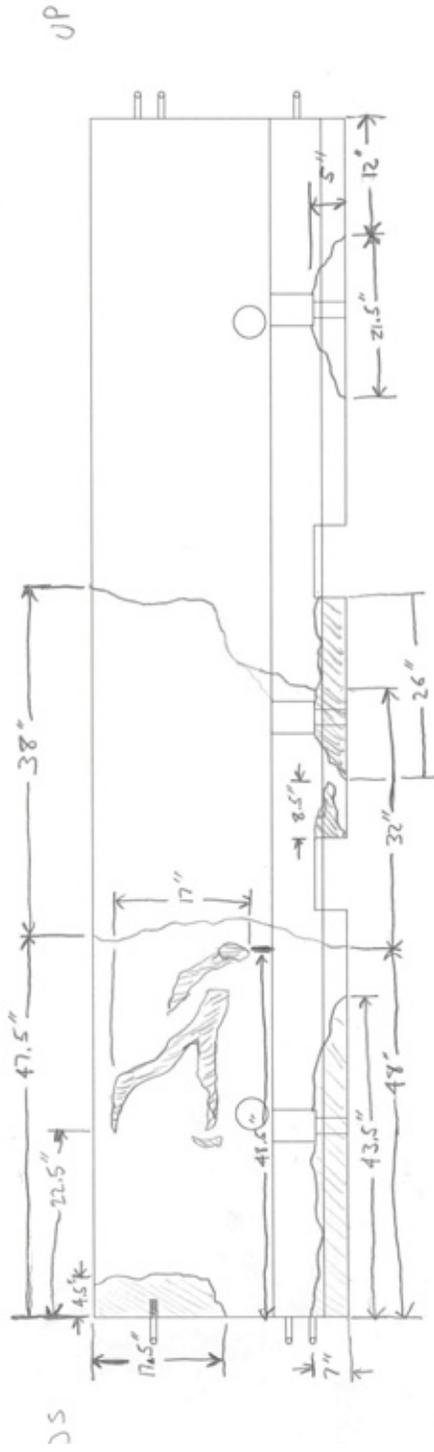
Figure E-1. Concrete Damage – Front Face Barrier No. 8, Test KTB-1

Figure E-2. Concrete Damage – Back Face Barrier No. 8, Test KTB-1

Figure E-3. Concrete Damage – Front Face Barrier No. 9, Test KTB-1

Figure E-4. Concrete Damage – Back Face Barrier No. 9, Test KTB-1

Major Barrier Damage Barrier no. 8 - front face



ELEVATION VIEW

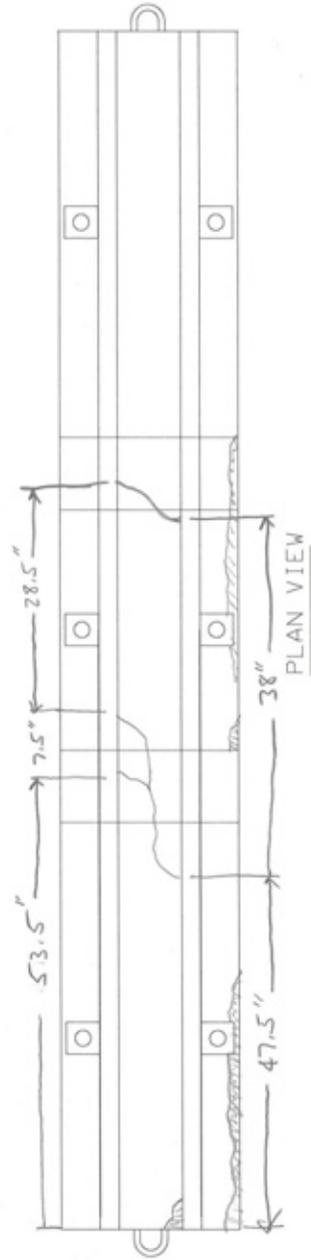
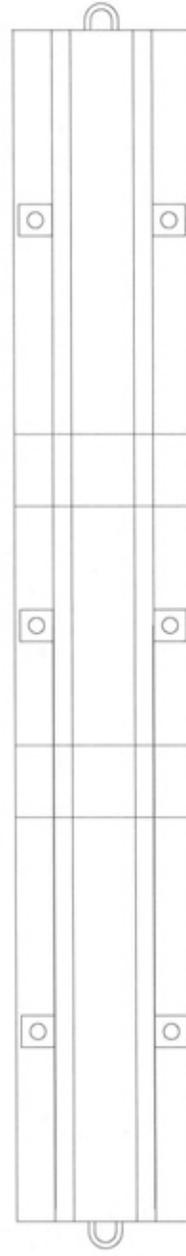


