Nebraska
UNIVERSITY OF
Lincoln

Midwest Roadside Safety Facility

September 1, 2017

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Dear Jodi Thomas, Brian, Andy, and Steve:

The Midwest Roadside Safety Facility (MwRSF) of the University of Nebraska-Lincoln (UNL) is submitting the research costs associated with one FY2018 research project sponsored by the Ohio Department of Transportation (ODOT). The project is entitled,

RPFP-18-CORRAL-1: Development of an Optimized MASH TL-4 Kansas Corral Rail (FY2018)
Costs: $401,400

On behalf of Dr. Ronald K. Faller, Mr. Robert W. Bielenberg, Mr. Scott K. Rosenbaugh, Mr. Jim Holloway, and Ms. Karla Lechtenberg of MwRSF, the Board of Regents of the University of Nebraska-Lincoln is submitting one fixed-cost proposal in the amount of $401,400, as provided in Attachment 1. The proposed project period begins October 1, 2017 and ends September 30, 2019. This application has been administratively approved on behalf of the Board of Regents by the appropriate University of Nebraska officials. A copy of the proposal is provided in Attachment A.

The scope of work for this research includes: (1) a literature review of previous MASH and NCHRP 350 TL-4 open concrete bridge rails and collection of bridge deck details from participating states; (2) design and analysis of potential modifications to the Kansas corral rail to meet MASH TL-4 safety criteria, consider future pavement overlays, mitigate head slap concerns, and limit structural damage to the bridge deck during impacts; (3) selection of a preferred corral rail design by the participating states; (4) development of CAD details for the bridge rail; (5) construction of test article at MwRSF's outdoor testing facility; (6) conducting three TL-4 full-scale vehicle crash tests into the revised corral rail according to test designation nos. 4-10, 4-11, and 4-12 of AASHTO's *Manual for Assessing Safety Hardware* (MASH); (7) analysis and evaluation of crash test results along with determination of the zone of intrusion (ZOI); (8) development of transitions from the corral rail to a standardized concrete end buttress; (9) documentation and preparation of summary research report; (10) system removal, site cleanup, and disposal of debris; and (11) submission of FHWA eligibility letter for the successfully tested railing system and preparation of CAD details for the Task Force 13 Hardware Guide.

Note that MwRSF will be responsible for acquiring and fabricating the bridge rail and simulated bridge deck and constructing the system at MwRSF's outdoor testing facility. Mill certifications and material specifications will be sought from the vendor's of the construction materials and barrier hardware. All full-scale vehicle crash tests will be performed, evaluated, documented, and reported according to the TL-4 guidelines provided in MASH. The test will be conducted according to MwRSF's list of accredited testing services granted by the A2LA laboratory accreditation body. The research cost includes a set of DVDs/CDs for their records and dissemination which document the test results with digital crash movie files and digital photographs. Fifteen (15) copies of each research and test report will be provided to the sponsors. This research proposal is good for 30 days.

If this project is accepted and awarded, please notify the Office of Sponsored Programs in writing with your decision. Questions regarding the technical aspects of this proposal should be directed to Dr. Faller at (402) 472-6864. Administrative and/or fiscal questions should be directed to Ms. Kate Carlin at (402) 472-3601.

Sincerely,

Ronald K. Faller

Ronald K. Faller, Ph.D., P.E.
Director & Research Associate Professor

Approved by,

Jeanne Wicks

Jeanne Wicks
Director

PROJECT TITLE:

RPFP-18-CORRAL-1: Development of an Optimized MASH TL-4 Kansas Corral Rail (Kansas, Iowa, South Dakota, and Virginia)

STATE'S PROBLEM STATEMENT:

Historically, rigid concrete bridge rails satisfying Test Level 4 (TL-4) criteria have been 32 in. tall. However, with the adoption of MASH and an increase in both mass and impact speed for the single-unit truck, TL-4 tests on 32-in. tall sloped-face barriers have repeatedly resulted in the 10000S vehicle rolling over the barrier. As such, bridge rails taller than 32 in. are now required to meet the MASH TL-4 criteria. Additionally, designers will often further increase the height of a bridge rail in preparations of future roadway overlays. Increasing a concrete bridge rail's height may lead to better containment of single-unit trucks, but it can also lead to an increase in head slap incidence for occupants in passenger vehicles. Past research regarding the geometry of rigid concrete barriers has also indicated that certain barrier shapes, such as safety shapes, increase the propensity for vehicle climb, instability, and rollover. Thus, an optimized geometric shape that considers vehicle stability, occupant head ejection, and pavement overlays is desired for new TL-4 bridge rails.

Further, the effect of increased impact loads to TL-4 open concrete or corral railings has not been evaluated with respect to MASH. The increased impact severity associated with MASH TL-4 criteria will increase impact loads imparted to the deck and could lead to deck damage. Retrofitting stronger bridge rails onto existing bridge decks not designed for these increased loads may lead to deck damage during severe impacts.

Kansas Department of Transportation (KDOT) currently utilizes an NCHRP 350 TL-4 compliant 32-in. tall open concrete corral rail on many of its bridges. The KDOT corral rail, or a similar variation, is also used to some extent across over 22 states including, Nebraska, Illinois, Virginia, Indiana, Iowa, Ohio, Minnesota, Missouri, Texas, and Wisconsin. However, there are concerns with respect to KDOT's corral rail meeting MASH TL-4 based on the rail height and load concerns noted previously. Therefore, a need exists to modify and evaluate the KDOT open concrete corral rail to MASH TL-4 in order to increase safety, optimize the design to control installation costs, and minimize damage to the bridge deck.

BACKGROUND:

During the years of NCHRP Report No. 350, rigid TL-4 barriers were typically designed and successfully tested with a height of 32 in. With the adoption of MASH, the single-unit truck vehicle became 4,400 lb. heavier and the impact speed was increased from 50 mph to 56 mph. These increases in mass and impact speed have resulted in the MASH single-unit truck rolling over the top of multiple 32-in. tall rigid, concrete barriers. Studies at both MwRSF and TTI have indicated that the required height for a concrete barrier or bridge rail to contain MASH single unit trucks is approximately 36 in.

