EVALUATION OF AN EXISTING STEEL POST ALTERNATIVE FOR THE THRIE BEAM BULLNOSE GUARDRAIL SYSTEM

Submitted by

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

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

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

John D Reid, Ph.D.
Professor

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

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Mohammad Dehdashti
Minnesota Department of Transportation
1500 W Co Rd B2
Roseville, MN 55113
651-234-7606

Subject: Evaluation of an Existing Steel Post Alternative for the Thrie Beam Bullnose Guardrail System

Dear Mr. Dehdashti:

Recently, the Minnesota Department of Transportation (MnDOT) funded a research project through the Midwest States Regional Pooled Fund to evaluate an existing steel post alternative for the thrie beam bullnose barrier system previously developed at the Midwest Roadside Safety Facility (MwRSF). MnDOT had an interest in the replacement of the wooden breakaway posts used in the current bullnose system with proprietary breakaway steel posts. The research project consisted of evaluation of current breakaway steel post designs, investigation and selection of a candidate post design, and full-scale testing of the bullnose system with a steel post alternative. The full-scale testing was to consist of two tests conducted according to the evaluation criteria of NCHRP Report 350:

1) Test 3-38, an impact of a 2000P vehicle on the Critical Impact Point (CIP) of the system at a speed of 100 km/h and an angle of 20 degrees, and
2) Test 3-31, an impact of a 2000P vehicle with the center of the vehicle aligned with the center of the nose of the system at a speed of 100 km/h and an angle of 0 degrees.

The evaluation of the steel post alternative for the bullnose system project has been completed. A steel post alternative was selected followed by two full-scale crash tests. Unfortunately, both crash tests failed as the vehicle in each test ramped up the guardrail and vaulted the system. This letter summarizes the work completed.

Alternative Steel Post Selection

The first phase of the development of a steel post alternative for the bullnose system was investigation and selection of a candidate steel post. The scope of the project dictated that the breakaway steel post design be chosen from the field of existing proprietary steel post designs due to the cost and time associated with development of a new, non-proprietary breakaway steel post design specifically for this application. To this end, current breakaway steel post manufacturers were contacted and asked to submit candidate steel post designs as well as sample posts and design details. Review of the manufacturer responses along with engineering input from MwRSF researchers led to the selection of two potential post designs. These designs were the Road Systems, Inc. (RSI) Hinged Steel Post and the RSI Plug Weld Post. The selected posts are shown in Figures 1 and 2.

In order to evaluate the candidate steel post designs, component testing was conducted on both of the potential steel post designs and the wooden CRT post used in the current bullnose system. The component testing consisted of impacting all three post types with a 728-kg bogie vehicle at a speed of 31.19 km/h and an angle of 36 degrees from the weak axis of the posts. The impact behavior of these types of breakaway posts was well quantified under weak and strong axis impacts. However, the behavior of the posts when impacted at intermediate angles was not documented. Thus, the impact angle for the component tests was chosen to simulate an oblique impact angle on the posts similar to what would be observed in the CIP test of the bullnose system. The goal of the testing was to determine the peak loads and energy levels generated by the posts in order to decide which post would perform best in the bullnose system.

The results from the component testing are shown in Figures 3 and 4. Figure 3 displays the force versus deflection properties for the three posts, and Figure 4 displays the energy versus deflection data. Comparison of the data from the three post types yielded valuable insight into selection of an alternative breakaway steel post for the bullnose system. The force deflection data from the testing showed that both the RSI Plug Weld Post and RSI Hinged Steel Post developed lower peak loads than a wooden CRT post. However, investigation of the energy data found that the RSI Plug Weld Post did not release cleanly upon impact and absorbed much more energy than either the RSI Hinged Steel Post or the CRT post. The RSI Hinged Steel Post was observed to absorb the least amount of energy prior to release.

Discussions were held with the researchers, the project sponsor, and the post manufacturer to determine which steel post alternative to use in the bullnose system. The researchers believed that any alternative breakaway post design used with the bullnose system would need to develop peak loads less than or equal to those of the CRT post used in the original design and disengage or fail in a brittle manner in order to function properly. It was clear from the component testing that the RSI Hinged Steel Post failed in a much more brittle manner and absorbed far less energy than the RSI Plug Weld Post, and thus would be expected to perform more like the CRT posts used in the original bullnose system. Discussions with RSI also revealed that the RSI Hinged Steel Post would be their primary manufactured breakaway post design in the future and that supplies of the RSI Plug Weld Post would be potentially limited. Thus, it was decided that the RSI Hinged Steel Post was the best alternative post option for the bullnose system.

Design details for the RSI Hinged Steel Post and the thrie beam bullnose system with the RSI Hinged Steel Post substituted for the wooden breakaway posts are shown in Figures 5 through 17. The bullnose system was unchanged from the original design other than post nos. 1 through 9 which were replaced with RSI breakaway steel posts. Note that the post no. 1 in the original bullnose system was a wooden BCT post in a 2,438-mm long steel foundation tube. This post was replaced by an RSI steel anchorage post that differed from the RSI Hinged Steel Post in that it used a breakaway mechanism based on fracture at the base of the post, it had a soil plate on the lower section for development of anchor loads, and the top section was fabricated with a cutout in the web to accommodate a standard cable anchorage. This design was then used to conduct the first full-scale crash test.

Test No. SBN-1

The first test of the thrie beam bullnose system with breakaway steel posts, test no. SBN-1, was conducted according to NCHRP Report 350 test designation 3-38. The test consisted of a 2000-kg pickup truck impacting the CIP of the bullnose at a speed of 100 km/h and an angle of 20 degrees. The CIP for a non-gating system, such as the bullnose, was defined as the point in the installation where it was unknown if the system would capture or redirect the vehicle. For test SBN-1, this point was located at post no. 2. The CIP test was chosen as the first test because it was believed that the CIP impact would be the more difficult of the two test conditions for the system to pass. This was based on the fact that the breakaway steel posts would be loaded at an intermediate angle rather than directly along the strong or weak axis.

In test no. SBN-1, a 2,020-kg pickup truck impacted the CIP of the bullnose system at a speed of 103.1 km/h and an angle of 20.1 degrees. The results from test no. SBN-1 are summarized in Figure 18. During test no. SBN-1, the bullnose system with breakaway steel posts failed to capture the impacting vehicle. As the pickup truck penetrated into the system, the vehicle ramped up the guardrail and vaulted the system. Review of the test results and comparison of the behavior of the system with the successful testing of the original bullnose system revealed that the failure of the test was largely due to the upstream anchorage at post no. 1. In test no. SBN-1, post no. 1 was an RSI steel anchorage post. This post developed upstream anchorage far longer during the impact event than the wooden BCT post used in the original design. Film analysis showed that the upstream anchorage at post no.1 remained active until approximately 240 msec in test no. SBN-1, while in the CIP test of the original bullnose, test no. MBN-8, the upstream anchor at post no. 1 remained active for only 154 msec. The retention of the upstream anchorage in test no. SBN-1 led to a reduction in the penetration of the pickup truck into the system and a corresponding reduction in the formation of a pocket in the guardrail to effectively capture the front of the vehicle. This can be observed in the comparison of the overhead sequential photographs from test nos. MBN-8 and SBN-1, as shown in Figures 19 and 20, respectively.

Design No. 2

Two options were proposed following test no. SBN-1 to improve the performance of the system. The first option was to develop a controlled release anchorage system. This option involved quantifying the required performance of the anchorage system for a variety of impacts. Impacts from the critical impact point and further downstream would require sufficient anchorage capacity to redirect the vehicle. Impacts occurring upstream of the CIP would require release of the anchorage. It was not known exactly what level of fixed anchorage capacity that would accomplish these two desired results. This option would have required additional simulation, component testing, and full-scale testing and may have lead to significant added time and cost to the project.

A second option was proposed based on the anchorage of the original bullnose design. The anchorage system employed in the original bullnose development used a 2,438-mm long foundation tube and a BCT post. This setup was proposed to replace the design for post no. 1 used in test no. SBN-1. This or course would require the use of wood in the system. While this option addressed the anchorage release, there was no way at this juncture to quantify whether the system would respond in the same way as the original bullnose testing, and full-scale crash testing of this option would be required.

Based on the reduced cost and time required, it was decided that the project would proceed using the second option. Thus, a second full-scale test was conducted on the bullnose system with breakaway steel posts with post no. 1 replaced with a wooden BCT post in a 2,438-mm long foundation tube, as shown in Figure 21.

Test No. SBN-2

In test no. SBN-2, a 2,002-kg pickup truck impacted the CIP of the bullnose system at a speed of 101.3 km/h and an angle of 20.7 degrees. The bullnose system design for this test was unchanged from test no. SBN-1 other than the replacement of post no. 1 with a standard BCT post. The results from test no. SBN-2 are summarized in Figure 22. During test no. SBN-2, the bullnose system with breakaway steel posts failed to capture the impacting vehicle. As the pickup truck penetrated into the system, the vehicle ramped up the guardrail and vaulted the system. Review of the test results and comparison of the behavior of the system with the previous test nos. MBN-8 and SBN-1 yielded information regarding the failure of the test. The initial performance of the system in test no. SBN-2 was improved over that of the previous test. The upstream anchor released earlier in the event and the vehicle penetrated farther into the system and was more effectively captured. However, as the vehicle was being captured, it appeared that the vehicle rode up the debris from the failed steel posts and attached wood blockouts, thus causing the vehicle to vault the guardrail and resulting in the subsequent failure of the test due to loss of vehicle containment. Because the RSI Hinged Steel Posts were hinged about the base as their failure mechanism, the tops of the posts and the blockouts did not disengage and clear away from underneath the guardrail and provided collected materials for the impacting vehicle to climb up.

Summary and Discussion

The objective of research described in this summary letter was to evaluate existing steel breakaway post alternatives for the thrie beam bullnose barrier system. The research began with identifying and selection of a candidate steel breakaway post. The RSI Hinged Steel Post was chosen as the most appropriate available post based on engineering judgment and component testing. Next, a full-scale crash test, test no. SBN-1, was conducted on the bullnose system with breakaway steel posts. Test no. SBN-1 was an impact of a 2,020-kg pickup truck on the CIP of the bullnose system at a speed of 103.1 km/h and an angle of 20.1 degrees. The CIP for the system was located at post no. 2. Test no. SBN-1 was unsuccessful due to the upstream anchorage at post no. 1 remaining active longer than the standard BCT anchorage, which resulted in ineffective vehicle capture and vaulting of the guardrail. It was decided that the second test, test no. SBN-2, would be conducted as a repeat of the first test with post no. 1 replaced by a standard wooden BCT post. Test no. SBN-2 was an impact of a 2,002-kg pickup truck on the CIP of the bullnose system at a speed of 101.3 km/h and an angle of 20.7 degrees. Test SBN-2 was also deemed unsuccessful due to failure of the system to capture the impacting vehicle and override of the guardrail. However, it should be noted that the initial performance of the system in test no. SBN-2 was significantly improved. Override of the guardrail in test no. SBN-2 was attributed to the pickup truck riding up the debris of the failed RSI Hinged Steel Posts and blockouts.

Review of the research conducted herein suggests that replacement of the original wood breakaway posts used in the thrie beam bullnose design with steel breakaway posts is a difficult task. While steel breakaway posts have been successfully used for end terminal designs in the past, it appears that the bullnose system is more sensitive to some of the subtle differences between wooden and steel breakaway posts. The wooden CRT and BCT posts used in the original design take advantage of several inherent properties of wood that are difficult to replicate with steel breakaway post designs. These properties include brittle fracture at relatively low impact loads and clean disengagement of the post from its base. The researchers at MwRSF believe that currently available breakaway steel posts designs do not adequately take this combination of factors into account.

