Third Quarter 2007 Progress Report
Midwest Roadside Safety Facility
Mid-States Regional Pooled Fund
October 25, 2007

Projects with Full-Scale Crash Tests This Quarter

Test SR-8, the last test in the currently funded project, was performed on August 1^{st}. While the truck was brought to a controlled stop, wheels down, the system failed to capture the vehicle, so the test must be considered a failure. Given that this is the last funded crash test of the system the direction of the project will need to be considered in the next pooled fund meeting. A summary of SR-7 and SR-8 is appended to this report.



Projects with Pending Full-Scale Crash Tests

Development of a Four-Strand, High-Performance Cable Barrier

A series of bogie tests were completed this Quarter to evaluate system hardware. Excavation work on the v-ditch has been completed. System construction is complete. Three full-scale crash tests of the new system utilizing update vehicles (1 @ 1100C, 1 @ 2270P and 1 @ 10,000S) are planned to verify performance in a V-ditch. After significant delays due to weather (as shown), the first test of this system was performed in October, 2007. A 2270P vehicle was safely redirected and the system is being reconstructed for an 1100C test. This will be reported in more detail in the 4^{th} Quarter report.

Testing of Cable Terminal for High Tension Cable (1100C & 2270P)

Work on this project will commence after testing of the high-tension system.

Performance Limits for 6-inch high Curb Placed in Advance in Advance of the MGS

A series of high speed curb tests are planned in the 3^{rd} Quarter to evaluate vehicle trajectory. This data will be utilized as input to the modeling effort for the project. This modeling effort will determine the worst case location for the rail behind the curb for both the 1100C and 2270P to allow a single test to demonstrate the suitability of locating the MGS system any distance behind the curb.

Standardizing Posts and Hardware for MGS Transition

Bogie testing of posts for this system has been undertaken in this quarter. Modeling of the system and final design are near finalization. Full-scale testing is planned for the 4^{th} Quarter.

Development of an MGS Bridge Rail

A literature review and preliminary design are planned for the 4th Quarter.

Development of a Temporary Concrete Barrier Transition

After a survey of the States, we are going to utilize a 42" high single slope permanent barrier for this study. This barrier is the practical worst case identified as important. Currently we are casting the wall section and using finite element analysis to design the transition.

Paper Studies

Cost-Effective Measures for Roadside Design on Low Volume Roads

The first field trip was completed during the 3rd Quarter. We are looking at additional sites in Butler, Saunders and Johnson counties in Nebraska.

Submission of Pooled Fund Guardrail Developments to AASHTO TF-13 Hardware Guide

To date 19 systems have been submitted to TF-13 for review and approval. Ten systems were approved for the Guide at the September meeting. Nine more were submitted for review in September. We are currently waiting for comments.

Development of Warrants for Median Barrier System

The analysis of accidents for this study has been completed. A report should be completed in the 4th Quarter.

Cost Effective Upgrading of Existing Guardrail System

The literature review of previous w-beam accident studies has been completed. We are currently looking for highway sites for the study.

Awaiting Reporting

Evaluation of Transverse Culvert Safety Grate

The culvert grate on a 3:1 slope performed well with both the 2000P and 820C vehicle. Report in progress, a TRB paper was prepared and accepted for 2008.

Approach Slopes for W-Beam Guardrails Systems

As a conclusion of this testing, the MGS guardrail system can safely be located any offset distance from the travel way on slopes of 8:1 or flatter. A draft report is currently under internal review.

Retest of the Cable End Terminal

Based on successful testing of this system, a draft report of the project is currently under internal review.

Flare Rates for MGS W-Beam Guardrail

This testing has shown that the MGS can be installed at up to a 5:1 flare rate to the travel way. A report on this project will be initiated. We have prepared a paper for the 2007 TRB meeting based on this project. Report under internal review.

Midwest Guardrail System on Breakpoint of a 2:1 Slope

An MGS system utilizing 9' W6X9 posts spaced at 75" was tested utilizing a 2270P update vehicle on 12/15/06. The vehicle was safely redirected.

Three-Cable Guardrail

The system, utilizing non-tensioned cable, an offset distance of 48" from the breakpoint of the slope and 4' post spacing was tested on 11/1/06. The vehicle was safely redirected. Report under internal review.

Termination of Temporary Concrete Barrier

An anchor system utilizing 2 driven steel anchors from the existing cable system was tested with a 2270P impacting 4' 3.6" upstream of the joint between barriers 1&2. The test met all salient test criteria.

Concept Development of a Bridge Pier Protection System for Longitudinal Barrier

A full-scale test of the pier protection system was run on July 3rd. The 2000P vehicle impacted the system 64.8 mph and at 25.65° The vehicle had minimal contact with the pier and met all other salient criteria. The barrier as designed had minimal displacement and would be considered structurally adequate for the design impact.

Reports Published this Quarter

Stolle, C.S., Faller, R.K., and Polivka, K.A., Dynamic Impact Testing of S76x8.5 (S3x5.7) Steel Posts for Use in Cable Guardrail Systems, Draft Report to the Midwest States' Regional Pooled Fund Program, Transportation Research Report No. TRP-03-186-07, Project No. SPR-3(017)-Year 14, Project Code: RPFP-04-01, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, August 6, 2007.

Bielenberg, R.W., Faller, R.K., Rohde, J.R., Reid, J.D., Sicking, D.L., Holloway, J.C., Allison, E.M., and Polivka, K.A., Midwest Guardrail System for Long-Span Culvert Applications, Draft Report to the Midwest States' Regional Pooled Fund Program, Transportation Research Report No. TRP-03-187-07, Project No. SPR-3(017)-Year 15, Project Code: RPFP-05-04, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, August 17, 2007.

Stolle, C.S., Polivka, K.A., Bielenberg, R.W., Reid, J.D., Faller, R.K., Rohde, J.R., and Sicking, D.L., Phase III Development of a Short-Radius Guardrail for Intersecting Roadways, Draft Report to the Midwest States' Regional Pooled Fund Program, Transportation Research Report No. TRP-03-183-07, Project No. SPR-3(017)-Year 12, Project Code: RPFP-02-02, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, August 21, 2007.

Wiebelhaus, M.J., Polivka, K.A., Faller, R.K., Rohde, J.R., Sicking, D.L., Holloway, J.C., Reid, J.D., and Bielenberg, R.W., Evaluation of Rigid Hazards Placed in the Zone of Intrusion, Draft Report to the Midwest States' Regional Pooled Fund Program, Transportation Research Report No. TRP-03-151-07, Project No. SPR-3(017)-Year 13, Project Code: RPFP-03-03, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, August 29, 2007.

Eller, C.M., Polivka, K.A., Faller, R.K., Sicking, D.L., Rohde, J.R., Reid, J.D., Bielenberg, R.W., and Allison, E.M., Development of the Midwest Guardrail System (MGS) W-Beam to Thrie Beam Transition Element, Draft Report to the Midwest States' Regional Pooled Fund Program, Transportation Research Report No. TRP-03-167-07, Project No. SPR-3(017)-Years 11-12 and 16, Project Codes: RPFP-01-04, RPFP-02-05, and RPFP-06-04, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, September 10, 2007.

Rosenbaugh, S.K., Sicking, D.L., and Faller, R.K., Development of a TL-5 Vertical Faced Concrete Median Barrier Incorporating Head Ejection Criteria, Draft Report to the Midwest States' Regional Pooled Fund Program, Transportation Research Report No. TRP-03-194-07, Project No. SPR-3(017)-Year 15, Project Code: RPFP-05-01, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, September 26, 2007.

Pooled Fund Consulting Summary

Midwest Roadside Safety Facility
July 2007– October 2007

This is a brief summary of the consulting problems presented to the Midwest Roadside Safety Facility over the past quarter and the solutions we have proposed.

Problem # 1 – Existing Guardrail on Slope

State Question:

In this contract, we are widening the Tri-state Tollway embankments for the fourth lane to be constructed in 2008 (Southbound) and 2009 (Northbound). The work included topsoil removal, embankment and retaining wall construction. No work was performed on the existing pavement or shoulder. The intent of this first contract was to leave the existing guardrail in place. In 2008 or 2009, the guardrail would be removed and replaced with new.

During construction,the contractor designed mechanically stabilized retaining walls required longer tie-backs than assumed in design. This required additional excavation that extended to the guardrail/back of shoulder and resulted in a need to support the guardrail when the shoulder is reopened to traffic at the end of this contract.

A solution was suggested to drive a new post behind the existing to provide necessary support. Will this work? If not do you have any other options to consider.

They have removed the embankment from around/behind the guardrail posts to a depth of about 2’ below the original grade. The existing guardrail is our former strong post system with 6’-9” long posts, and a top of rail height of 27.5”, using 6” blockouts.

Does their suggestion to drive additional posts to back up the existing appear feasible? What would we need to determine an appropriate post length and size?

It does not seem likely to me that the back up posts would work. It appears that a vehicle deflecting the rail over the 2’ vertical drop might roll or snag on the posts. My suggestion was that they re-establish some fill around and behind the posts. Another thought might be to add a rub rail below the w-beam.

Any comments or other ideas would be welcomed.

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MwRSF Response:

Hello David!

It is my understanding that your current situation involves the placement of guardrail posts at the slope breakpoint. However, it is unclear to me in the drawing as to whether the side slope is a 2:1 or flatter. If the roadside embankment is 2:1 or flatter, MwRSF has developed two different TL-3 guardrail systems for this situation. The first system was developed several years ago and utilized metric height (27 ¾-in.), strong-post W-beam guardrail with 8-in. blocks and 7-ft long steel posts spaced 37 ½-in. on center (half-post spacing). The second system was recently developed using the MGS technologies. For this MGS W-beam guardrail, a 31-in. mounting height was used with 9-ft long steel posts, 12-deep blockouts, and a standard post spacing (6 ft – 3 in.).

As an alternative, it would be acceptable to re-establish the 2 ft of compacted roadside fill behind the posts in order to allow for the installation of standard, strong-post W-beam guardrail systems. However, it would seem to me to be much more costly to redo the earthwork than to place one of the two recommended guardrail systems described above.

Finally, I am not in favor of utilizing the second backup post behind another one as we would not know how this combination would perform under full-scale testing.

P.S. – If your other guardrail system is already in place, it may be possible to drive intermediate posts measuring 7-ft long in order top account for the half-post spacing posts. Then, the rail would likely need to be raised to the metric rail height of 27 ¾ in. along with the replacement of 6-in. blocks with 8-in. blocks. With this system, the only non-standard part would be every other post would be 3-in. shallower than designed using system no. 1 noted above. I will see whether Bob or Dean have anything to add to this comment or if they disagree with this last possible alternative.

Ron Faller

Problem # 2 – Multiple Questions

State Question:

Hi Ron!

I've been saving up some of my questions for you and I figure now I've got enough to shoot you an email. But before I get into the real nuts-and-bolts questions, I was wondering if you have any knowledge regarding an email list the pooled fund states requested at the last meeting. We requested that MwRSF send out some sort of an "update" email periodically to all the states in order to share questions that had been asked and answers you had provided. Do you remember this? If so, do you know what the status is?

Okay, on to the "real" stuff:

1. We’ve had several questions/issues come up recently regarding bridge end sections:
    a. The amount of reinforcing required in our “standard” end section is believed to be contributing to voids in the concrete (this is only speculation). Would it be feasible to reduce the amount of steel without affecting the crashworthiness of the guardrail connection? If so, what is the minimum strength requirement for the end section?

    b. How much variability are we allowed when it comes to the shape of an end section? Specifically – how much can we vary the overall length of the end section and the angle of the leading chamfer? Looking at other states’ standards, there appears to be quite a variety of shapes used. Am I to assume they have all been crash tested?

    c. Due to the proximity of our first guardrail post to the leading edge of our end sections, some contractors have complained that they cannot drive that post and must instead excavate and backfill by hand. Is it possible to increase that gap distance or must it stay constant?

    d. I have seen other states lengthen or shorten the “overlap” of the guardrail connection at the bridge end based on some conditions. Do you know what this is accomplishing? What are your thoughts on this practice?

2. Are you aware of any research regarding what effect, if any, low temperatures would have on the crashworthiness of steel bridge rails?

3. On some of our construction jobs I have seen where a contractor has overlapped freestanding Temporary Barrier Rail directly in front of a permanent concrete barrier or bridge rail as a means of terminating the TBR. Typically this has been accomplished with only one or two sections of TBR resting in front of the permanent barrier. Would you consider this an approved practice? If not, would there be a minimum number of TBR sections that would need to be overlapped in front of the permanent barrier in order for it to function properly?

4. Finally, do you have a method for attaching the MGS directly to a paved sidewalk or through the top of an intake? If not, are we able to develop our own based on a current design with standard guardrail?

Hopefully this is not too much for you to digest all at once. If so, please tell me and I will send any future questions individually. Of course, if you need copies of any of our current standards referenced above, just let me know. I appreciate your help.

-Chris

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MwRSF Response:

Chris:

Thanks for the email inquiry and questions.

With regard to your first question, I am not aware of the email list being prepared by Amy or Jodi and for dealing with State DOT questions. For some reasons, I do not recall this discussion. However, the discussion that I do recall involved setting up a email group for addressing correspondence on the "Implementation of the MGS" project using consulting funds. I have yet to obtain an email list for this effort from Amy/Jodi but will remind them that we asked for this at the spring meeting. Maybe my mind is going out and I cannot remember the other issue that you raised. However, that same list could be used for these State DOT questions as well.

Now, I will attempt to address your real issues. As such, my responses will be contained below and following the individual questions.

Ron

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

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1. We've had several questions/issues come up recently regarding bridge end sections:
   a. The amount of reinforcing required in our "standard" end section is believed to be contributing to voids in the concrete (this is only speculation). Would it be feasible to reduce the amount of steel without affecting the crashworthiness of the guardrail connection? If so, what is the minimum strength requirement for the end section?

** TL-3/TL-4 bridge end sections have traditionally been designed to withstand lateral impact loads of approximately 100 to 120 kips and longitudinal impact loads of approximately 90 to 110 kips. From your question, it appears as though the IA DOT would like to reduce the number of vertical bars near the end sections, although I am making this assumption. This can be completed as long as the the structural capacity remains the same use different combinations of bar sizes and/or more or larger longitudinal bars. A yield-line analysis at the end of the barrier would need to be performed to replicate your capacity of the crash worthy design. We likely cannot reduce its strength and obtain approval of the design without testing unless it provides equivalent or greater capacity.

b. How much variability are we allowed when it comes to the shape of an end section? Specifically – how much can we vary the overall length of the end section and the angle of the leading chamfer? Looking at other states' standards, there appears to be quite a variety of shapes used. Am I to assume they have all been crash tested?

** When making changes to the shape of the end section, one should follow accepted crashworthy details such as the slope of the toe (could be flatter but not steeper), the coping or cutback at the end to reduce wheel snag on corners, etc. Yes, other variations may be acceptable, but one should discuss with us your proposed changes first so that we can provide feedback in advance of making such changes. It may also be helpful for your staff to provide to us the desirable details used by other states so that we could determine whether they have been crash tested or not.

c. Due to the proximity of our first guardrail post to the leading edge of our end sections, some contractors have complained that they cannot drive that post and must instead excavate and backfill by hand. Is it possible to increase that gap distance or must it stay constant?

** There are other transition designs available that do not use the 18.75-in. post spacing and a short span from post 1 to the buttress end. If desirable, we show provide the IA DOT with a list of other crashworthy transition details that may eliminate with field installation problem. It is not recommended to change post locations of the crashworthy designs without testing.

d. I have seen other states lengthen or shorten the "overlap" of the guardrail connection at the bridge end based on some conditions. Do you know what this is accomplishing? What are your thoughts on this practice?

** I have a personnel opinion that some states are providing extra overlap of the thrie beam guardrail (part of the transition) onto the concrete buttress end because they may feel that there reinforced ends have insufficient strength if impacted directly in this region. If adequate structural capacity of the RC buttress exists, there is no reason to have significant overlap of the concrete end other that to bolt the terminal connectors in place and have adequate steel placed around this connection to prevent its pullout and premature wall fracture.