Research has shown that the sloped face of safety-shape barriers contributes to increased vehicle instability and rollover, especially with regard to small cars. These studies have shown that 8.5 percent of safety shape barrier accidents result in rollover, and that safety shape median barriers pose over twice the rollover rate of other median barriers. The increased rollover potential with these barrier shapes becomes critical because rollover accidents double the risk of incapacitating and fatal injuries.

Vertical-face barriers have been shown to provide the largest reduction in vehicle rollover when compared with safety shape barriers through both computer simulation and full-scale crash testing. A detailed study of the safety of permanent concrete safety-shape barriers, completed in 1989, indicated that safety-shape barriers were much more likely to cause impacting vehicles to rollover than other types of barrier. Further, this study indicated that safety-shape barriers produced higher injury and fatality rates than any other barrier system. Full-scale crash tests have been conducted on many different safety shape portable concrete barrier systems. These crash tests clearly indicated significant vehicle climb when these barriers are struck by light truck test vehicles. One full-scale test of a vertical shape portable barrier comprised of steel Hsections demonstrated little to no propensity for the light truck vehicle to climb the barrier, thus indicating a much lower propensity for causing vehicle rollover.

KDOT currently uses a vertical-shape, open concrete bridge rail or corral rail that was accepted under the TL-4 impact safety standards published in NCHRP Report No. 350. Details of the current KDOT corral rail system with and without curb are shown in Figures 1 through 5. KDOT desires for the corral rail to remain available for use following MASH implementation. However, modifications of the test vehicles and impact conditions in MASH will require that the design be analyzed, potentially modified and full-scale crash tested based on several concerns. First, the TL-4 MASH test with the 1100C small car requires an impact at 62 mph and an angle of 25 degrees, while the previous NCHRP Report No. 350 small car test required an impact angle of only 20 degrees. The increase in the small car impact angle may potentially increase vehicle snag, vehicle instability, and occupant risk, especially with respect to the open concrete rail. Second, similar wheel snag and instability concerns exist with respect to open concrete rails during impacts with the pickup truck vehicle (2270P). Third, the mass of the pickup truck (2270P) and single-unit-truck (SUT) (10000S) vehicles were increased in MASH to 5,000 lb. and 22,000 lb., respectively, and the impact speed for test designation no. 4-12 with the SUT vehicle was increased from 49.7 mph to 56 mph. These changes in vehicle mass and impact conditions have increased the impact loads imparted to roadside bridge rails. Analysis of NCHRP Report No. 350 and MASH tests of rigid barrier systems have shown increases in impact loading between 14 – 50 percent for the pickup truck vehicle and 11 – 54 percent for the SUT vehicle. Finally, the increased speed and mass of the 10000S vehicle test in MASH has indicated a need for increased rail height as compared to TL-4 bridge rails evaluated under NCHRP Report No. 350 due to rollover of the bridge rail by the SUT. Currently, the minimum height of a rigid, concrete barrier evaluated to MASH TL-4 with the 10000S vehicle has been suggested as 36 in. due to a successful crash test on a single-slope parapet. Thus, the current KDOT bridge rail may need to consider increased rail height in order to meet MASH TL-4.

Texas A&M Transportation Institute (TTI) has recently completed MASH testing of a 42-in. tall open concrete bridge rail system, as shown in Figure 6. This system was successfully evaluated to TL-5, and it was successfully tested with both the 2270P and 1100C passenger vehicles. While this open concrete bridge rail has some similar features to the KDOT design, the TTI bridge rail differs significantly in that it incorporated a 9-in. tall curb at the base, was 10 in. taller, and had different post and joint details. The inclusion of the curb at the base of the rail may mitigate some of the wheel snag and vehicle stability concerns posed by an open concrete bridge rail without a curb. However, the evaluation of the TTI open concrete bridge rail system may provide valuable insight into potential modifications for the KDOT corral rail.

In addition to potential modifications required to the bridge rail in order to meet MASH TL-4, KDOT desires that the bridge rail consider 3 in. asphalt overlays while maintaining the safety performance of bridge rail. The increase in bridge rail height required for overlay consideration may require some modification of reinforcing steel and bridge rail anchorage. The current KDOT corral rail does not have considerations for mitigation of occupant head ejection during passenger vehicle impacts. Previous concrete barriers and bridge rail systems developed at MwRSF incorporated design geometries to prevent an occupant's head from contacting the side of the barrier. Increasing the bridge rail height to accommodate pavement overlays may require some alteration of the geometry at the top of the bridge rail to meet head ejection envelope limitations.

Finally, the Midwest Pooled Fund has been developing a MASH TL-3 standardized concrete end buttress for the attachment of thrie beam approach guardrail transitions. The objective of this buttress design was to allow the attachment of any MASH TL-3 compliant thrie beam approach guardrail transition to a standard parapet design that could accommodate approach guardrail transitions with or without curbs and various post spacing and post configurations. This standardized concrete end buttress has recently completed MASH TL-3 evaluation for both a standard 31-in. tall thrie beam approach guardrail transition and a 34-in. tall thrie beam approach guardrail transition that allows for pavement overlays. It is desired that the MASH TL-4 corral rail design be developed with appropriate transitions to interface with the standardized concrete end buttress.

OBJECTIVE:

The objective of this research effort is to develop a MASH-compliant TL-4 open concrete, corral railing based on the existing KDOT NCHRP 350 TL-4 32-in. tall corral rail. The railing will be designed for strength, vehicle stability, and to minimize installation costs while accommodating pavement overlays. Efforts will also be made to optimize load transfer into the deck, thereby minimizing the risk of damage to the bridge deck. Details would be developed for both interior and end regions of the bridge rail, any necessary height transitions, and configurations near expansion joints. Any developed vertical transitions will be compatible with the standardized concrete end buttress research being conducted in Midwest Pooled Fund study RPFP-15-AGT-1 and RPFP-17-AGT-3. Finally, full-scale crash testing will be conducted to evaluate the corral rail shape, strength, load transfer to the deck, and the zone of intrusion (ZOI) for the new bridge rail.

RESEARCH PLAN:

The development of the revised KDOT corral rail will begin with a review of previously-tested MASH and NCHRP Report 350 open concrete bridge rails with a focus on structural reinforcement, connection to the bridge deck, head ejection mitigation, and rail geometry. In addition, MwRSF will collect bridge deck details from the participating states for consideration in the design process.