A second study has subsequently been funded by MnDOT to develop a universal, non-proprietary breakaway post. This effort will design a breakaway post that does not use wood, but that mimics the behaviors of the wooden CRT posts that are used in a wide variety of roadside hardware systems. This study is currently underway, and it is hoped that the results of this design effort will be applicable to the thrie beam bullnose system as well.

If you have any questions regarding this information or need any other information, please feel free to contact me by phone at (402) 472-9064 or by email at rbielenberg2@unl.edu.

Sincerely,

Robert W. Bielenberg, M.S.M.E., E.I.T.
Research Associate Engineer
Midwest Roadside Safety Facility
527 Nebraska Hall
Lincoln NE, 68588-0529
402-472-9064
rbielenberg2@unl.edu

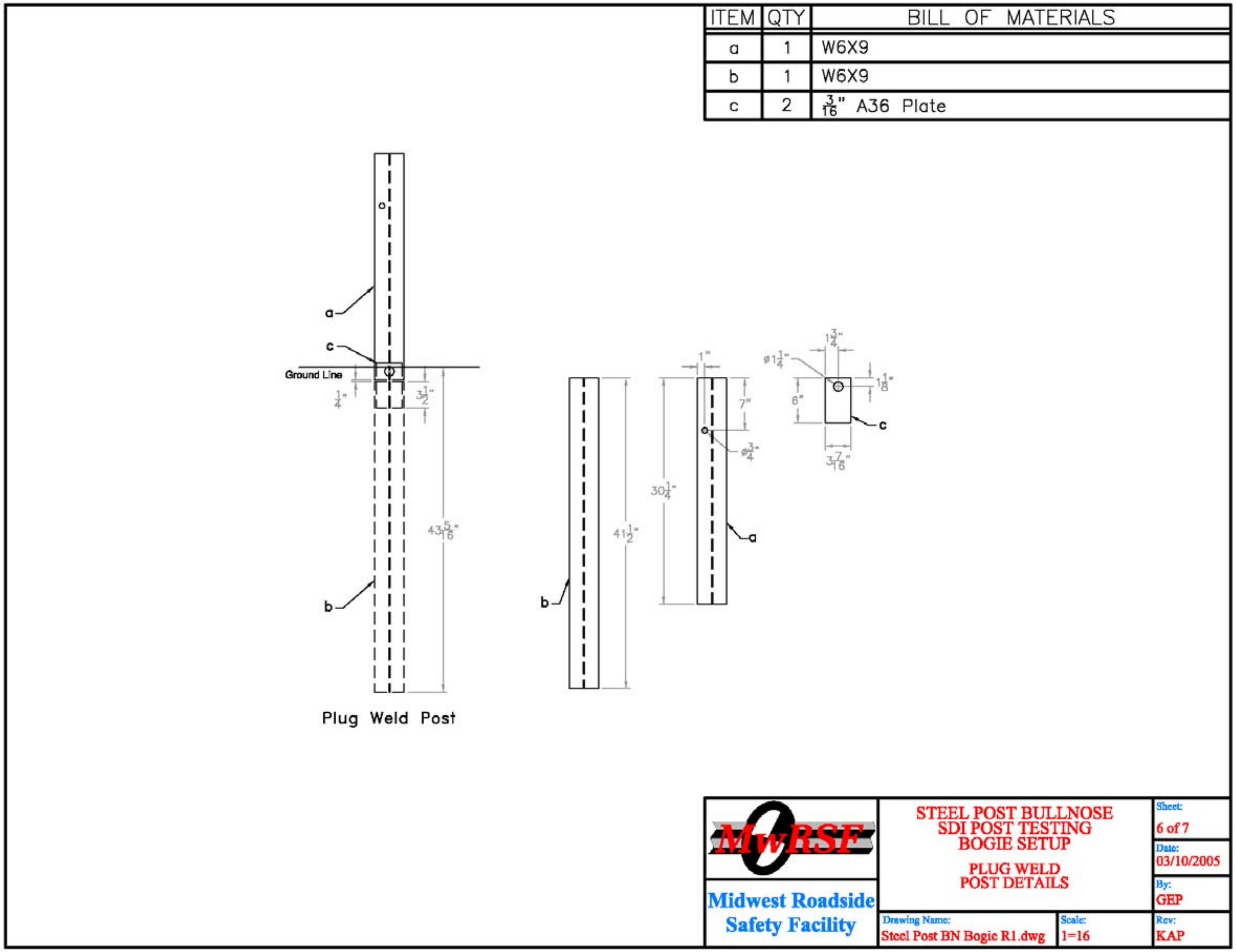


Figure 1. Breakaway Post Component Testing, Plug Weld Post Design

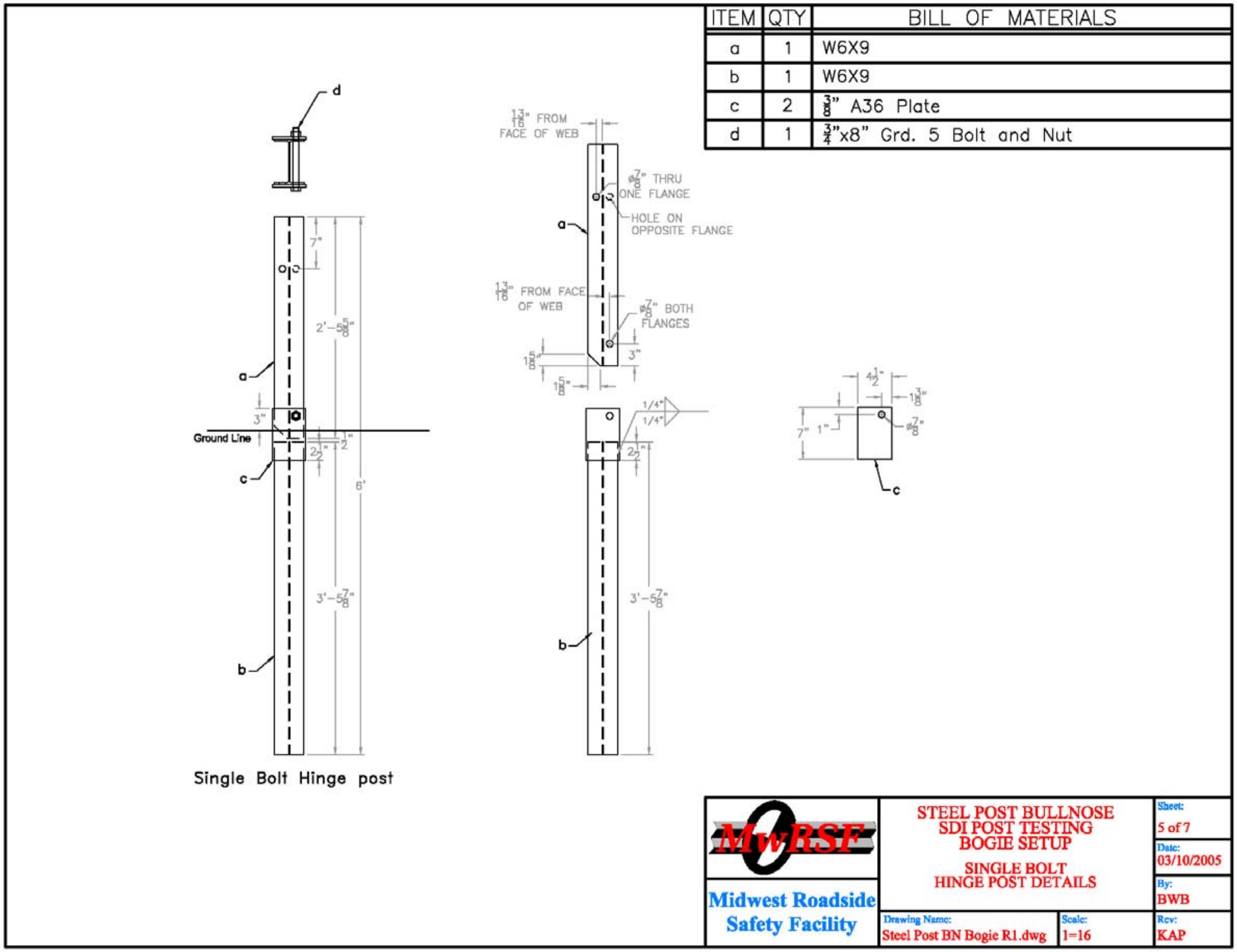