2. Are you aware of any research regarding what effect, if any, low temperatures would have on the crashworthiness of steel bridge rails?

   ** Unfortunately, I am not aware of any specific research into this topic.

3. On some of our construction jobs I have seen where a contractor has overlapped freestanding Temporary Barrier Rail directly in front of a permanent concrete barrier or bridge rail as a means of terminating the TBR. Typically this has been accomplished with only one or two sections of TBR resting in front of the permanent barrier. Would you consider this an approved practice? If not, would there be a minimum number of TBR sections that would need to be overlapped in front of the permanent barrier in order for it to function properly?

   ** I would not consider acceptable the practice of using two free-standing, 12-ft long, TBR sections for downstream anchorage near and directly in front of a permanent barrier installation. Instead, our best engineering judgment would be to overlap at least 8 TBRs past the end of the permanent barrier and maintain a clear gap of 24 in. between the barrier bases. Our concern with freestanding TBRs directly in front of permanent barriers is that the freestanding barrier could pocket at the end of the permanent barrier. Thus, the provision for 24 in. allows for some normal deflection without pocketing over the first 2-ft of barrier translation. Actually, all 100 ft of barrier would not need to be spaced 24 in. in front of the permanent barrier. Instead, approximately 3 barriers lengths, or 37.5 ft, would need to incorporate the offset. Then, barrier 4 could be gradually tapered back toward the permanent barrier at 9.2 degrees with barriers 5 through 8 parallel to the permanent barrier and touching it.

4. Finally, do you have a method for attaching the MGS directly to a paved sidewalk or through the top of an intake? If not, are we able to develop our own based on a current design with standard guardrail?

   ** At this time, we have not considered how to attach the MGS to paved sidewalks, but it is reasonable that rectangular leave-outs placed around the posts would allow for adequate post rotation, similar to what was used for the MwRSF post in rock study and the TTI guardrail in paved mow-strip study. Second, it would be acceptable to span over the intakes if they are 25-ft long or less. Recall that the MGS was adapted to long-span culvert applications using 3 CRT posts on each side of the long span.

Problem # 3 – Long Span Guardrail with Curb

State Question:

Does the long-span MGS function properly when installed flush with a standard 6” curb? For some reason, I was thinking the area directly below and behind the long-span system had to be free from any snag points or obstacles.

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MwRSF Response:

We had not originally envisioned a 6-in. curb placed in advance of the long-span MGS. As such, we do not have crashworthy details for leaving a post out of a MGS design that is also placed behind a curb. Using our best engineering judgment, it may be possible to consider using the long-span design where 3 CRT posts span each side of the 12-ft 6-in. gap. The one unknown is whether the pickup truck will ride up the unsupported guardrail length after impacting the curb and twist the rail enough to allow vehicle climb and vaulting of the system. However, I do not believe that this undesirable behavior would result.

Ron Faller

Problem # 4 – Guardrail post in concrete and other urban considerations

State Question:

Ron, Dean, and Bob

Is the following correct interpretation of the current state of research on guardrail? When guardrail posts are installed with in a sidewalk (see picture1 and 2) the concrete prevents the post from pivoting like it is suppose to. Therefore, a guardrail installed as in the picture does not meet 350 requirements. Would this also be true for asphalt installed around guardrail?

Second question:

If you have a narrow median, higher design speeds, high ADT, and urban section. How does a designer end a barrier with a crash cushion or EAT and not leave a large median opening (need mountable curb to EAT or cushion correctly see pictures: plan view and east London rd)?

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MwRSF Response:

Erik:

Thanks for the recent inquiry regarding guardrail post installations!

With regard to your first question on guardrail systems installed within concrete pads, we recommend that States do not place guardrail posts within rigid pavements for several reasons. First, wood and steel posts are designed to rotate laterally in the soil for a specified distance while providing a soil resistive force on each post. The work done by the rotating posts in soil allows for a portion of the impacting vehicle's kinetic energy to be dissipated as well as helps the guardrail provide for a smooth vehicle redirection. When guardrail posts are placed in rigid pavements, the expected post-soil interaction is altered. For example, wood posts placed in concrete may cause premature post fracture and a significant reduction in the post's energy absorption capacity. As such, guardrail installations requiring asphalt or pavement surfacing under the guardrail must consider special leave-outs around the posts where surfacing allows for the proper post translation in the soil. Both MwRSF and TTI have developed special guardrail systems and recommendations for these applications. First, MwRSF researchers developed design guidelines for placing steel posts in holes where subsurface rock is encountered. Second, TTI researchers later developed recommendations for the blocked-out region surrounding posts when mow strips are needed under guardrail systems. In both systems, consideration for the allowance of post rotation was deemed critical.

In your second question, the details of the median situation make it appear as though continuous barrier protection is likely warranted (i.e., narrow median, higher design speeds, and high ADT). However, you note that large median openings exist in combination with use of guardrail end terminals and crash cushions. From the photographs, it appears that these attenuation devices are located therein in order to shield rigid obstacles and not to prevent crossovers along the entire median length. You describe the need for openings in this median application, what are the specific needs - intersecting streets, etc.? It would be helpful to have additional information on this second topic in order for us to better assist you.

Dean/Bob:

Please feel free to add your thoughts to either of the matters identified above!

Ron

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

Problem # 5 – Guardrail post in concrete and other urban considerations – Part 2

State Question:

Dr. Faller,

The problem I see is the need for end treatments (energy absorbing terminals, and crash cushions) and the cross sectional/operational problems the flat or near flat approaches can cause on urban projects. Would it be possible to to design some type of end treatment that could be used behind vertical curb? For an example, (probably would not work in a median <14 feet), the MwRSF bullnose system behind vertical curb.

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MwRSF Response:

Erik:

From your clarification, it is my understanding that you desire a means by which you can effectively prevent vehicles from crossing the narrow, flat, paved medians in urban region and in advance of impact attenuation devices. You suggested using curbs to perform this roadway delineation and to prevent unwanted, intentional crossovers. The use of curbs in combination with and in front of crash cushions and guardrail end terminals is not recommended at this time due to the expected vehicular instabilities that would occur in advance of the vehicle to barrier impact. In the past, the Pooled Fund group has asked for a proposal for studying this problem. However, this project was not funded. At this time and following the summer TRB meeting, a NCHRP problem statement is being prepared on this topic. Hopefully, it will be selected and funded for an upcoming research project.

Ron

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

Problem # 6 – Short-Radius Guardrail Status

State Question: (Note this question was actually from FHWA, but we felt it was a question worth including in the consulting summary)

Ron:

Last week we learned from Dean that the latest test of the short-radius guardrail failed the test with the 2000P under TL-3 conditions. Dean also mentioned that he would have no doubt that the same design would pass TL-2 conditions.

The State of Delaware has a situation where they need a short radius barrier. The specific question I was asked related to the NCHRP Report 230 design discussed in our Technical Advisory 5040.32: http://www.fhwa.dot.gov/legsregs/directives/techadvs/t504032.htm

The drawings are attached. The question was "The 8-foot design notes that the washer should be removed from the center post. Should the washers also be removed from the two posts closest to the center in the other designs?"

Now, my questions are:

1) Does your testing of the "new" short radius designs support removing those washers?
2) Should we scrap 5040.32 entirely and go with the MWRSF design even though it has not yet met Report 350?

Many thanks,

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MwRSF Response:

Hi Nick,

Ron asked me to respond to your questions regarding the old w-beam short radius design you attached in your email and the TL-3 short-radius design we are currently working on.

With regards to your first question about the posts in the 8' nose section, I have a couple of comments. First, we would not recommend any the center post in the nose of the system because it is not mounted in a foundation tube. Thus, even though it is a CRT post, it will rotate in the soil about its strong axis and create a ramp that increases the potential for impacting vehicles to override the system. We have removed the center post in our current TL-3 design for that reason. As far as the two posts at the edge of the nose section, we have used extra strong post-rail connections at those posts in the current version of the TL-3 short-radius. We have increased the post-rail connection strength in the current design in order to keep the posts attached to the rail and prevent them from becoming debris under the wheels of the truck that can cause the vehicle to override the rail. We have observed that vehicles impacting short-radius systems display significant yaw motion as they are captured due to the geometry of the system. Breakaway posts in the system that become detached from the guardrail has been observed to get under the wheels of the vehicle as it yaws and allow the vehicle to override the rail. Thus, we would recommend that the washer be left on the post rail connection at those posts.

Your second question was whether or not we believe that the old design should be abandoned in favor of our current design. We believe that the old design should be abandoned for several reasons, and I will list a few of the most pressing. First, we do not believe that a W-beam system is capable of capturing both the small car and pickup truck size vehicles effectively. Second, we do not believe that the W-beam design has sufficient capacity to contain the pickup truck vehicle. Third, we do not believe that the system has sufficient anchorage to redirect vehicles along the side of the system.

As Dean mentioned, our current short-radius system has not met the TL-3 impact conditions at this time, however, we believe the system is much better than the older W-beam and thrie beam short-radius systems currently available. We are also confident that this design will meet TL-2. We would be willing to submit the details of the current design so that states could use it as a best available alternative as long as the following caveats are recognized.

1. The MwRSF short-radius design is still under development and should not be considered the final version of the design. Further development of the system is planned and design details for the system may change in the future.
2. Not all of the required TL-3 tests have currently been evaluated on the MwRSF short-radius design. We have been approaching the design of the system in a manner that addresses the most critical impacts first, so some tests in the required matrix remain to be resolved. Thus, the overall system behavior has not been entirely quantified at this time.
3. The current MwRSF short-radius design places the bridge rail and approach transition on the TL-3 or primary roadway side of the system and uses an end terminal on the TL-2 or secondary roadway. This configuration was chosen based on engineering judgment as the most critical installation for testing purposes. Some installations may be different than the tested system in that they may have the bridge rail and end terminal on the opposite sides or some other configuration. These alternative configurations have not been thoroughly evaluated at this time and their behavior is not known.
4. The performance of the MwRSF short-radius to date leads us to believe that it will certainly meet TL-2 impact criteria as designed due to the lower impact speeds and corresponding kinetic energy levels.

Hopefully this answers your questions as to our thoughts. Please contact me with any further comments and questions.

Bob Bielenberg, MSME, EIT
Research Associate Engineer
Midwest Roadside Safety Facility

Problem # 7 – Vertical Adjustment of the Midwest Guardrail System

State Question:

We are looking at installing some new Midwest Guardrail System to replace corroded weathering steel guardrail. This is a very worthy safety improvement, and we want to get it accomplished as quickly as possible. However, the location is programmed for a resurfacing project to follow within a handful of years (3 to 5 probably). The resurfacing thickness will be 4.25 inches, and thus the height of the relatively new guardrail would be out of tolerance. We are wondering if it would be acceptable to specify an additional bolt hole in the flange of the steel post such that the wood blockout could be raised by about 4" to match the new height of the overlay? This would raise the top of the blockout and rail by this amount above the top of the steel post. Also, we would be able to add some fill material around the posts, but it would be very difficult and expensive to compact this mechanically. Perhaps we could use a dense graded aggregate that would at least develop some cohesion with moisture and natural settling into place. Is this a reasonable method to allow for one vertical adjustment of the MGS? Would there be any other steps we could take to make this idea successful?

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MwRSF Response:

David:

I have spoken with several of my colleagues regarding the MGS situation that you will likely encounter with the future overlay. For the standard MGS, we believe that the MGS will perform acceptably if you raise the rail height approximately 4 in. along with a similar increase in the asphalt overlay. As such, you could have an extra guardrail hole placed in the post's flange such that the rail and blockout could be raised at a later date. Note that with a longer load height above the ground line, the posts will yield at a lower magnitude of load and result is higher dynamic rail deflections.

There are additional issues to consider. Originally, the MGS R&D program was begun with 5-ft long foundation tubes. When the rail was raised, so was the slope of the anchor cable. This resulted in the foundation tubes to begin to be pulled upward and out of the ground during impacts. Further testing with 6-ft long tubes showed that this behavior was mitigated. Now, with another increase in rail height, it may be necessary to use even longer foundation tubes, such as 7 or 8-ft long tubes. Since we have used 8-ft tubes in other systems, you may want to use that length to ensure that pullout will not occur.

Finally, it has been noted that one could also use non-standard posts (slightly longer) such that the post would extend slightly above the blockout when first installed and also would use two holes in the posts. The extended post would be a reminder that this guardrail was intended for a future overlay.

In summary, we feel that your proposed MGS applications would be acceptable when incorporating the primary consideration noted above.

Ron

Ronald K. Faller, Ph.D., P.E.

Problem # 8 – W-Thrie Transition

State Question:

Karla: I'm just looking at the "W-beam to Stiff Bridge Transition (MWT-5)" and need confirmation if this is the detail we would apply for a transition to a safety shape or vertical concrete bridge rail, which I assume has also been successfully crash tested. If correct I'm assuming we would show the thrie beam terminal connector (RTE01b) being bolted to the nested 12 ga thrie beams at post 19 (which would actually be the concrete bridge rail similar to STB05).

If similar to STB05, I'm assuming we would also delete post 18. If not correct, I'm assuming we may need to use additional posts at 475mm centres similar to STB06.

One other question with the MWT-5 detail is the use of a half length of 12 ga thrie beam between posts 15 and 13, which also has the thicker asymmetric 10 ga thrie beam on one side and the nested 12 ga thrie beams on the other. This seems a little odd to use a thinner piece of steel (instead of a half length of 10 ga thrie beam) at this location when the intent is to stiffen the system as you approach the bridge rail. I have to ask this question as I'm sure I'll be asked this question by our installers once installations start. My preference would be to specify a half length of 10 ga thrie beam at this location, however if the 12 ga is what is recommended and crash tested, and there is uncertainty about 10 ga, we will specify the 12 ga.

Thanks, Mark.

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MwRSF Response:

Hi Mark,

We have no problem with you attaching the transition system to a concrete bridge rail as long as the bridge rail is 350 approved, is very stiff and rigid, and has the appropriate flare backs and/or tapers as have been 350 approved previously for approach guardrail transitions. Yes, you would want to attach the thrie beam terminal connector to the nested 12-gauge thrie beam at post 19. There would be no need to remove post 18. We have tested a few approach guardrail transitions to concrete barriers that have been 350 approved if you would like that information. One note…STB05 and STB06 are only 230 approved

At this time, we do not feel that we can recommend 10-gauge thrie beam in place of the 6-ft 3-in. long, single (non-nested) 12-gauge The new approach guardrail transition system has been configured with an additional 6-ft 3-in. long, single (non-nested) 12-gauge thrie beam rail, followed by the new asymmetrical, 10-gauge W-beam to thrie beam transition section. It is our current opinion that all of the prior nested thrie beam transition systems should be modified to include the additional 6-ft 3-in. thrie beam section as well as the asymmetrical transition section. In addition, the existing approach guardrail transition systems will require a longer transition length for which the support posts are installed and using a reduced post spacing. As part of another change, W6x12 steel posts were implemented in order to provide a more gradual change in lateral stiffness of the overall guardrail system.
Hope this helps.
Karla

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October 15, 2007

Amy Starr, P.E.
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Subject: Status Update on the Development of a Short-Radius Guardrail for Intersecting Roadways

Dear Amy Starr:

The Midwest Roadside Safety Facility has been conducting research for the Midwest States Regional Pooled Fund Program toward the development of a short-radius guardrail for intersecting roadways. The final two budgeted tests of the short-radius guardrail project have been conducted. The purpose of this letter is to inform the sponsoring states of the status of those two tests as well as to present options for the future development of the short-radius guardrail system.

For reference purposes, the current details for the short-radius guardrail system, as used in test no. SR-8, are shown in Figures 1 through 19. The two tests summarized herein were conducted under the performance requirements for the Proposed Update to NCHRP Report 350. Previous testing of the short-radius system was conducted under the guidelines set forth in NCHRP Report 350, but it was decided to conduct all tests after test no. SR-6 according to the Proposed Update to NCHRP Report 350. This decision was made to insure that the final short-radius system would meet the most recent safety requirements when it was completed.