Following the literature review, the existing NDOR bridge rail will be analyzed to determine if the railing has sufficient structural capacity in both the rail and the rail-to-deck connection to adequately contain the higher impact loads associated with MASH TL-4. The researchers will also develop a revised rail geometry considering minimum TL-4 height, pavement overlays, and head slap mitigation. If necessary, the research team will implement structural improvements to the bridge rail to meet any potential deficiencies and enhance the overall bridge rail design. The researchers will analyze and revise both interior sections and end sections (expansion joints). The open concrete rail will be designed with consideration of a minimum deck thickness. This deck thickness and reinforcement will be based upon the deck designs of the participating states and agreed upon by the sponsors. Modifications to the bridge deck and post reinforcement will be made during the design process to accommodate the MASH TL-4 impact loads and mitigate deck damage.

Currently the corral rail design has versions with and without an integrated curb. The design and analysis of the corral rail will focus on the version without the curb as it is believed this design is more critical in terms of structural capacity, load transfer to the bridge deck, and vehicle snag on the bridge rail posts. If evaluation of the bridge rail is successful without a curb, it is anticipated that versions of the corral rail with the integrated curb would be acceptable.

CAD details of the proposed corral rail design will be submitted to the sponsoring states for review and comments. Modifications to the design will be made in order to meet the needs of the sponsoring states. Once a final design has been agreed upon, MwRSF will develop the necessary geometry and height transitions for the corral rail to interface with the standardized concrete end buttress developed through the Pooled Fund for the connection of approach guardrail transitions.

Following the analysis and design effort, the researchers will evaluate the revised corral rail to the MASH criteria through full-scale crash testing. All testing will be conducted on the open concrete rail version of the system. MASH 2016 requires three full-scale crash tests to evaluate longitudinal barriers to MASH TL-4. Those tests are listed in Table 1.

Table 1. MASH TL-4 Test Matrix for the Revised Kansas Corral Rail

Test No.	Vehicle	Speed (mph)	Angle (deg)	Impact Point	Other Notes
4-10	1100C	62	25	3.6 ft from post	Evaluated at maximum rail height
4-11	2270P	62	25	4.3 ft from post	Evaluated at maximum rail height
4-12	10000S	56	15	4.3 ft from joint	Evaluated at minimum rail height

Test designation no. 4-10 with the 1100C vehicle will be required to evaluate occupant risk measures and the potential for vehicle snag on the upstream end of posts. Test designation no. 4-11 is required to evaluate concerns for increased bridge rail loading, potential vehicle snag at joints and posts, and instability. Test designation no. 4-12 with the 10000S vehicle will evaluate the overall structural capacity of the bridge rail and its ability to contain and redirect the SUT vehicle. Full evaluation of the corral rail design would likely require multiple test versions of each test designation to evaluate design differences between the end and interior sections of the bridge rail. However, it is believed that selection of a critical configuration for each test can be combined with conservative design of the bridge rail to limit the number of required tests.

MwRSF is proposing three full-scale crash tests to evaluate the revised corral rail to MASH TL-4. MwRSF will focus on the testing and evaluation of the corral rail with passenger vehicles at the maximum rail height to evaluate the potential for vehicle snag on posts, vehicle stability, and occupant risk concerns. Thus, test designation nos. 4-10 and 4-11 will be conducted on the interior section of the revised KDOT corral rail at the maximum rail height. Evaluation of passenger vehicles at expansion joints or end sections would not be required if the end sections employed similar post geometries and were designed to limit vehicle snag. Previous anchored portable concrete barrier testing and a PL-2 open concrete rail testing suggests that 4-in. wide gaps may be permissible. However, a more conservative approach may be to limit the gaps to 2 in. Cover plates or other shielding mechanisms could also be applied to alleviate snag concerns. The need for passenger vehicle tests adjacent to the end sections may still need to be revisited based the configuration of the final system design. It should also be noted that it may be worthy to consider evaluation of the end section with passenger vehicles to build further confidence in the safety performance of the system based on the recent switch to new vehicle types as part of the implementation of MASH and the lack of experience and knowledge regarding the performance of the new vehicle types with certain types of hardware. Additionally, it should be noted that any tests within the evaluation matrix deemed non-critical may eventually need to be evaluated based on additional knowledge gained over time or additional FHWA eligibility letter requirements.

One test designation no. 4-12 would be required evaluate the structural capacity of the bridge rail and the ability of the bridge rail to contain the single unit truck. Test designation no. 4-12 will be conducted adjacent to the weakest structural location in the bridge rail. This location may be at an expansion joint or other suitable location dependent on the structural capacity of the bridge rail. Previous testing of TL-5 bridge rails at MwRSF and TTI have focused on developing end sections that have the same strength and capacity as interior regions. Thus, the bridge rails were evaluated through full-scale testing with the heavy truck vehicles at the end section or a joint where it was anticipated that loading of the bridge rail and the deck would be most critical. A similar approach is proposed here. If the design of the corral rail results in end sections that are significantly higher capacity than the interior section, then full-scale crash test designation no. 4-12 would be conducted on an interior section of the bridge rail. Additionally, test designation no. 4-12 will be conducted at the lowest height representing the 3-in. pavement overlay as the lower height is more critical when attempting to capture and redirect the 10000S vehicle.

MwRSF will prepare CAD drawings of the revised KDOT corral rail and fabricate and install the bridge rail system at the MwRSF's Outdoor Testing Facility. Accommodations will be made at the test facility for evaluating the bridge rail at two effective heights, as noted previously. MwRSF will construct two systems for the testing. A 125-ft long section of bridge rail will be installed for test designation 4-12. This bridge rail will be installed in a pit with a 60-ft long simulated bridge deck installed 3 in. below grade with a 3-in. deep overlay to create the minimum effective height for the bridge rail. The use of the simulated bridge deck for test designation no. 4-12 will allow for evaluation of bridge deck damage under the most critical loading condition. Test designation nos. 4-10 and 4-11 will .be conducted on a 60-ft long section of bridge rail installed at the maximum effective rail height on the concrete tarmac at the test facility. The full-scale crash tests will be conducted, documented, and evaluated by MwRSF personnel in accordance with the MASH TL-4 guidelines. The test will be conducted according to MwRSF's list of accredited testing services granted by the A2LA laboratory accreditation body (A2LA Cert. No. 2937.01). Test data and videos will be analyzed to estimate impact loads and the ZOI for the corral rail.