Figure 2. Breakaway Post Component Testing, Hinged Steel Post Design

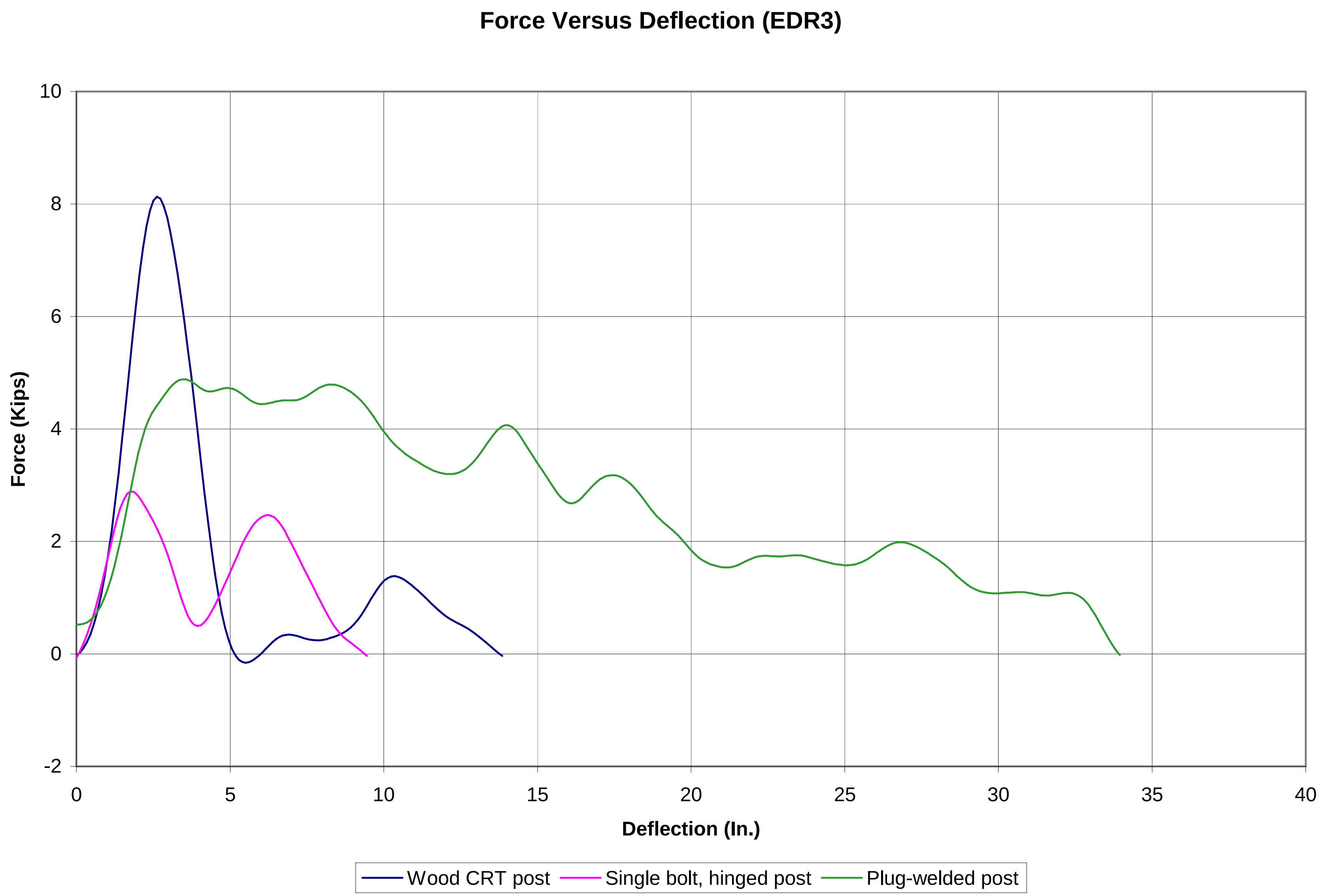


Figure 3. Component Test Results, Force vs. Deflection

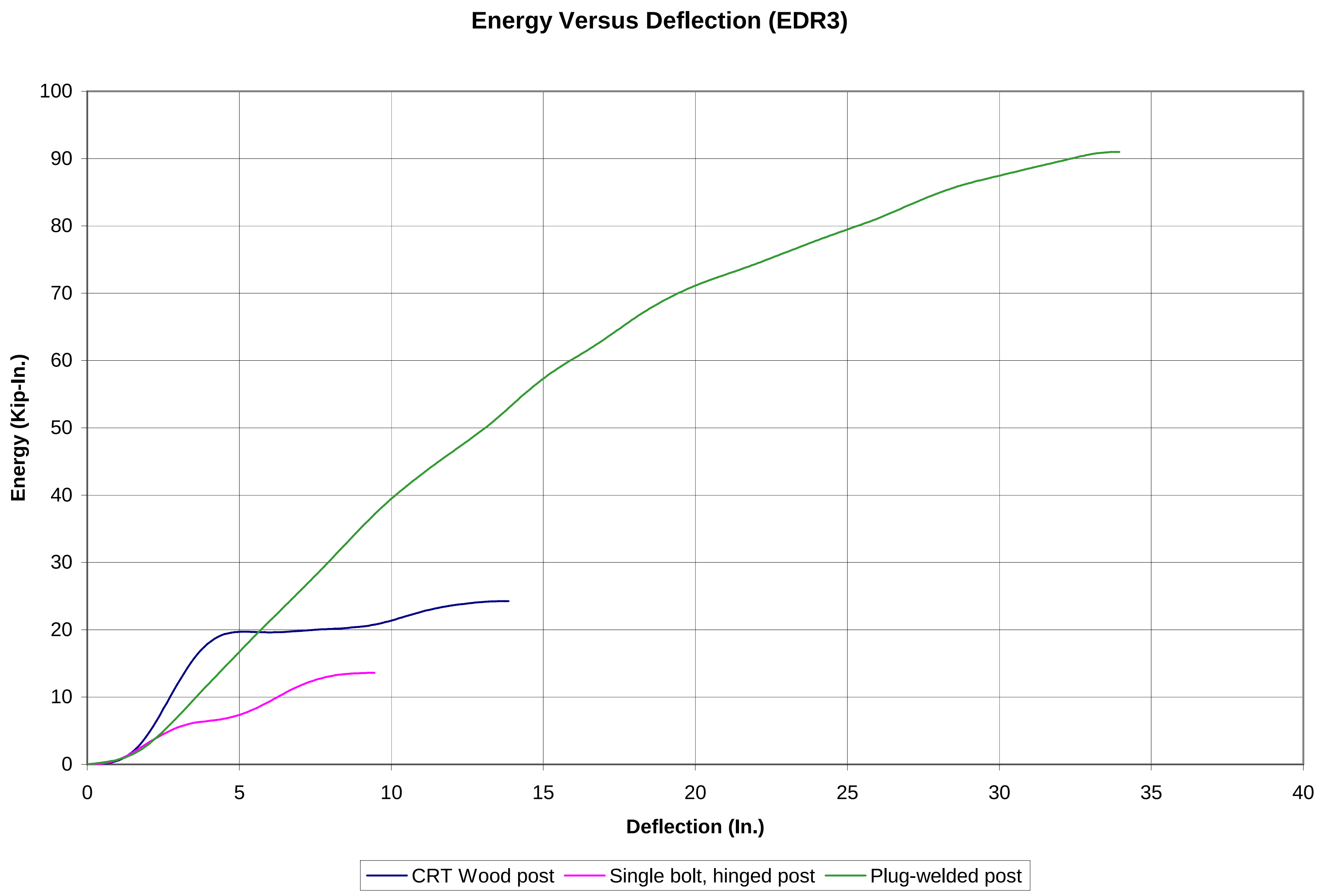


Figure 4. Component Test Results, Energy vs. Deflection

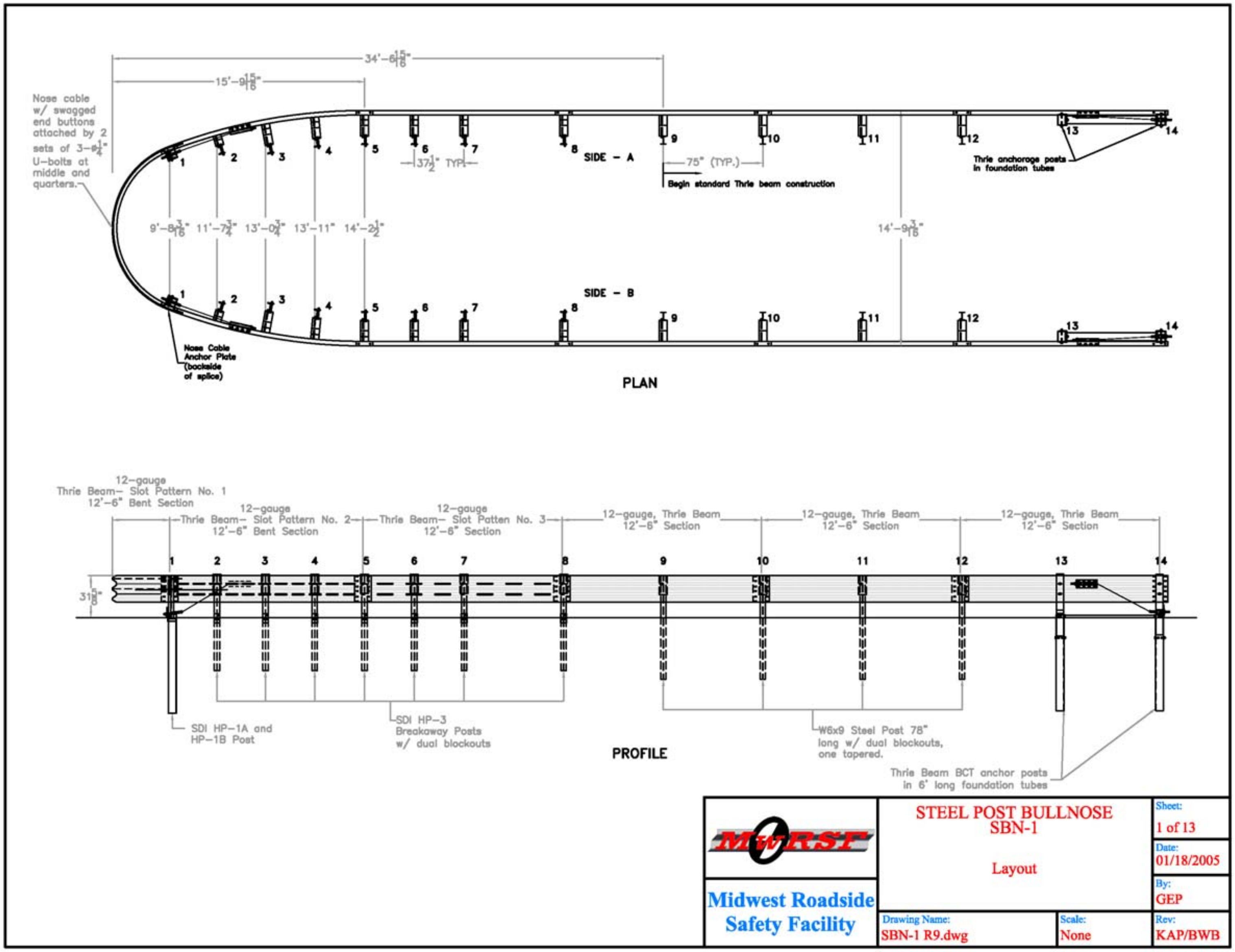


Figure 5. Steel Post Bullnose System, Test No. SBN-1

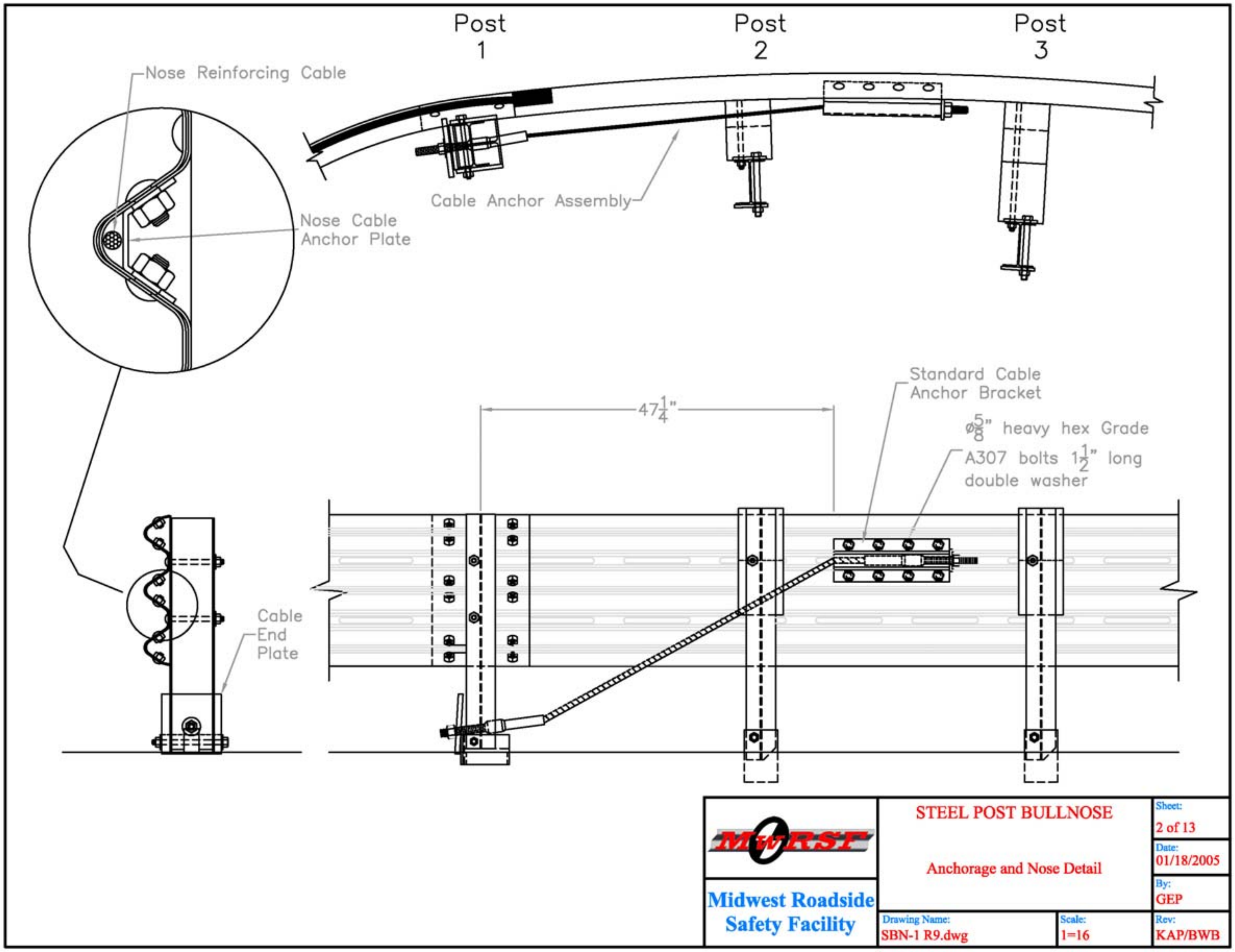


Figure 6. Steel Post Bullnose System, Test No. SBN-1