Test No. SR-7

Test no. SR-7 was conducted according to the test requirements for test designation 3-33. Test 3-33 is a TL-3 test of a vehicle impacting at 100 km/h at a nominal angle of 15 degrees on the center of the barrier nose.

In test no. SR-7, the 2,263-kg (4,989-lb) pickup truck impacted the short radius guardrail system at a speed of 100.3 km/hr (62.3 mph) and at an angle of 18.1 degrees. The impact immediately deformed the nose section inward and captured the front of the pickup truck. As the vehicle proceeded further into the system, fracturing posts and deforming guardrail, it began to yaw in a clockwise direction. The vehicle continued to yaw and move downstream into the center of the short radius system until approximately 0.400 sec. At this time, the vehicle began to pitch forward, thus lifting the rear of the vehicle. As the vehicle continued to yaw and move downstream, the left-rear tires of the truck overrode the thrie beam guardrail on the primary side of the short-radius system. The override of the guardrail caused subsequent roll of the pickup truck which cause the vehicle the roll onto its side at approximately 1.2 sec. The vehicle came to a stop on its left side at 12.8 m (42 ft) longitudinally and 5.6 m (18 ft 6 in.) laterally from impact. Sequential photographs are shown in Figures 20 through 23. Test no. SR-7 was judged to be unacceptable due to the override of the guardrail and subsequent roll of the pickup truck.

Due to the failed performance of the short radius guardrail system in test no. SR-7, a safety performance evaluation was conducted in order to determine what design changes, if any, could improve the performance of the short radius guardrail system. A thorough review of the test data revealed four potential causes of the vehicle instability observed in the test. First, high-speed video from the test showed that debris from the fractured posts and anchorage hardware interacted with the rear wheels of the pickup truck. This interaction led to the rear wheels riding up and tripping on the debris, which in turn caused the rear of the vehicle to pitch up and over the guardrail as the vehicle yawed. A second potential cause for the vehicle instability was related to the release of the cable anchor for the primary side of the system. The cable anchor for the primary side of the short-radius system wraps around the base of post no. 1P and then is routed diagonally across to post no. 1S. During test no. SR-7, it was observed that the primary side anchor cable did not release cleanly from post no. 1S. The poor release of the cable at post no. 1S caused that post to be pulled towards the rear wheels of the truck after it fractured, thus adding to the debris beneath those wheels. Third, as the rail continued to deform in front of the pickup, the BCT bearing plate, which remained attached to the cable anchor, contacted the cable anchor bracket located on the front side of post no. 1P. The BCT bearing plate became wedged against the foundation tube and the cable anchor bracket, thus causing the nut on the threaded end and the BCT bearing plate to disengage from the cable end fitter. The re-engagement of the cable anchor at post no. 1P was not desirable because it would have caused tension to develop in the rail and may have pulled the rail down, thus contributing to the inadequate capture of the vehicle. A final potential cause for the vehicle instability in test no. SR-7 was the behavior of the nose section slot tabs. Previously testing with the bullnose median barrier system had shown that the capture of the pickup truck vehicle was most effective when the slot tabs in the nose section of the rail tore through allowing the top sections of the rail to slide above the bumper and interlock the truck. Review of the nose section rail behavior in test no. SR-7 found that the slot tabs in the nose section did not tear through, which resulted in less effective interlock of the nose section with the front of the pickup truck.

Following the analysis of test no. SR-7, several design changes were implemented to improve the safety performance of the short radius guardrail system. First, the transverse holes in post nos. 1P, 1S, and 2S were enlarged from 64 mm (2.5 in.) to 76 mm (3 in.) in diameter to facilitate a cleaner release of the cable anchor and improve the breakaway performance of the posts to prevent them from becoming debris that interacted with the vehicle. The modified posts were named BSR posts, or “Breakaway Short Radius” posts, since they were unique to the short radius system. Second, rectangular plate washers were added on the front side of the rail to post nos. 1S, 2S, 1P, 2P, 3P, and 4P. The plate washers were designed to retain the posts on the guardrail to prevent them from becoming debris in the path of the impacting vehicle. Third, the cable anchor bracket on the front side of post no. 1P was reduced in size to allow the anchor cable to release more easily and prevent the BCT bearing plate and nut from wedging against post no. 1P, as was observed in test no. SR-7. Finally, the outer slot tabs in the nose section of the short-radius system were reduced from 50.8-mm (2-in.) wide to 25.4-mm (1-in.) wide. This change was made to allow the slot tabs to tear more easily, thus allowing the rail corrugations to separate and more effectively capture the vehicle.

Test No. SR-8

The revised short-radius design was then full-scale crash tested in test no. SR-8. Test no. SR-8 was conducted according to the test requirements for test designation 3-33. Test 3-33 is a TL-3 test of a vehicle impacting at 100 km/h at a nominal angle of 15 degrees on the center of the barrier nose.

In test no. SR-8, the 5,000-kg (2,268-lb) pickup truck impacted the short-radius guardrail system at a speed of 101.0 km/hr (62.8 mph) and at an angle of 17.9 degrees. The impact immediately deformed the nose section inward and captured the front of the pickup truck. The slot tabs on the lower rail section tore in test no. SR-8 which allowed the top two corrugations of thrie beam to capture the pickup truck more effectively. Post nos. 1S fractured, remained attached to the guardrail, and released the cable anchor cleanly. As the vehicle proceeded further into the system, fracturing posts and deforming guardrail, it began to yaw in a clockwise direction. The vehicle continued to yaw and move downstream into the center of the short radius system until approximately 0.526 sec. At this time, post no. 2S had moved underneath the left-rear wheel of the vehicle. The pickup truck began to pitch forward, thus lifting the rear of the vehicle. As the vehicle continued to yaw and move downstream, the left-rear tires of the truck overrode the thrie beam guardrail on the primary side of the short-radius system. The vehicle continued to yaw after overriding the guardrail, but it remained upright throughout the test. The vehicle came to rest at approximately 2.656 sec, located 15.5 m (51 ft) downstream and 1.4 m (4 ft-6 in.) behind the guardrail system. Sequential photographs are shown in Figures 24 through 27. Test no. SR-8 was judged to be unacceptable due to the override of the guardrail.

Following the analysis of test no. SR-8, the test results were reviewed in order to identify potential causes of the failure of the system. Review of the test results demonstrated that the revised short-radius design performed much better than the design used in test no. SR-7. Improvement was observed in the reduction of debris, release of the cable anchorage, and the capture of the pickup truck. In spite of the improved performance, the test did fail due to override of the guardrail. The cause of the vehicle override of the guardrail was a combination of the yaw motion of the pickup truck and the pitching of the rear of the truck due to interaction of the left-rear wheel with post no. 2S, as mentioned previously. Post no. 2P was attached to the guardrail using a plate washer, but the guardrail bolt at post no. 2P was located in one of the long slots in the valley of the thrie beam on the primary side of the system. As such, the plate washer was not sufficient to keep the post attached to the rail and prevent it from become debris that interacted with the pickup truck.

Future Options

At this time, the funding for further development and testing of the short-radius guardrail system has been exhausted. Currently, there has been one successful full-scale crash test on the system, test no. SR-5. Test no. SR-5 was a successful test of the short-radius system conducted as a modified test designation 3-31. This test impacted the short-radius system with the centerline of a 2,000-kg (4,409-lb) pickup truck aligned with the tangent side of the system at a speed of 100 km/h at a nominal angle of 0 degrees. While this test performed acceptably, design changes to the short-radius and the switch to testing under the safety requirements of the Proposed Update to NCHRP Report 350 may require that the test be rerun depending on input from the Federal Highway Administration.

MwRSF has reviewed the current status of the short-radius guardrail system and believe that there are several possible options for the future of the design. These possible options include:

1. Continue to develop the short-radius design as a Test Level 3 system according to the Proposed Update to NCHRP Report 350.
    a. Based on the results of test no. SR-8, MwRSF believes that there is potential for the short-radius to be developed into a successful TL-3 system. In order to do so, changes to the design would be necessary to eliminate the override of the guardrail. It has been proposed that a more robust attachment between the post and the guardrail be used in order to prevent posts from becoming debris beneath the truck. This connection would be more robust than the plate washer used in test no. SR-8. A second proposed option would be to mount additional guardrail or a cable element along the primary side of the system to raise the effective height of that side of the system and reduce the potential for rollover.
    b. A total of five tests would need to be completed successfully prior to FHWA approval. There is a potential that some of these tests, such as test 3-31 could be waived based on previous testing.
2. Development of a Test Level 2 short-radius design.
    a. The Texas Transportation Institute (TTI) is currently conducting research to develop a TL-2 short-radius guardrail system. TTI is using older short-radius guardrail testing in combination with information on the development of the TL-3 short-radius system described herein in their design process. This research could provide a lower test level option that is still better than current short-radius design available for state DOT use.
3. Implementation of the current short-radius design as the best available option.
    a. While the current short-radius guardrail system has not met the requirements for TL-3 approval, MwRSF believes that the current system is far better than older w-beam and thrie beam short-radius designs. As such, it is believed that the Midwest States Regional Pooled Fund Program members could implement the current short-radius design and expect an increase in the performance and safety over their current short-radius guardrail designs.
4. Redesign the short-radius system based on new concepts.
    a. The testing and development of the short-radius system to date has shown that the current design using standard post and rail components may not be the most effective form of protection for intersecting roadways. MwRSF has brainstormed several concepts that have the potential to be a more effective means of protecting motorists in these situations. These concepts use a combination of technologies based on crash cushion and end terminal design to attempt to mitigate some of the shortcomings of the current short-radius design. It is possible that these more

unconventional designs may prove to be the most effective solution for the problem of protecting intersecting roadways.

We would like to get feedback from the Midwest States Regional Pooled Fund Program members as to which option they would like to pursue. We would also be interested in any additional options that the states conceive of separately from those listed above.

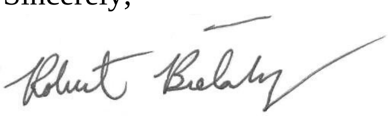
Summary and Discussion

In summary, MwRSF has conducted the final two budgeted tests of the short-radius system. Both of the tests were unsuccessful. The results of the final test, test no. SR-8, showed significant improvement in the behavior of the design. This suggested that the design was getting much closer to being a viable solution. However, significant design, analysis, and testing is needed before a TL-3 solution is available.

We would ask that the Midwest States Regional Pooled Fund members review the information contained in this letter along with previous reports on the short-radius system development and reply to MwRSF regarding the future status of the short-radius system.

