COMPARATIVE STUDY
OF
KANSAS and FHWA GUARDRAIL TRANSITION DESIGNS
USING
BARRIER VII COMPUTER SIMULATION MODEL

by

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1. INTRODUCTION

1.1 Problem Statement

In Technical Advisory T5040.26 dated 28 January 1988, the FHWA (1) has approved five W-Beam guardrail transition designs and two Thrie Beam guardrail transition designs for field installation. The seven transition designs approved were successfully crash tested in accordance with the recommended criteria in NCHRP 230 (2) under the impact conditions of a 4,500 lb. automobile at 60 mph and 25 deg.

Highway and bridge engineers in the Kansas Department of Transportation (KDOT) favor the Thrie Beam type of transition design over the W-Beam type of transition design because it eliminates the need for the use of a W-Beam rubrail which can trap drifting snow. Unfortunately, neither of the two Thrie Beam transition designs approved by the FHWA are acceptable because one of the designs specified the use of three different size posts which creates an inventory problem, and the other design would require costly bridgerail end wall modifications.

Evaluating the safety performance of a guardrail transition design by conducting full-scale vehicle crash tests in accordance with the criteria in NCHRP 230 is very costly. The first of several crash tests on a transition design will cost around $25,000, whereas, each succeeding test will cost around $15,000. On the average, three crash tests are required to confirm a guardrail transition design.

It is the opinion of KDOT engineers and research engineers of the University of Nebraska (UNL) that it is possible to evaluate the safety performance of a guardrail transition design using an accurately calibrated BARRIER VII Computer Simulation Model (3), thereby, eliminating the need to conduct costly full-scale vehicle crash tests. This type of evaluation would be based on a "comparative" BARRIER VII simulation study of FHWA approved guardrail transition designs with KDOT guardrail designs.

1.2 Objective of Study

The objectives of this study were (1) to accurately calibrate the BARRIER VII Computer Simulation Model with full-scale vehicle crash test data, and (2) to conduct BARRIER VII Model simulations to evaluate the safety performance of Kansas guardrail transition designs in "comparison" to selected FHWA approved guardrail transition designs.

2. CALIBRATION OF BARRIER VII MODEL

The BARRIER VII Model (3) was calibrated using the data from full-scale vehicle crash tests on roadside traffic barriers. A discussion of the critical factors considered in the calibration process is presented in the work to follow.

2.1 Vehicle Crushing Stiffness

The simulation vehicle selected for this study was a 1977 Plymouth Fury weighing approximately 4,500 lbs. The vehicle was representative of the full-scale crash test vehicles used by Post (4) of Nebraska and Bronstad (5) of SwRI in evaluating the safety performance of guardrail-bridgerail transition designs. The dimensions of the vehicle are shown in Figure 1.

The vehicle crushing stiffness was idealized by springs located at 19 contact points around the vehicle. The locations of the springs relative to the vehicle center-of-gravity are shown in Figure 1. For illustration purposes, the force-deflection relationship of Spring No. 3 is shown in Figure 2. The stiffness of the sheet metal before bottoming on a stiff structural member is represented by Line (K_1); the stiffness of the stiff structural member after bottoming is represented by Line (K_2); and the stiffness in unloading is represented by Line (K_3). The properties for each spring were estimated from visual observations and measurements of the vehicle structure in the vicinity of the spring.

Fine adjustment of the spring properties were determined from the results of a full-scale vehicle crash test conducted by Buth (6) of TTI on an instrumented concrete wall. The final calibration results are shown in Table 1. The force-deflection properties of each spring are contained in Appendix B. Although it was determined to be of no major concern, the separation phenomenon of the vehicle from the barrier when parallel is discussed in detail in Appendix F.

2.2 Soil Stiffness

The relationship established by Jeyapalan (7) of TTI between laterally applied dynamic loads and the rotational displacements of 6-in. wide guardrail posts in non-frozen dry soil is shown in Figure 3. For all practical purposes, the load-displacement relationship can be idealized as being elastic-plastic with complete failure occurring at a displacement of 20-in.

Assuming a parabolic soil pressure distribution, Ataullah (8) determined that the dynamic load on a post to cause yielding in the soil was proportional to the bearing width of the post against the soil. In the calibration of BARRIER VII with a full-scale vehicle crash test conducted by Post (4) on a single Thrie Beam bridgerail transition design, the proportionality constant was determined to be equal to a value of 1.83 lb/in. in non-frozen dry soil. The final results of the calibration are shown in Table 2. The soil stiffness for various size posts under lateral and longitudinal loads are shown in Figure 4.

2.3 Vehicle Snagging Potential

As illustrated in Figure 5, snagging of the front vehicle wheel hub and rim can occur on the end of concrete bridgerail walls with: (1) W-Beam guardrail transition designs without a rubrail, and (2) Thrie Beam guardrail transition designs.

Bligh (9) of TTI determined and verified by conducting full-scale vehicle crash tests that BARRIER VII can be used to predict vehicle snagging for W-Beam transitions without a rubrail by plotting the path of the undeformed wheel hub as shown in Figure 5a. This finding indicates that the wheel hub and rim is able to easily slide under the W-Beam guardrail member.

Insight into vehicle wheel hub and rim snagging on the end of a concrete bridgerail wall with a single Thrie Beam guardrail transition design was provided by Post (4) in conducting full-scale vehicle crash tests for Nebraska. The severity of snagging shown in

Figure 6 was reported by Post as moderate. Snagging occurred as a result of localized plastic deformations of the lower part of the Thrie Beam in the vicinity of the wheel hub and rim, thereby, allowing the deformed section of the Thrie Beam to wrap 3-in. around the end of the tapered bridgerail wall.

A sketch illustrating the concept of vehicle snagging on the end wall of a bridgerail with a Thrie Beam transition is shown in Figure 5b. After local plastic deformations in the Thrie Beam begin, the path of the deformed wheel hub is assumed to remain parallel to the path of undeformed wheel hub due to a constant load on the wheel hub.

The BARRIER VII model simulations of the paths of the undeformed and deformed wheel hub on the Nebraska single Thrie Beam transition design crash tested by Post (4) is shown in Figure 7. The local plastic deformations in the Thrie Beam began about 8-in. beyond Post No. 2. The predicted 3 1/2-in. of snagging on the tapered end wall compares well with the 3-in. of snagging measured in the crash test.

3. VALIDATION OF BARRIER VII MODEL WITH SwRI CRASH TESTS

The final check on the validation of the BARRIER VII Model calibrated in the previous section of this study was based on the simulation of full-scale vehicle crash tests on guardrail transition designs conducted by Bronstad (5) of the SwRI.

Of the eleven transition designs crash tested by Bronstad, three designs with bridgerail end walls similar to end walls in Kansas were selected for the validation study. The three designs selected were as follows:

1. Double W-Beam with wood posts, W-Beam rubrail, and straight concrete bridgerail end wall (Test T-5).

2. Single Thrie Beam with wood posts and straight concrete bridgerail end wall (Test T-1).

3. Double Thrie Beam with steel posts and straight concrete bridgerail end wall (Test T-7).

The comparison of the results from the SwRI crash tests and the BARRIER VII Model simulations are shown in Tables 3 through 5.

In general, the comparisons were considered to be satisfactory. The vehicle exit angle in the SwRI Test T-1 (Table 4) was lower than predicted by the BARRIER VII Model because of the slight rotations of the damaged end wall.

4. SIMULATION COMPARATIVE STUDIES

4.1 FHWA Guardrail Transition Designs (Base Controls)

In Technical Advisory T5040.26 dated 28 January 1988, the FHWA (1) has approved five W-Beam guardrail transition designs and two Thrie Beam transition designs for field installation. The seven transition designs approved were successfully crash tested in accordance with the recommended criteria in NCHRP 230 (2) under the impact conditions of a 4,500 lb. automobile at 60 mph and 25 deg.

Of the seven FHWA approved guardrail transition designs, two designs were selected as base control designs for the "comparative" BARRIER VII Computer Model simulation study. The two designs selected had bridgerail end walls that were most representative of the straight vertical end walls in Kansas. The designs selected were as follows:

1. Double W-Beam with rubrail, steel posts and straight concrete bridgerail end wall. Design details shown in Figure 8.

2. Double W-Beam with rubrail, wood posts and straight concrete bridgerail end wall. Design details shown in Figure 9.

4.2 Kansas Guardrail Transition Designs

Nine Kansas guardrail transition designs were initially selected by KDOT for the "comparative" BARRIER VII Computer Model simulation study. The nine designs were later revised and reduced to six designs. The two test matrix research plans are contained in Appendix A. Upon beginning the simulation study and analyzing one of the more promising designs, it became readily apparent that several of the designs in test matrix plan were structural inadequate and would result in vehicle wheel snagging on the end wall of the bridgerail. These inadequate designs were either modified or eliminated from the study. The five final Kansas designs on which simulations were conducted were as follows:

1. Double Thrie Beam, steel posts and straight concrete bridgerail end wall. Design details shown in Figure 10.

2. Double Thrie Beam, wood posts and straight concrete bridgerail end wall. Design details shown in Figure 11.

3. Single Thrie Beam, steel posts with base plates, and straight concrete bridgerail end wall. Design details shown in Figure 12.

4. Double W-Beam, steel posts, rubrail, and straight concrete bridgerail end wall. Design details shown in Figure 13.

5. Combination Double/Single Thrie Beam, steel posts, and tapered concrete bridgerail end wall. Design details shown in Figure 14.

4.3 Comparison of FHWA and Kansas Transition Designs

Except for the Double W-Beam (Figure 13), the post spacings in the FHWA and Kansas guardrail transition designs simulated in the comparative study were approximately identical. The first 4 posts from the end of the bridgerail were closely spaced or about 1 ft-6 3/4 in. on centers; the next 4 posts were spaced 3 ft-1 1/2 in. on centers; and the remaining posts were spaced 6 ft-3in. on centers.

The vehicle impact conditions used in the comparative simulation study were in accordance with the criteria in NCHRP 230 (2). The impact conditions were as follows:

Vehicle Weight	. . .	4,500 lb.
Impact Speed	. . .	60 mph
Impact Angle	. . .	25 deg

The BARRIER VII Computer Model input/output data are contained under separate cover in Appendices B through E.

The results of the comparative BARRIER VII simulation study are summarized in Tables 6 through 12. The three severity levels of vehicle wheel snagging on the end wall of the bridgerail were based on the results from full-scale vehicle crash tests conducted by Post (4). Out of the four Kansas Thrie Beam transition designs simulated, only the one design with a tapered bridgerail end wall showed promise in which no vehicle wheel snagging occurred.

The comparison of the vehicle point of impact from the bridgerail end wall versus maximum guardrail transition deflection and vehicle exit speed for the FHWA base control designs and the KDOT designs are shown in Figures 15 and 16, respectively.

Referring to Figure 15, the following comparisons were reached in regard to the maximum guardrail transition deflections for vehicle impacts of 4 ft. and beyond the end of the bridgerail wall.

1. All five of the Kansas designs were stronger than the FHWA design with steel posts.

2. The Kansas Double Thrie Beam design with wood posts and the Kansas Single Thrie Beam design with steel posts and base plates were both stronger than the FHWA design with wood posts.

3. The Kansas Double Thrie Beam design with steel posts, the Kansas Double/Single Thrie Beam design with steel posts and tapered end wall, and the FHWA design with wood posts were all equal in strength.

4. The Kansas Double W-Beam design with steel posts and rubrail had a strength in between the FHWA designs with steel posts and wood posts.

Referring to Figure 16, the following comparisons were reached in regard to the vehicle exit speed in which no vehicle wheel snagging was predicted to have occurred.

1. The Kansas Double/Single Thrie Beam transition design with steel posts and tapered bridgerail end wall, and the Kansas Double W-Beam transition design with steel

posts, rubrail, and straight bridgerail end wall had higher vehicle exit speeds than the FHWA transition designs with steel posts and wood posts.

In Figure 16, the higher the vehicle exit speed the lower the change in vehicle speed, and therefore, the lower the occupant risk injury.