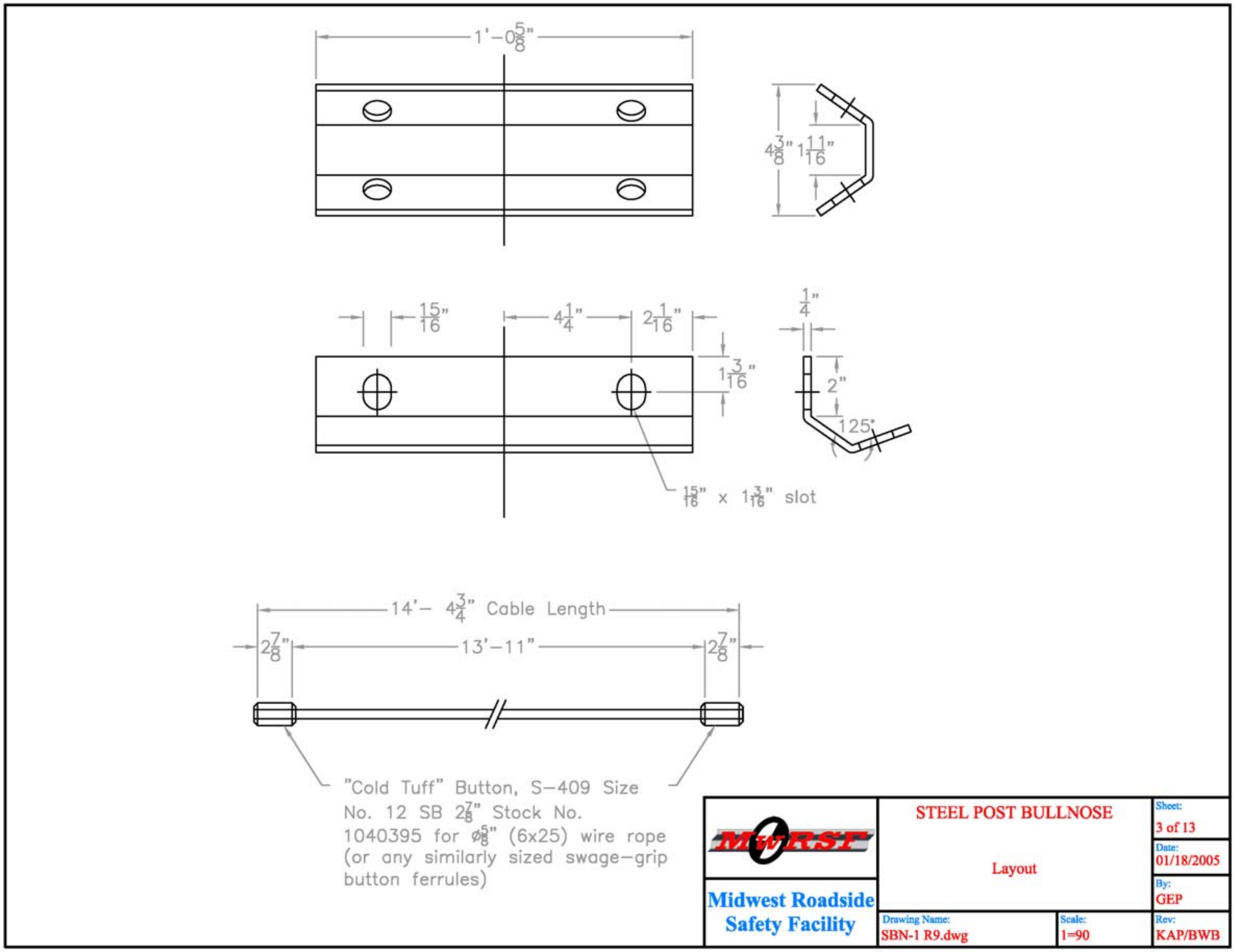


Figure 7. Steel Post Bullnose System, Test No. SBN-1

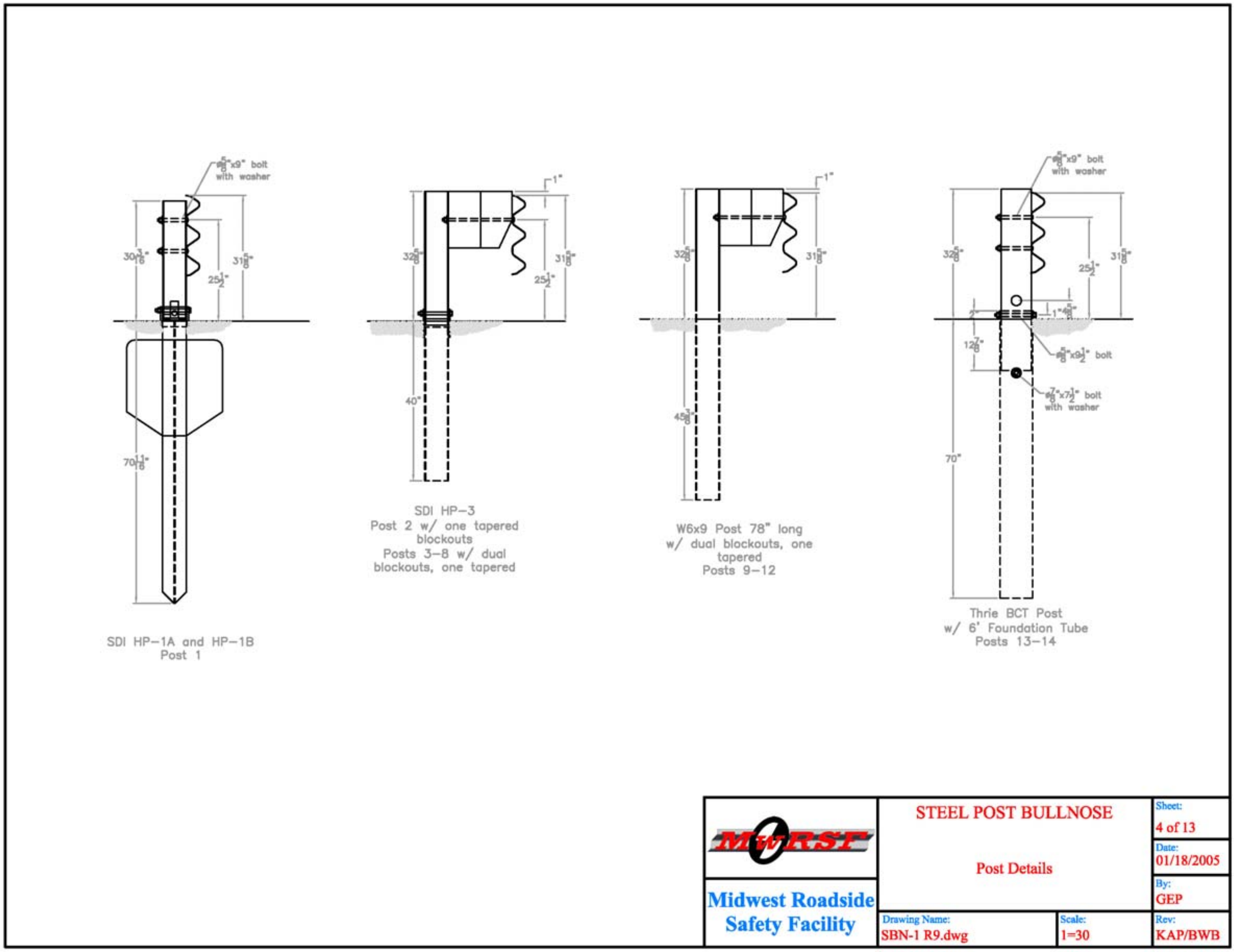


Figure 8. Steel Post Bullnose System, Test No. SBN-1

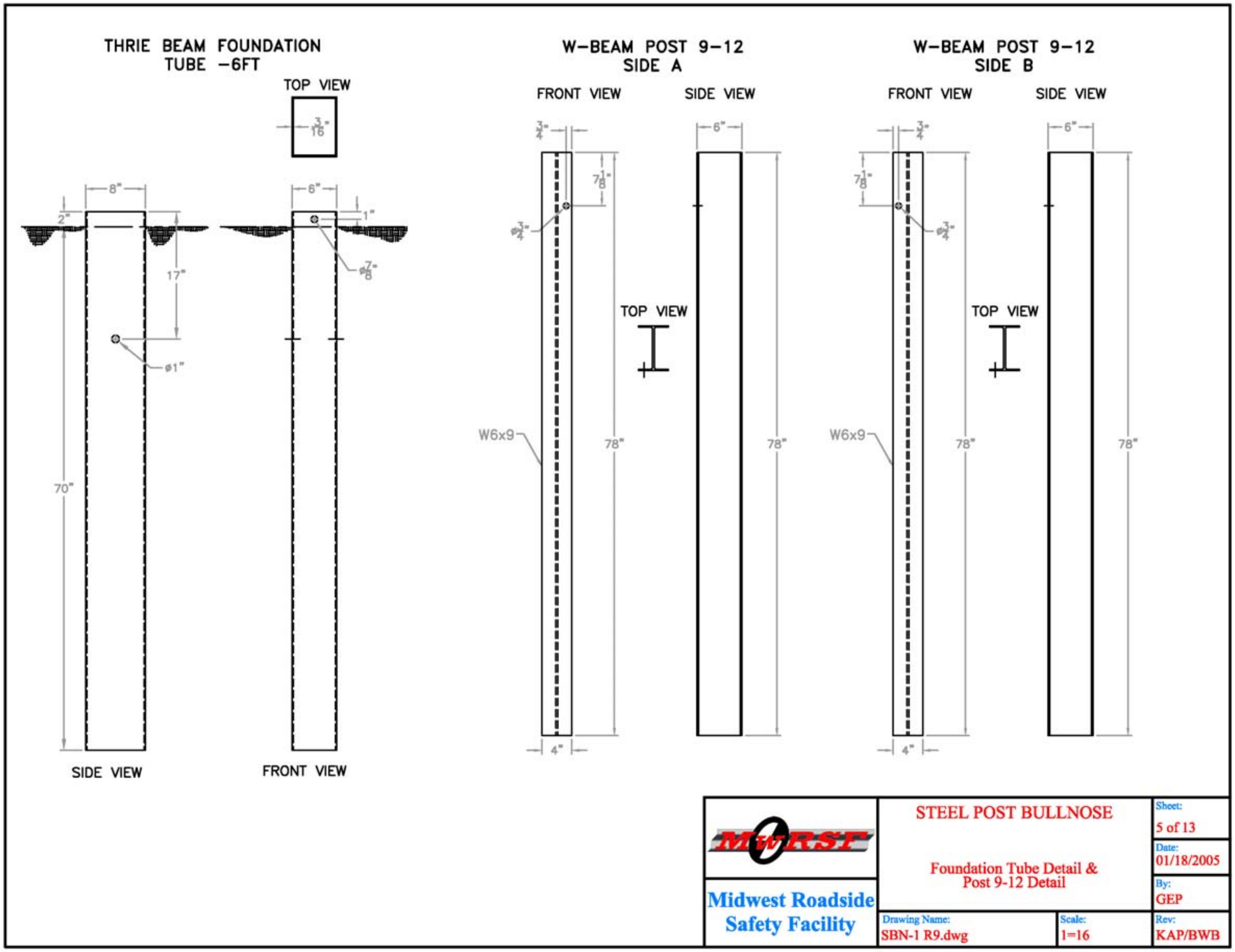


Figure 9. Steel Post Bullnose System, Test No. SBN-1

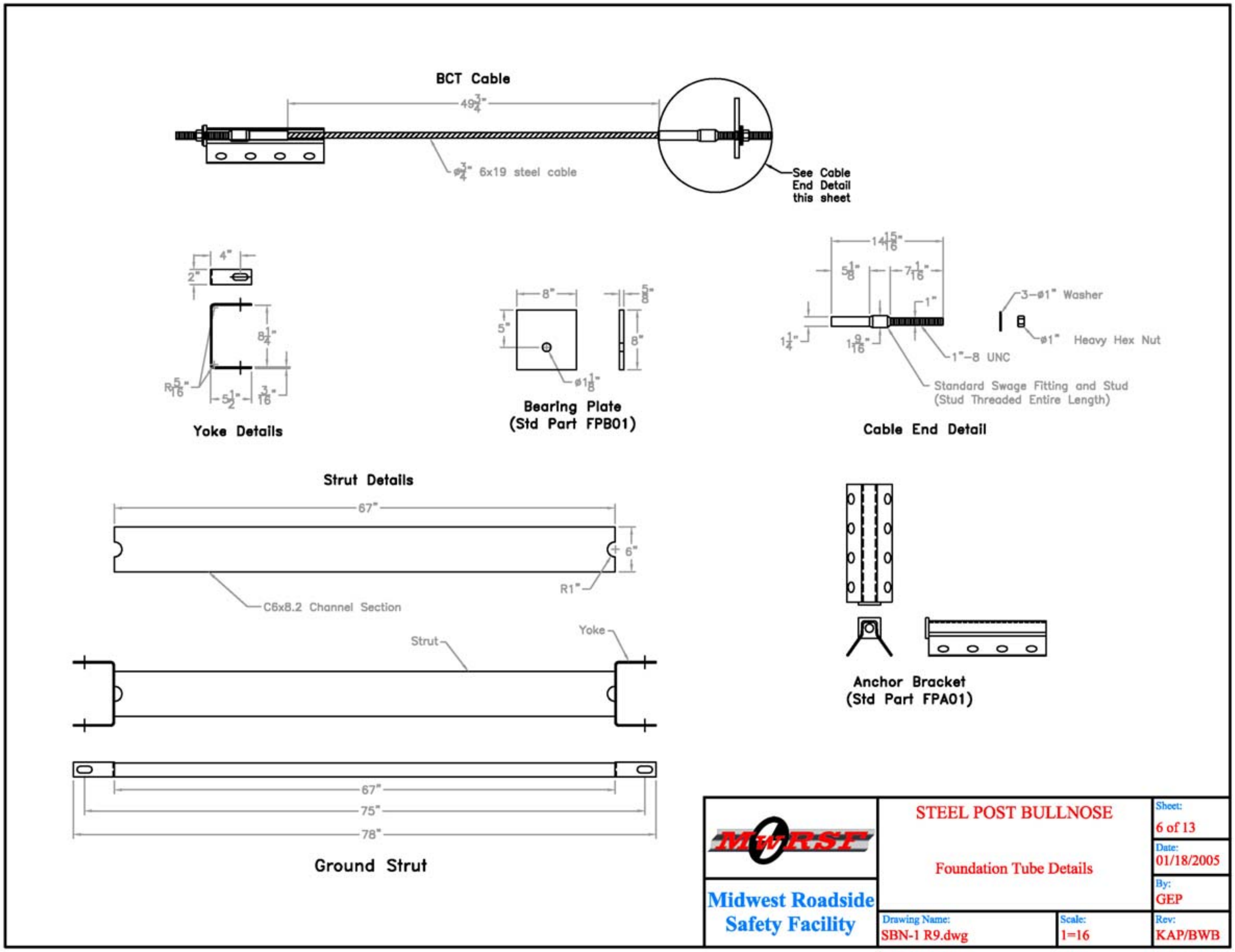


Figure 10. Steel Post Bullnose System, Test No. SBN-1

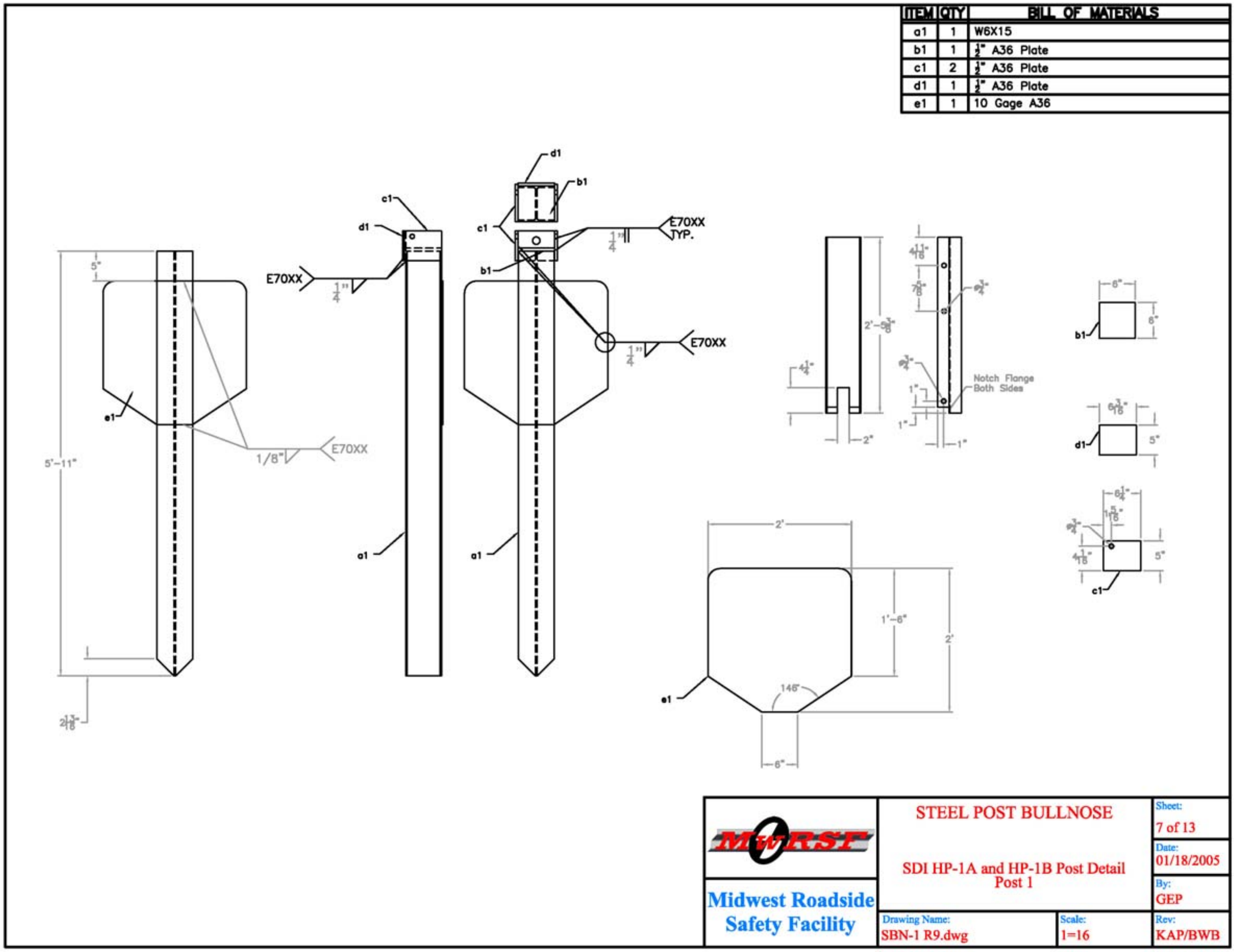
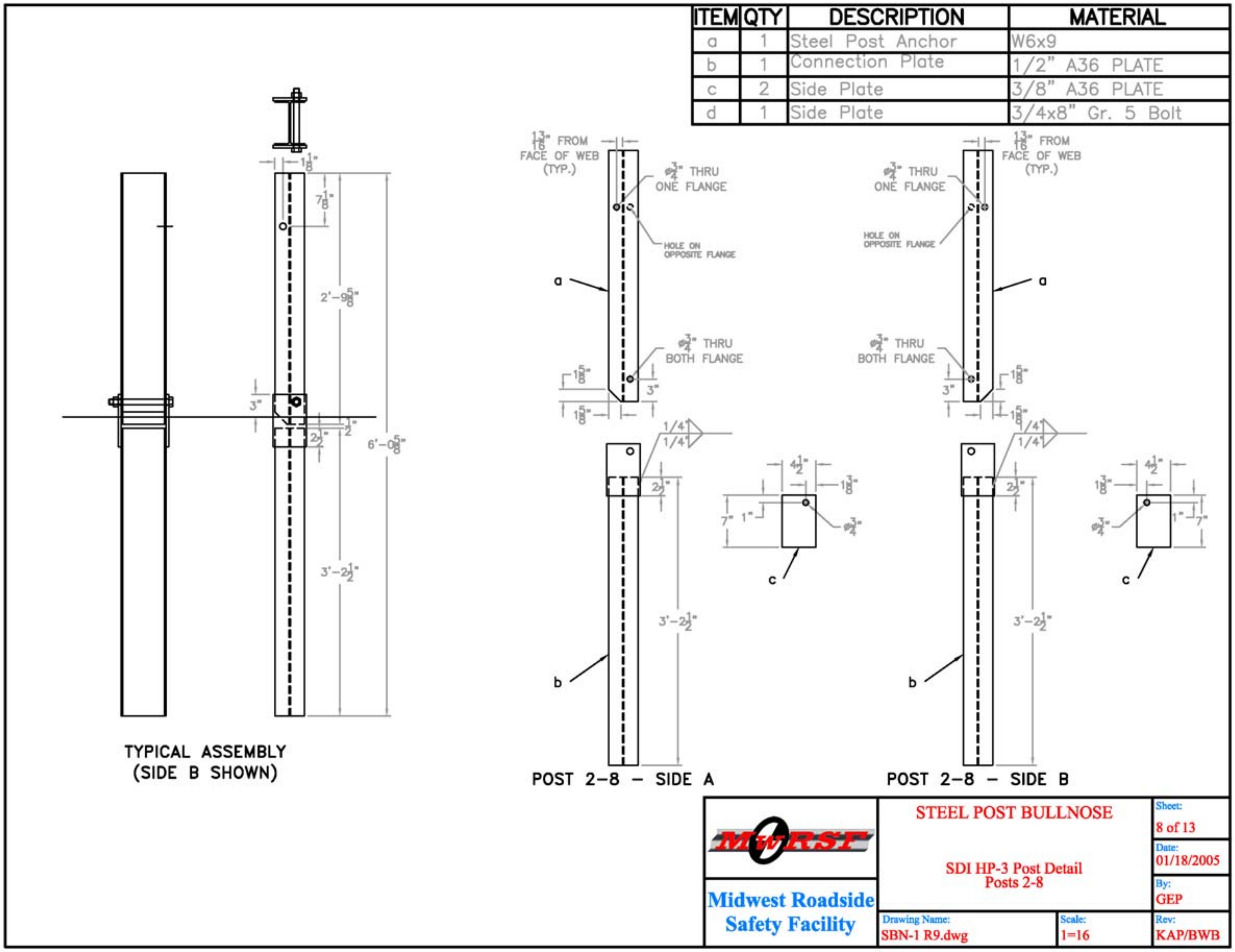