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,



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rbielenberg2@unl.edu

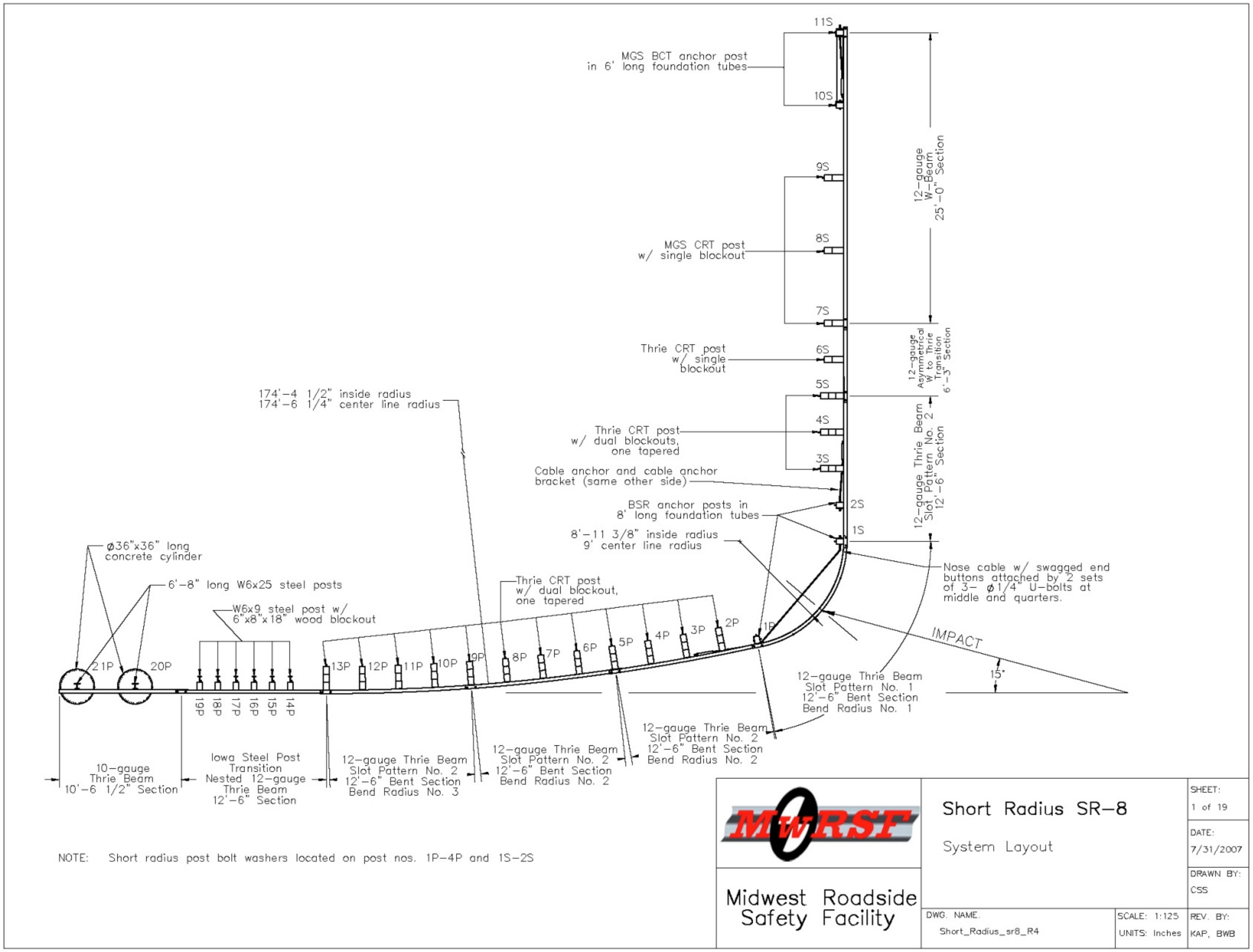


Figure 1. Short-Radius Design Details, Test No. SR-8

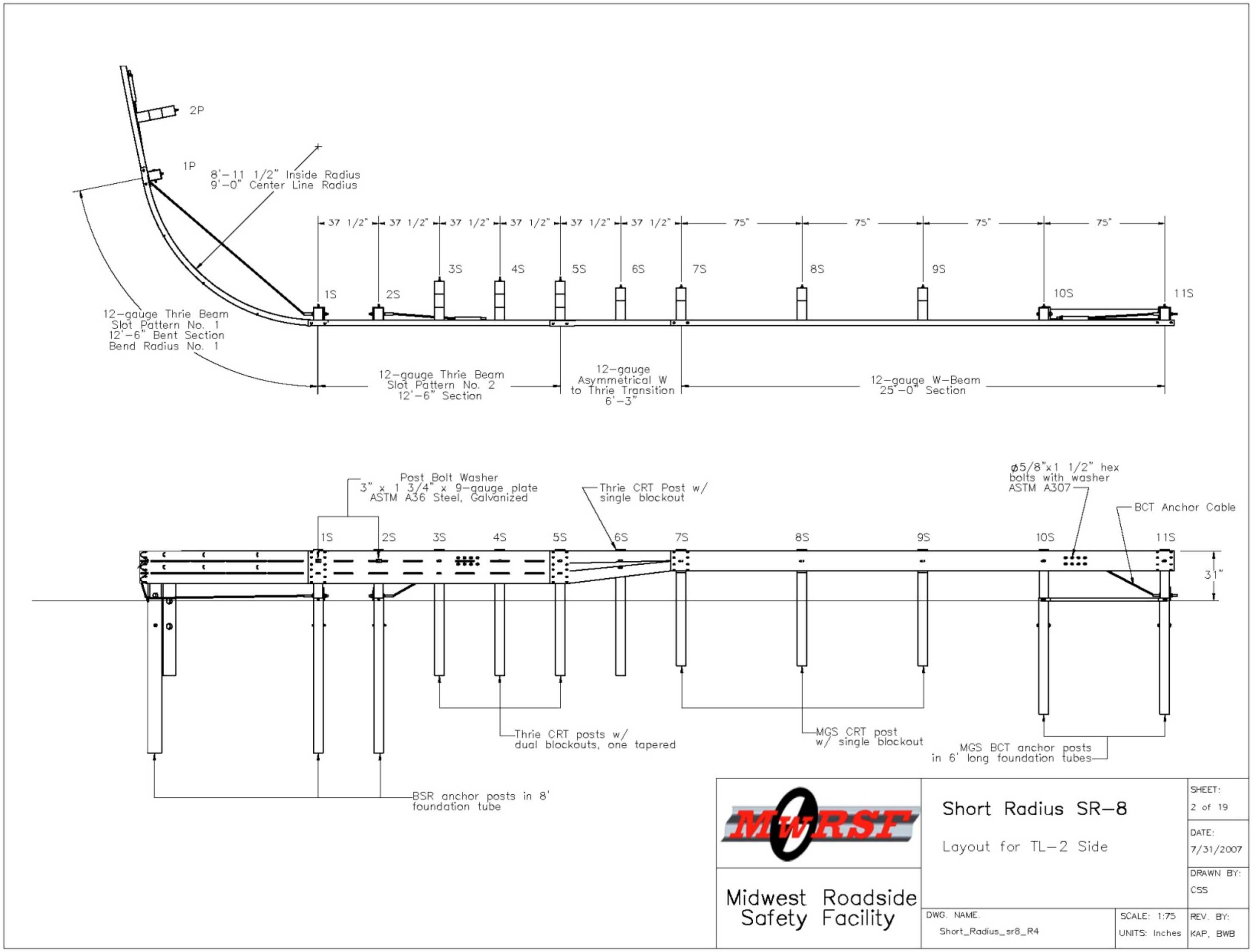
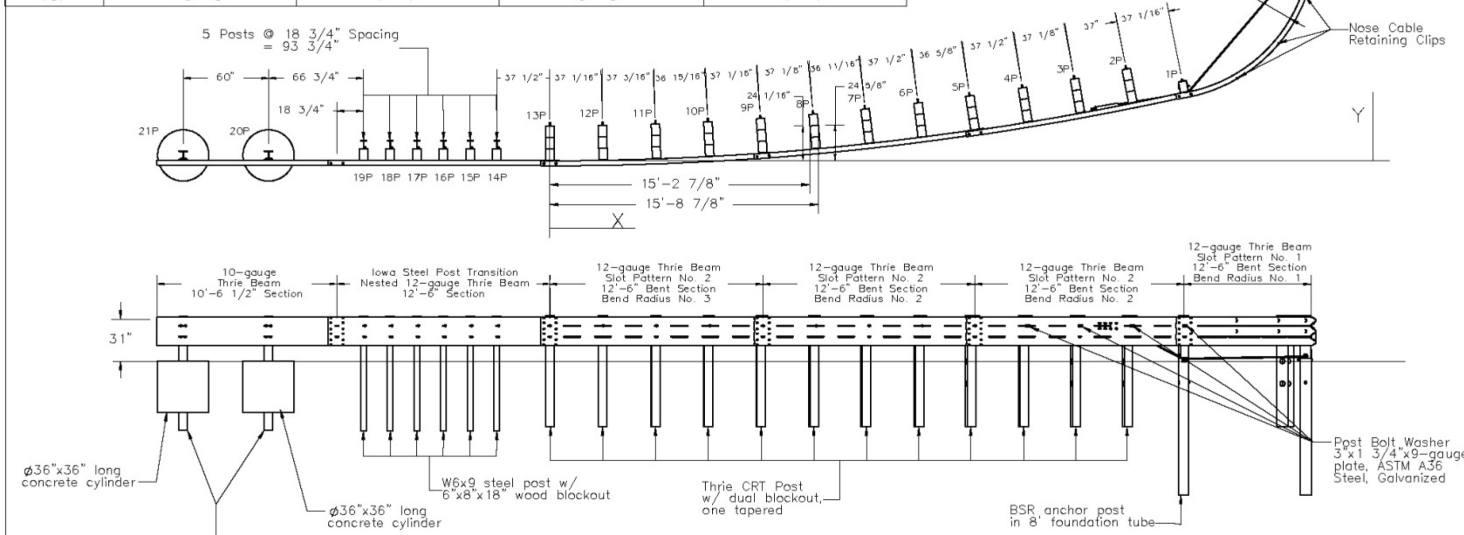


Figure 2. Short-Radius Design Details, Test No. SR-8

Post No.	Front Face D.S. Edge		Front Face U.S. Edge	
	X	Y	X	Y
1P	36'–11 1/16"	3'–11 5/8"	37'–4 5/8"	4'–0 5/8"
2P	33'–7 7/8"	4'–7 5/8"	34'–1 3/4"	4'–8 13/16"
3P	30'–7 5/16"	4'–0 3/4"	31'–1 1/4"	4'–1 13/16"
4P	27'–6 9/16"	3'–6 1/2"	28'–0 1/2"	3'–7 7/16"
5P	24'–5 1/2"	3'–0 13/16"	24'–11 7/16"	3'–1 3/4"
6P	21'–4 15/16"	2'–7 15/16"	21'–10 7/8"	2'–8 11/16"
7P	18'–3 11/16"	2'–3 5/8"	18'–9 5/8"	2'–4 3/8"
8P	15'–2 7/8"	2'–0 1/16"	15'–8 7/8"	2'–0 5/8"
9P	12'–1 11/16"	1'–9 1/8"	12'–7 11/16"	1'–9 9/16"
10P	9'–0 9/16"	1'–6 13/16"	9'–6 9/16"	1'–7 3/16"
11P	5'–11 1/2"	1'–5 1/4"	6'–5 1/2"	1'–5 7/16"
12P	2'–10 1/4"	1'–4 1/4"	3'–4 1/4"	1'–4 3/8"
13P	–0'–3"	1'–4"	0'–3"	1'–4"



Midwest Roadside Safety Facility

Short Radius SR–8

Layout for TL–3 Side & Post Locations

SHEET: 3 of 19
DATE: 7/31/2007
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SCALE: 1:100 UNITS: Inches
REV. BY: KAP, BWB