5. CONCLUSIONS and RECOMMENDATIONS

5.1 Satisfactory Transition Designs

The comparative BARRIER VII Computer Model simulation study showed that two of the five Kansas guardrail transition designs will provide equal or better performance than the FHWA approved Double W-Beam guardrail transition designs with steel or wood posts, W-Beam rubrail and straight bridgerail end wall. The two Kansas designs were:

1. Kansas Double/Single Thrie Beam Design with Steel Posts and Tapered Bridgerail End Wall (Figure 14).

2. Kansas Double W-Beam Design with Steel Posts, Tubular Rubrail, and Straight Bridgerail End Wall (Figure 13).

In this study, it was assumed that vehicle wheel snagging will not occur on the FHWA and the Kansas Double W-Beam transition designs with a rubrail. Also, it was shown that vehicle wheel snagging will not occur on the Kansas Double Thrie Beam transition design with a tapered bridgerail end wall. Since vehicle wheel snagging will not occur, it is recommended that the two Kansas transition designs defined above be approved by the FHWA for field installation without conducting full-scale vehicle crash tests.

5.2 Promising Transition Design

In this study, it was shown that vehicle wheel snagging will occur on the Kansas Single Thrie Beam transition design with steel posts, 8-in. wide soil bearing plates and straight bridgerail end wall. However, this design has promise of being a satisfactory design if the single Thrie Beam member is replaced by a double Thrie Beam member.

If the Double Thrie Beam member modification is made, it is recommended that BARRIER VII Computer Model simulations be conducted to evaluate the potential of vehicle wheel snagging.

TABLES

Table 1

VEHICLE CRUSHING CALIBRATION

Type Vehicle	:	1975 Plymouth Fury
Vehicle Weight	:	4,740 lb.
Impact Speed	:	59.8 mph
Impact Angle	:	24.0 deg.
Type Barrier	:	Conc. Wall (Instrumented)

ITEM	TTI Crash Test	BARRIER VII Simulation
Vehicle Exit Speed (mph)	42.4	44.6
Vehicle Exit Angle (deg)	14.0	14.6
Vehicle Accelerations 50 ms avg.		
Lateral (g)	15.4	15.6
Longitudinal (g)	9.1	11.7
Vehicle Impact Force 50 ms avg.		
Lateral (kips)	78.3	79.6
Vehicle Time when Parallel to Barrier* (ms)	198	200

*The separation phenomenon of the vehicle from the barrier when parallel was determined to be of no major concern. See Appendix F for a detailed discussion.

Table 2

SOIL STIFFNESS CALIBRATION

Type Vehicle	:	1977 Plymouth Fury
Vehicle Weight	:	4,400 lb.
Impact Speed	:	61 mph
Impact Angle	:	25 deg
Type Transition	:	Single Thrie Beam
Impact Point	:	Bet. Post Nos. 2 & 3
Type Soil	:	Dry Silty Clay (CL)

ITEM	Nebraska Crash Test	BARRIER VII Simulation
Max. Dynamic Barrier Deflection (in.)	14	12
Vehicle Exit Speed (mph)	39	36
Vehicle Exit Angle (deg)	11	10

Table 3

BARRIER VII Validation: SwRI Crash Test T-5

Test Vehicle	:	1978 Plymouth
Vehicle Weight	:	4,700 lb.
Impact Point	:	Post No. 5
Impact Speed	:	58.9 mph
Impact Angle	:	25.8 deg.
Transition	:	Double W-Beam with Wood Posts
Soil	:	Dry

ITEM	SwRI Crash Test	BARRIER VII Simulation
Max. Dynamic Guardrail Deflection (in.)	10.9	11.1
Vehicle Exit Speed (mph)	37.7	36.0
Vehicle Exit Angle (deg)	8.0	6.7

Table 4

BARRIER VII Validation: SwRI Crash Test T-1

Test Vehicle	:	1978 Plymouth Vehicle
Weight	:	4,658 lb.
Impact Point	:	Bet. Post Nos. 4 & 5
Impact Speed	:	61.5 mph
Impact Angle	:	25.2 deg
Transition	:	Single Thrie Beam with Wood Posts
Soil	:	Dry

ITEM	SwRI Crash Test	BARRIER VII Simulation
Max. Dynamic Guardrail Deflection (in.)	9.4	9.6
Vehicle Exit Speed (mph)	36.8	38.1
Vehicle Exit Angle (deg)	11.2	17.0

Table 5

BARRIER VII Validation: SwRI Crash Test T-7

Test Vehicle	:	1978 Dodge
Vehicle Weight	:	4,675 lb.
Impact Point	:	Bet. Post Nos. 8 & 9
Impact Speed	:	58.9
Impact Angle	:	25.1
Transition	:	Double Thrie Beam with Steel Posts
Soil	:	Dry

ITEM	SwRI Crash Test	BARRIER VII Simulation
Max. Dynamic Guardrail Deflection (in.)	13.9	16.9
Vehicle Exit Speed (mph)	42.0	41.1
Vehicle Exit Angle (deg)	5.7	5.0

Table 6
BARRIER VII SIMULATIONS:
BASE CONTROL DESIGN WITH STEEL POSTS

Vehicle Impact Point		Railing		Snagging of Wheel on End of Bridgerail				Vehicle Exit Conditions	
Post Number	Distance From Bridge End (ft-in)	Maximum Deflection @ Height of 21 in. (in)	Distance From Bridge End (ft-in)	None	Minor (0-1 in.)	Moderate (1-3 in.)	Severe (3-6 in.)	Speed (mph)	C.G. Path (deg)
2	2-5 3/4	0.3	0-5 1/2	X				44.2	7.5
3	4-1/2	4.0	1-8 3/8	X				39.6	15.0
4	5-7 1/4	7.4	2-5 3/4	X				35.9	22.0
5	8-8 3/4	12.2	4-1/2	X				36.0	19.0

Table 7
BARRIER VII SIMULATIONS:
BASE CONTROL WITH WOOD POSTS

Vehicle Impact Point		Railing		Snagging of Wheel on End of Bridgerail				Vehicle Exit Conditions	
Post Number	Distance From Bridge End (ft-in)	Maximum Deflection @ Height of 21 in. (in)	Distance From Bridge End (ft-in)	None	Minor (0-1 in.)	Moderate (1-3 in.)	Severe (3-6 in.)	Speed (mph)	C.G. Path (deg)
2	2-5 3/4	0.3	0-5 1/2	X				44.2	6.5
3	4-1/2	3.5	1-8 3/8	X				40.0	16.0
4	5-7 1/4	6.0	2-5 3/4	X				38.0	19.0
5	8-8 3/4	10.1	5-1/2	X				38.6	14.0

Table 8
BARRIER VII SIMULATIONS:
DOUBLE THRIE BEAM WITH STEEL POSTS

Vehicle Impact Point		Railing		Snagging of Wheel on End of Bridgerail				Vehicle Exit Conditions	
Post Number	Distance From Bridge End (ft-in)	Maximum Deflection @ Height of 21 in. (in)	Distance From Bridge End (ft-in)	None	Minor (0-1 in.)	Moderate (1-3 in.)	Severe (3-6 in.)	Speed (mph)	C.G. Path (deg)
1	1-10 1/2	0.1	2-7 7/8	X				45.2	6.0
2	3-5 1/4	2.6	1-10 1/2			X		42.5	9.5
3	5-0	5.6	2-7 7/8			X		39.2	17.0
4	6-6 3/4	7.8	3-5 1/4	X				37.8	20.0
5	9-8 1/4	11.0	5-0	X				39.4	12.0

Notes (1) The vehicle exit speed will be lower than indicated in those cases in which snagging occurred.

Table 9
BARRIER VII SIMULATIONS:
DOUBLE THRIE BEAM WITH WOOD POSTS

Vehicle Impact Point		Railing		Snagging of Wheel on End of Bridgerail				Vehicle Exit Conditions	
Post Number	Distance From Bridge End (ft-in)	Maximum Deflection @ Height of 21 in. (in)	Distance From Bridge End (ft-in)	None	Minor (0-1 in.)	Moderate (1-3 in.)	Severe (3-6 in.)	Speed (mph)	C.G. Path (deg)
1	1-10 1/2	0.1	2-7 7/8	X				45.2	6.0
2	3-5 1/4	2.1	0-11 1/4		X			43.0	9.0
3	5-0	4.7	2-7 7/8			X		40.3	10.5
4	6-6 3/4	6.6	3-5 1/4	X				39.7	14.0
5	9-8 1/4	9.4	5-9 3/8	X				41.2	8.0

Notes (1) Same as Table 8.

Table 10
BARRIER VII SIMULATIONS:
SINGLE THRIE BEAM WITH STEEL POSTS AND BASE PLATES

Vehicle Impact Point		Railing		Snagging of Wheel on End of Bridgerail				Vehicle Exit Conditions	
Post Number	Distance From Bridge End (ft-in)	Maximum Deflection @ Height of 21 in. (in)	Distance From Bridge End (ft-in)	None	Minor (0-1 in.)	Moderate (1-3 in.)	Severe (3-6 in.)	Speed (mph)	C.G. Path (deg)
2	3-5 1/4	2.8	0-11 1/4			X		42.5	9.0
3	5-0	4.9	1-10 1/2		X			40.2	18.0
4	6-6 3/4	6.6	2-7 7/8	X				39.8	14.0

Notes (1) Same as Table 8.

Table 11
BARRIER VII SIMULATIONS:
DOUBLE W-BEAM WITH STEEL POSTS AND RUBRAIL

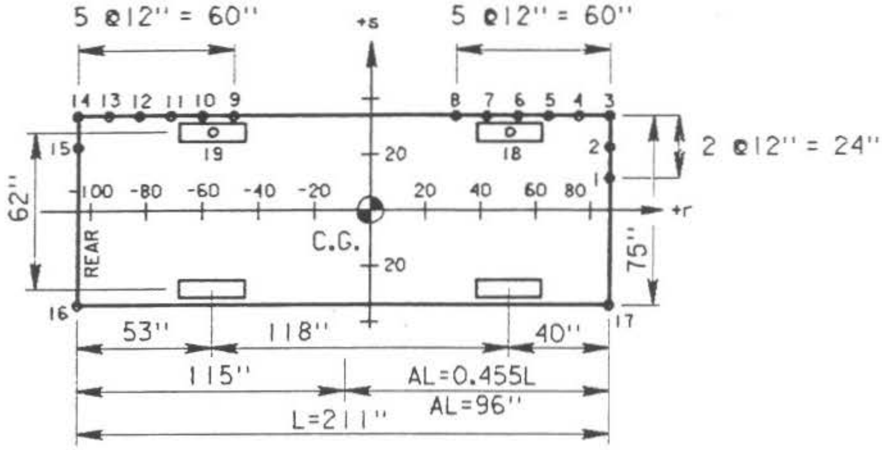
Vehicle Impact Point		Railing		Snagging of Wheel on End of Bridgerail				Vehicle Exit Conditions	
Post Number	Distance From Bridge End (ft-in)	Maximum Deflection @ Height of 21 in. (in)	Distance From Bridge End (ft-in)	None	Minor (0-1 in.)	Moderate (1-3 in.)	Severe (3-6 in.)	Speed (mph)	C.G. Path (deg)
1	0-11 1/4	negligible	-	X				45.0	4.0
2	1-10 1/2	0.1	0-11 1/4	X				44.7	7.0
3	3-5 1/4	1.9	1-4 7/8	X				42.5	10.0
4	5-0	5.3	1-10 1/2	X				39.3	16.0
5	6-6 3/4	8.2	2-7 7/8	X				38.7	15.0

Table 12
BARRIER VII SIMULATIONS:
COMBINATION DOUBLE/SINGLE THRIE BEAM WITH
STEEL POSTS AND TAPERED END WALL

Vehicle Impact Point		Railing		Snagging of Wheel on End of Bridgerail				Vehicle Exit Conditions	
Post Number	Distance From Bridge End (ft-in)	Maximum Deflection @ Height of 21 in. (in)	Distance From Bridge End (ft-in)	None	Minor (0-1 in.)	Moderate (1-3 in.)	Severe (3-6 in.)	Speed (mph)	C.G. Path (deg)
2	3-3 3/4	2.6	1-9	X				42.8	9.5
3	4-10 1/2	5.4	2-6 3/8	X				39.3	17.0
4	6-5 1/4	7.4	3-3 3/4	X				38.2	18.5
5	9-6 3/4	10.7	4-10 1/2	X				39.6	11.5

Notes (1) Same as Table 8.