At the conclusion of the research effort, a summary report will be completed to document the analysis, design revisions, testing, and evaluation of the MASH TL-4 KDOT corral rail as well as any recommendations for implementation and bridge rail installation. MwRSF would also submit the bridge rail system to FHWA for an eligibility letter and prepare corresponding Task Force 13 Hardware Guide drawings.

Major Task List:

1. Project Planning and Correspondence
    a. General project planning and documentation
    b. Literature review of previous MASH and NCHRP 350 TL-4 open concrete bridge rails
    c. Collect bridge deck details from participating states
    d. Development of CAD details for design concepts, fabrication, testing, as well as transitions to the standardized end buttress

2. Design and Analysis
    a. Structural analysis of current KDOT Corral Rail capacity.
    b. Determination of rail geometry considering minimum TL-4 height, pavement overlays, and head slap mitigation
    c. Modify existing KDOT NCHRP-350 TL-4 corral railing including interior sections, end sections, expansion joints, and any necessary transitions
    d. Design and modification of bridge deck and post reinforcement for chosen critical bridge deck
    e. Review and comment regarding proposed design by Kansas, Iowa, South Dakota, and Virginia
    f. Development of transition to standardized concrete end buttress

3. Full-Scale Crash Testing
    a. Construction of test article – Procurement of barrier hardware and assembly of barrier system at MwRSF's Outdoor Testing Facility.
        i. 125 ft of corral rail at minimum height with overlay and 60 ft of simulated bridge deck installed in test pit
        ii. 60 ft of corral rail installed on concrete tarmac at maximum height without overlay
    b. Conduct full-scale crash tests
        i. MASH test designation no. 4-10
        ii. MASH test designation no. 4-11
        iii. MASH test designation no. 4-12
    c. System removal - Removal and disposal of system components upon completion of test matrix.
    d. Data analysis
        i. Transducer and video analysis for crash tests.
        ii. Determination of ZOI

4. Reporting and Project Deliverables
    a. Sponsor correspondence and update presentations

b. Compile summary report to document research effort, including literature review, design, CAD details, crash testing, and recommendations for implementation and/or further research
c. Report editing (internal and sponsor review)
d. Submit test results to FHWA for eligibility letter
e. Complete drawings and submittal to Task Force 13 Hardware Guide
f. Project closing (printing, dissemination, accounting)

BENEFITS:

Successful development of the revised corral would provide states with a MASH TL-4 option when constructing new bridges or upgrading existing bridges. The bridge rail will provide unique benefits in that it will be optimized for vehicle containment and stability, load distribution into the deck, and cost while also allowing for future roadway overlays.