Figure 3. Short-Radius Design Details, Test No. SR-8

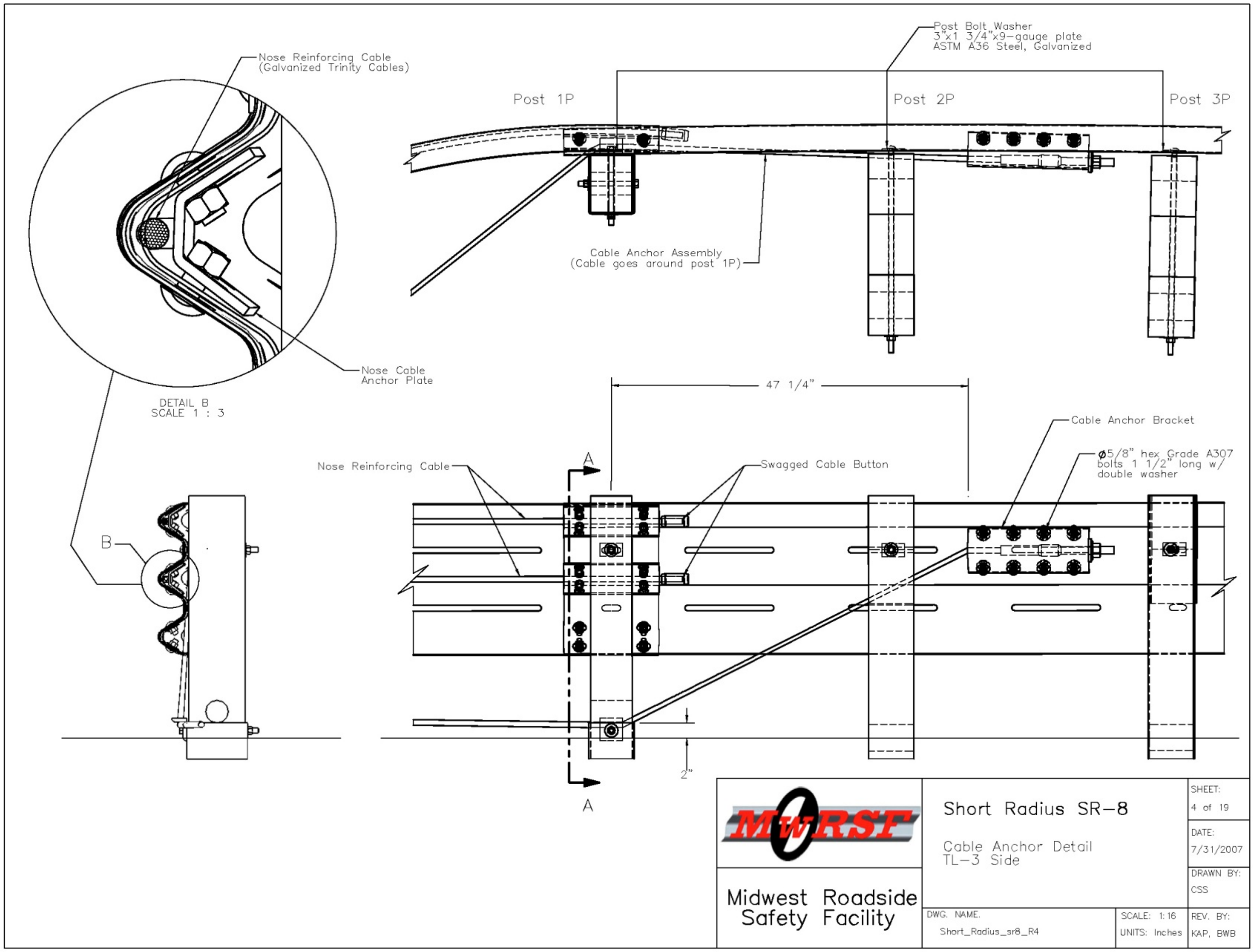


Figure 4. Short-Radius Design Details, Test No. SR-8

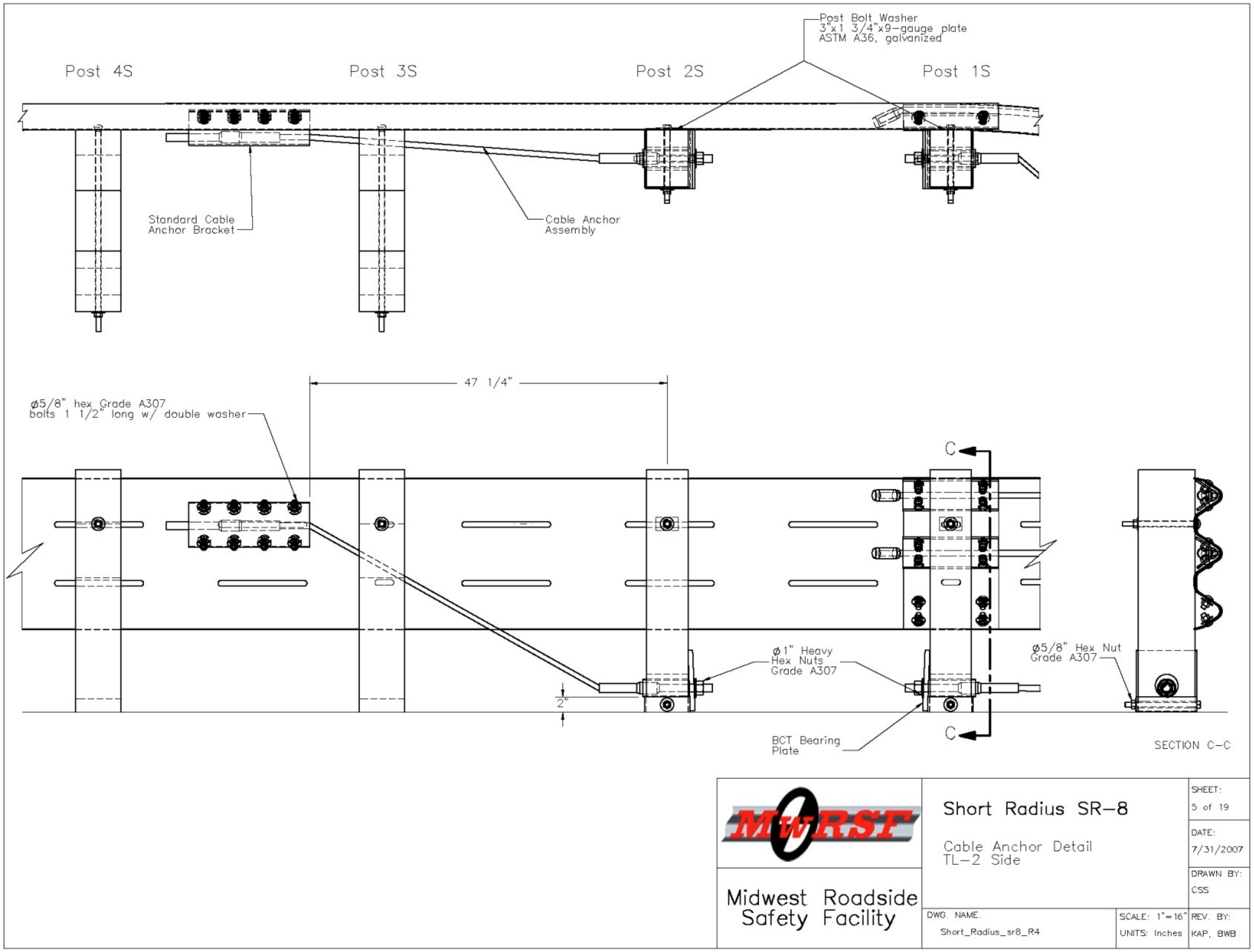


Figure 5. Short-Radius Design Details, Test No. SR-8

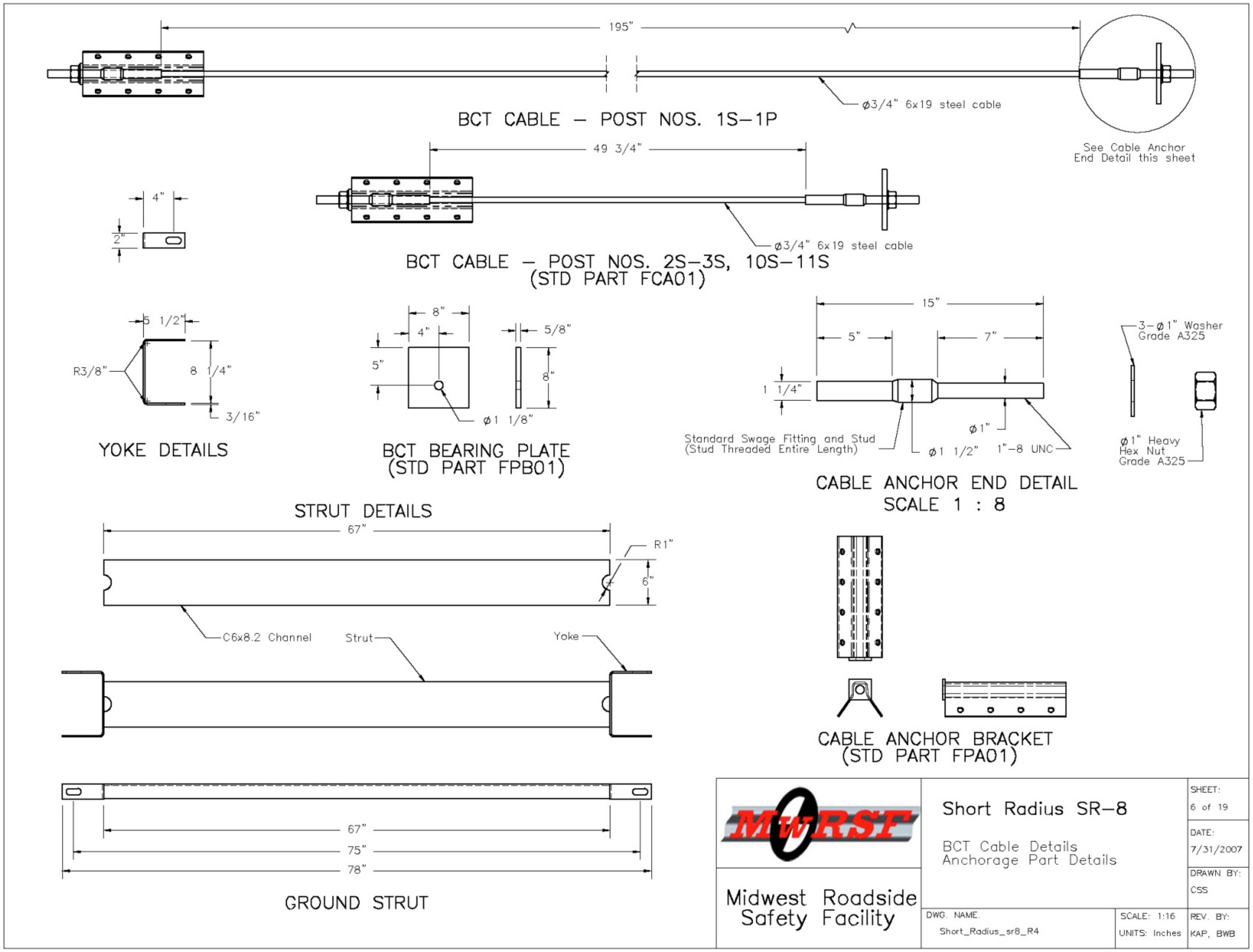


Figure 6. Short-Radius Design Details, Test No. SR-8

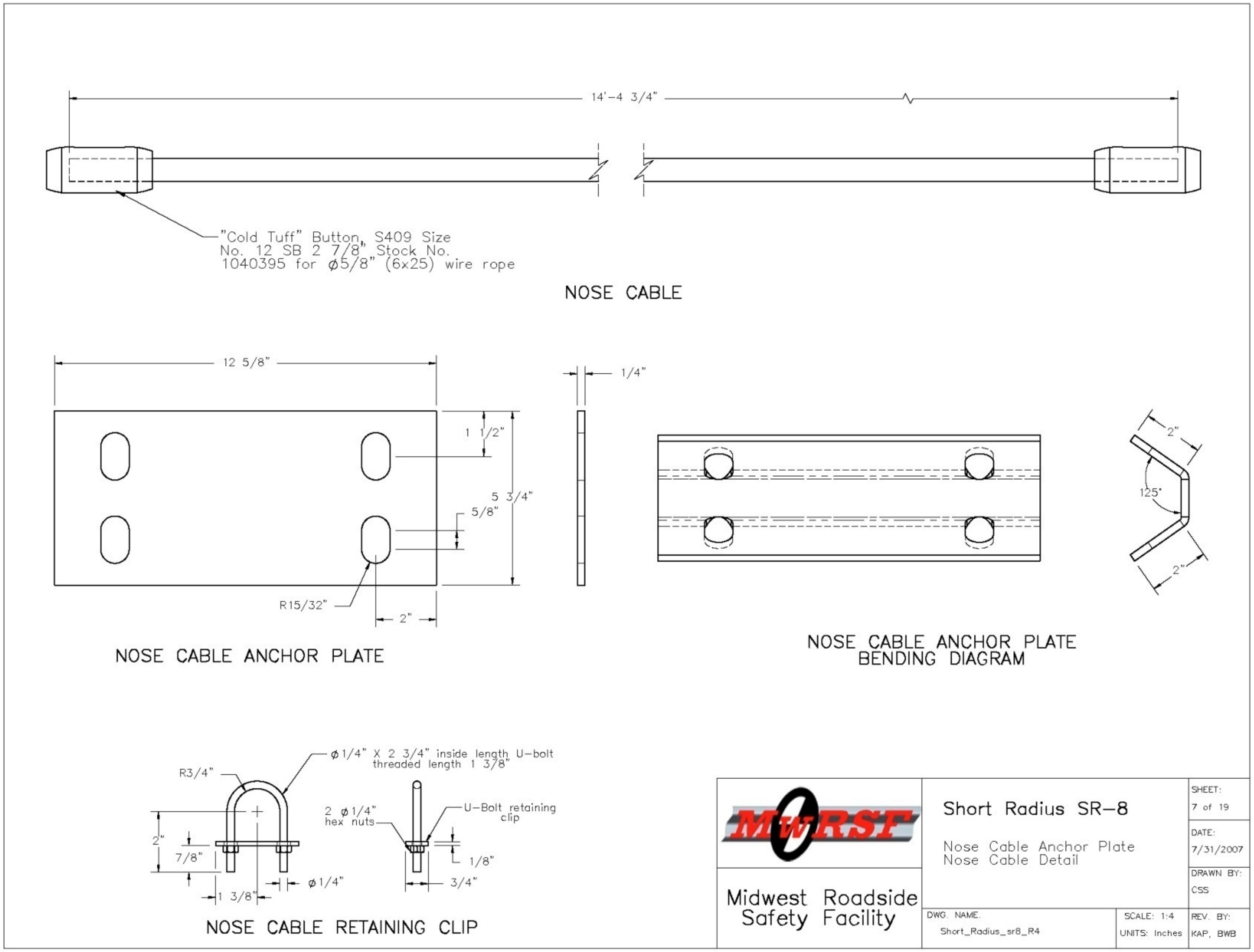


Figure 7. Short-Radius Design Details, Test No. SR-8

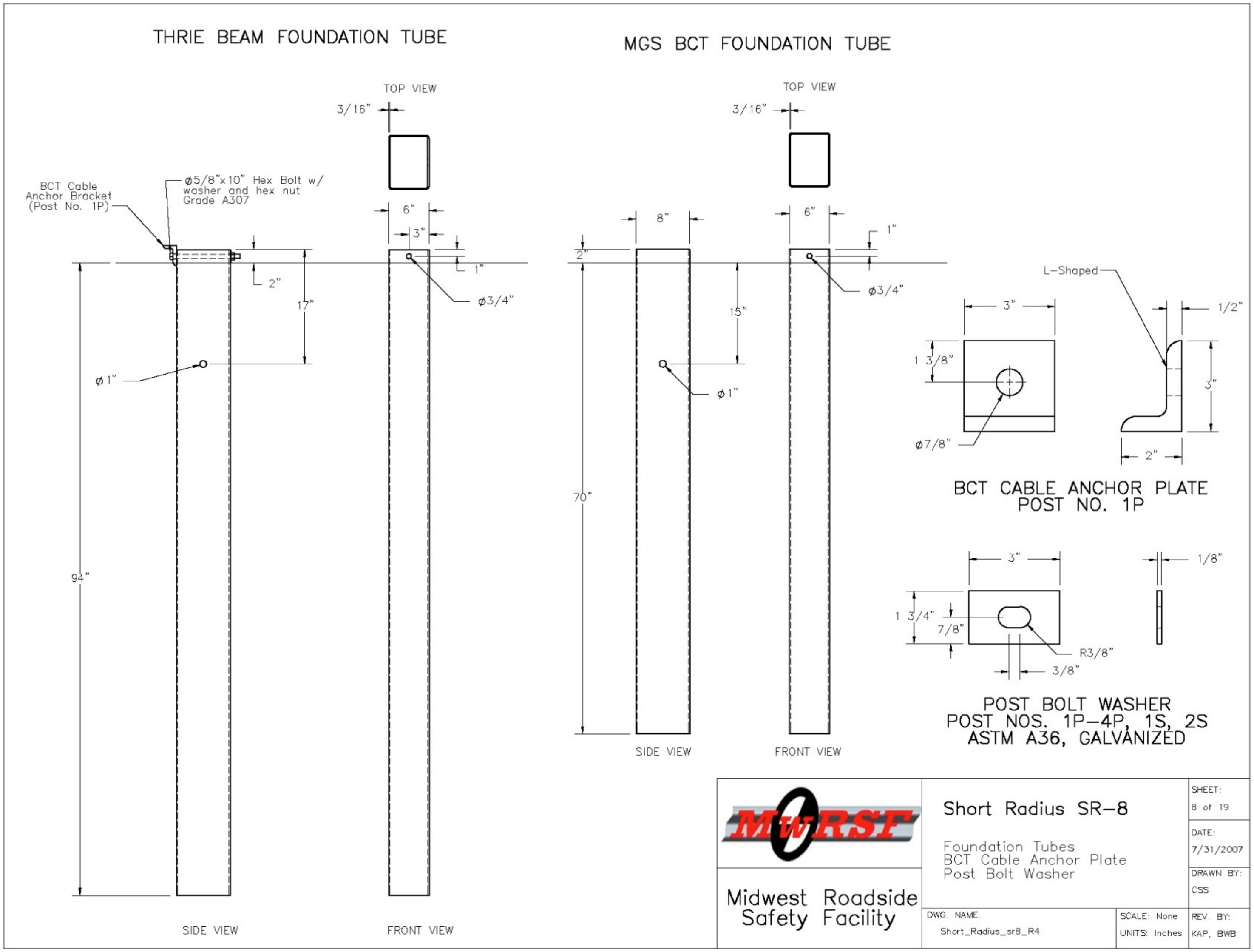


Figure 8. Short-Radius Design Details, Test No. SR-8

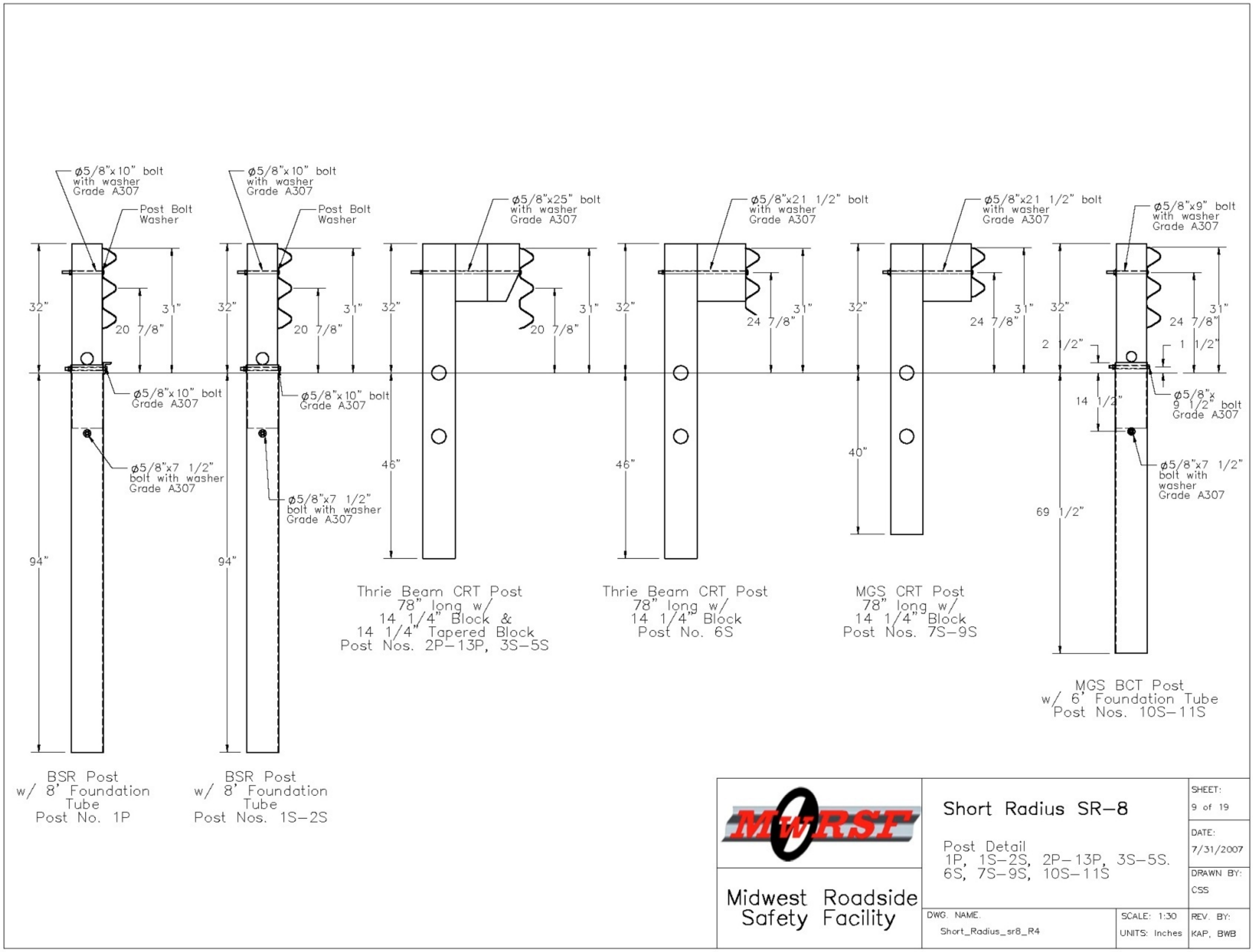


Figure 9. Short-Radius Design Details, Test No. SR-8

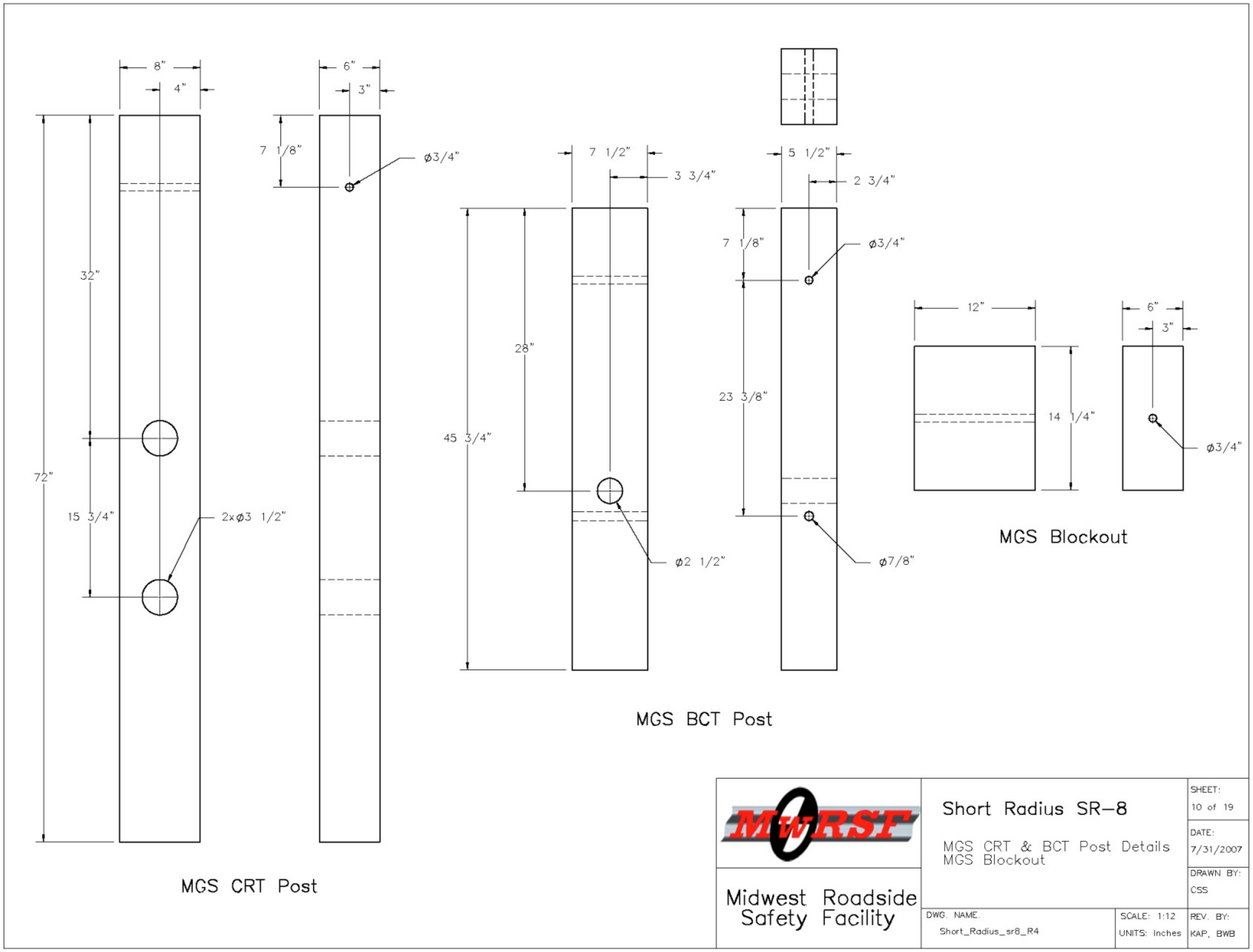