FIGURES



AUTOMOBILE 1977 PLYMOUTH FURY

	CONTACT POINT NO.	COORDINATES r (in.)	s (in.)
SHEET METAL	1	96.0	13.5
	2	96.0	25.5
	3	96.0	37.5
	4	84.0	37.5
	5	72.0	37.5
	6	55.0	37.5
	7	48.0	37.5
	8	36.0	37.5
	9	-55.0	37.5
	10	-67.0	37.5
	11	-79.0	37.5
	12	-91.0	37.5
	13	-103.0	37.5
	14	-115.0	37.5
	15	-115.0	25.5
	16	-115.0	-37.5
	17	96.0	-37.5
WHEEL HUBS	18	56.0	33.0
	19	-62.0	33.0

FIGURE 1

IDEALIZATION OF SIMULATION VEHICLE

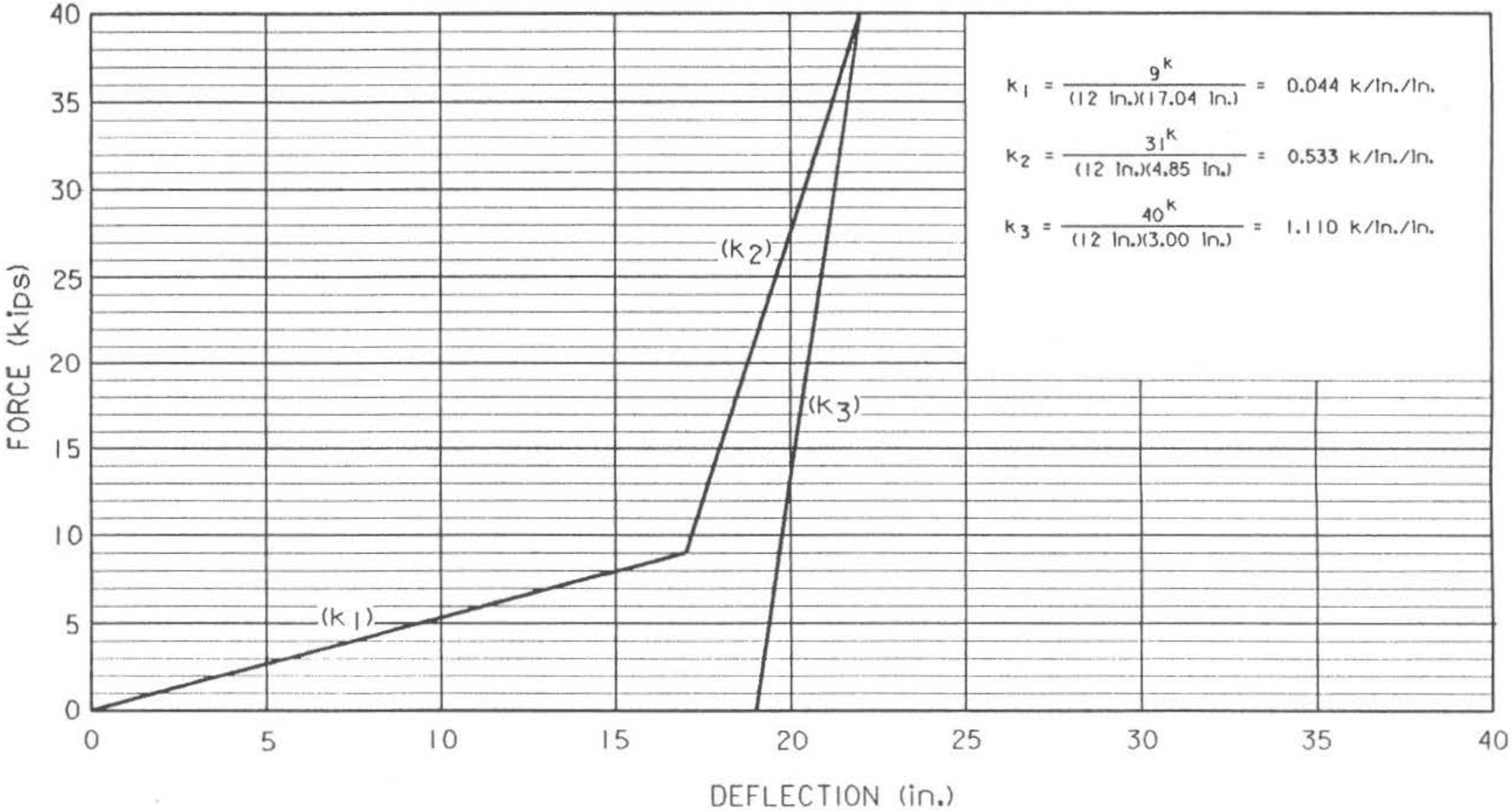


FIGURE 2

VEHICLE SPRING LOAD-DEFLECTION RELATIONSHIP
FOR CONTACT POINT NO. 3