Figure E-1. Concrete Damage - Front Face Barrier No. 8, Test KTB-1

Major Barrier Damage; Barrier No. 8 - Back Face



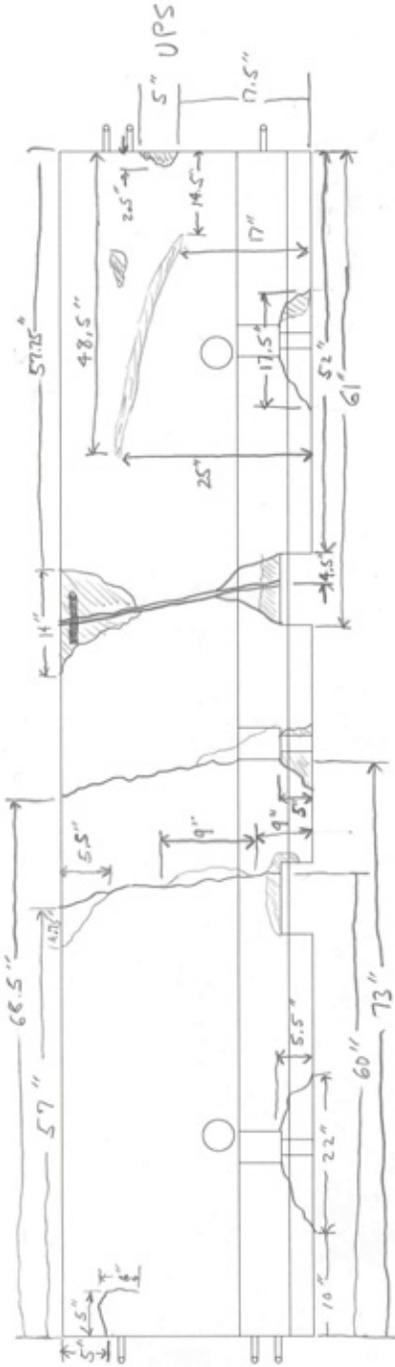
ELEVATION VIEW



PLAN VIEW

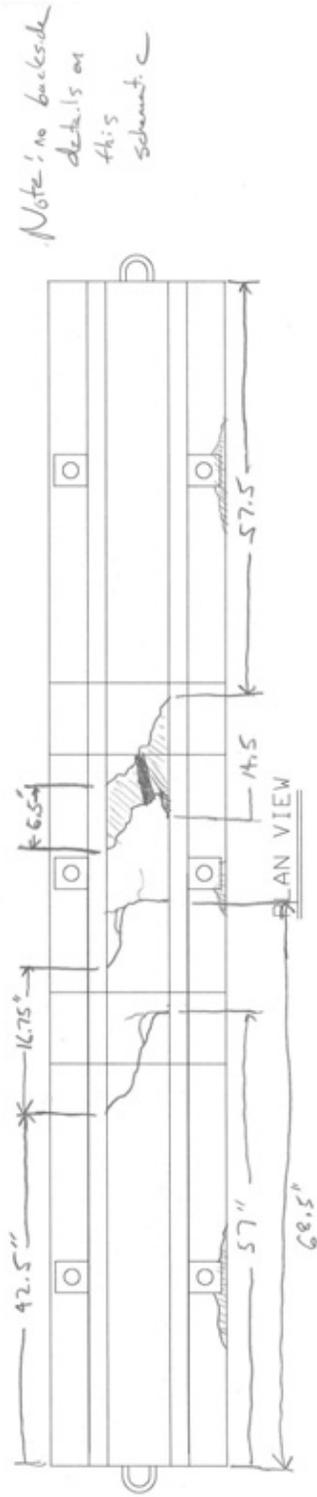
Figure E-2. Concrete Damage – Back Face Barrier No. 8, Test KTB-1

Major Cracks Barrier No. 9 - Front face



15

ELEVATION VIEW



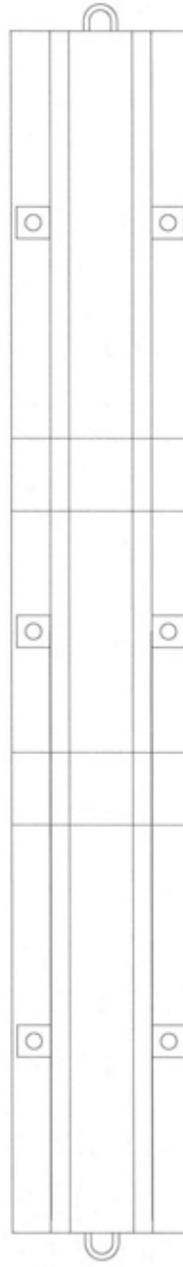
PLAN VIEW

Figure E-3. Concrete Damage – Front Face Barrier No. 9, Test KTB-1

Major Barrier Damage: Barrier no 9 back face



ELEVATION VIEW



PLAN VIEW

Figure E-4. Concrete Damage – Back Face Barrier No. 9, Test KTB-1

APPENDIX F

Occupant Compartment Deformation Data, Test KTB-1

Figure F-1. Occupant Compartment Deformation Data, Test KTB-1

VEHICLE PRE/POST CRUSH INFO

TEST: KTB-1
 VEHICLE: 1997/GMC/WHITE

| POINT | X | Y | Z | X' | Y' | Z' | DEL X | DEL Y | DEL Z |
|-------|---------|-------|--------|-------|-------|--------|-------|-------|-------|
| 1 | 54.25 | 2.25 | -1.5 | 52 | 2.5 | -4 | -2.25 | 0.25 | -2.5 |
| 2 | 53.75 | 8.25 | -1 | 54.5 | 8.25 | -3.5 | 0.75 | 0 | -2.5 |
| 3 | 56.5 | 12.5 | -0.75 | 56 | 12.25 | -3.5 | -0.5 | -0.25 | -2.75 |
| 4 | 59 | 19.5 | 1.25 | 54.25 | 17.75 | -3.5 | -4.75 | -1.75 | -4.75 |
| 5 | 58 | 28.25 | 0.5 | 55.25 | 25.75 | -2 | -2.75 | -2.5 | -2.5 |
| 6 | 48 | 3.5 | 0 | 45.5 | 3.5 | -2.5 | -2.5 | 0 | -2.5 |
| 7 | 48.5 | 6.75 | 0.25 | 47.75 | 6.75 | -2.5 | -0.75 | 0 | -2.75 |
| 8 | 50.5 | 9.25 | 4 | 49.75 | 8.5 | 1.5 | -0.75 | -0.75 | -2.5 |
| 9 | 53.75 | 16.25 | 4.5 | 51.25 | 14 | 1.5 | -2.5 | -2.25 | -3 |
| 10 | 53.5 | 27.25 | 4.5 | 52.75 | 24 | 2.5 | -0.75 | -3.25 | -2 |
| 11 | 41.25 | 3.75 | 0.25 | 40.75 | 3.75 | -2 | -0.5 | 0 | -2.25 |
| 12 | 41.5 | 9 | 3 | 41.5 | 8.5 | 1 | 0 | -0.5 | -2 |
| 13 | 45 | 15 | 6 | 44.5 | 13.25 | 3.5 | -0.5 | -1.75 | -2.5 |
| 14 | 45.75 | 21.5 | 6.25 | 45.25 | 19.5 | 5 | -0.5 | -2 | -1.25 |
| 15 | 45.25 | 27 | 6.75 | 45.25 | 24 | 6.25 | 0 | -3 | -0.5 |
| 16 | 36 | 5.5 | 0.5 | 36.75 | 5.5 | -1 | 0.75 | 0 | -1.5 |
| 17 | 38.75 | 13.5 | 5.5 | 38.25 | 12 | 4.25 | -0.5 | -1.5 | -1.25 |
| 18 | 40 | 21.75 | 6 | 39.5 | 19.25 | 4.25 | -0.5 | -2.5 | -1.75 |
| 19 | 39.5 | 27.5 | 6.5 | 40 | 26.25 | 5.75 | 0.5 | -1.25 | -0.75 |
| 20 | 28.25 | 7 | 0.75 | 28.25 | 7 | -1 | 0 | 0 | -1.75 |
| 21 | 29.25 | 16.75 | 5.25 | 29.5 | 15.25 | 4.5 | 0.25 | -1.5 | -0.75 |
| 22 | 29.25 | 27.5 | 5.25 | 29.5 | 26.25 | 4.25 | 0.25 | -1.25 | -1 |
| 23 | 16.25 | 12 | 4 | 16.25 | 11.5 | 2.5 | 0 | -0.5 | -1.5 |
| 24 | skipped | | | | | | 0 | | |
| 25 | 17.25 | 21 | 5 | 16.5 | 20.5 | 4 | -0.75 | -0.5 | -1 |
| 26 | 28.25 | 32 | -5.25 | 27.25 | 31.75 | -6.25 | -1 | -0.25 | -1 |
| 27 | 44.75 | 9.25 | -26.5 | 45 | 9 | -27.5 | 0.25 | -0.25 | -1 |
| 28 | 42 | 25.5 | -25.75 | 42 | 25.5 | -26.75 | 0 | 0 | -1 |
| 29 | | | | | | | | | 0 |
| 30 | | | | | | | | | |