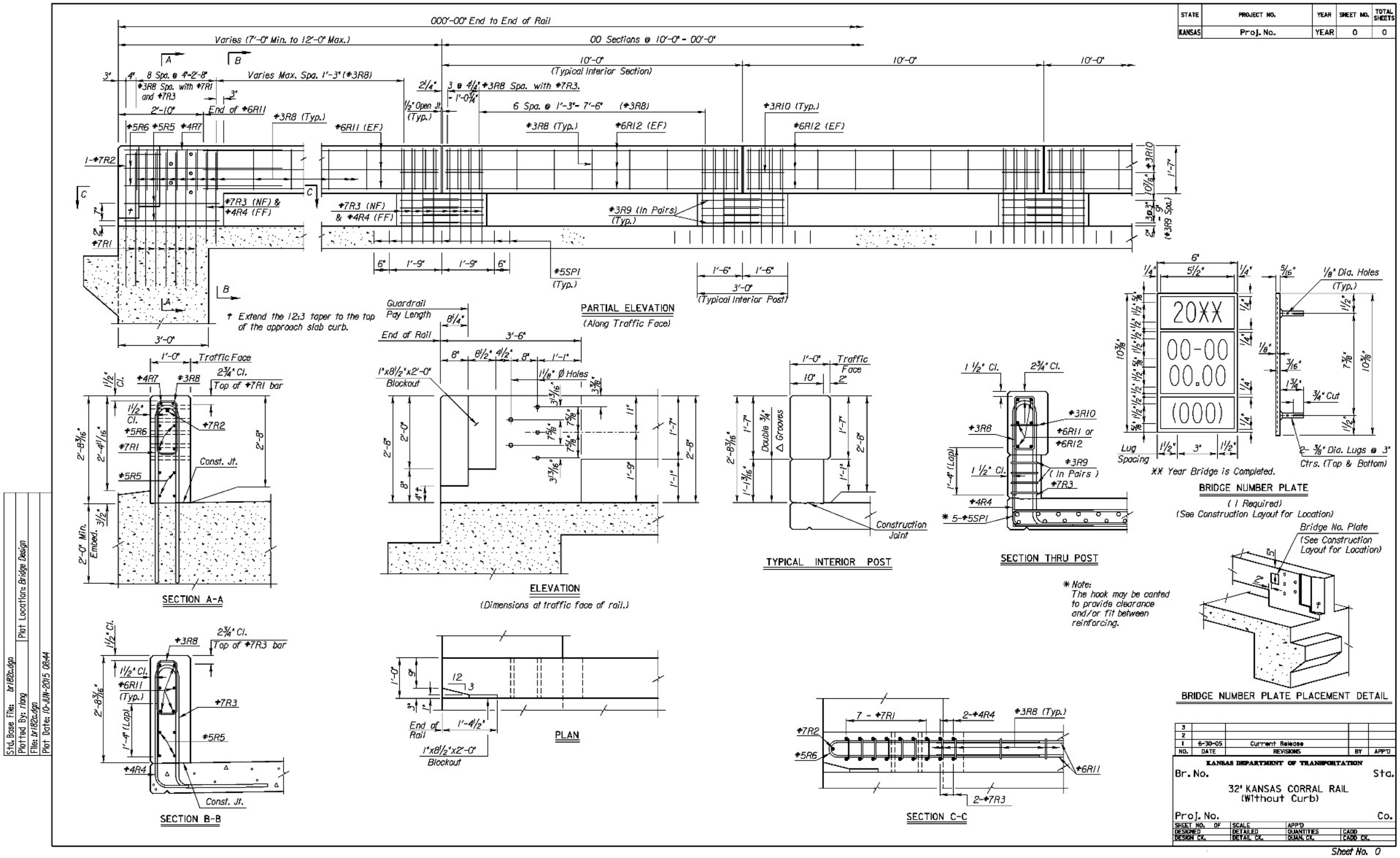

Figure 1. KDOT Open Concrete Corral Rail Details

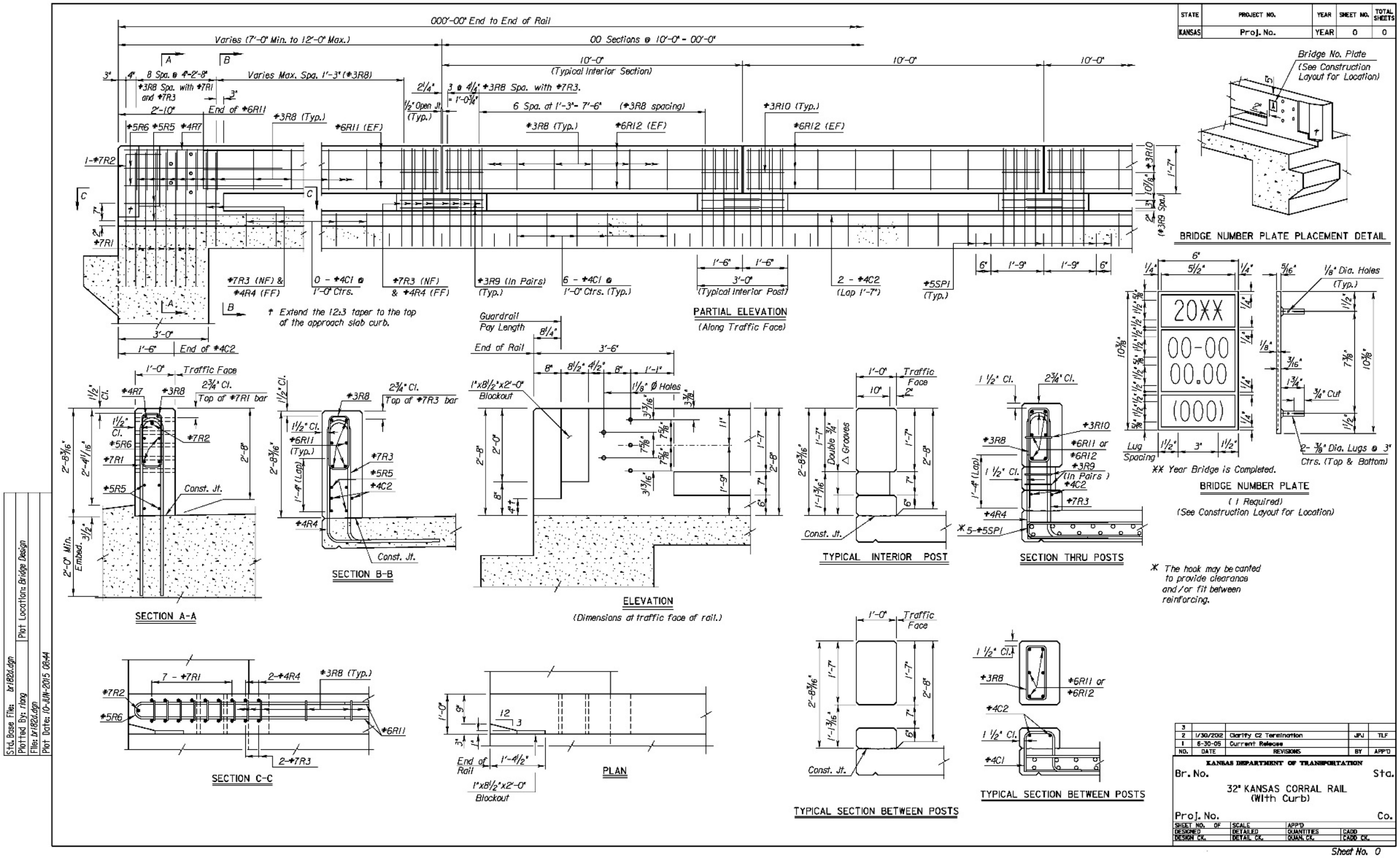

Figure 2. KDOT Open Concrete Corral Rail Details

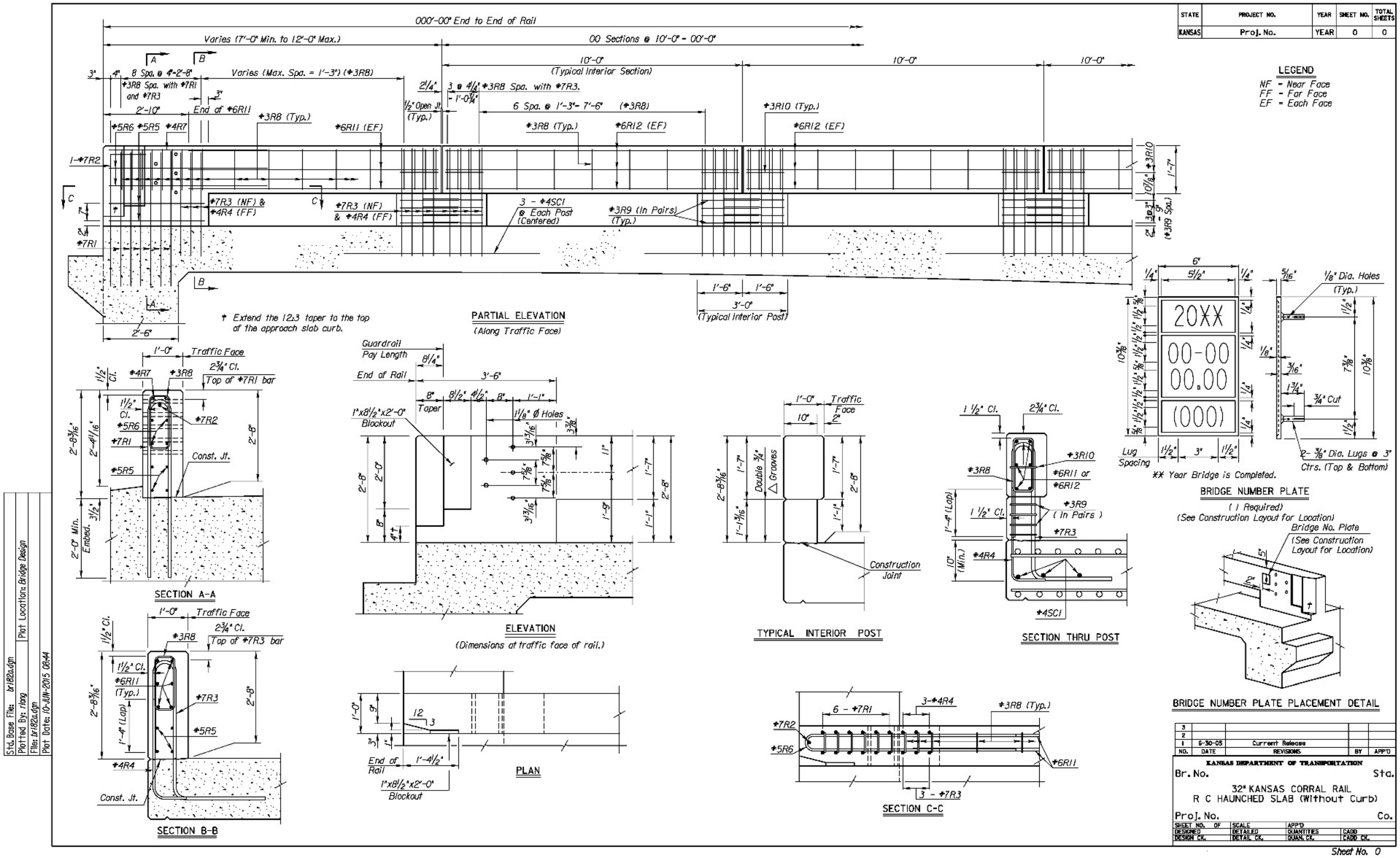

Figure 3. KDOT Open Concrete Corral Rail Details

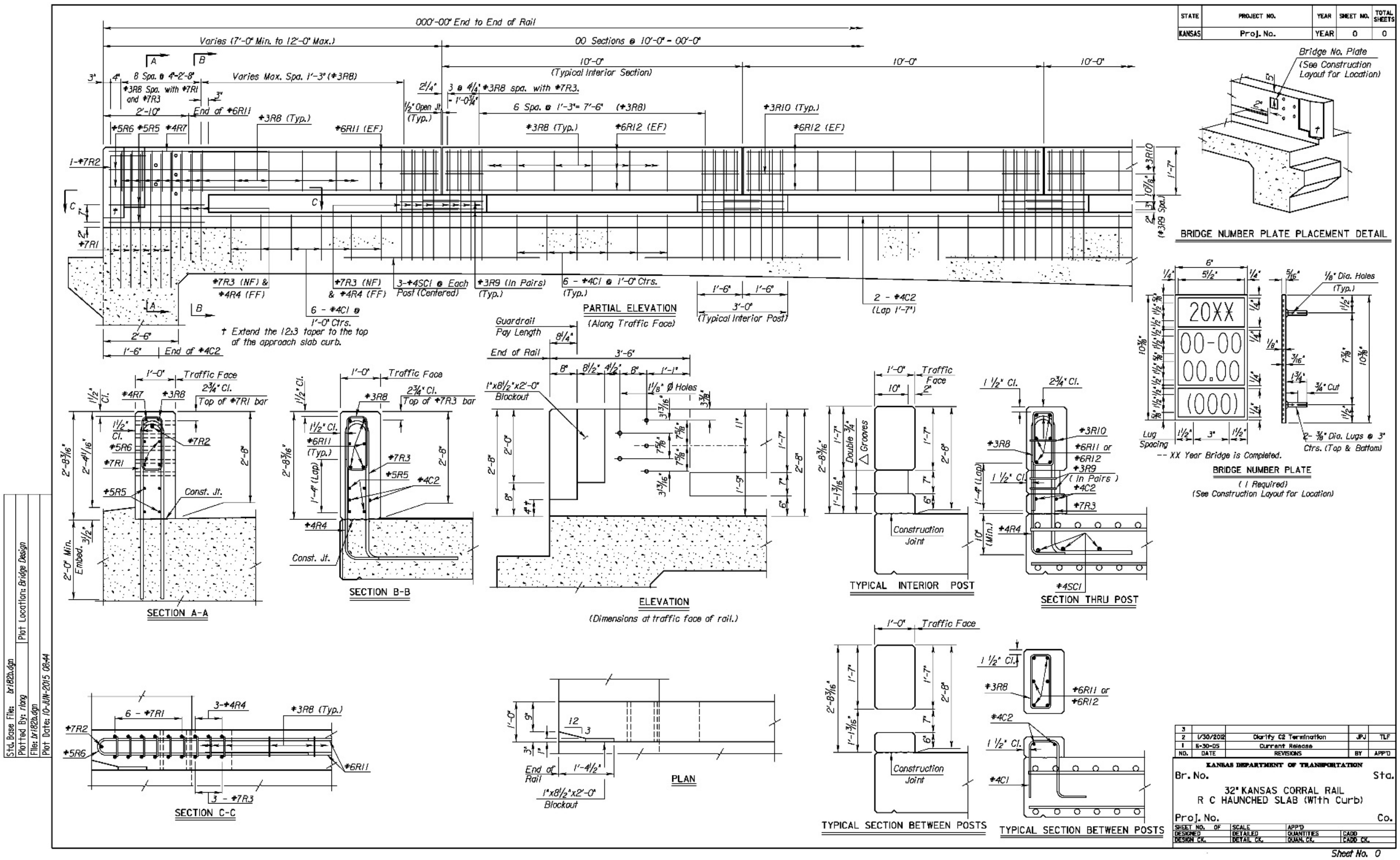

Figure 4. KDOT Open Concrete Corral Rail Details

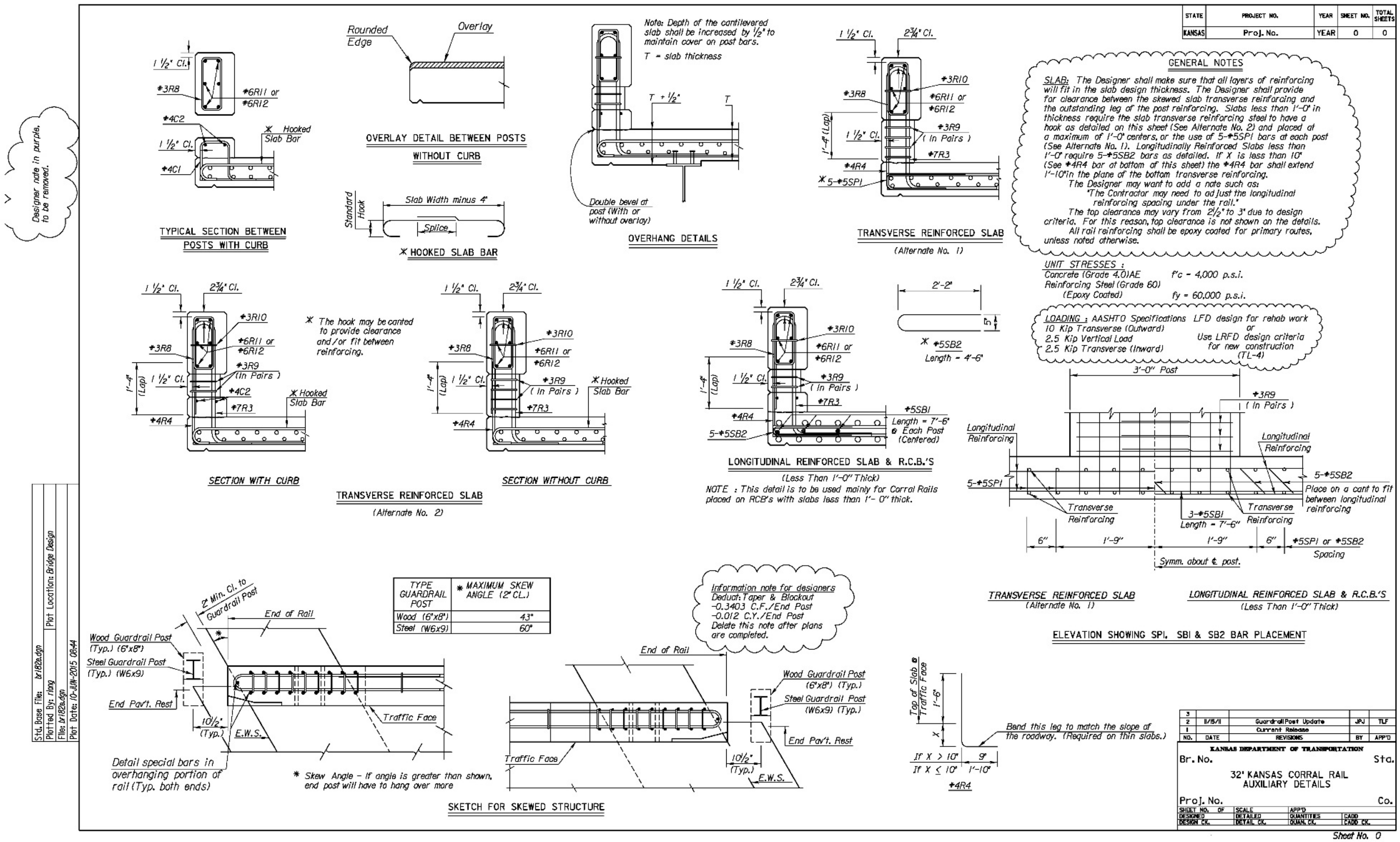

Figure 5. KDOT Open Concrete Corral Rail Details

Figure 6. TTI TL-5 Open Concrete Bridge Rail System

Table 1. RPFP-18-CORRAL-1: Development of an Optimized MASH TL-4 Kansas Corral Rail (Kansas, Iowa, South Dakota, and Virginia) – Budget

Item	Bridge Railing Design, Construction, Crash Testing, and Removal									Total Cost ($)
	Project Planning & Management, Client Correspondence, Progress Updates, Literature Review, Prepare 3-D CAD Details of Tested System, Document & Archive Mill Certifications	