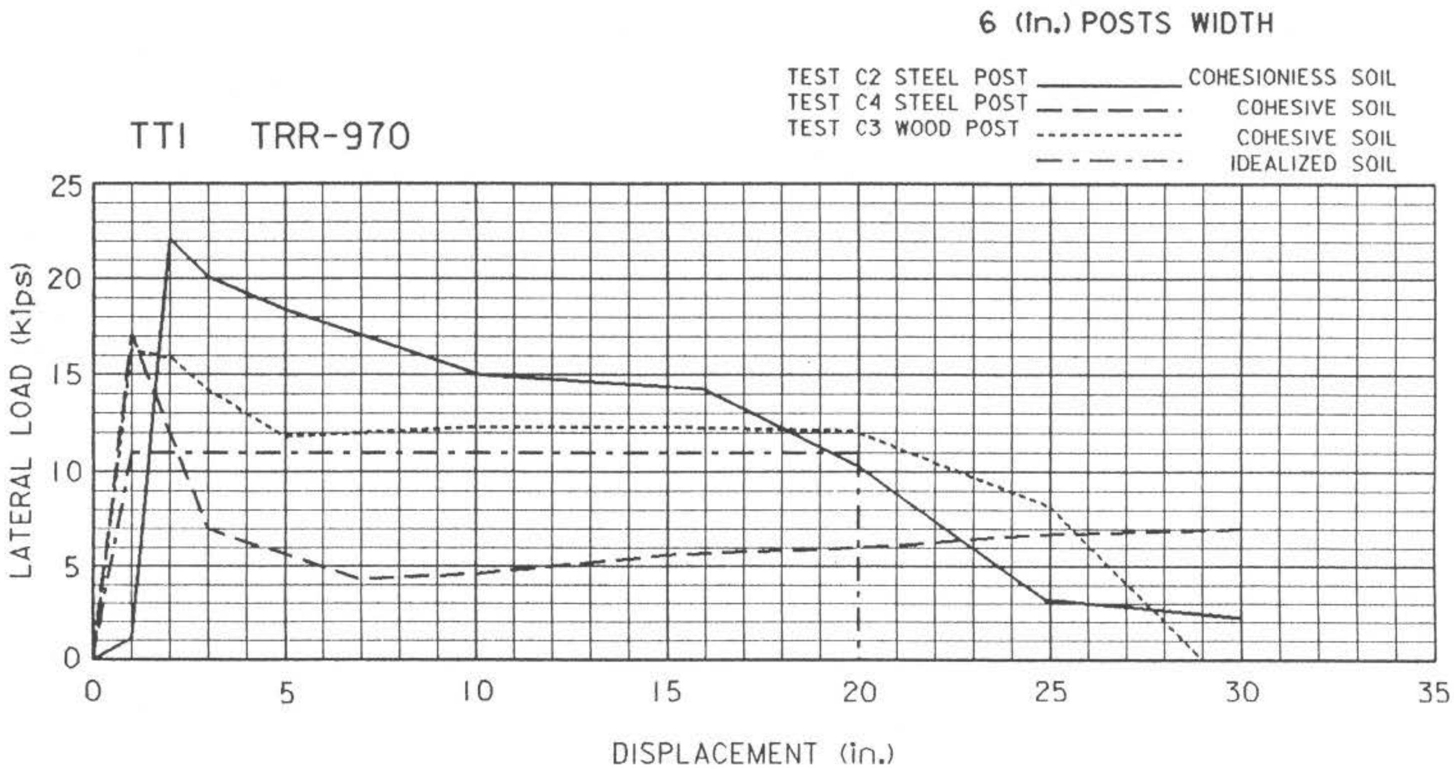


FIGURE 3

TTI DYNAMIC TESTS ON POSTS IN DRY SOIL

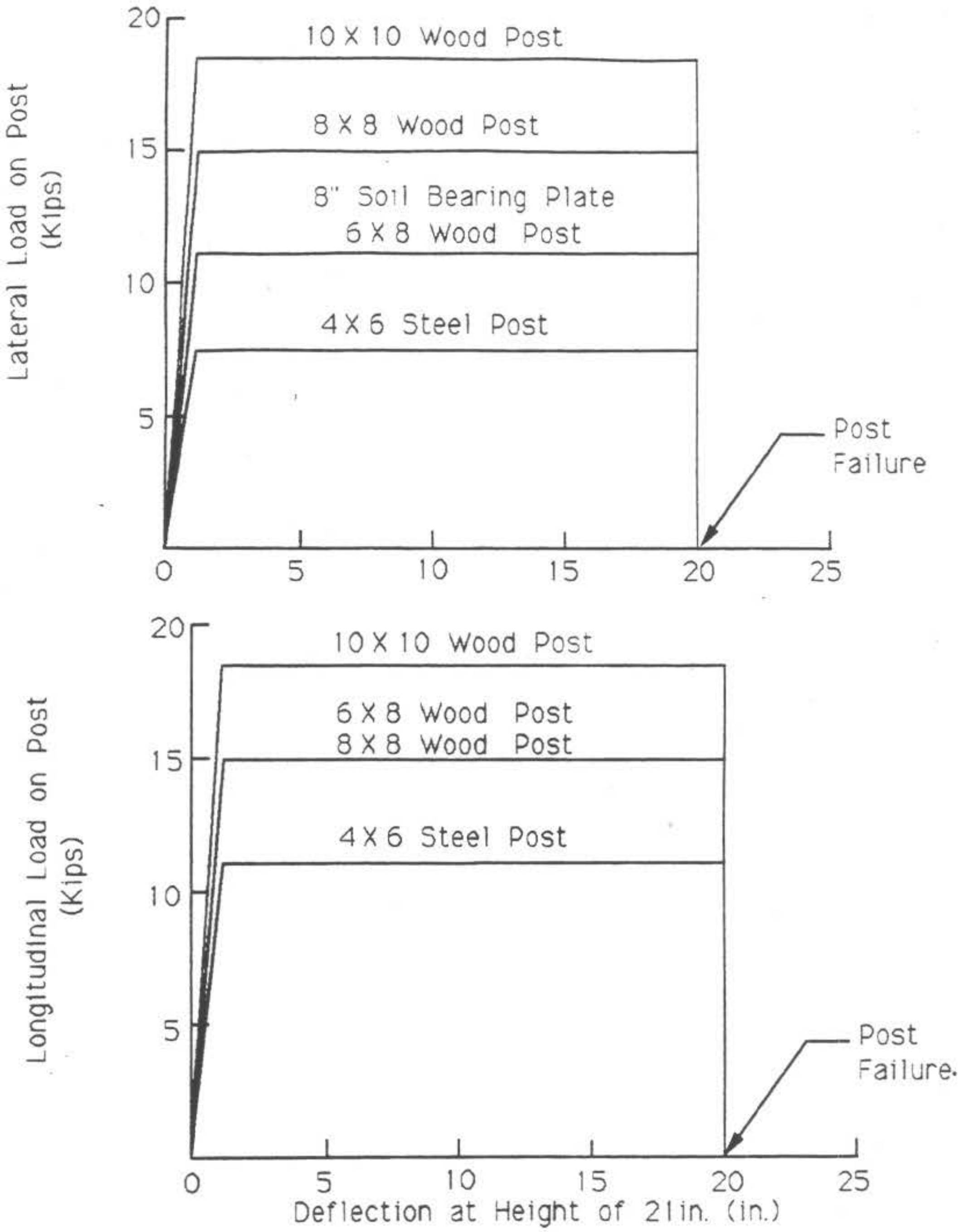


FIGURE 4
IDEALIZED SOIL STIFFNESS for VARIOUS SIZE POSTS
IN DRY SILTY CLAY SOIL

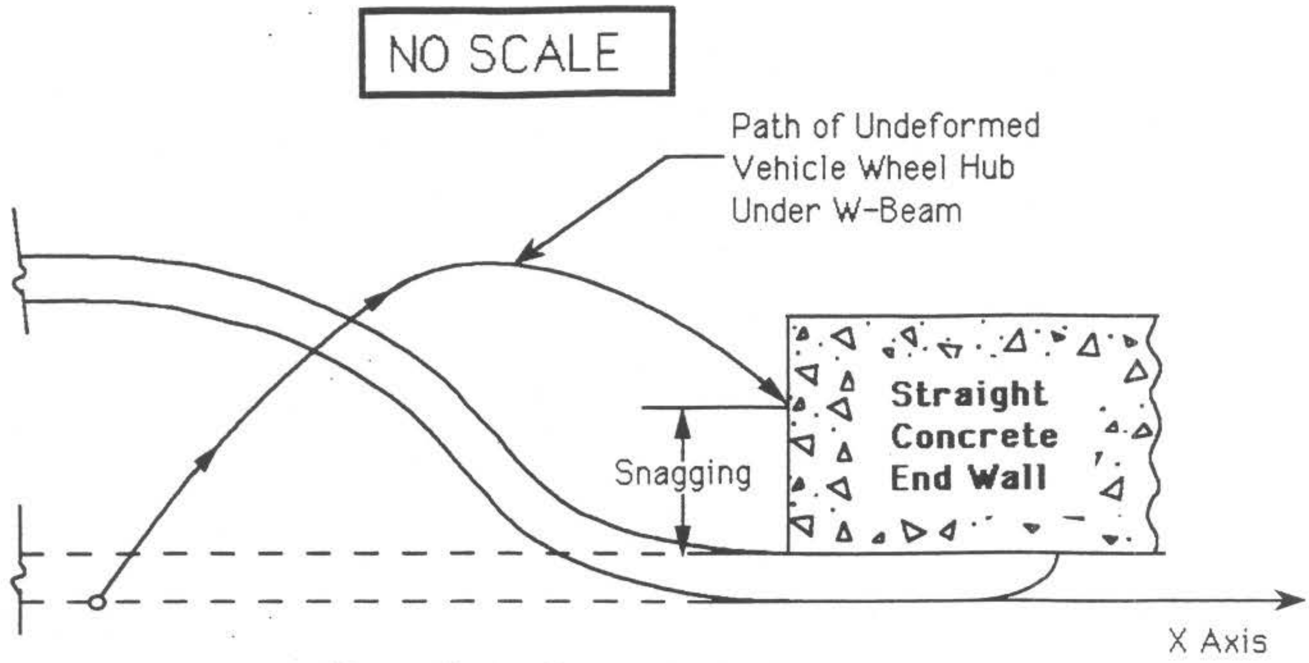


Figure 5a. W-Beam with No Rubrail

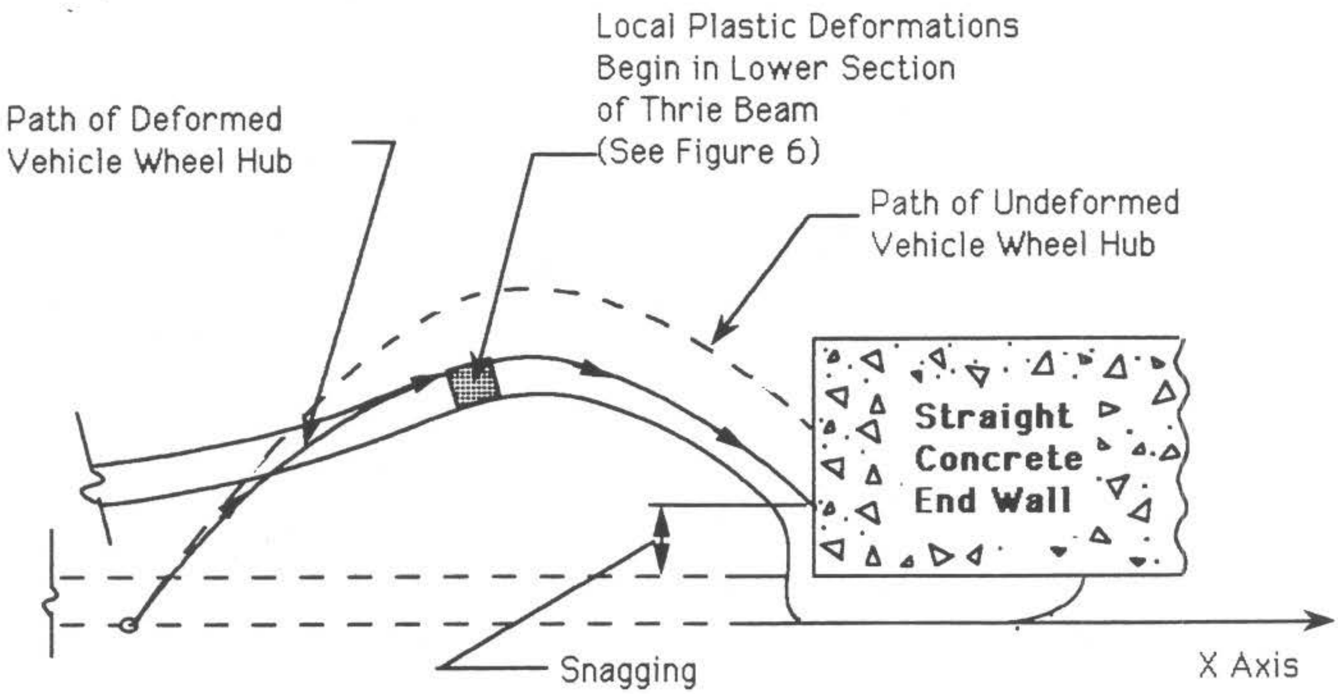


Figure 5b. Thrie Beam

FIGURE 5

VEHICLE SNAGGING METHODOLOGY

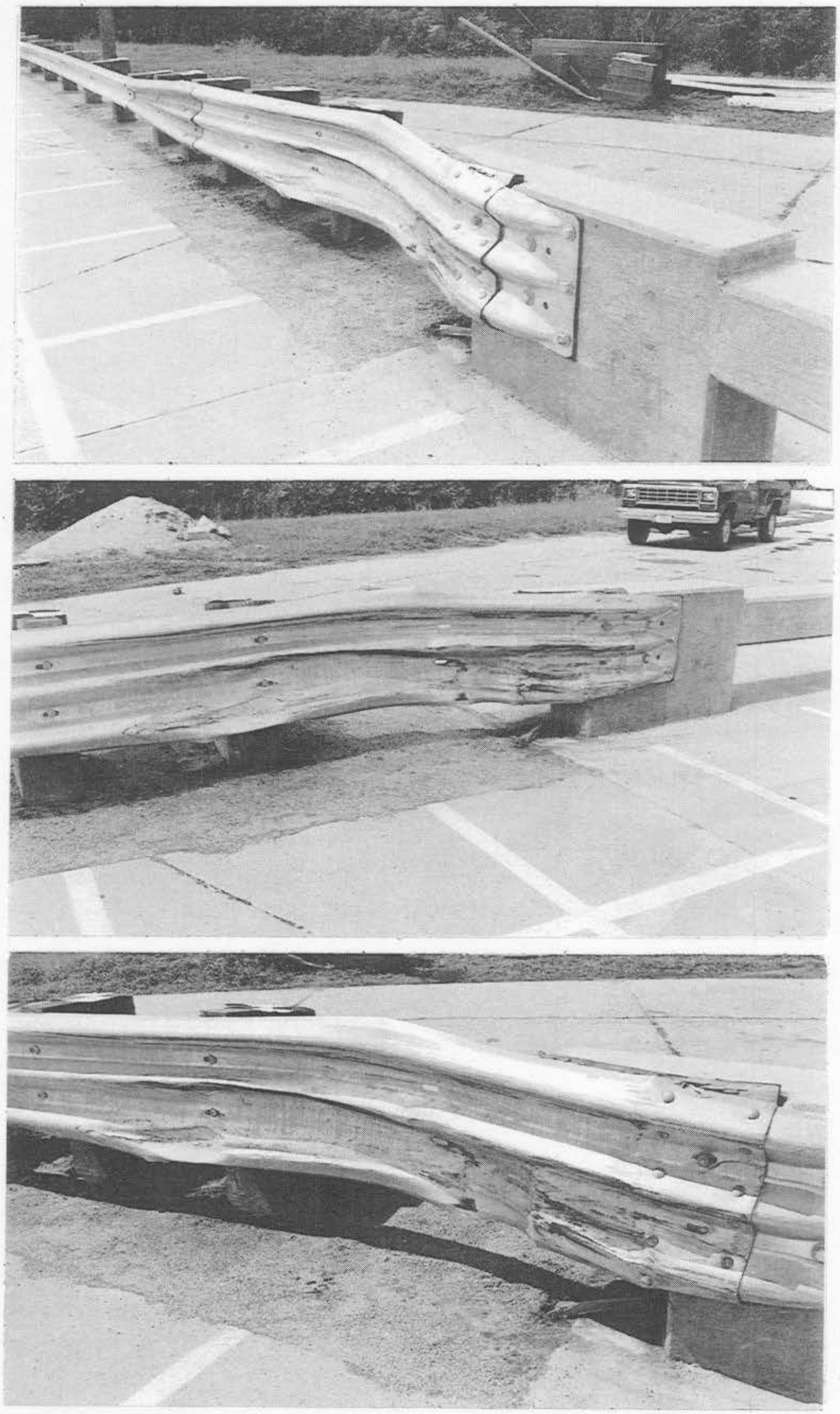


FIGURE 6

VEHICLE SNAGGING ON NEBRASKA SINGLE THRIE BEAM TRANSITION DESIGN (TEST NO. 3)