ORIENTATION AND REFERENCE INFO

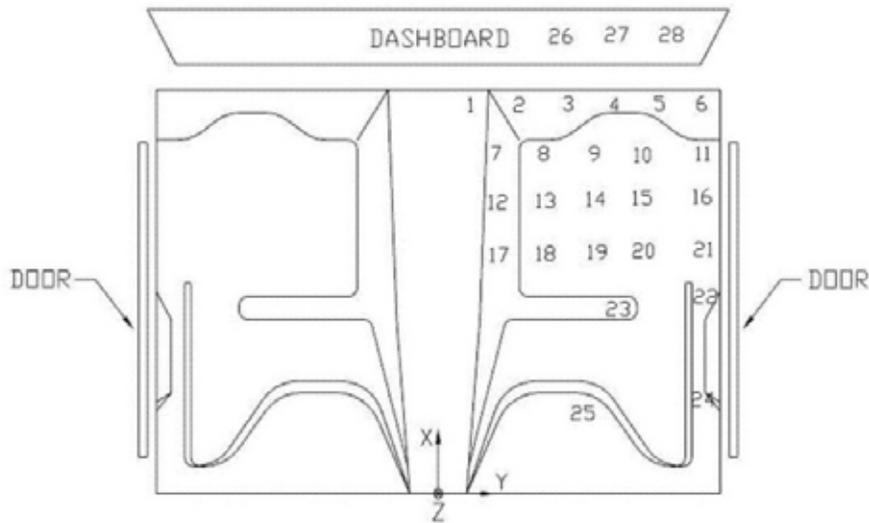


Figure F-1. Occupant Compartment Deformation Data, Test KTB-1

APPENDIX G

Accelerometer Data Analysis, Test KTB-1

Figure G-1. Graph of Longitudinal Deceleration, Test KTB-1