Strucutral Analysis of Current Corral Rail, Determination of Rail Geometry, Design of Barrier, Deck, Connections, Expansion Joints, and Height Transitions	Site Preparation, Acquire, Fabricate, & Install 60-ft Reinforced Concrete Corral Rail Anchored to Concrete Tarmac	Test No. 1 MASH Designation No. 4-10 TL-4 Crash Test without Overlay 1100C Small Car @ CIP 2,425 lb - 62 mph - 25 degrees	Remove Damaged Hardware, Acquire, Fabricate, Install Components to Repair System & System Removal After Test	Test No. 2 MASH Designation No. 4-11 TL-4 Crash Test without Overlay 2270P Pickup Truck @ CIP 5,000 lb - 62 mph - 25 degrees	Site Preparation, Acquire, Fabricate, & Install 125-ft Reinforced Concrete Corral Rail Anchored to Bridge Deck & Concrete Tarmac & System Removal After Test	Test No. 3 MASH Designation No. 4-12 TL-4 Crash Test with Overlay 10000S Single-Unit Truck @ CIP 22,046 lb - 56 mph - 15 degrees	Prepare AASHTO TF13 Hardware Drawings, File FHWA Letter, Preparation of Final Research Report Including Summary, Conclusions, and Recommendations	
	Costs ($)	Costs ($)	Costs ($) (2-4)	Costs ($)	Costs ($) (2-3, 5)	Costs ($)	Costs ($) (2, 6-8)	Costs ($)	Costs ($)	
Labor Operating Costs (1)	$20,282	$25,510	$20,970	$30,846	$4,452	$33,221	$61,637	$43,909	$21,874	$262,701
Testing Costs	$0	$0	$0	$10,891	$0	$16,976	$0	$20,786	$0	$48,653
Operating	$800	$800	$400	$840	$400	$840	$400	$1,110	$800	$6,390
Materials & Supplies	$200	$200	$11,838	$500	$2,300	$500	$30,927	$500	$200	$47,165
Travel	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Subtotal Costs	$21,282	$26,510	$33,208	$43,077	$7,152	$51,537	$92,964	$66,305	$22,874	$364,909
Overhead Costs (10%)	$2,128	$2,651	$3,321	$4,308	$715	$5,154	$9,296	$6,631	$2,287	$36,491
Total Project Costs	$23,410	$29,161	$36,529	$47,385	$7,867	$56,691	$102,260	$72,936	$25,161	$401,400