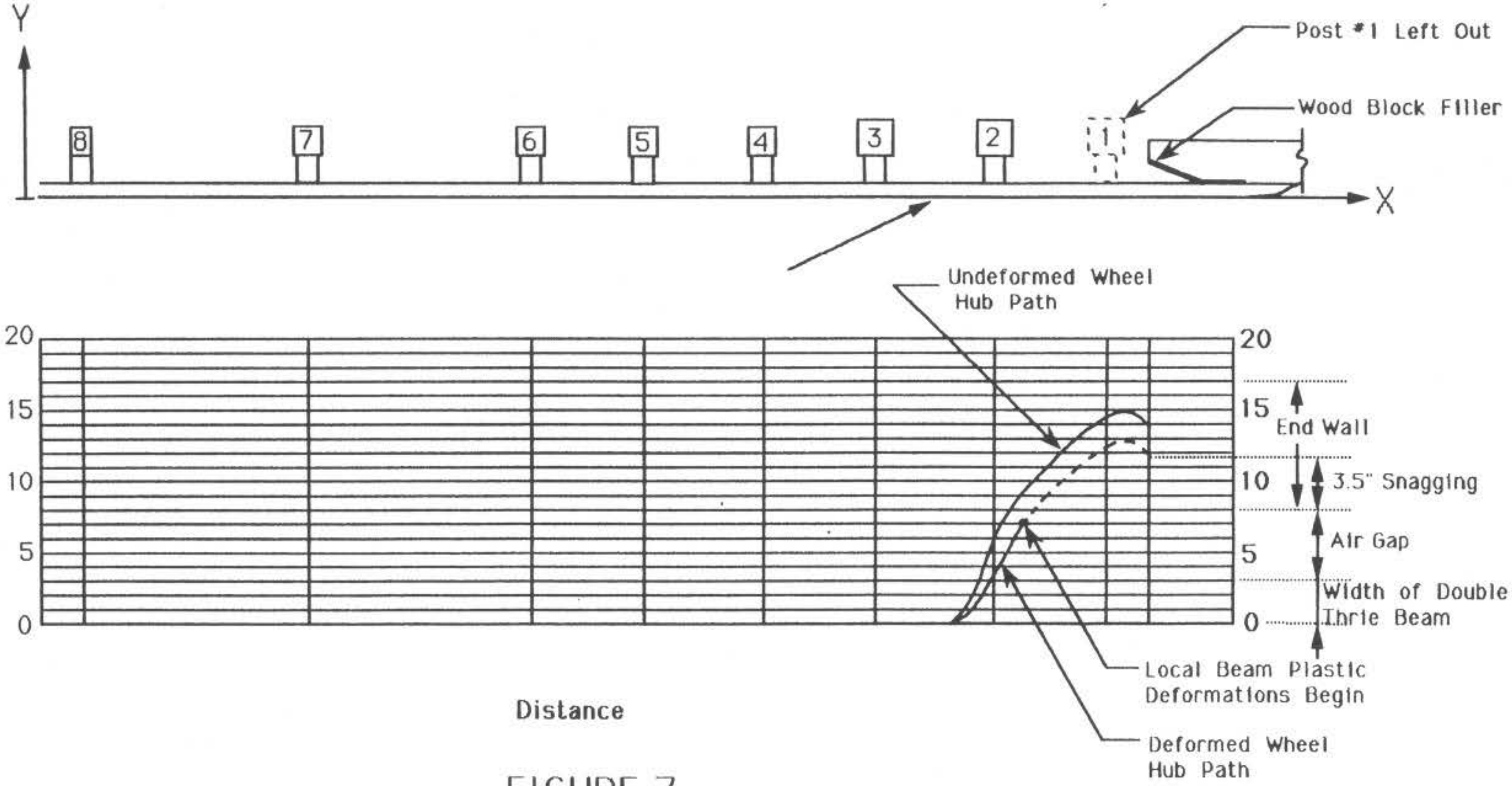


FIGURE 7

VEHICLE SNAGGING PREDICTION BASED ON
BARRIER VII SIMULATION

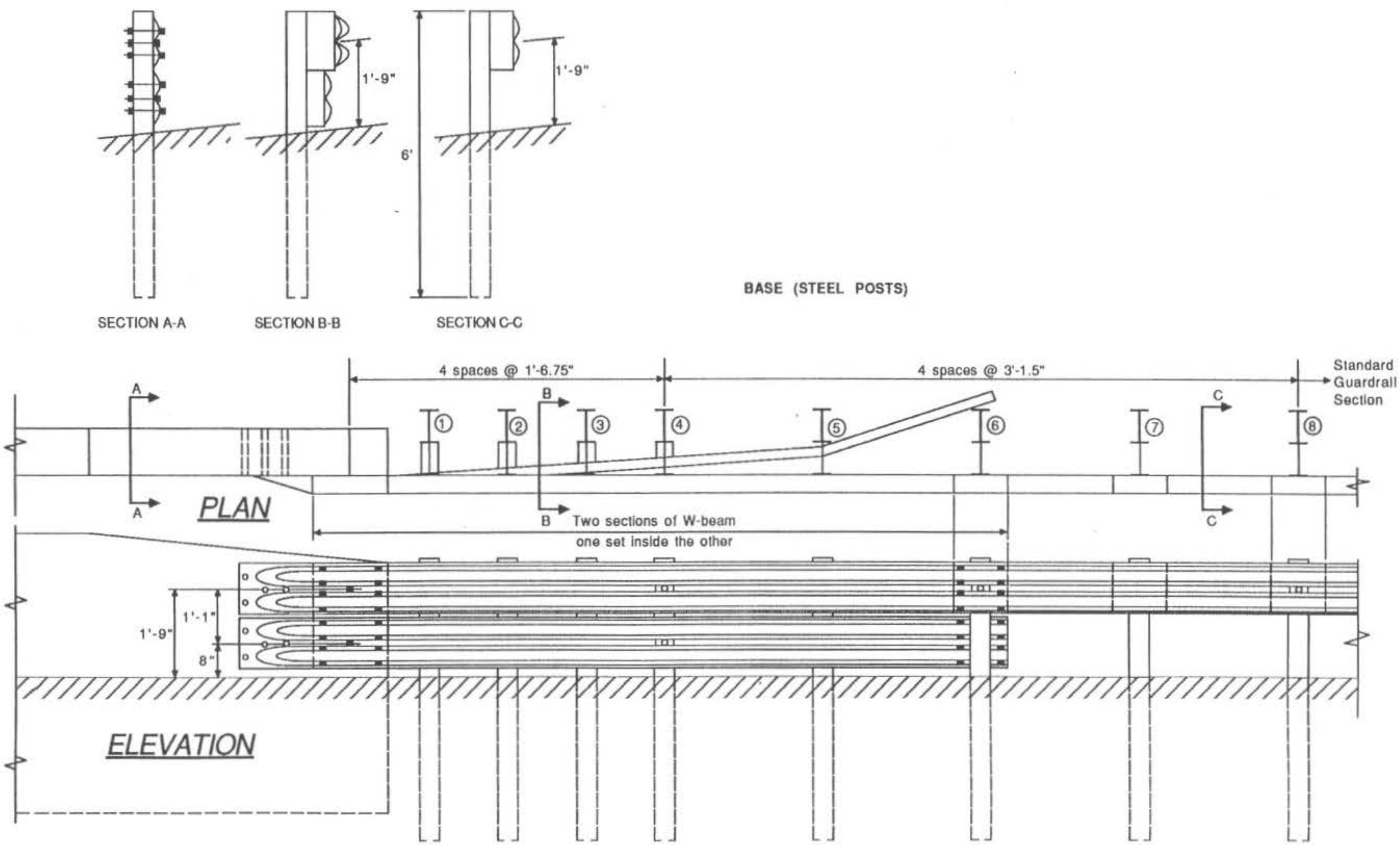


FIGURE 8

FHWA DOUBLE W-BEAM TRANSITION: STEEL POSTS AND RUBRAIL (BASE CONTROL)

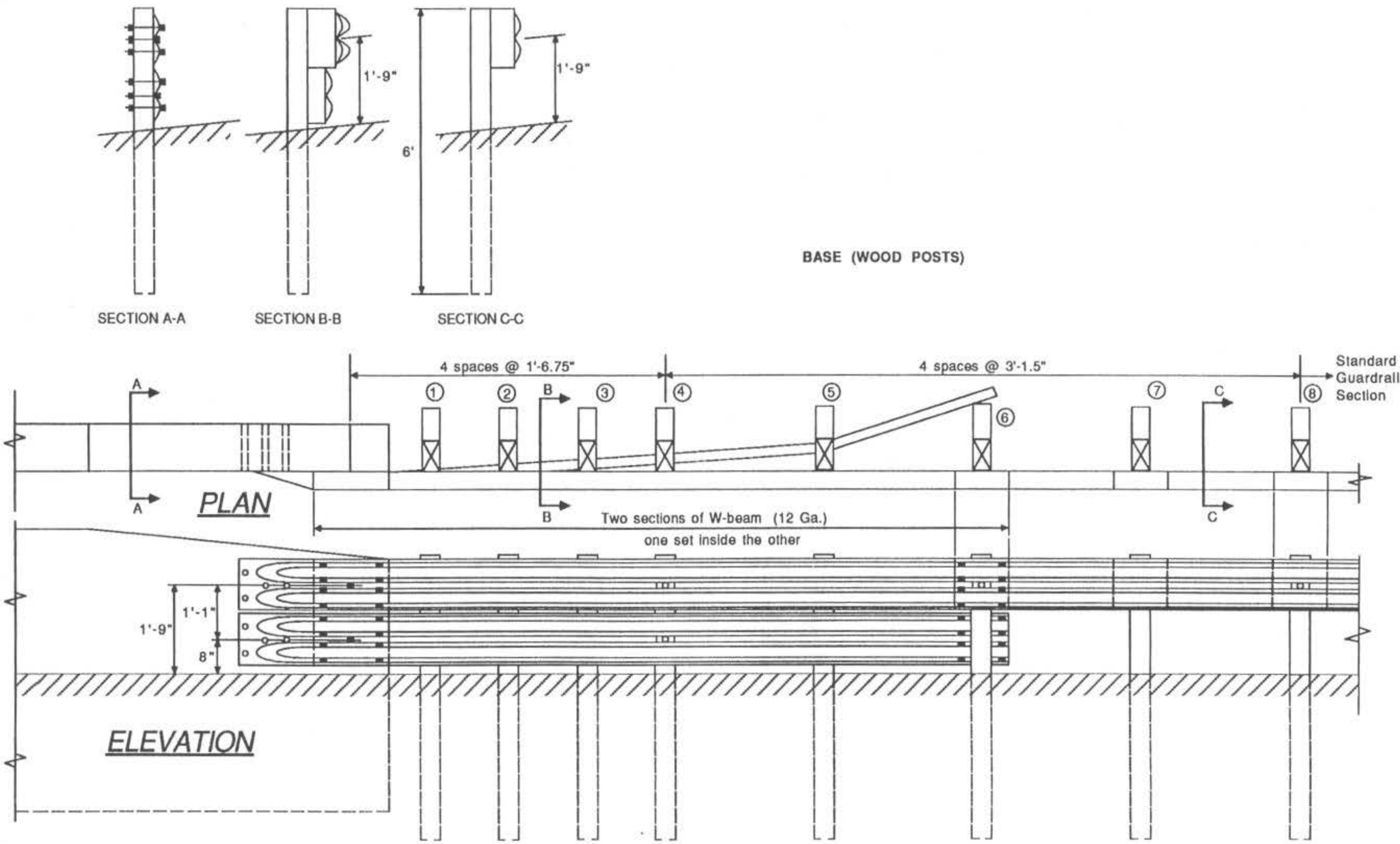


FIGURE 9

FHWA DOUBLE W-BEAM TRANSITION : WOOD POSTS AND RUBRAIL (BASE CONTROL)