Figure G-2. Graph of Longitudinal Occupant Impact Velocity, Test KTB-1

Figure G-3. Graph of Longitudinal Occupant Displacement, Test KTB-1

Figure G-4. Graph of Lateral Deceleration, Test KTB-1

Figure G-5. Graph of Lateral Occupant Impact Velocity, Test KTB-1

Figure G-6. Graph of Lateral Occupant Displacement, Test KTB-1

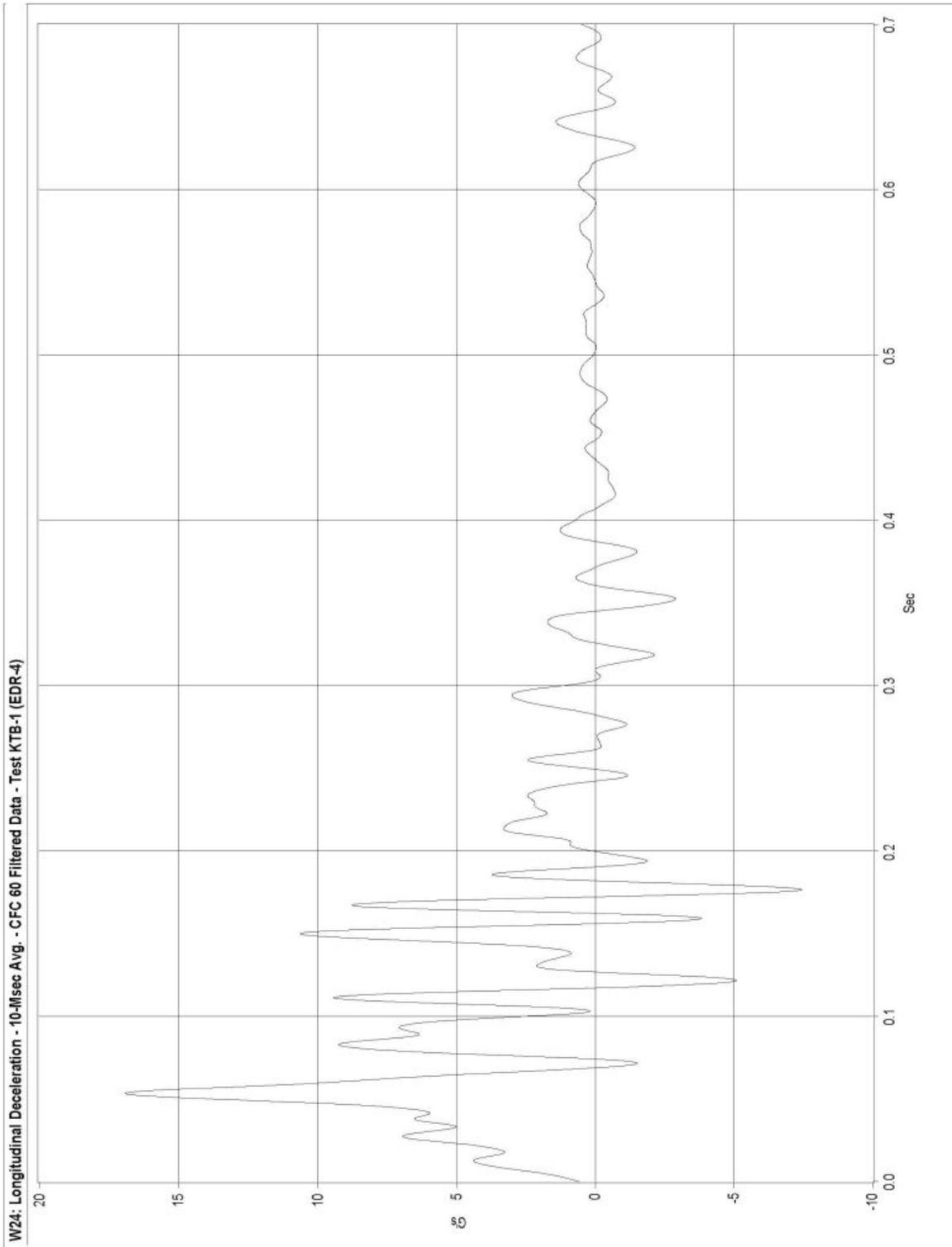


Figure G-1. Graph of Longitudinal Deceleration Test KTB-1

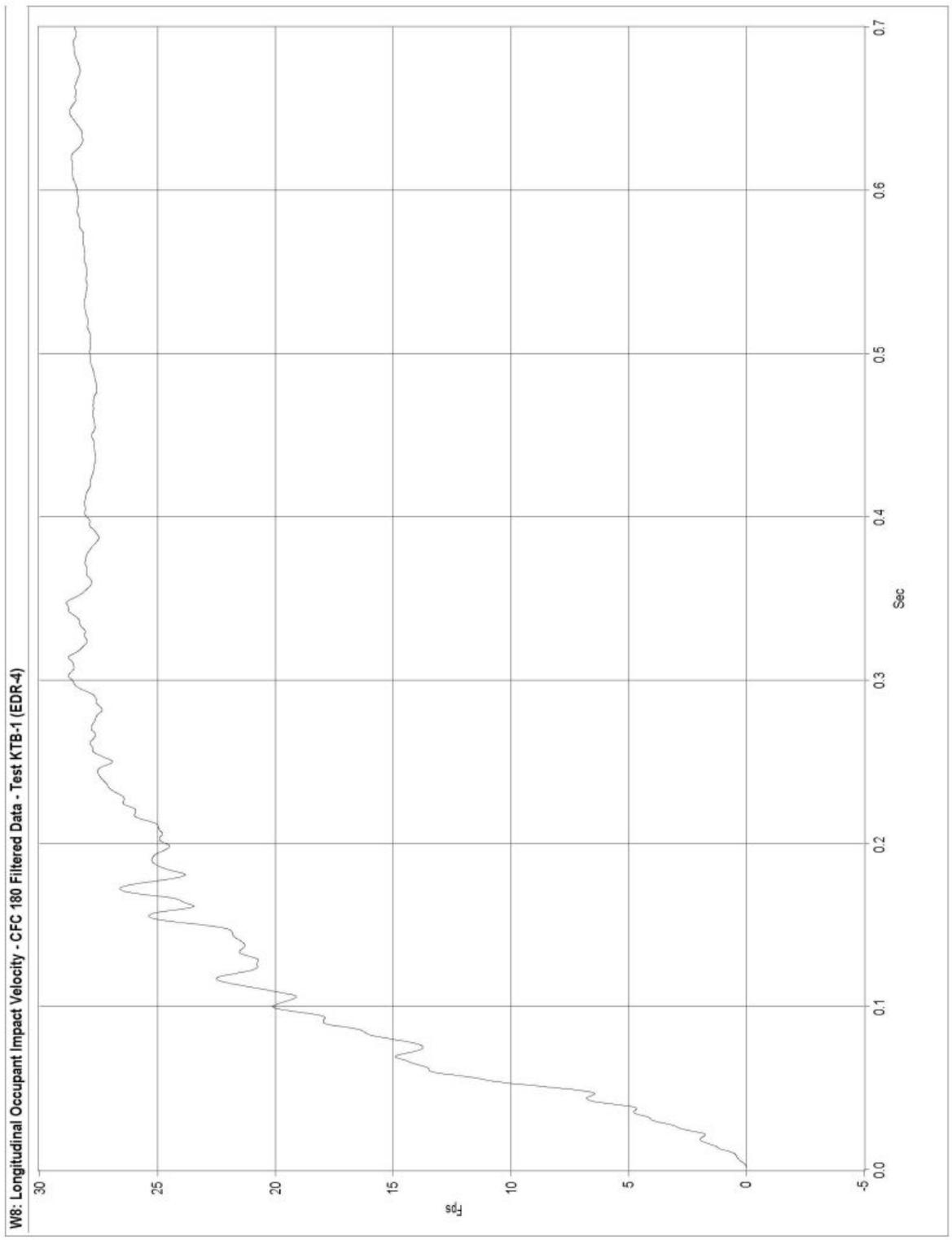


Figure G-2. Graph of Longitudinal Occupant Impact Velocity, Test KTB-1