Note (1) - Administrative labor costs are calculated as 2.4% of direct costs.
Note (2) - The cost estimate assumes that the MwRSF will purchase all materials for the reinforced concrete beam & post bridge rail, and have them delivered to MwRSF's Outdoor Testing Facility.
Note (3) - MwRSF will: acquire, fabricate, install, and remove the 60-ft long concrete beam & post bridge rail; dispose of debris; demolish systems; and restore testing site.
Note (4) - Construction Materials and Equipment Usage, Maintenance, Repair, and Rental Costs for Testing Program - $11,838 - Test 1
  Concrete - Rail (60 ft long x 12 in. deep x 26 in. tall)
    4.8 cu. yd plus 10% factor - 5.3 cu. yd x $125/cu. yd = $663
  Concrete - 5 Posts (36 in. wide x 10 in. deep x 13 in. tall)
    0.5 cu. yd plus 10% factor - 0.6 cu. yd x $125/cu. yd = $75
  Steel Reinforcement for Rail/Posts- Estimate $1,500
  Steel Reinforcement/Dowels for Barrier-To-Tarmac- Estimate $300
  Shipping - $1,000
  Steel Formwork Rental, Wood Formwork, Nails, Form Ties, Tarps, Blankets, Bracing, Supports, and Stakes - $5,000
  Construction Equipment Usage, Maintenance, Repair, & Rental - $1,500
  Epoxy - $800
  Miscellaneous Materials, Heating Fuel, Tent/Heating Structure - $1,000
Note (5) - Construction Materials and Equipment Usage, Maintenance, Removal, Repair, and Rental Costs for Testing Program - $800 - Test 2
  Bridge Rail Materials, As Needed - $500
  Shipping - $100
  Construction Equipment Usage, Maintenance, Repair, & Rental - $100
  Miscellaneous Materials - $100
Note (6) - MwRSF will: acquire, fabricate, install, and remove the 125-ft long concrete beam & post bridge rail and 60-ft long bridge deck; dispose of debris; demolish systems; and restore testing site.
Note (7) - Construction Materials and Equipment Usage, Maintenance, Repair, and Rental Costs for Testing Program - $28,427 - Test 3
  Concrete - Bridge Deck (60 ft long x 8 ft wide x 8 in. thick)
    11.9 cu. yd plus 10% factor - 13.1 cu. yd x $125/cu. yd = $1,638
  Concrete - Grade Beam (60 ft long x 24 in. x 30 in.)
    11.1 cu. yd plus 10% factor - 12.2 cu. yd x $125/cu. yd = $1,525
  Concrete - Rail (125 ft long x 12 in. deep x 26 in. tall)
    10.0 cu. yd plus 10% factor - 11.1 cu. yd x $125/cu. yd = $1,388
  Concrete - 12 Posts (36 in. wide x 10 in. deep x 13 in. tall)
    1.2 cu. yd plus 10% factor - 1.3 cu. yd x $125/cu. yd = $163
  Concrete Overlay on Bridge Deck (60 ft long x 8 ft wide x 3 in. thick)
    4.5 cu. yd plus 10% factor - 4.9 cu. yd x $125/cu. yd = $613
  Steel Reinforcement for Bridge Deck- Estimate $2,400
  Steel Reinforcement for Rail/Posts- Estimate $3,000
  Steel Reinforcement for Grade Beam- Estimate $1,100
  Steel Reinforcement/Dowels for Barrier-To-Tarmac- Estimate $500
  Steel Reinforcement/Dowels for Deck-To-Tarmac- Estimate $300
  MASH Strong Soil - $1,000
  Shipping - $2,000
  Steel Formwork Rental, Wood Formwork, Nails, Form Ties, Tarps, Blankets, Bracing, Supports, and Stakes - $7,000
  Construction Equipment Usage, Maintenance, Repair, & Rental - $2,000
  Epoxy - $800
  Miscellaneous Materials, Heating Fuel, Tent/Heating Structure - $3,000
Note (8) - System Demolition, Removal, Disposal, and Restoration Equipment Usage, Maintenance, Repair, and Rental Costs and Trash Fees for Test 3 - $2,500

Table 2. RPFP-18-CORRAL-1: Development of an Optimized MASH TL-4 Kansas Corral Rail (Kansas, Iowa, South Dakota, and Virginia) – Gantt Chart

Task No.	Task	Description	2017	2018				2019		
			QTR 4	QTR 1	QTR 2	QTR 3	QTR 4	QTR 1	QTR 2	QTR 3
1	Project Planning and Correspondence	General Project Planning and Documentation	■							
		Literature Review of TL-4 Open Concrete Bridge Rails	■	■						
		Collection of Bridge Deck Details from Sponsors	■							
		Develop CAD Details for Concepts, Fabrication, Testing, and Transitions			■	■	■	■		
2	Design and Analysis	Structural Analysis of Current Corral Rail		■						
		Determination of Rail Geometry		■						
		Modifications to Meet MASH TL-4 (Interior Sections, End Sections, Expansion Joints, and Transitions)		■	■	■				
		Design and Modification of Bridge Deck and Post Reinforcement			■	■				
		Sponsor Review of Proposed Design				■				
		Development of Transition to Standardized Concrete End Buttress				■				
3	Full-Scale Crash Testing	Construction of MASH TL-4 Corral Rail				■	■			
		Full-scale Crash Test No. 4-10					■	■		
		Full-scale Crash Test No. 4-11					■	■		
		Full-scale Crash Test No. 4-12					■	■		
		Data and Video Analysis					■	■		
		System Removal and Disposal							■	■
4	Reporting and Project Deliverables	Sponsor Correspondence / Update Presentations		■		■		■		■
		Research Report - First Draft		■	■	■	■	■	■	
		Report Editing (internal and sponsor)							■	■
		FHWA Eligibility Letter								■
		Task Force 13 Hardware Guide Drawings								■
		Project Closing (printing, dissemination, accounting)								■

Sponsored Programs

Attachments (1): Proposal and Budget

x.c. - Valerie Swartz, Business Manager
Robert Bielenberg, Research Engineer
Scott Rosenbaugh, Research Engineer
Karla Lechtenberg, Research Engineer
Jim Holloway, Research Associate Engineer and Test Site Manager