Figure 11. Steel Post Bullnose System, Test No. SBN-1



ITEM	QTY	DESCRIPTION	MATERIAL
a	1	Steel Post Anchor	W6x9
b	1	Connection Plate	1/2" A36 PLATE
c	2	Side Plate	3/8" A36 PLATE
d	1	Side Plate	3/4x8" Gr. 5 Bolt

Figure 12. Steel Post Bullnose System, Test No. SBN-1

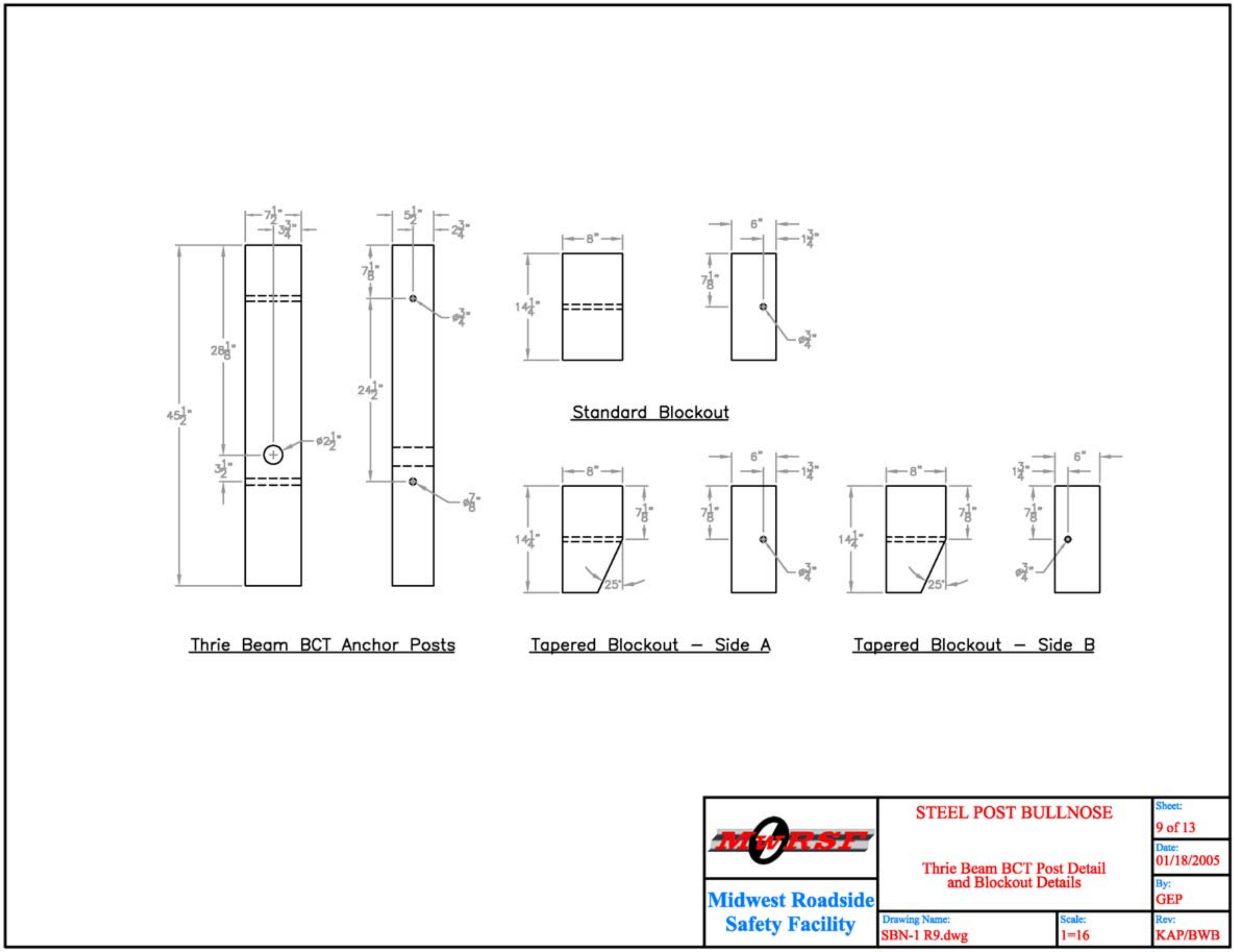


Figure 13. Steel Post Bullnose System, Test No. SBN-1

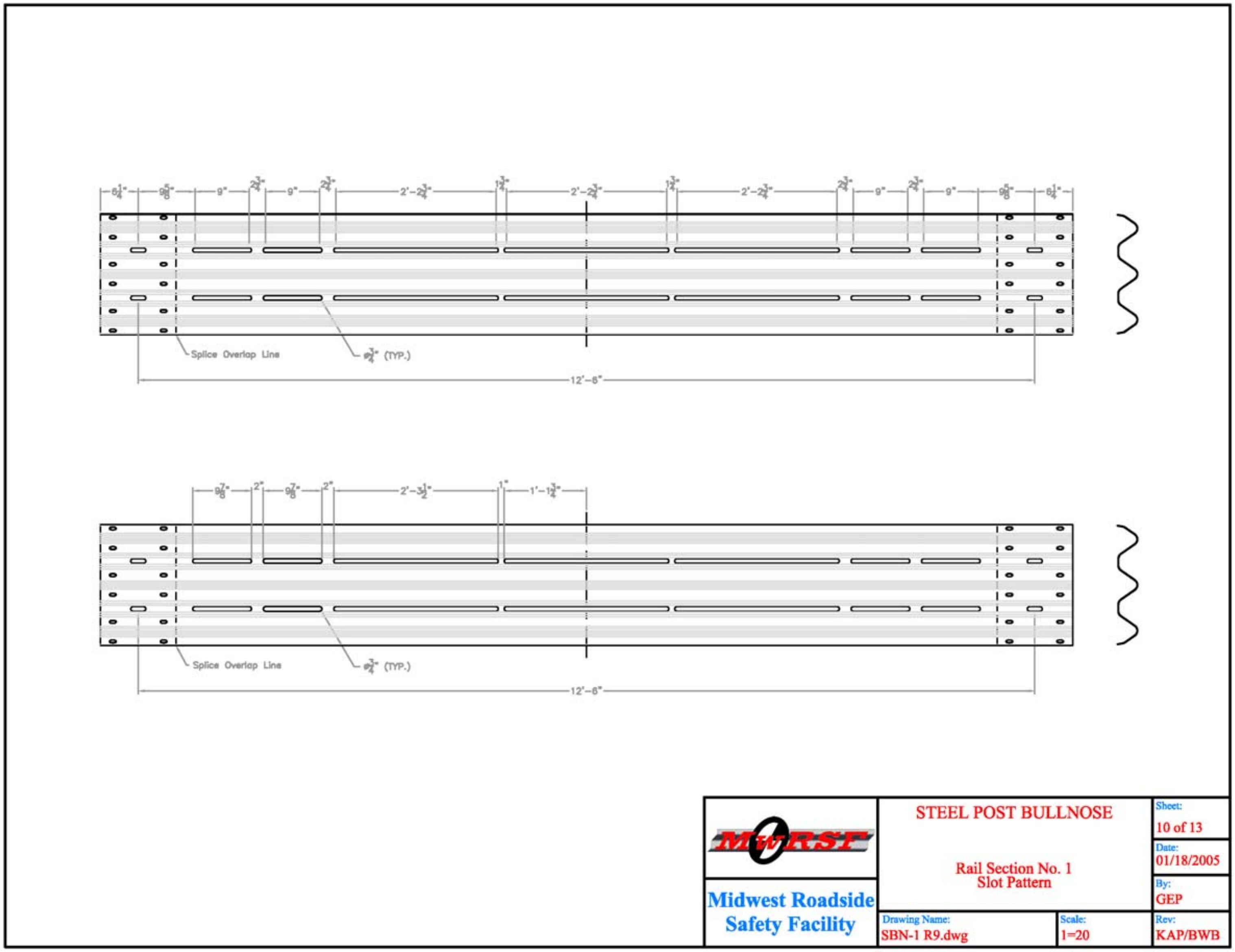


Figure 14. Steel Post Bullnose System, Test No. SBN-1

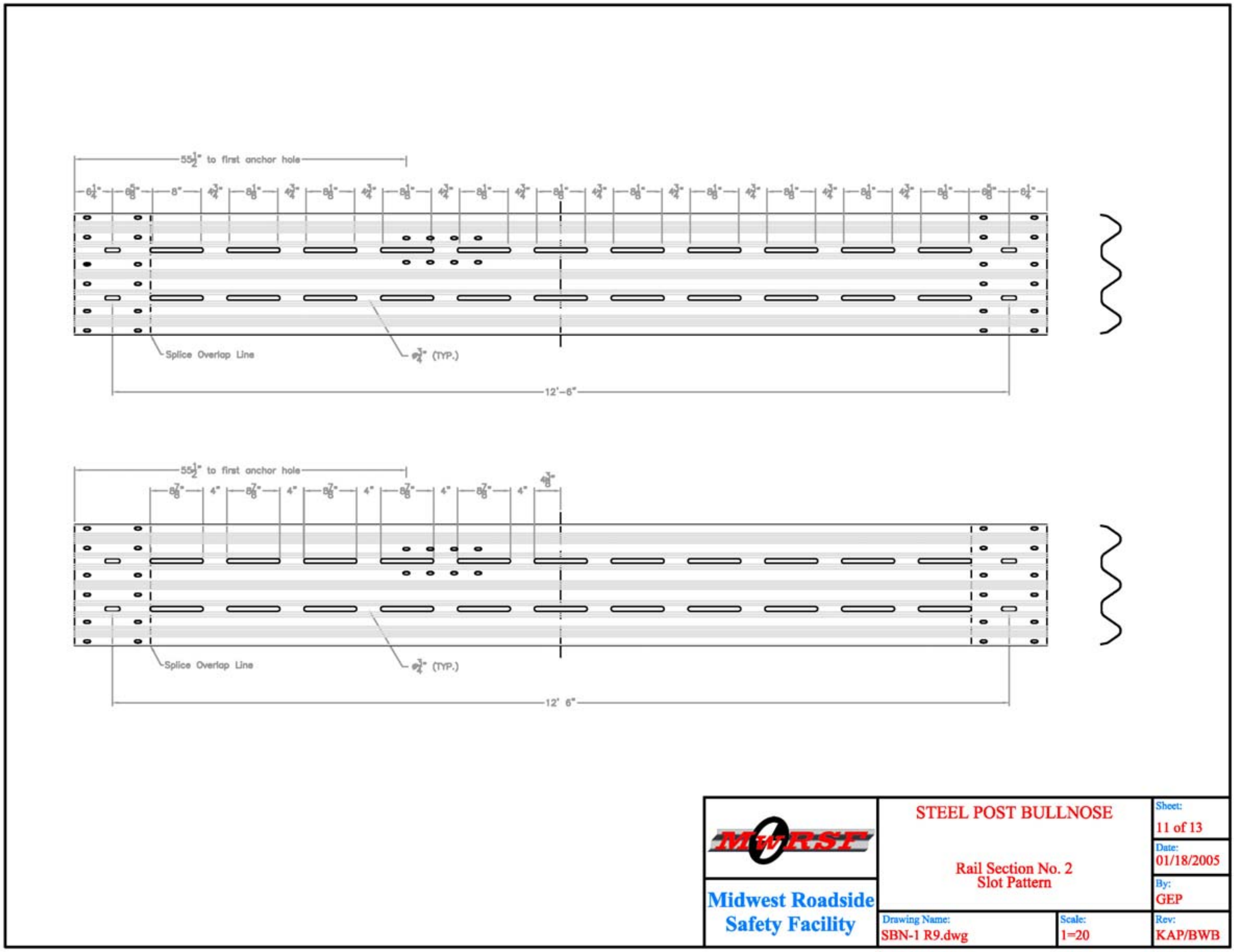


Figure 15. Steel Post Bullnose System, Test No. SBN-1

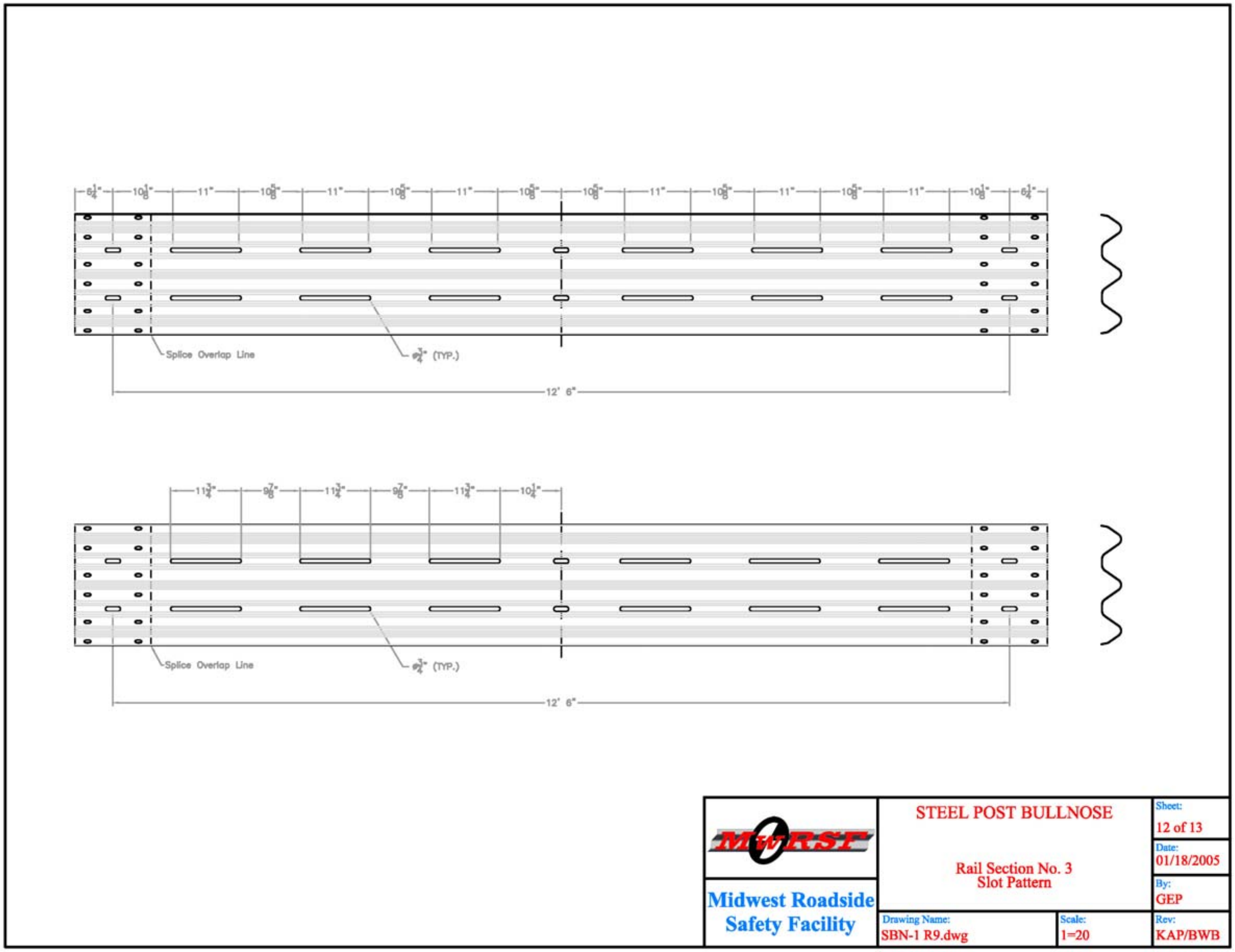


Figure 16. Steel Post Bullnose System, Test No. SBN-1

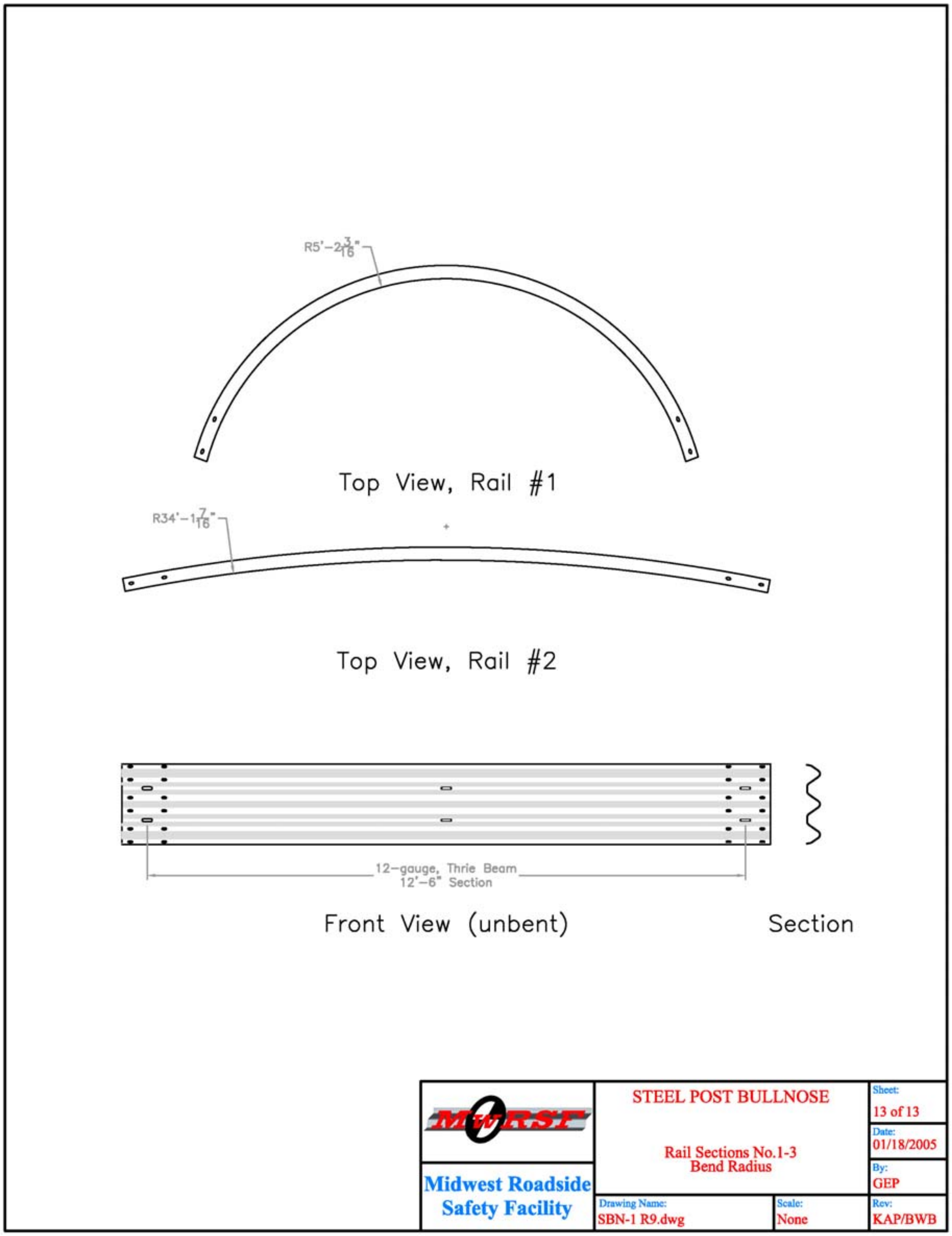
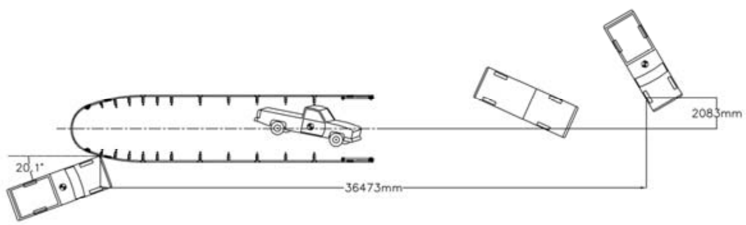
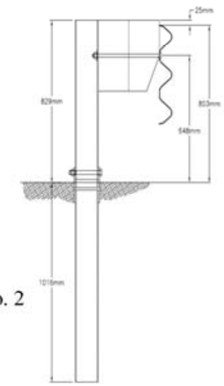


Figure 17. Steel Post Bullnose System, Test No. SBN-1





- Test Agency .... MwRSF
- Test Number SBN-1
- Date 9/14/05
- NCHRP 350 Test Designation 3-11
- Appurtenance .... Steel Post Bullnose
- Total Length .... 20.06 m
- Key Elements - Steel Thrie-Beam
  - Thickness .... 2.67 mm
  - Top Mounting Height .... 803 mm
- Key Elements - Steel Posts
  - Post No. 1 .... SDI HP-1 Breakaway
  - Post Nos. 3-8 .... SDI HP-3 Breakaway Posts
  - Post Nos. 9-12 .... W152 x 13.4 by 978 mm long
- Key Elements - Post Spacing
  - Post Nos. 1-7 .... 952.5 mm
  - Post Nos. 7-14 .... 1,905 mm