Figure 10. Short-Radius Design Details, Test No. SR-8

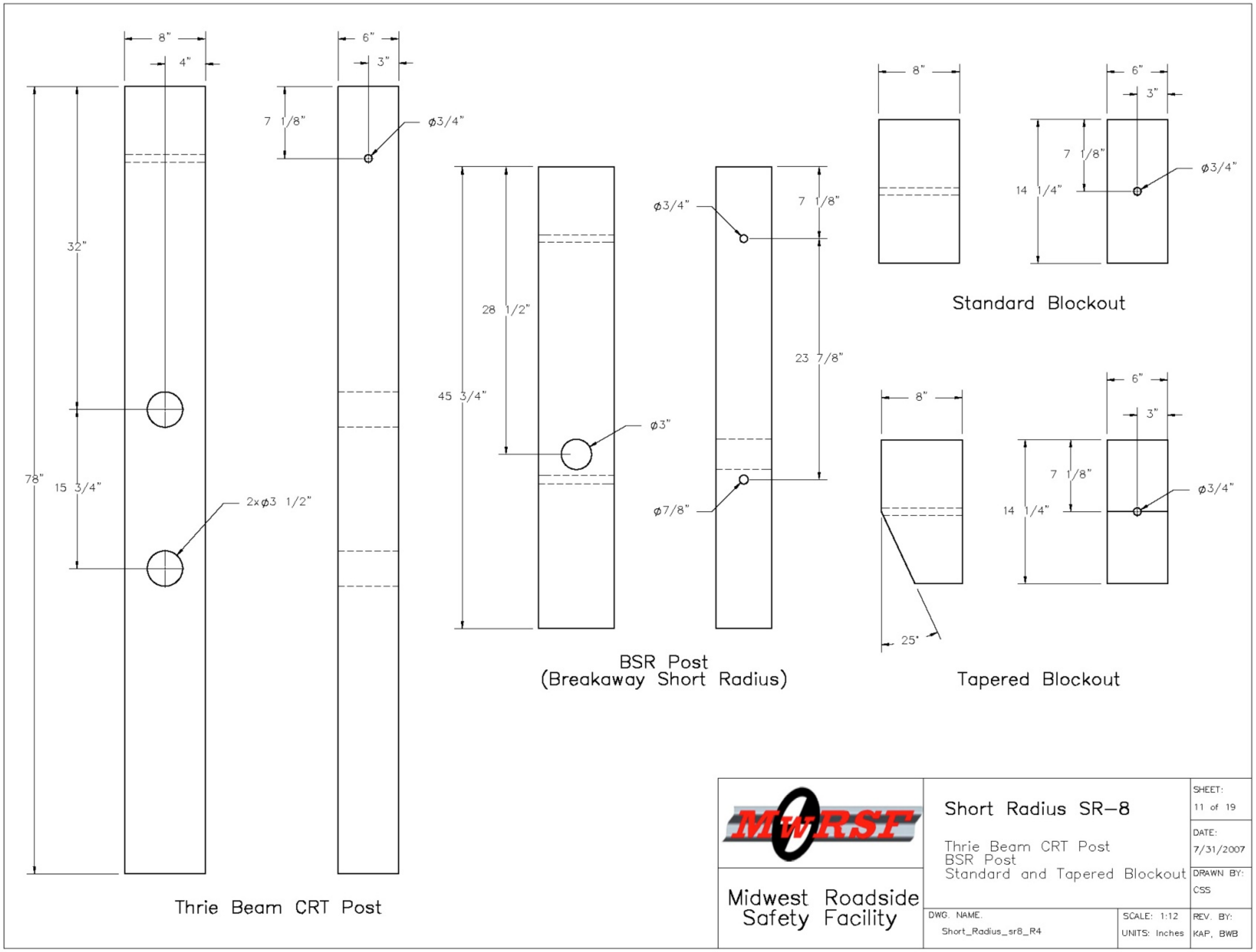


Figure 11. Short-Radius Design Details, Test No. SR-8

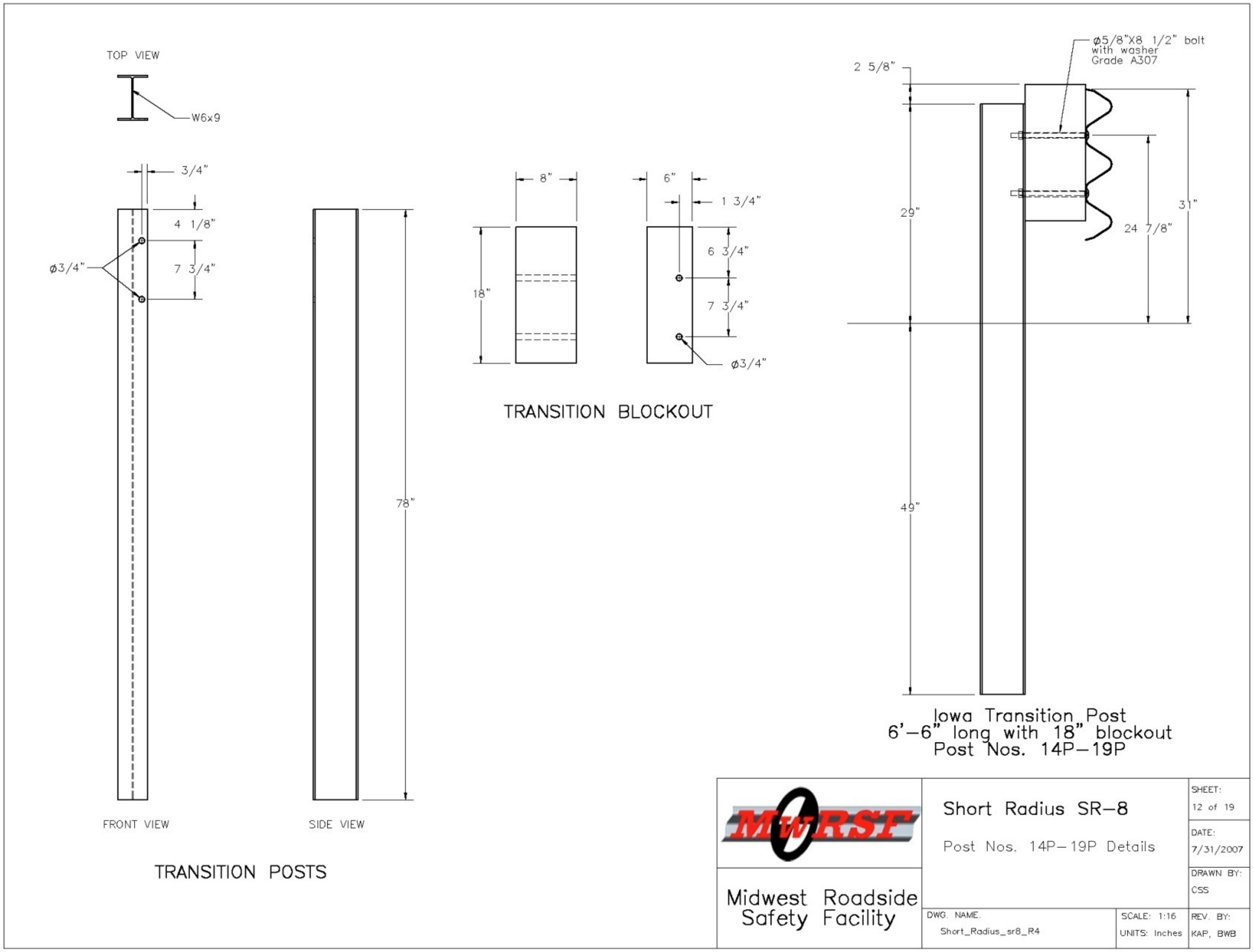


Figure 12. Short-Radius Design Details, Test No. SR-8

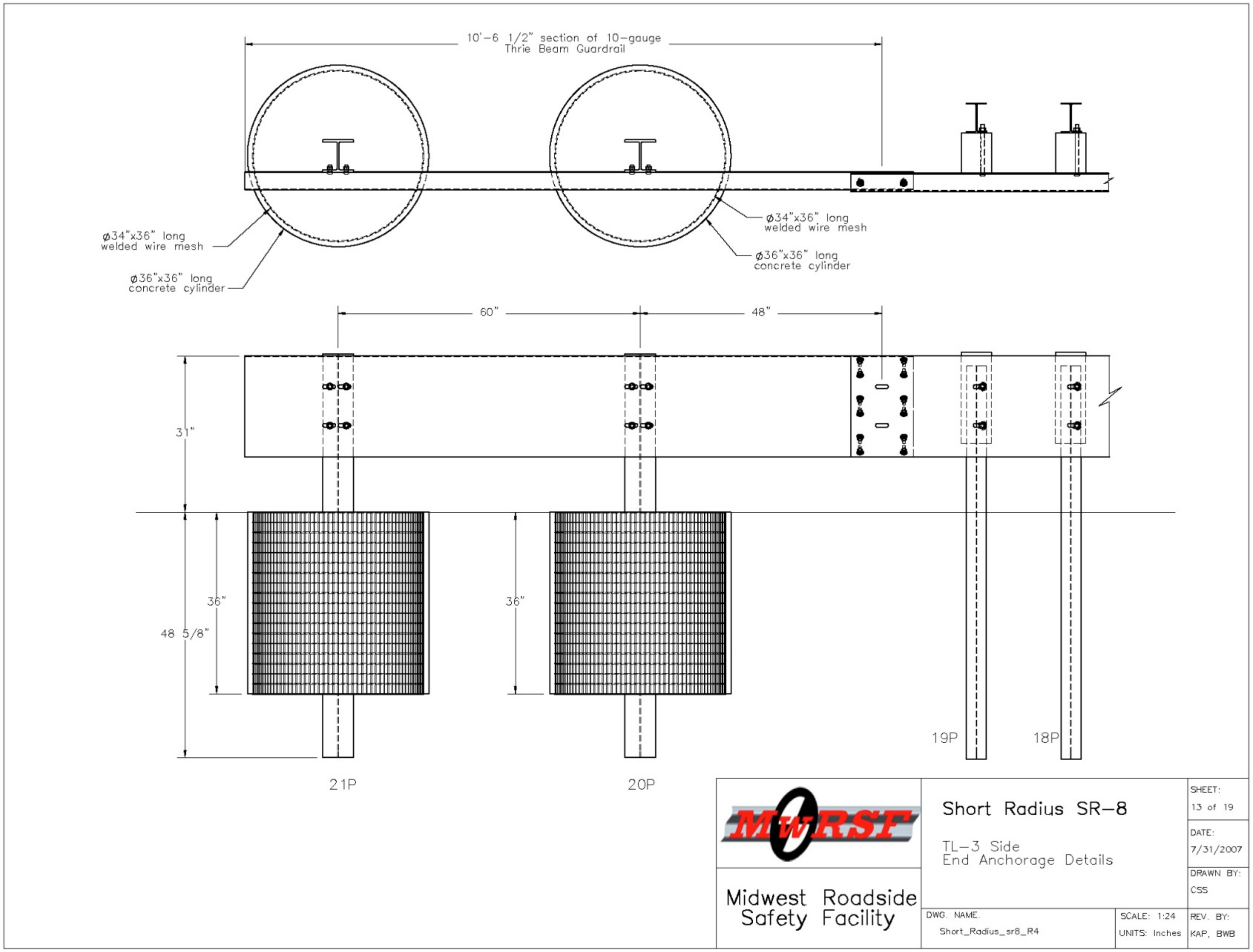


Figure 13. Short-Radius Design Details, Test No. SR-8

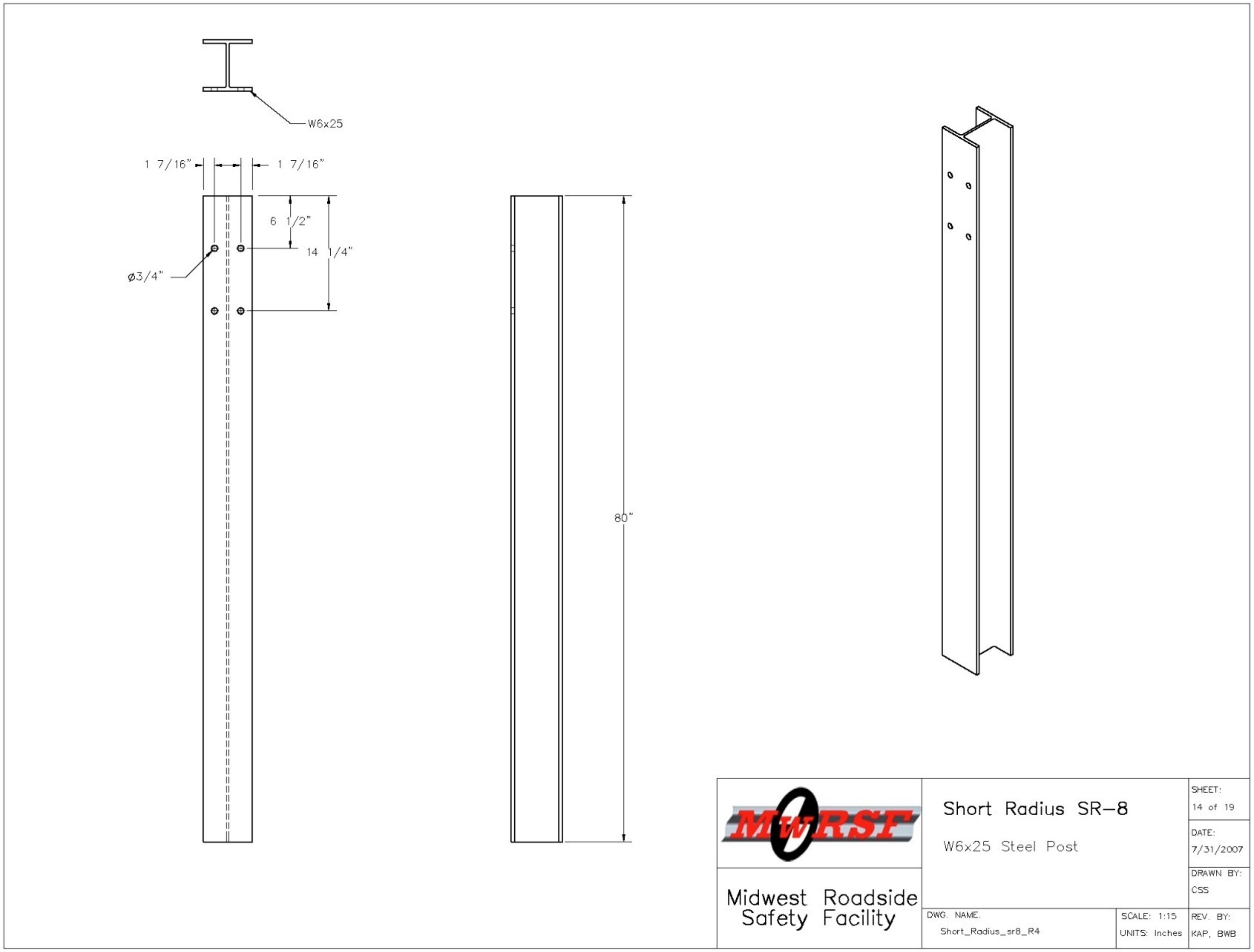


Figure 14. Short-Radius Design Details, Test No. SR-8

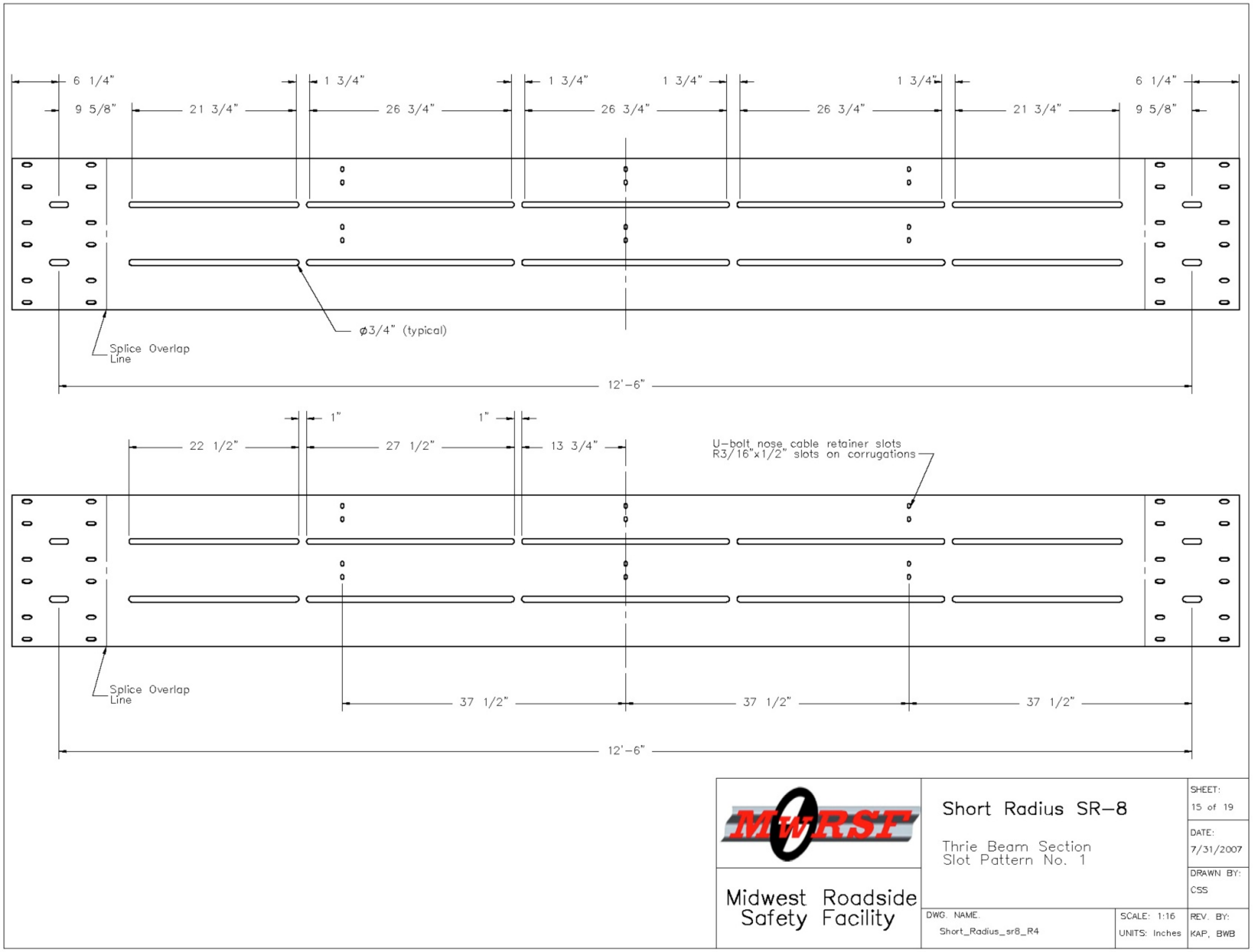


Figure 15. Short-Radius Design Details, Test No. SR-8

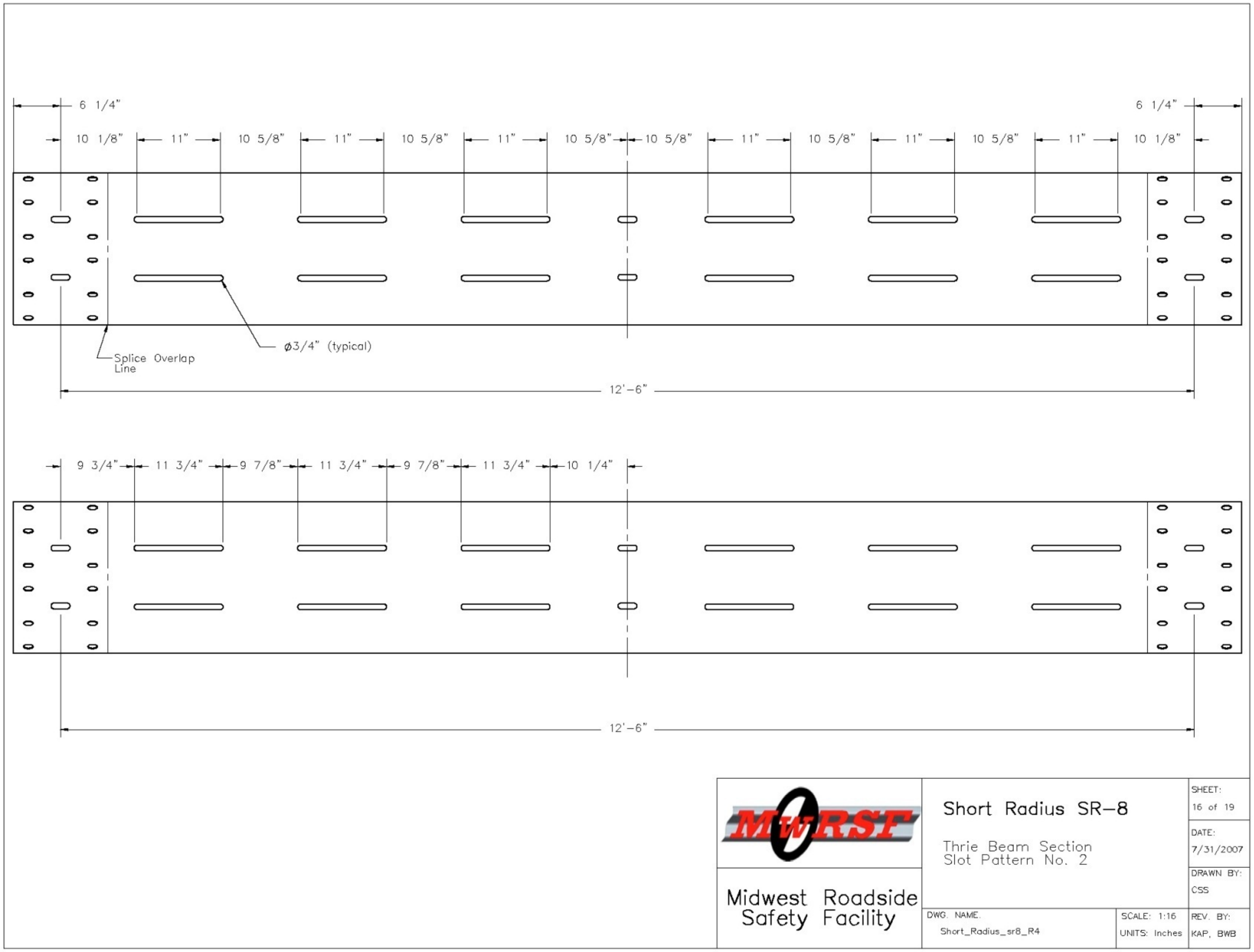


Figure 16. Short-Radius Design Details, Test No. SR-8