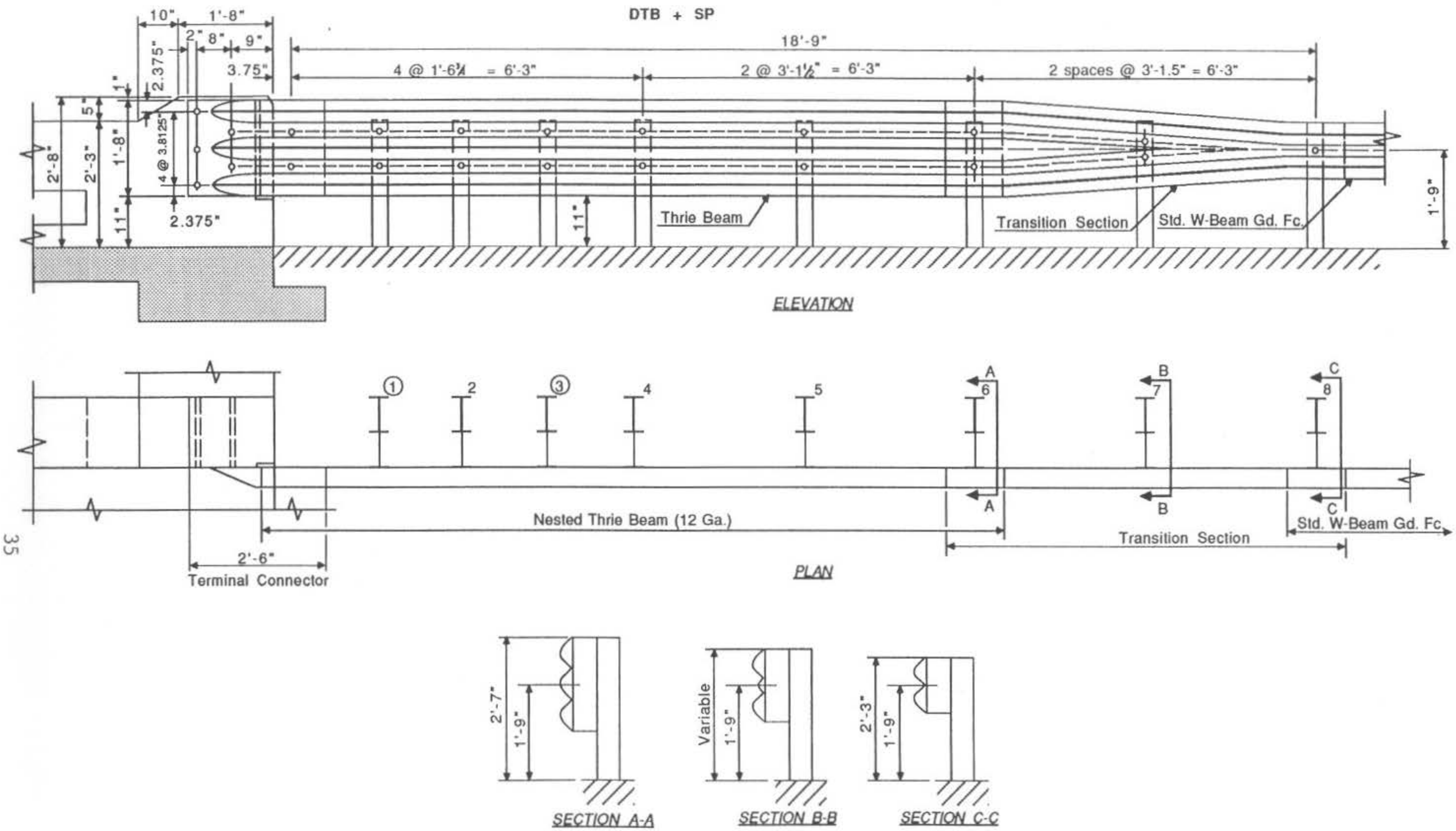


FIGURE 10

KANSAS DOUBLE THRIE BEAM : STEEL POSTS AND STRAIGHT END WALL

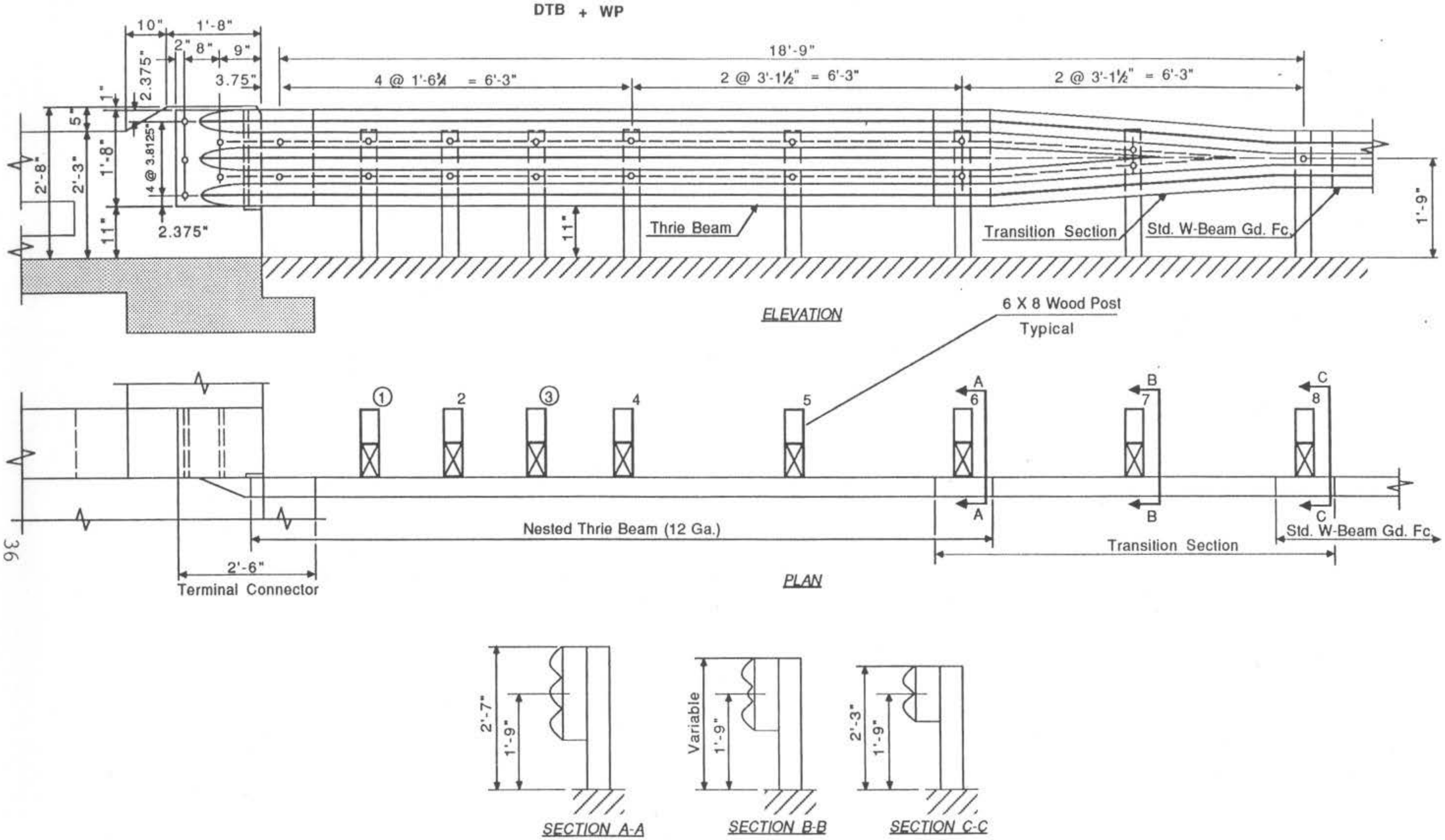


FIGURE 11

KANSAS DOUBLE THRIE BEAM : WOOD POSTS AND STRAIGHT END WALL

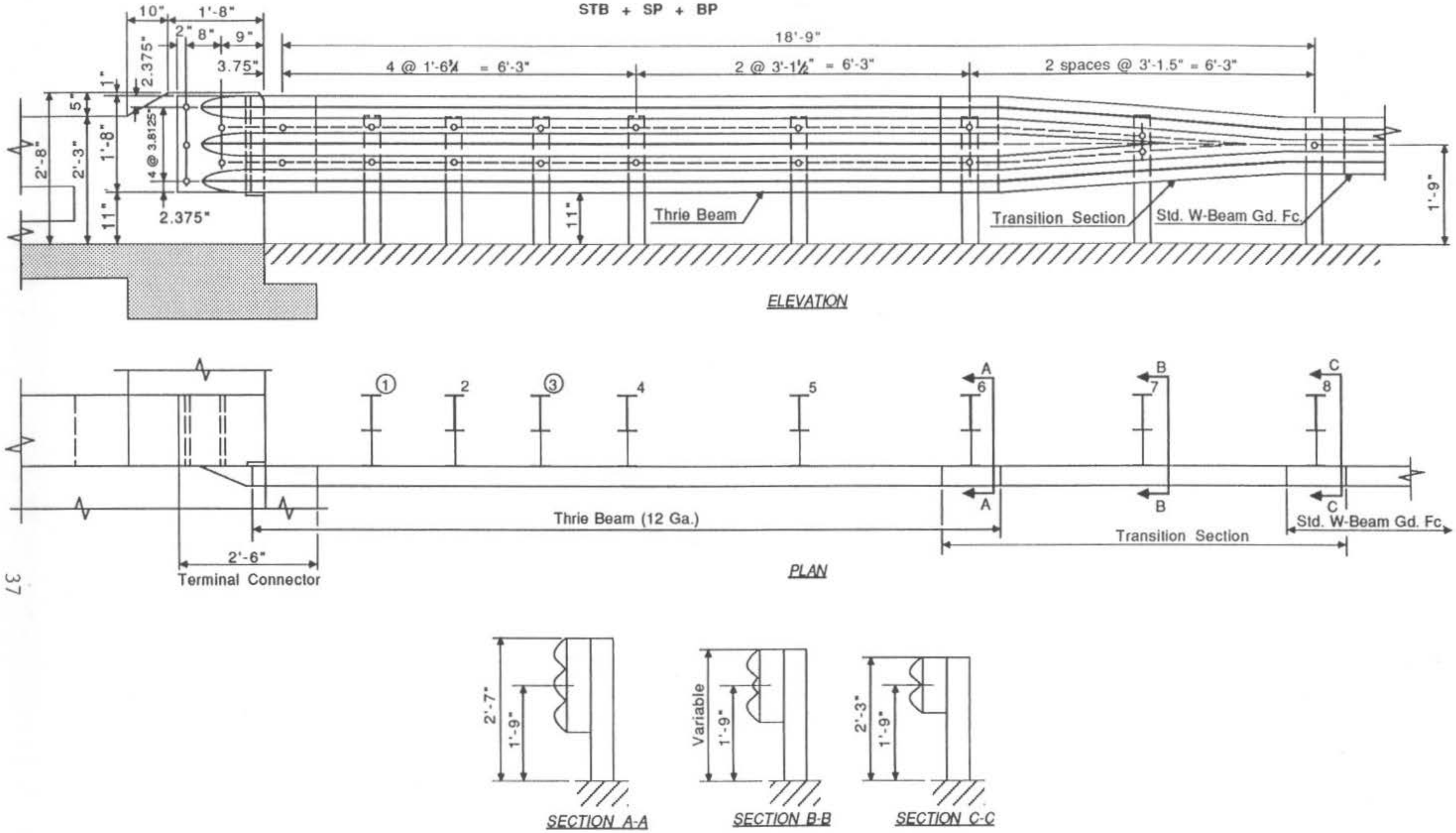


FIGURE 12

KANSAS SINGLE THRIE BEAM : STEEL POSTS WITH BASE PLATES AND STRAIGHT END WALL

DWB + SP + RR

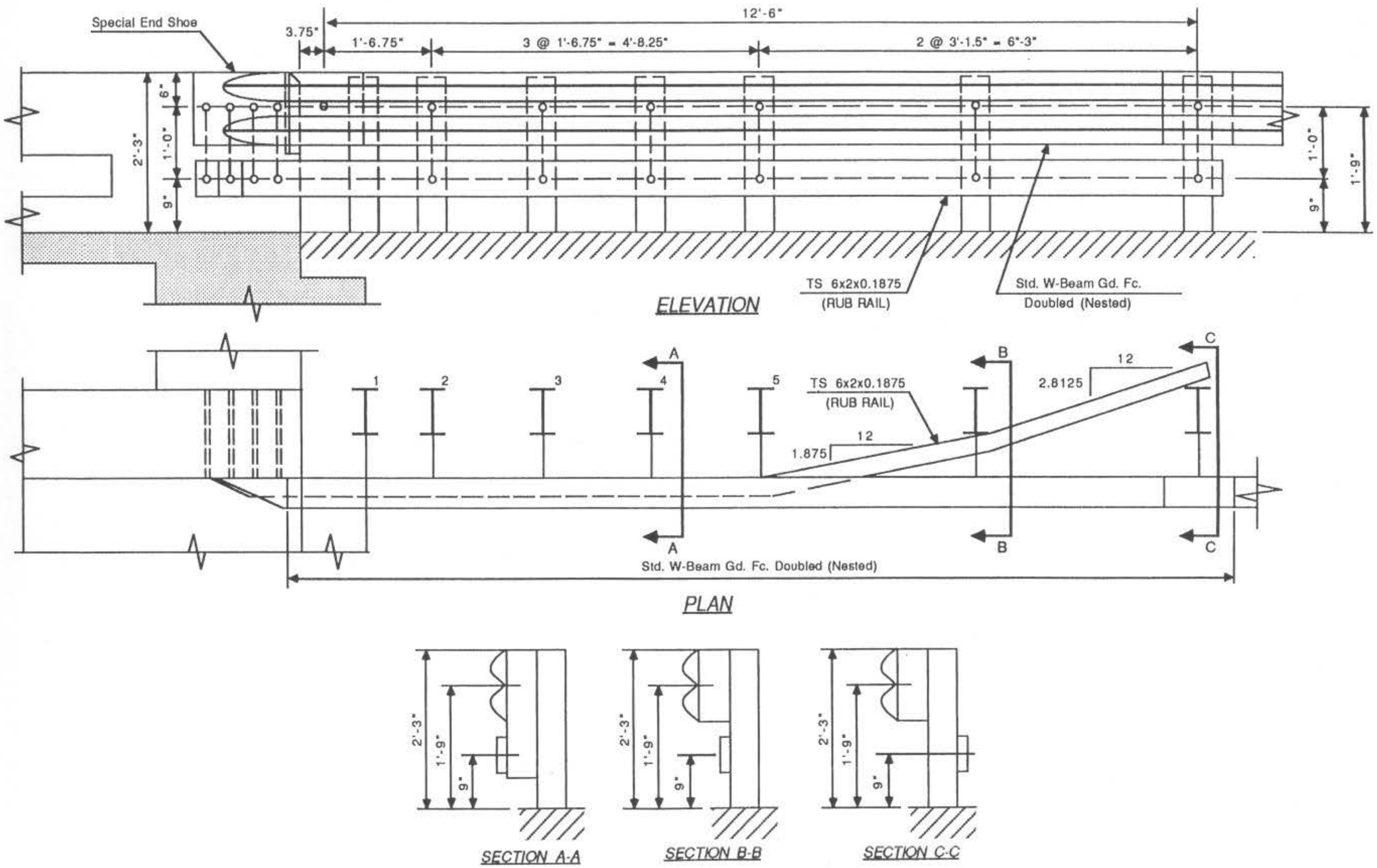


FIGURE 13

KANSAS DOUBLE W-BEAM: STEEL POSTS AND RUBRAIL WITH STRAIGHT END WALL

DTB + STB + SP

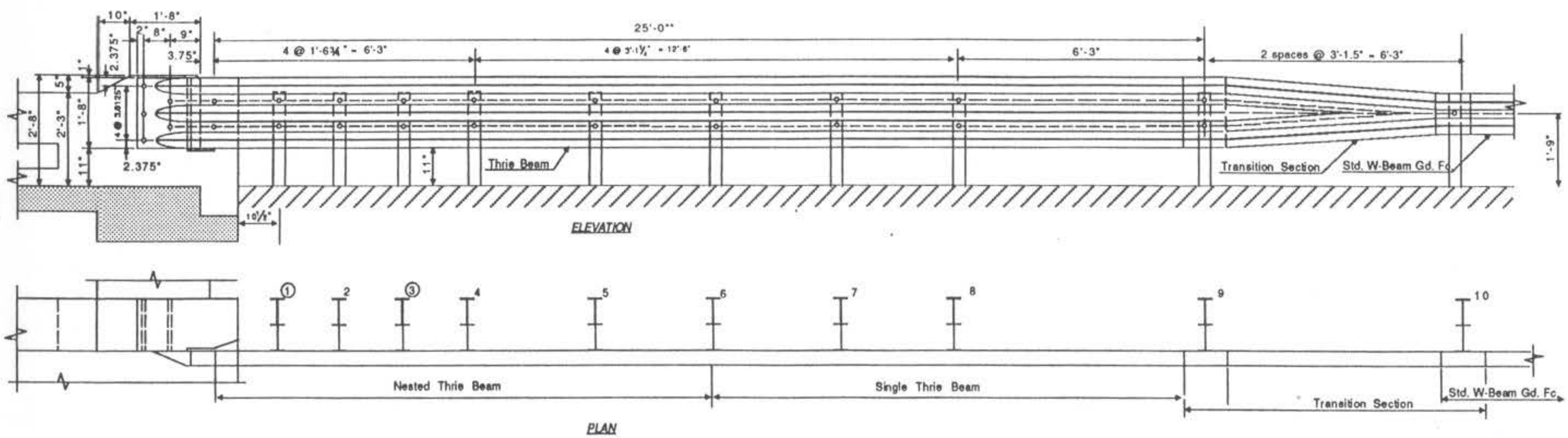