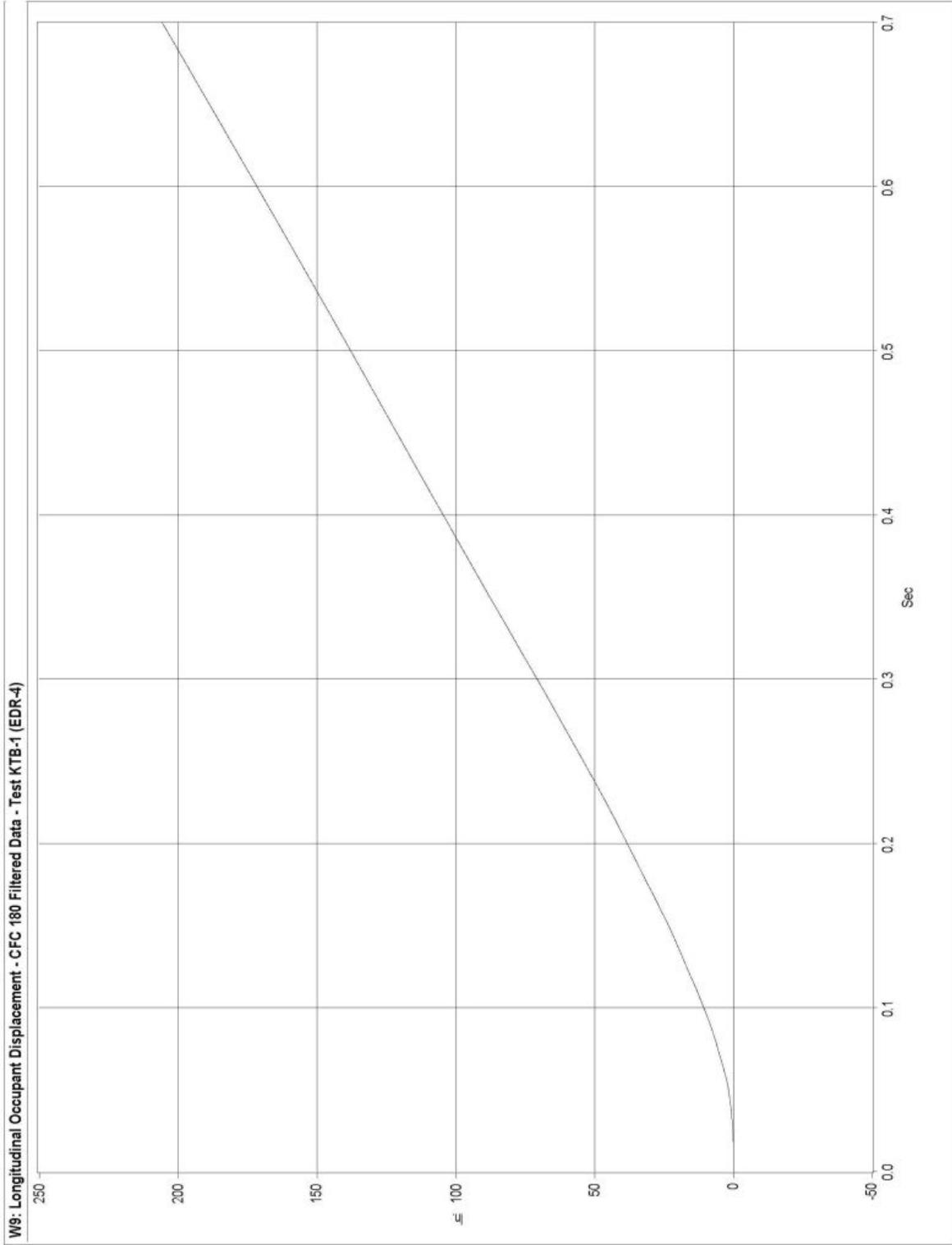


Figure G-3. Graph of Longitudinal Occupant Displacement, Test KT B-1

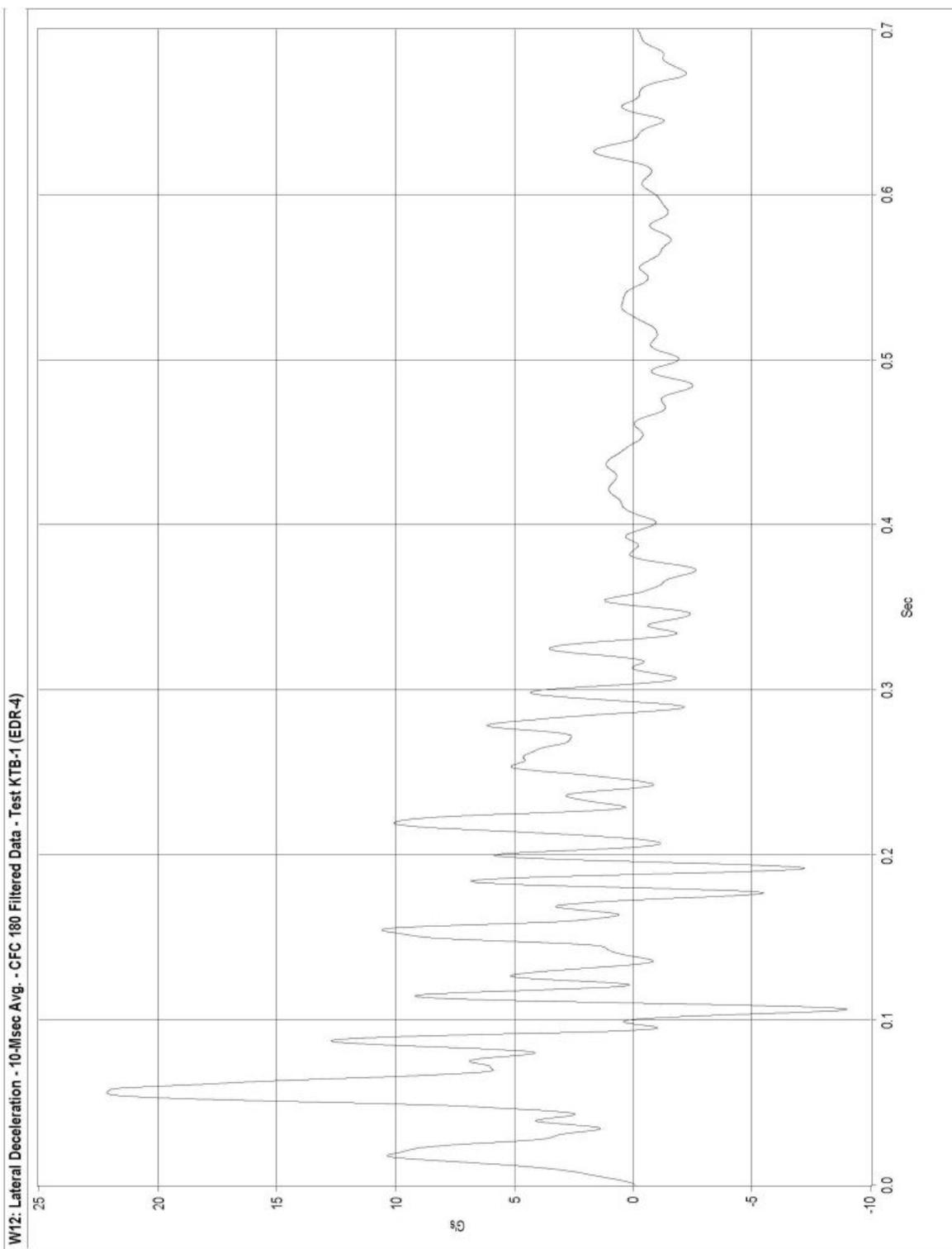


Figure G-4. Graph of Lateral Deceleration, Test KTB-1

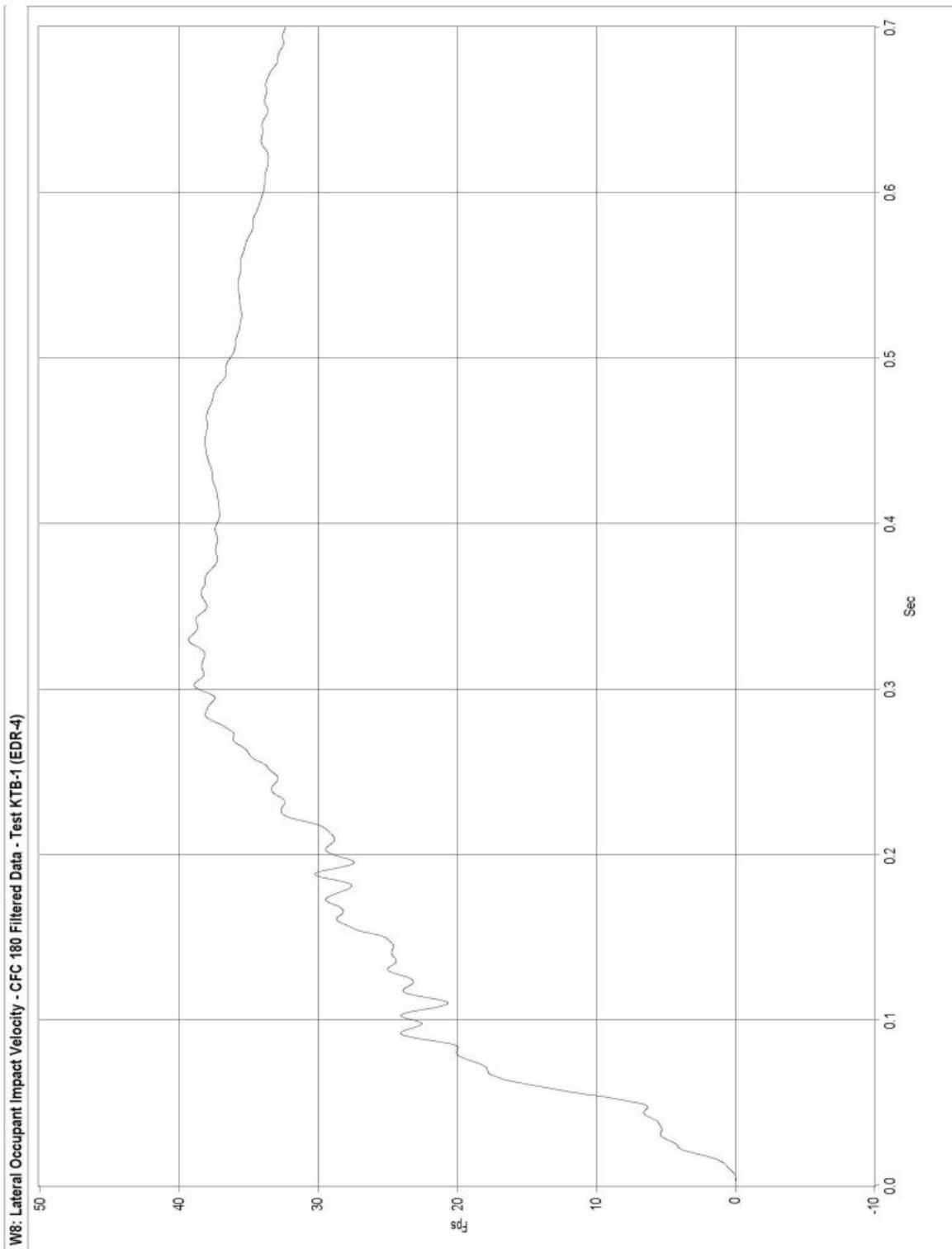