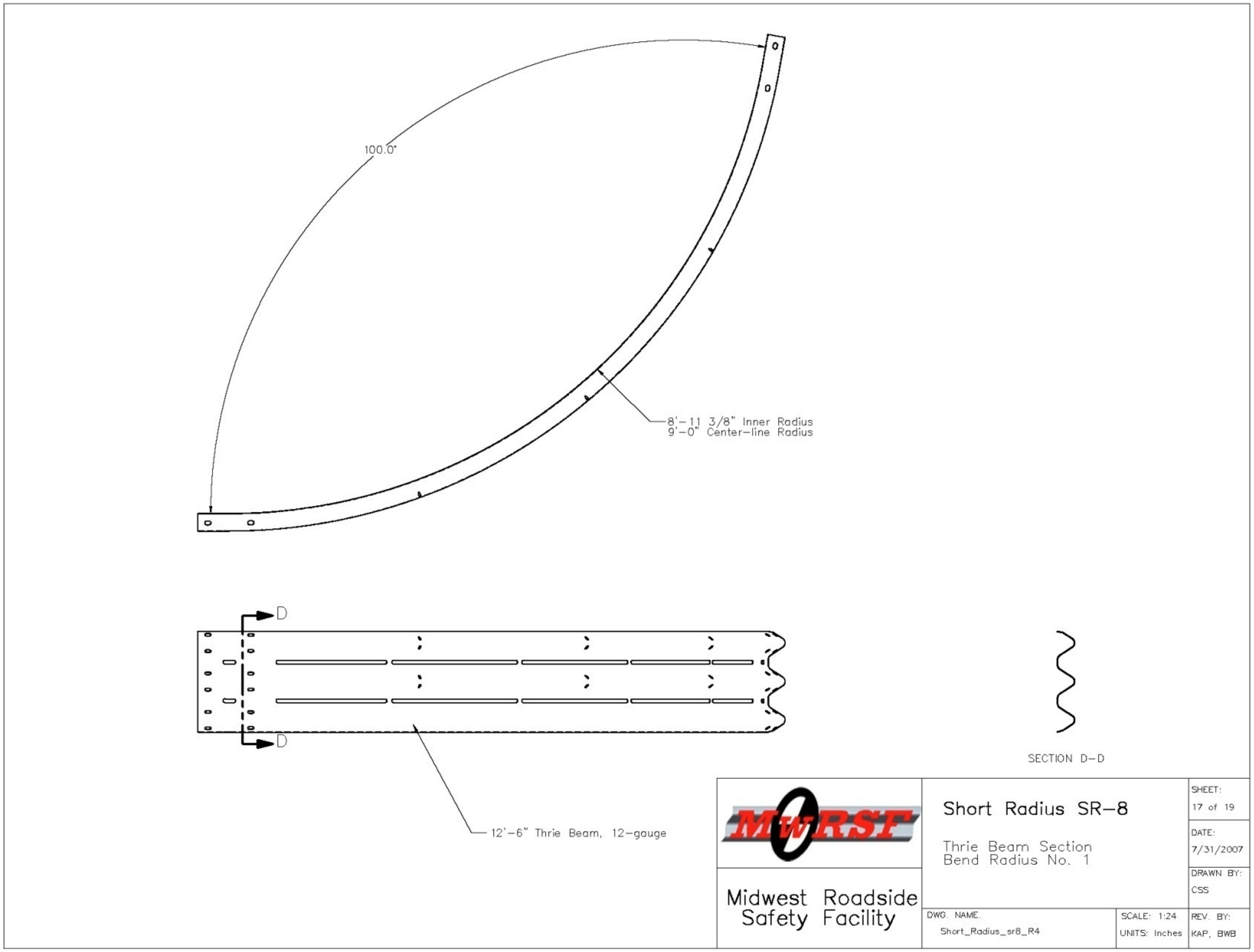


Figure 17. Short-Radius Design Details, Test No. SR-8

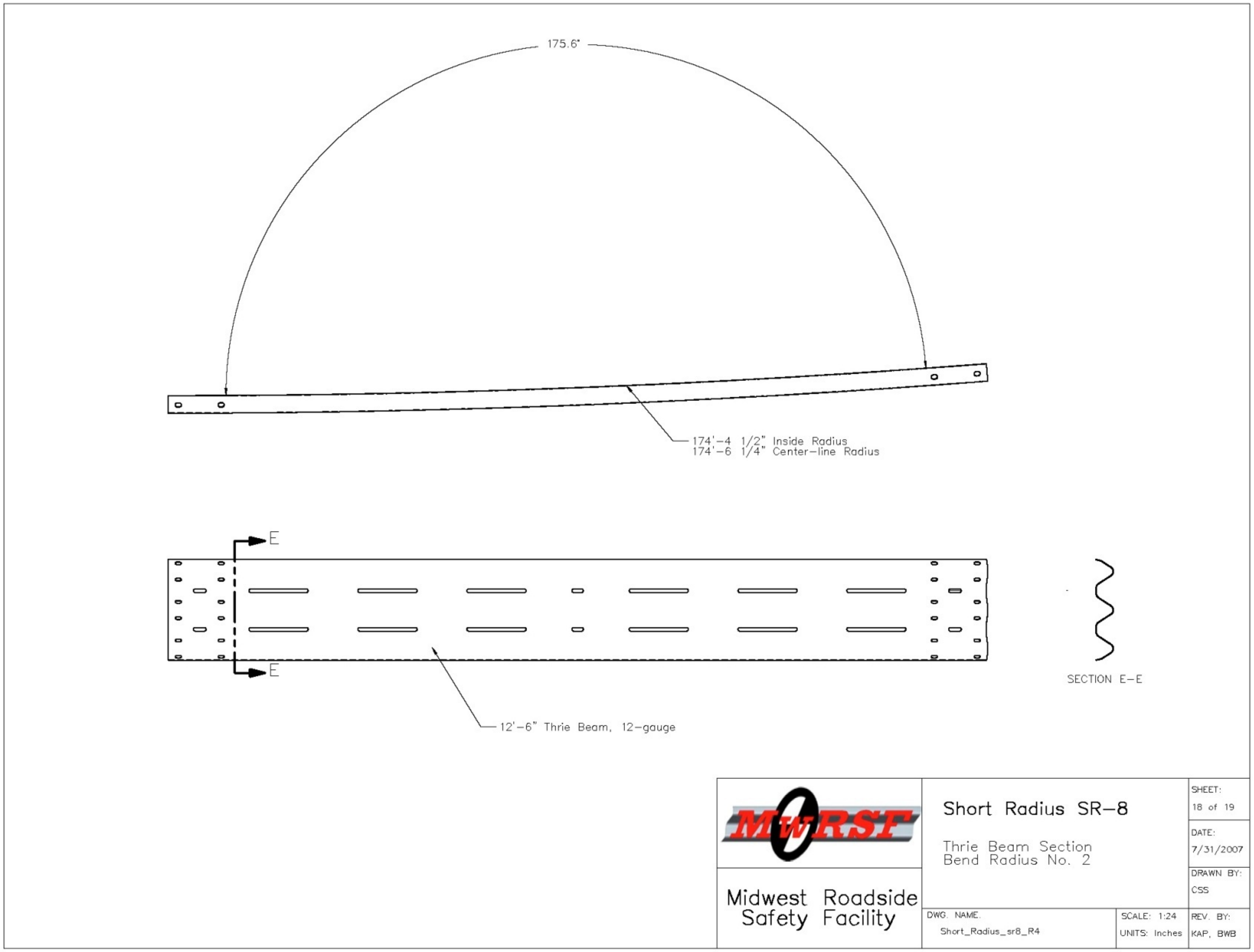


Figure 18. Short-Radius Design Details, Test No. SR-8

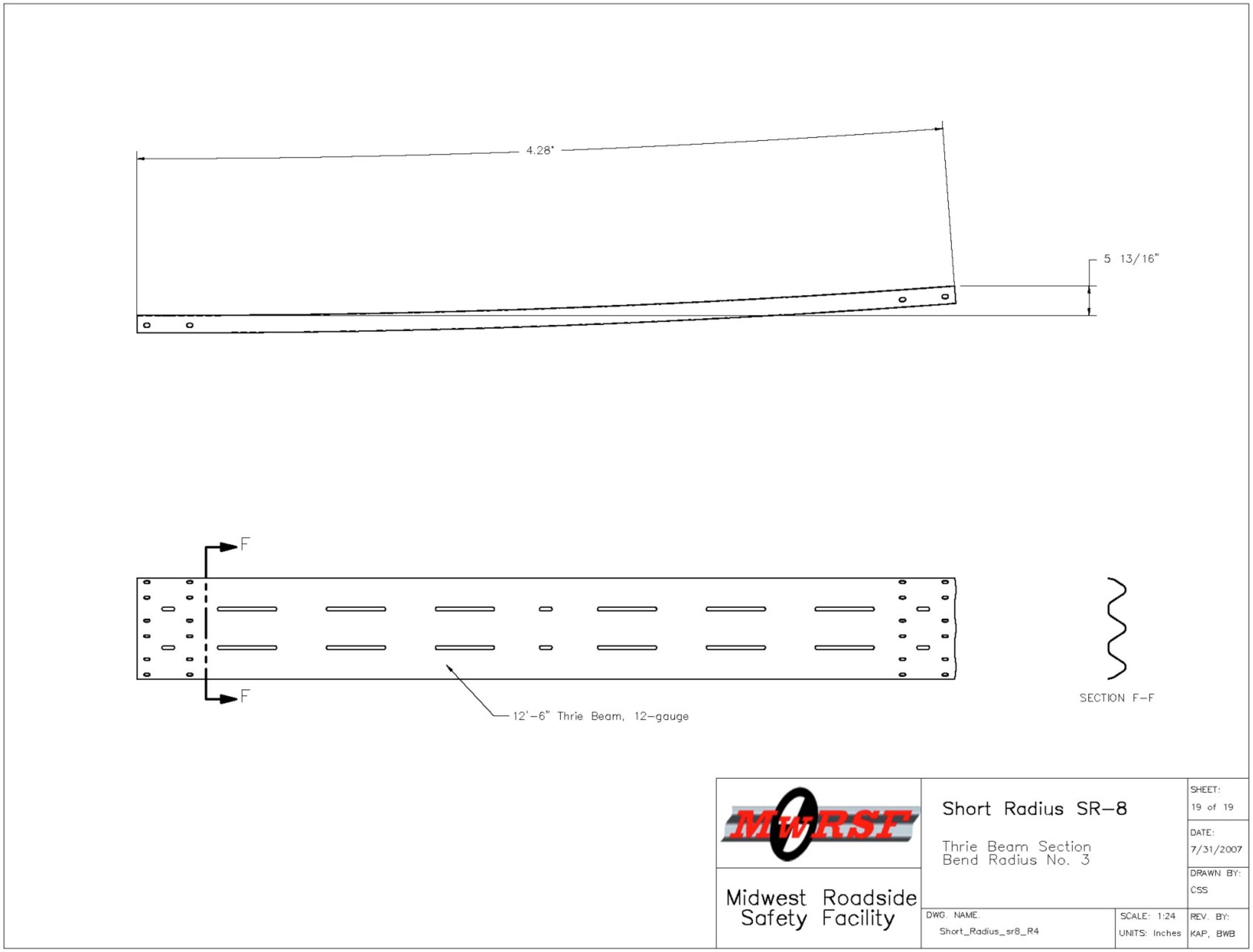
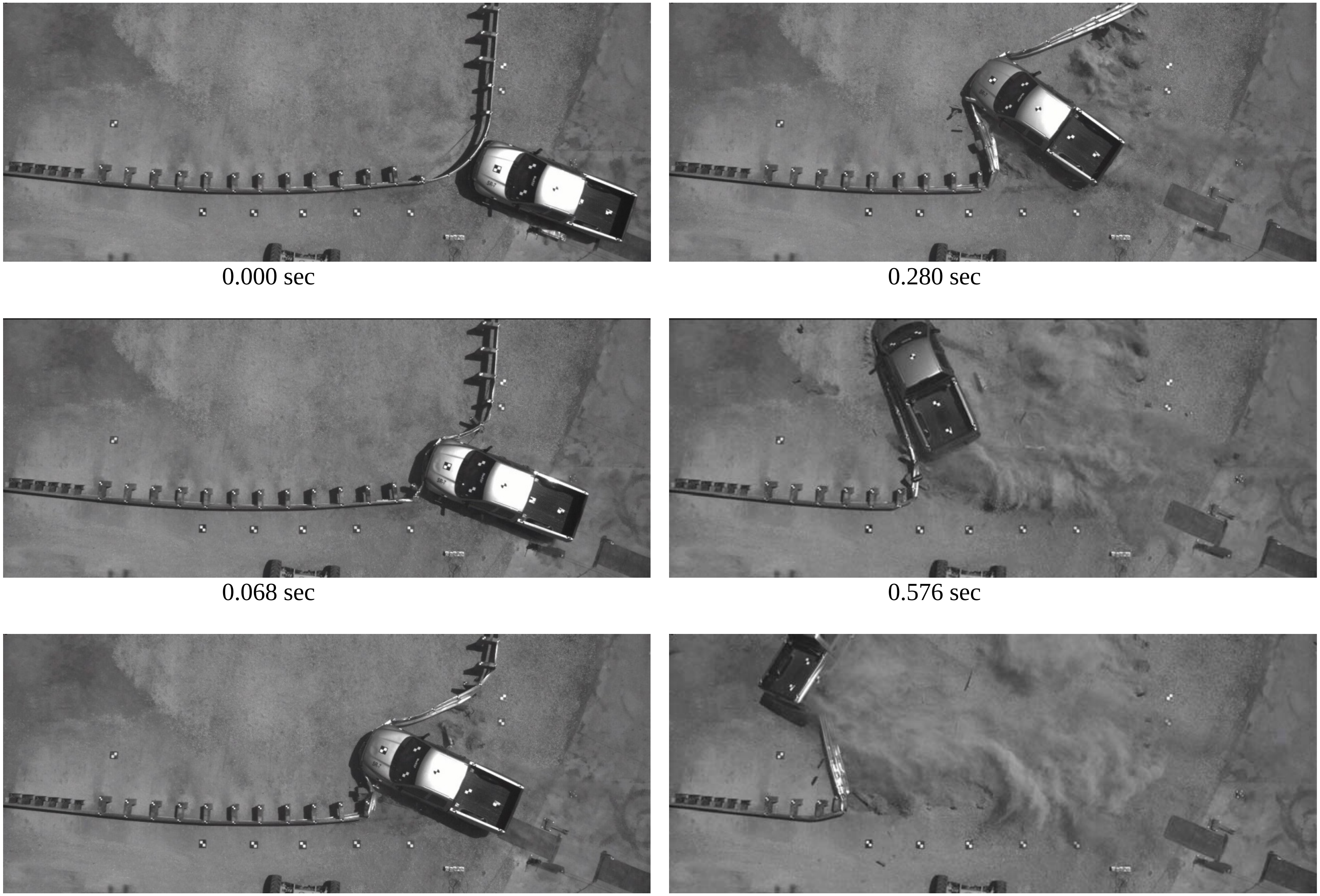


Figure 19. Short-Radius Design Details, Test No. SR-8



0.000 sec

0.280 sec

0.068 sec

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0.168 sec

0.958 sec

Figure 20. Sequential Photographs, Test No. SR-7

0.000 sec

0.066 sec

0.122 sec

0.174 sec

0.260 sec

0.382 sec

Figure 21. Sequential Photographs, Test No. SR-7

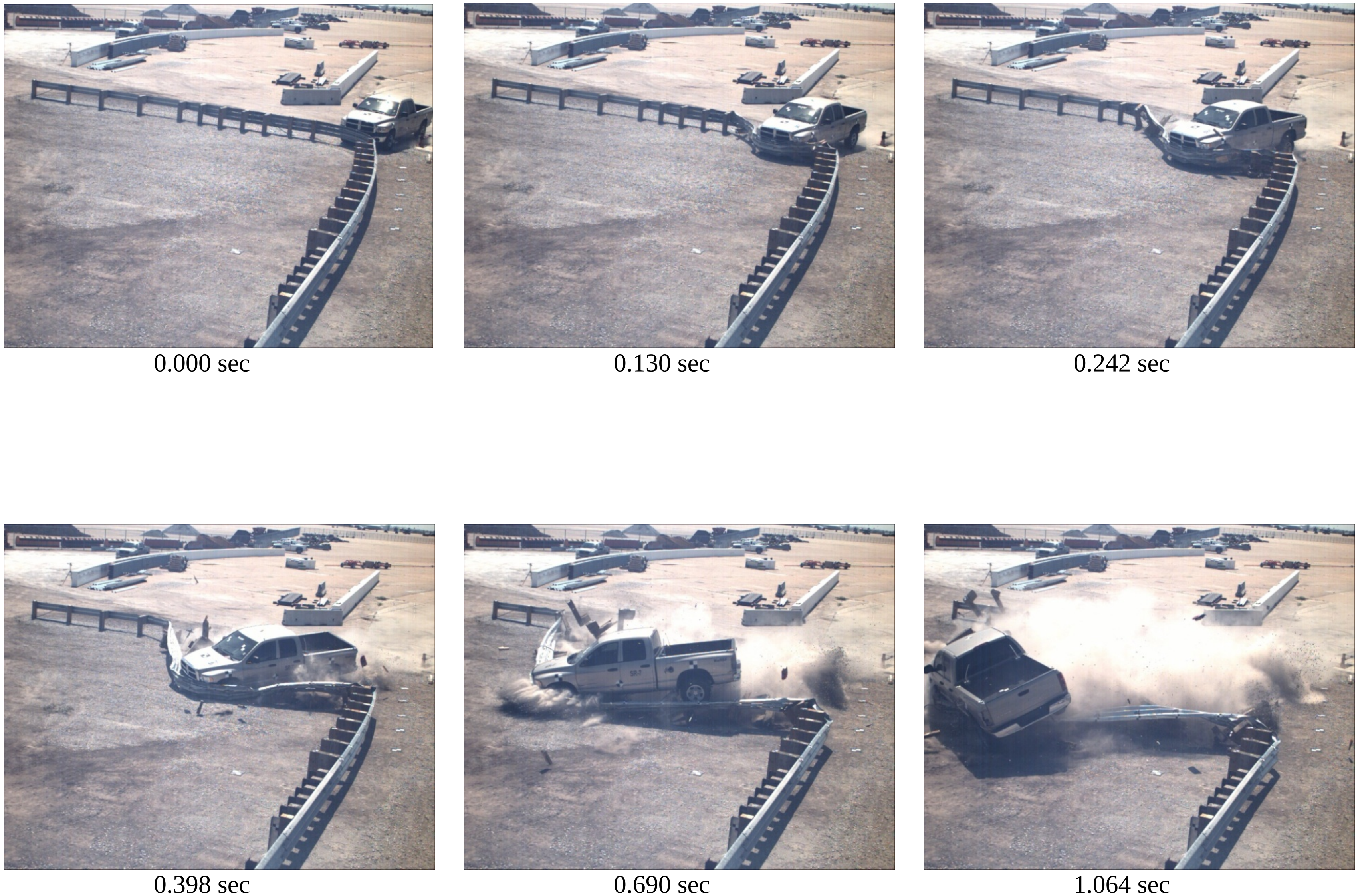