- Key Elements - Wood Spacer Blocks
  - Post Nos. 3-12 .... 152 mm x 203 mm by 362 mm long tapered
    152 mm x 203 mm by 362 mm long full-size
- Type of Soil .... Grading B - AASHTO M 147-65 (1990)
- Test Vehicle
  - Type/Designation 2000P
  - Make and Model .... 2000 GMC 2500 3/4-ton pickup truck
  - Curb .... 1,979 kg
  - Test Inertial .... 2,020 kg
  - Gross Static .... 2,020 kg
- Impact Conditions
  - Speed .... 103.1 km/h
  - Angle .... 20.1 degrees
  - Impact Location .... Centerline of Post No. 2
- Exit Conditions
  - Speed .... N/A
  - Angle .... N/A
  - Exit Box Criterion .... N/A
- Post-Impact Trajectory
  - Vehicle Stability .... Unsatisfactory
  - Stopping Distance .... 36.3 m longitudinal
    2.1 m lateral from centerline
- Occupant Impact Velocity
  - Longitudinal .... -7.03 m/s < 12 m/s
  - Lateral (not required) .... 2.18 m/s < 12 m/s
- Occupant Ridedown Deceleration
  - Longitudinal .... -8.18 Gs < 20 Gs
  - Lateral (not required) .... 11.52 Gs < 20 Gs
- THIV (not required) .... 7.26 m/s
- PHD (not required) .... 8.27 Gs
- Test Article Damage .... Extensive
- Test Article Deflections
  - Permanent Set .... N/A
  - Dynamic .... N/A
  - Working Width .... N/A
- Vehicle Damage .... Moderate
  - VDS[5] 11-LFQ-4/11-LFT-4
  - CDC[6] 11-LYA09
  - Maximum Deformation .... 44 mm at right-center floorpan