Figure G-5. Graph of Lateral Occupant Impact Velocity, Test KTB-1

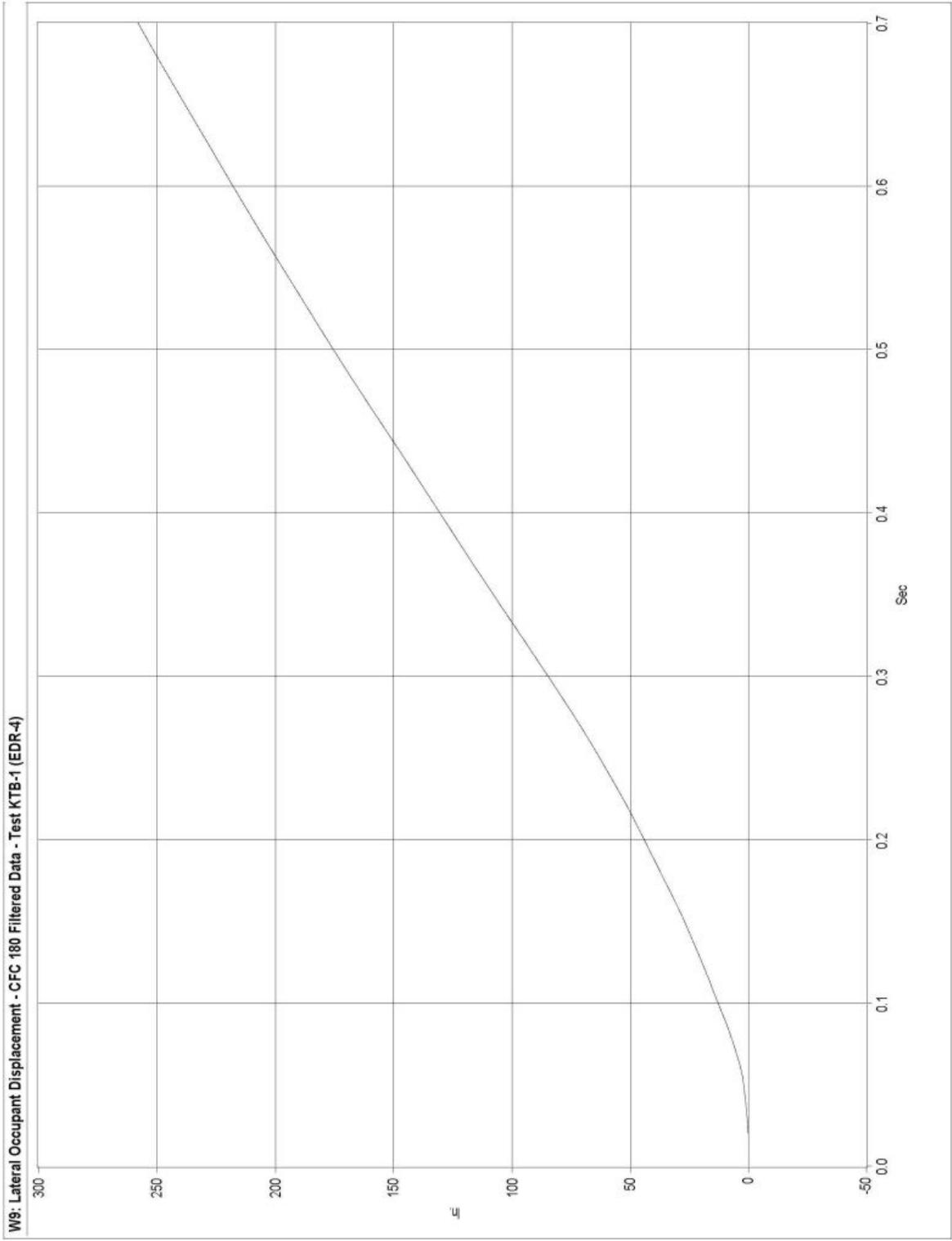


Figure G-6. Graph of Lateral Occupant Displacement, Test KTB-1

APPENDIX H

Roll and Yaw Data Analysis, Test KTB-1

Figure H-1. Graph of Roll Angular Displacements, Test KTB-1