Figure 22. Sequential Photographs, Test No. SR-7

0.000 sec

0.082 sec

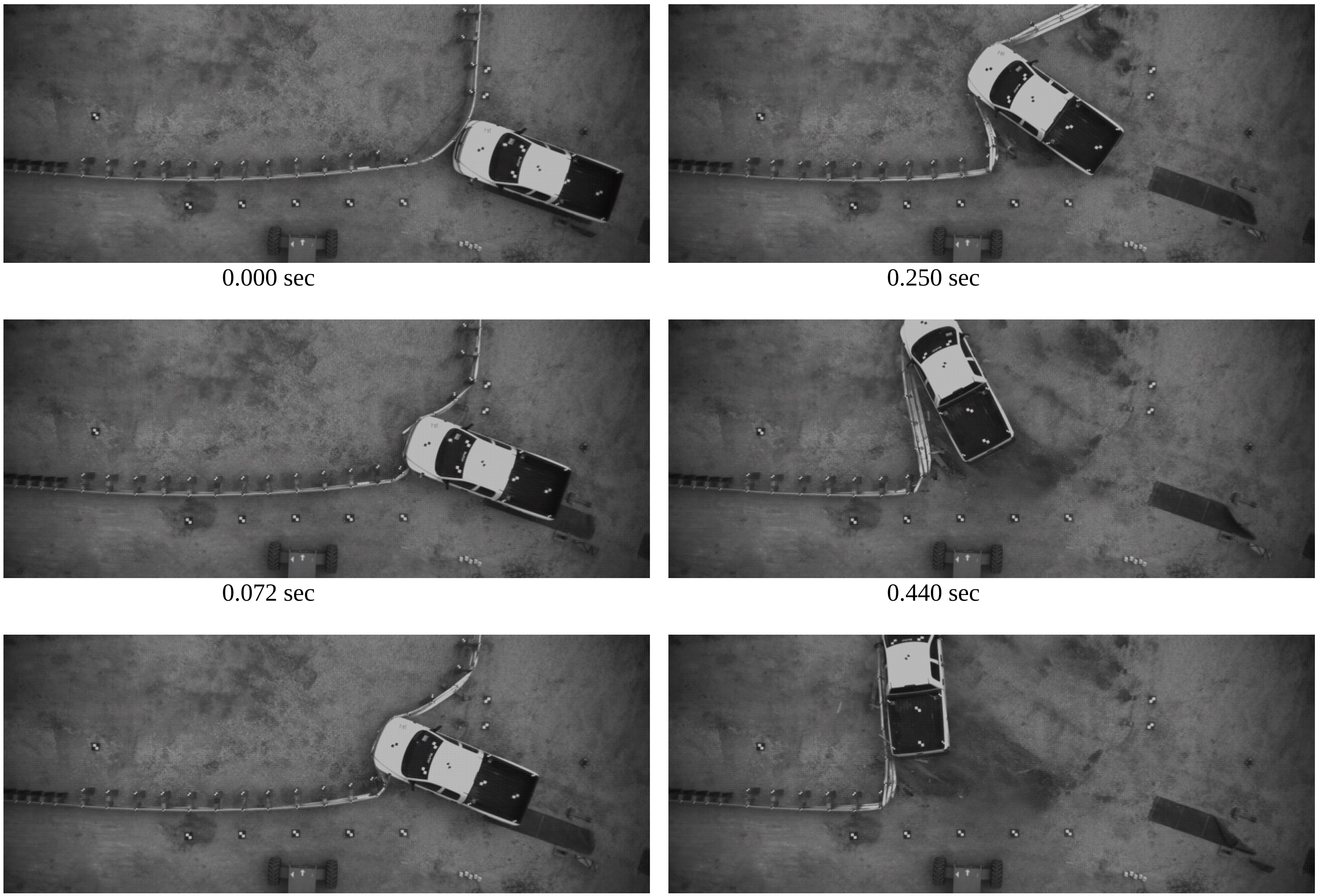
0.308 sec

0.416 sec

0.822 sec

1.320 sec

Figure 23. Sequential Photographs, Test No. SR-7



0.000 sec

0.072 sec

0.120 sec

0.250 sec

0.440 sec

0.556 sec

Figure 24. Sequential Photographs, Test No. SR-8

0.000 sec

0.126 sec

0.196 sec

0.274 sec

0.406 sec

0.570 sec

Figure 25. Sequential Photographs, Test No. SR-8

0.000 sec

0.064 sec

0.146 sec

0.266 sec

0.330 sec

0.448 sec

Figure 26. Sequential Photographs, Test No. SR-8

0.000 sec 0.096 sec 0.148 sec

0.274 sec 0.586 sec 1.078 sec

Figure 27. Sequential Photographs, Test No. SR-8