Figure 18. Summary of Test Results and Sequential Photographs, Test No. SBN-1

MBN-8

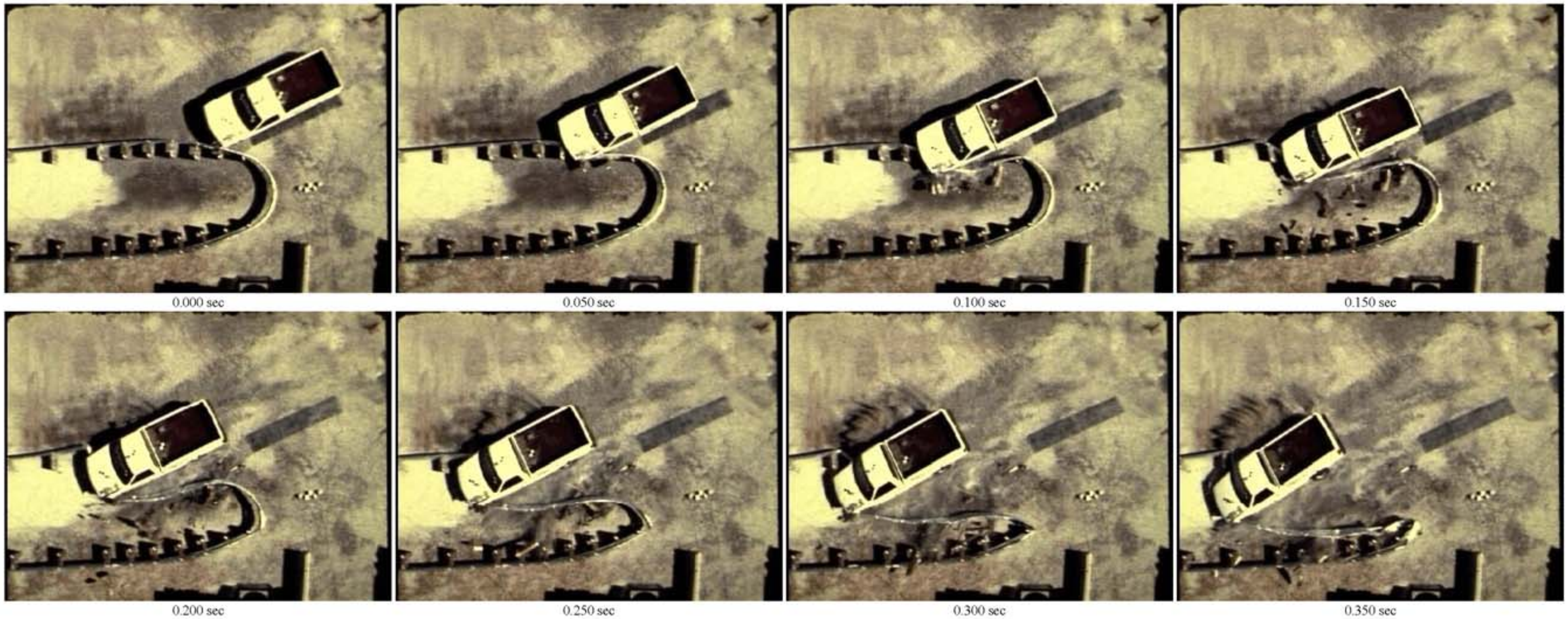


Figure 19. Overhead Sequential Photographs, Test No. MBN-8

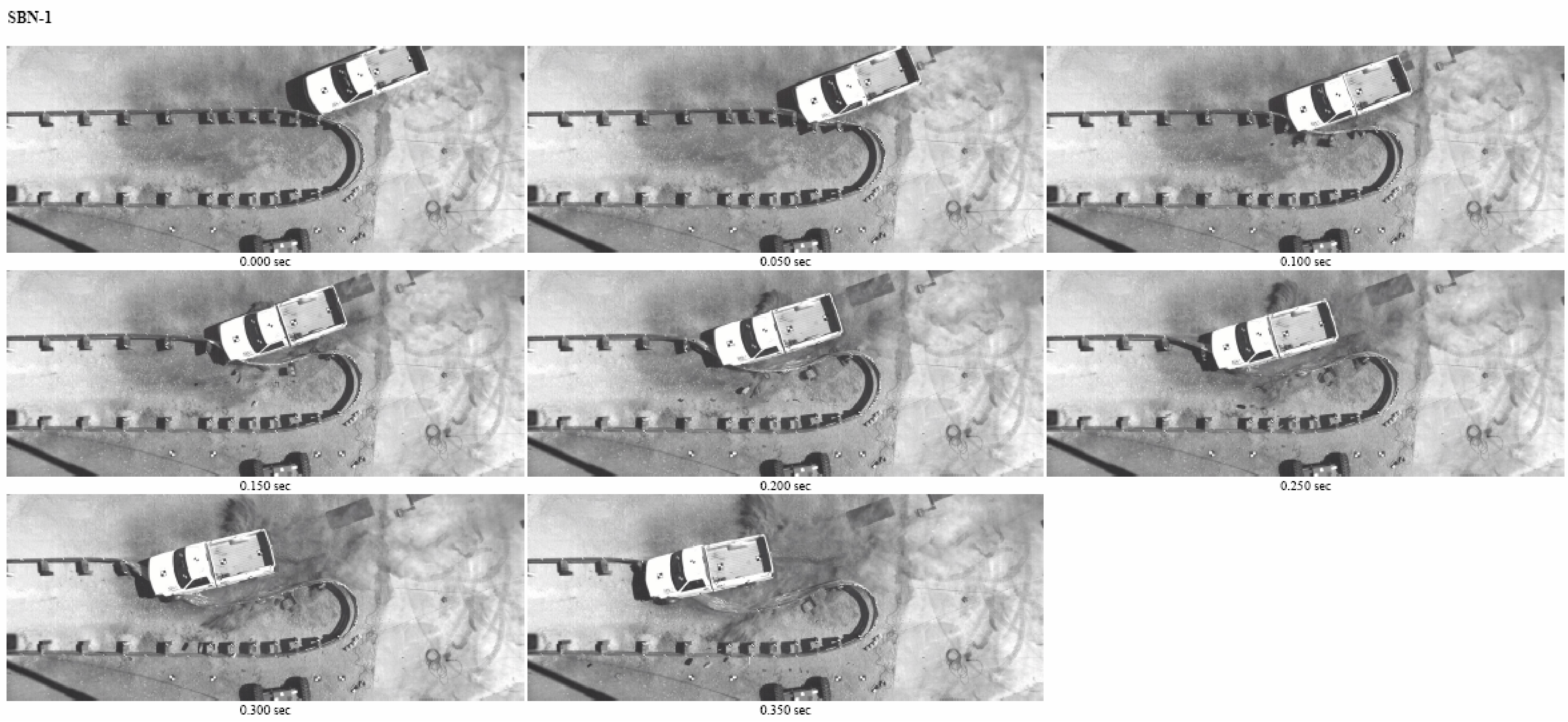


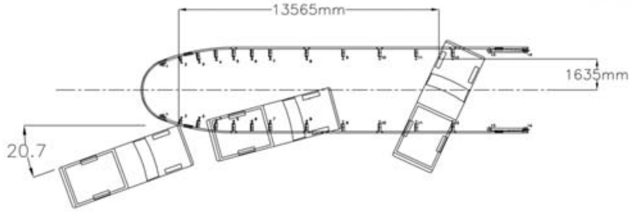
Figure 20. Overhead Sequential Photographs, Test No. SBN-1

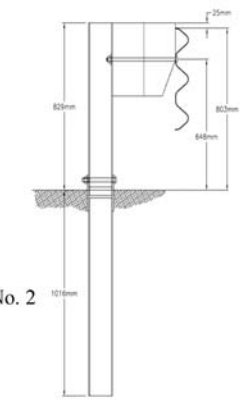
SBN-1

SBN-2

Figure 21. Post No. 1 for Test Nos. SBN-1 and SBN-2

0.000 sec | 0.154 sec | 0.300 sec | 0.464 sec | 0.712 sec





- Test Agency . . . . MwRSF
- Test Number SBN-2
- Date 1/25/06
- NCHRP 350 Test Designation 3-11
- Appurtenance . . . . Steel Post Bullnose Median Barrier
- Total Length . . . . 20.06 m
- Key Elements - Steel Thrie-Beam
  - Thickness . . . . 2.67 mm
  - Top Mounting Height . . . . 803 mm
- Key Elements - Steel Posts
  - Post No. 1 . . . . SDI HP-1 Breakaway
  - Post Nos. 3-8 . . . . SDI HP-3 Breakaway Posts
  - Post Nos. 9-12 . . . . W152 x 13.4 by 978 mm long
- Key Elements - Wood Posts
  - Post No. 1 . . . . Thrie Beam BCT Post in 2,438-mm foundation tube
- Key Elements - Post Spacing
  - Post Nos. 1-7 . . . . 952.5 mm
  - Post Nos. 7-14 . . . . 1,905 mm
- Key Elements - Wood Spacer Blocks
  - Post Nos. 3-12 . . . . 152 mm x 203 mm by 362 mm long tapered
    152 mm x 203 mm by 362 mm long full-size
- Type of Soil . . . . Grading B - AASHTO M 147-65 (1990)
- Test Vehicle
  - Type/Designation 2000P
  - Make and Model . . . . 2000 GMC 2500 3/4-ton pickup
  - Curb . . . . 1,980 kg
  - Test Inertial . . . . 2,002 kg
  - Gross Static . . . . 2,002 kg

- Impact Conditions
  - Speed . . . . 101.3 km/h
  - Angle . . . . 20.7 degrees
  - Impact Location . . . . Centerline of Post No. 2
- Exit Conditions
  - Speed . . . . N/A
  - Angle . . . . N/A
  - Exit Box Criterion . . . . N/A
- Post-Impact Trajectory
  - Vehicle Stability . . . . Satisfactory
  - Stopping Distance . . . . 13.6 m longitudinal
    1.5 m lateral from centerline
- Occupant Impact Velocity (350 Update)
  - Longitudinal . . . . -8.32 m/s < 12 m/s
  - Lateral . . . . 1.40 m/s < 12 m/s
- Occupant Ridedown Deceleration (350 Update)
  - Longitudinal . . . . -8.24 Gs < 20 Gs
  - Lateral . . . . -9.36 Gs < 20 Gs
- THIV (not required) . . . . 8.05 m/s
- PHD (not required) . . . . 11.25 Gs
- Test Article Damage . . . . Extensive
- Test Article Deflections
  - Permanent Set . . . . N/A
  - Dynamic . . . . N/A
  - Working Width . . . . N/A
- Vehicle Damage . . . . Moderate
  - VDS[5] 11-LFQ-3
  - CDC[6] 11-LFEN5
  - Maximum Deformation . . . . 13 mm at left-center floorpan

Figure 22. Summary of Test Results and Sequential Photographs, Test No. SBN-2