FIGURE 14

KANSAS DOUBLE/SINGLE THRIE BEAM : STEEL POSTS AND TAPERED END WALL

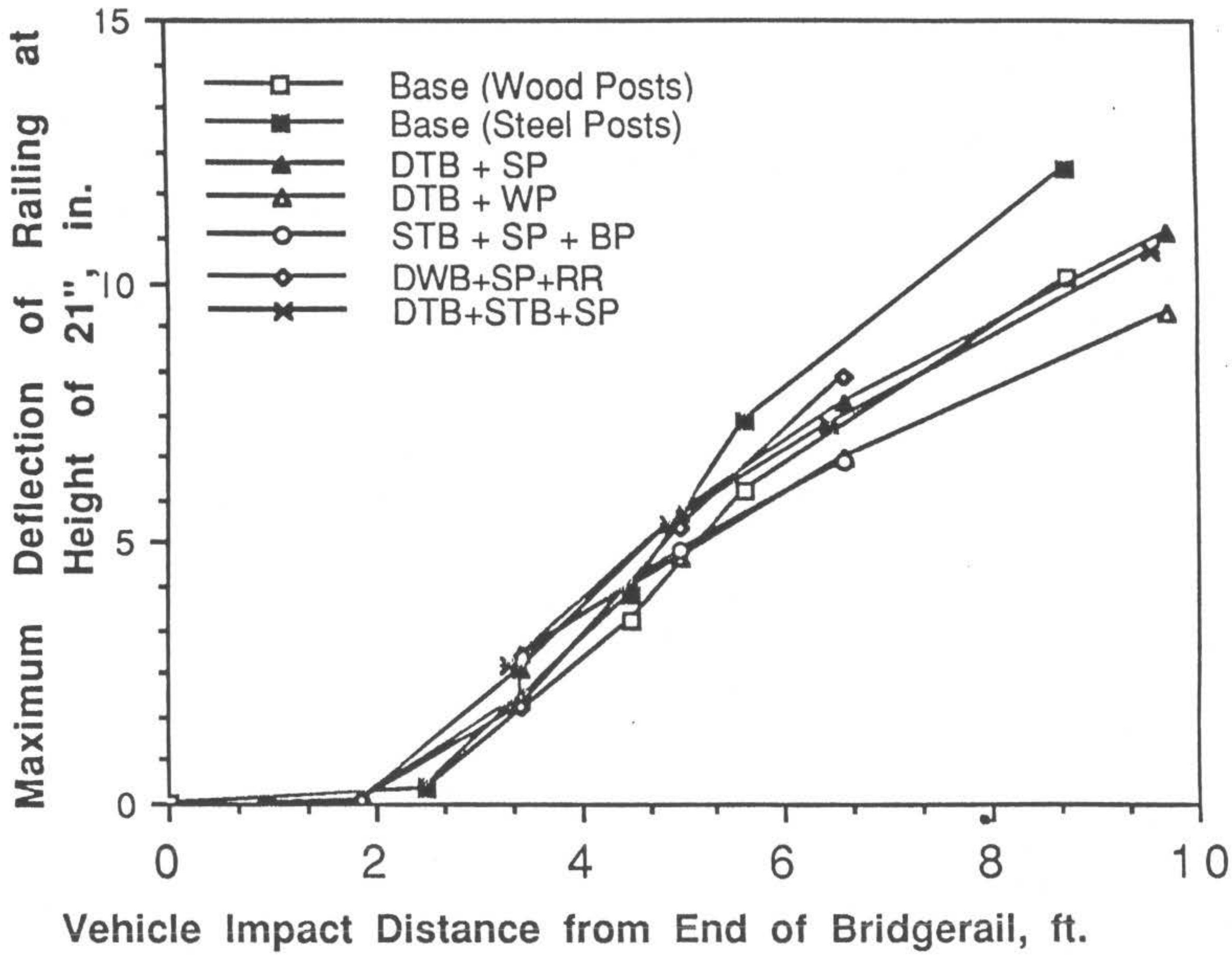


FIGURE 15
COMPARISON OF FHWA AND KANSAS TRANSITION DEFLECTIONS

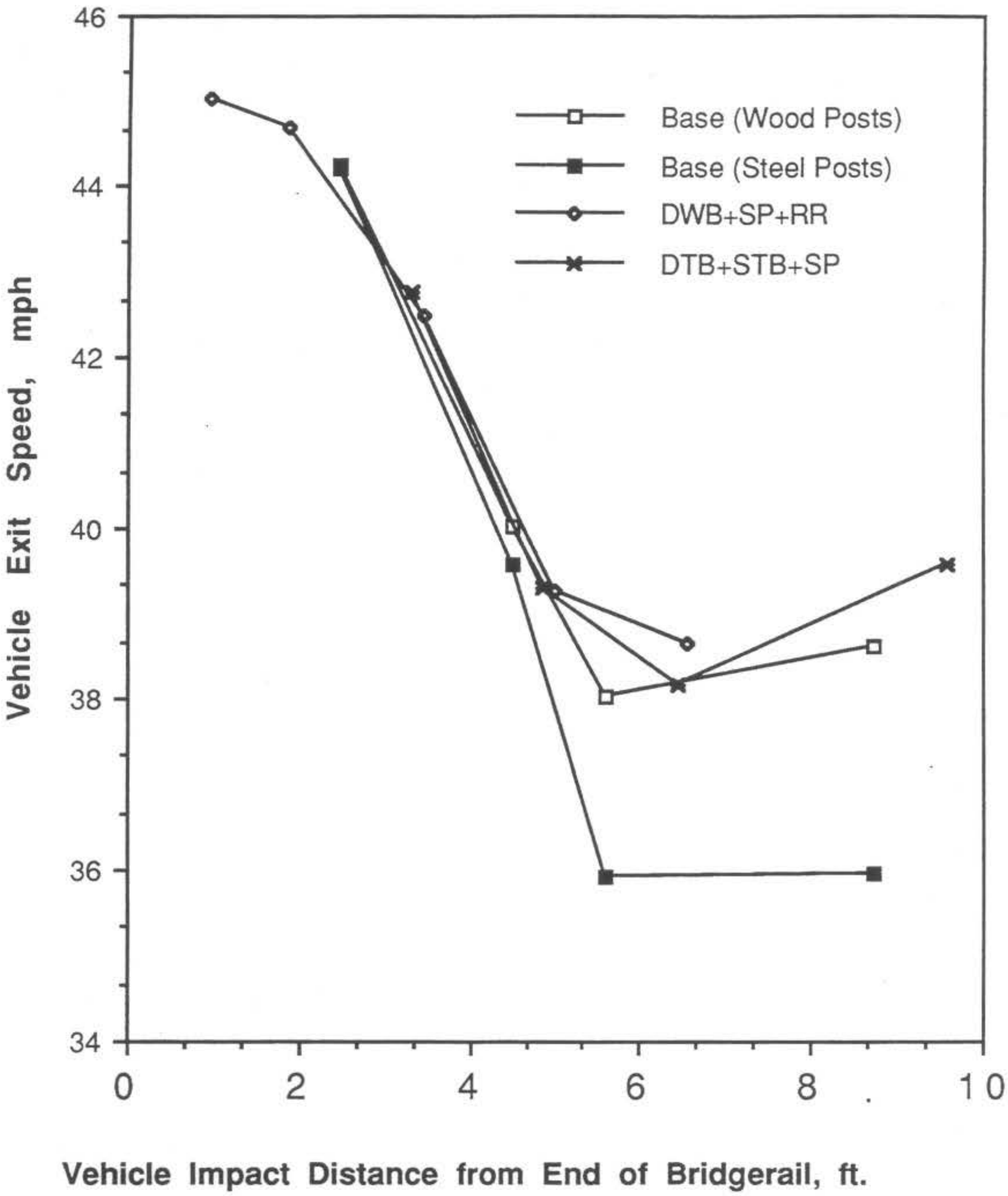


FIGURE 16
COMPARISON OF FHWA AND KANSAS VEHICLE EXIT SPEEDS

REFERENCES

1. FHWA "Guardrail Transitions," Technical Advisory T 5040.26, January 28, 1988.

2. NCHRP 230 "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances," National Cooperative Highway Research Program Report, March, 1981.