Figure H-2. Graph of Yaw Angular Displacements, Test KTB-1

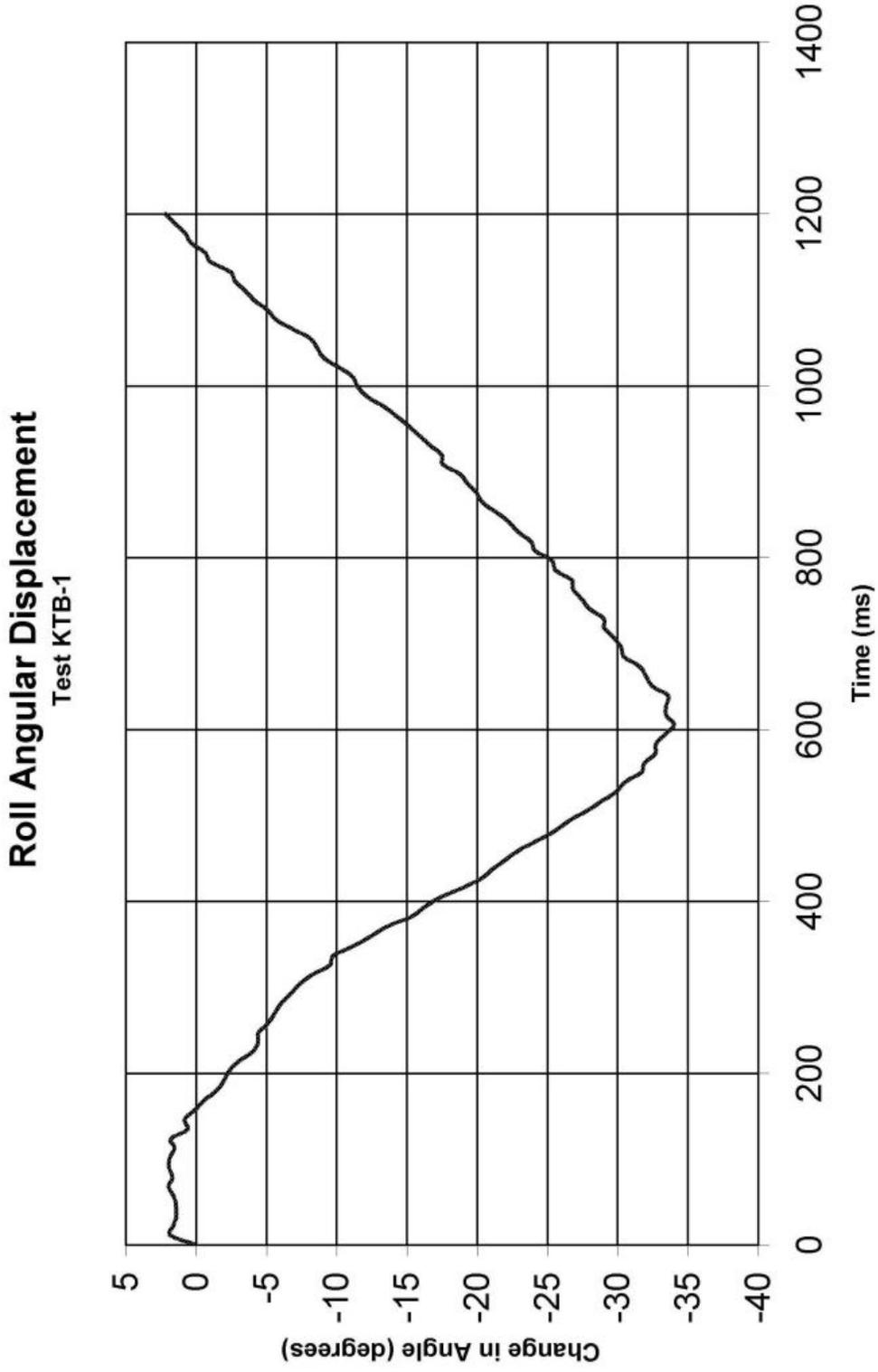


Figure H-1. Graph of Roll Angular Displacements, Test KTB-1

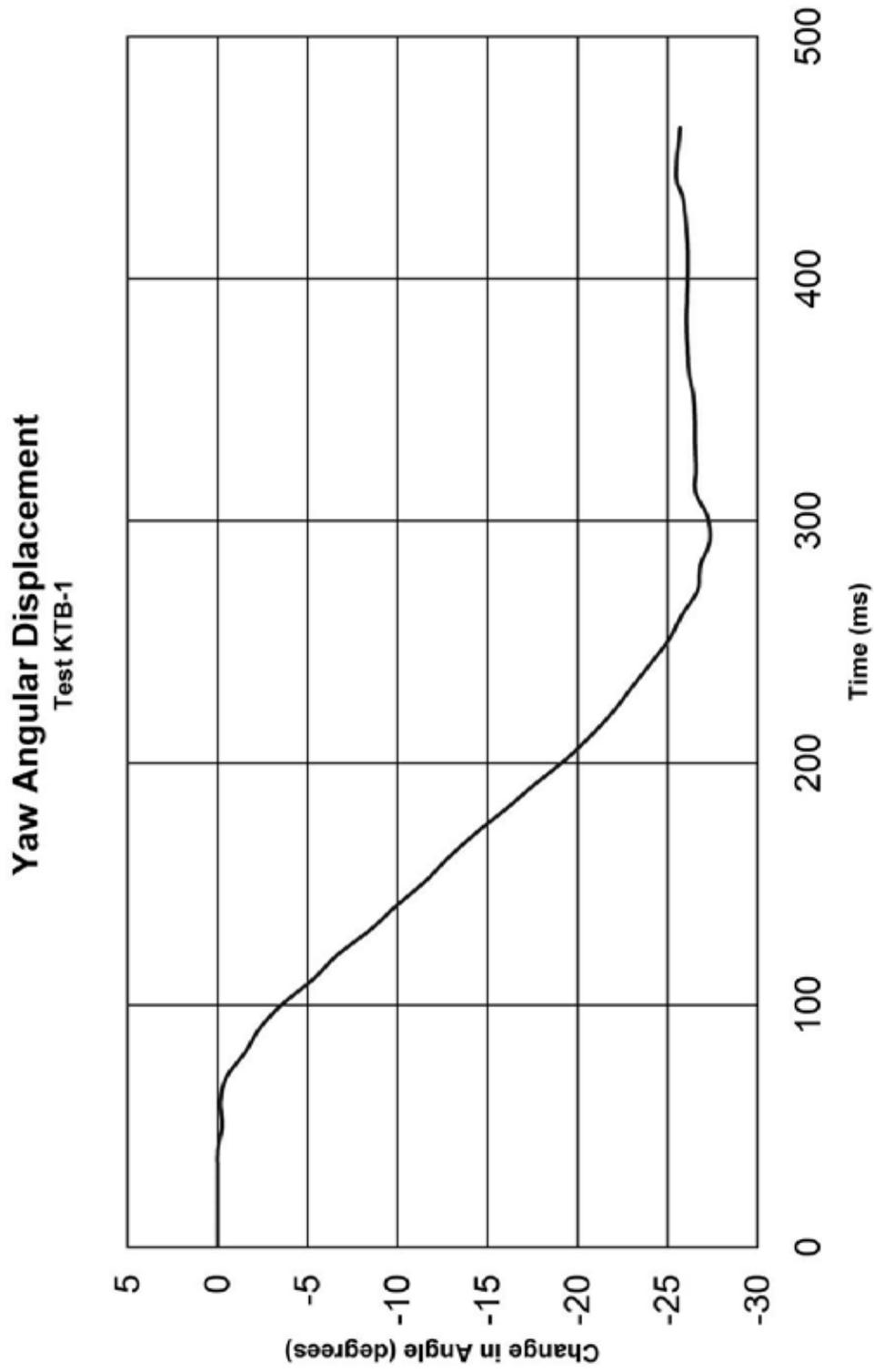


Figure H-2. Graph of Yaw Angular Displacements, Test KTB-1