3. Powell, G. H. "BARRIER VII: A Computer Program for Evaluation of Automobile Barrier Systems," Report No. FHWA-RD-73-51, Final Report, April, 1973.

4. Post, E. R., "Full-Scale Vehicle Crash Tests on Guardrail- Bridgerail Transition Designs with Special Post Spacing," Transportation Research Report TRP-03-008-87, Civil Engineering Department, University of Nebraska, May, 1987.

5. Bronstad, M.E., Ray, M.H., Mayer, J.B., and McDevitt, C.F., "Guardrail-Bridge Rail Transition Evaluations," TRR 1133, pp. 7-22, 1987.

6. Buth, E., Arnold, A., Campise, W.L., Hirsch, T.J., Ivey, D.L., and Noel, J.S., "Safer Bridge Railings," FHWA/RD-82/072, Volume 1: Summary Report, June, 1984.

7. Jeyapalan, J.K., Dewey, J.F., Hirsch, T.J., Ross, H.E., and Cooner, H., "Soil-Foundation Interaction Behavior of Highway Guardrail Posts," TRR970, pp. 37-47, 1984.

8. Ataullah, S., "An Analytical Evaluation of Future Nebraska Bridgerail-Guardrail Transition Designs Using Computer Simulation Model BARRIER VII," M.S. Thesis, Civil Engineering Department, University of Nebraska-Lincoln, August, 1988.

9. Bligh, R.P., Sicking, D.L., and Ross, H.E., "Development of a Strong Beam Guardrail/Bridge Rail Transition," Texas A & M University, 67th TRB Annual Meeting, Session 93, January, 1988 (Report in Print).

APPENDICES

APPENDIX A

University of
Nebraska
Lincoln

Department of
Civil Engineering
W348 Nebraska Hall
Lincoln, NE 68588-0531

April 13, 1988

Mr. James O. Brewer, P.E.
State Road Engineer
Kansas Dept. of Transportation
9th Floor, Docking State Office Bldg.
Topeka, KS 66612-1568

Dear Jim:

This letter is in reference to our telephone conversation on April 11, 1988.

The proposed BARRIER VII Computer model simulation runs on guardrail-bridge-rail transition designs are enclosed for your consideration. As we discussed, computer modeling is a rapid and inexpensive method to select the best design alternative before conducting expensive full-scale vehicle crash tests. The proposed design alternatives were made after consultation with Mr. Charles McDivett of the FHWA Safety Research and Development Office in McLean, Virginia.

The "effectiveness" of a transition design alternative will be determined by comparing the performance characteristics of the design alternative with that of a similar approved FHWA design, "Vertical Concrete Bridge Rail End: W-Beam with Rubrail and Steel Posts" (Figure 1B, Technical Advisory T504.26 Jan. 28, 1988). The performance characteristics will include dynamic deflections, occupant relative impact velocity, change in vehicle speed and vehicle exit angle.

In the event that the performance of one of the proposed transition design alternatives is uncertain or unsatisfactory, then a stronger design with wood posts or a stronger design with soil bearing plates on steel posts would be worthly of ocnsideration.

The cost to make one computer simulation run (includes report) will be $500. I estimate that computer simulation will reduce crash testing costs by at least 50%.

I am looking forward to the opportunity of working with you and other engineers from KDOT and FHWA on this project.

Respectfully,

Edward R Post

Dr. Edward R. Post, P.E.
Professor

enclosures (2)
cc: Dr. W. E. Kelly, P.E.
CE Chairman

Dr. E. R. Post, P.E. 11 Apr 88

KDOT TRANSITIONS (1/2)
(Proposed)

TRANSITION DESIGN	Impact Post Location – BARRIER VII: 1	2	3	4	5	Number of BARRIER VII Simulations(3)	Number of Crash Tests(3)
A. BASE CONTROL DESIGN (FHWA Figure 1B) Vertical Concrete Bridgerail End; W-Beam with Rubrail; Steel Posts (Technical Advisory Jan 28, 1988)		×	×	×	×	4	—
B. RETROFIT EXISTING DESIGN							
1. Steel Plate Guide Fence with Steel Posts (STD. 608.6A)							
a. Existing Design	×	×	×			3	
b. Add Rubrail(1)	×	×	×			3	} 1
c. Add Rubrail(1) & 2 Steel Posts		×		×	×	3	
C. NEW DESIGNS							
1. Barrier Curb: Single Thrie Beam w/ Steel Posts							
a. Add Rubrail(2)	×	×	×			3	} 1
b. Add Rubrail(2) & 1 Steel Post		×	×	×		3	
2. Barrier Curb: Double Thrie Beam w/ Steel Posts							
a. Add Rubrail(2)	×	×	×			3	} 1
b. Add Rubrail(2) & 1 Steel Post		×	×	×		3	
3. Barrier Curb: Double W-Beam w/ Steel Post							
a. Rubrail (6x2x.1875)		×	×	×	×	4	} 1
b. Rubrail + 1 Additional Steel Post		×	×	×	×	4	
						33	4

Notes (1) Rubrail Length = 12'-6"
(2) Rubrail Length = 6'-3½"
(3) Impact Conditions: 4,500 lb. auto @ 60 mph/25 deg.

KDOT TRANSITIONS

1. BARRIER VII Simulation Costs

33 runs @ $500/run $16,500

2. FULL-SCALE CRASH TEST Costs

a) Construction

Bridgerail $10,000

Guardrail 5,000

b) Tests & Analyses

4 tests @ $17,600/test $70,400

Total . . $85,400

E.R. Post
(UNL)

16 Apr '88

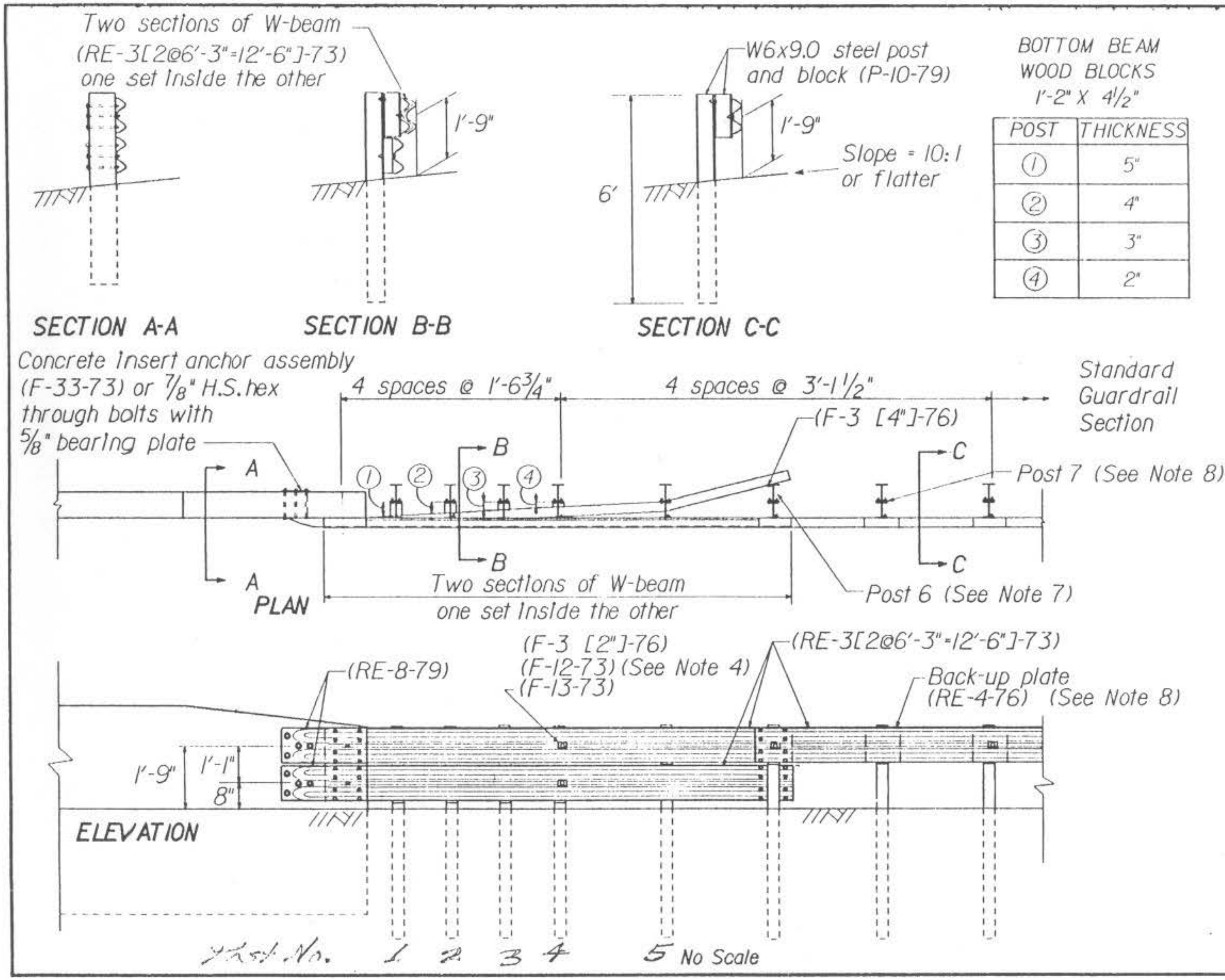
Table 1

BARRIER VII COMPUTER SIMULATIONS[(b)] ON KDOT GUARDRAIL-BRIDGERAIL TRANSITIONS

Item No.	TRANSITION DESIGN	Post Impact Location[(a)] 1	2	3	4	5	6	Number of Simulations
A.	BASE CONTROL DESIGN FHWA Tech. Advisory Jan 28, 1988 Vert. Conc. Bridgerail with Steel Posts and Rub Rail (Figure 1B)		×	×	×	×		4
B.	RETROFIT EXISTING DESIGN							
B.1.	Steel Plate Guide Fence w/ Steel Posts (STD 608.6A)							
B.1.a.	Add Rub Rail (TS 6×2×.1875) and Add 2 Steel Posts	⊗	×	⊗	×	×		5
C.	KANSAS RAIL DESIGNS (NEW)							
C.1.	Double Thrie Beam w/ Steel Posts							
C.1.a.	Add 1 Steel Post	⊗	×	×	×			4
C.1.b.	Add 2 Steel Posts	⊗		⊗		×		3
C.2.	Single Thrie Beam w/ Steel Posts							
C.2.a.	Add 2 Steel Posts	⊗		⊗		×		3
C.3.	Double W-Beam w/ Steel Posts							
C.3.a.	Rub Rail (TS 6×2×.1875)	×		×		×		3
C.3.b.	Rub Rail and Add 1 Steel Post	⊗	×	×				3
							Total	25

Notes (a) ⊗ denotes added post
(b) Impact Conditions: 4,500 lb. auto @ 60 mph/25 deg.

REG	STATE	PROJECT	SHEET NO.	TOTAL SHEETS



BOTTOM BEAM
WOOD BLOCKS
1'-2" X 4 1/2"

POST	THICKNESS
1	5"
2	4"
3	3"
4	2"

NOTES :

1. This guardrail transition is appropriate for connection to a vertical concrete shape and should not be connected directly to a concrete safety shape. Concrete safety shape barriers should be transitioned to a vertical shape at the guardrail connection.
2. Bridge rail ends and bridge parapets must be of adequate strength to accept full impact loading.
3. Standard barrier hardware has been used to develop this guardrail transition. Designations provided in parenthesis relate to standard elements detailed in "A Guide to Standardized Highway Barrier Rail Hardware," 1979, AASHTO-AGC-ARTBA Joint Cooperative Committee.
4. Use of plate washers (F-12-73) is optional.
5. Bottom beam blocks are offset drilled to sit squarely on the post flange. Blocks are attached with 5/8" carriage bolts (F-3[as required]-76).
6. The rubrail may be shop bent in the last 3 feet to facilitate installation.
7. Posts 1, 2, 3, 4, and 6 require an additional hole to attach lower blocks and/or lower beam.
8. At Post 7 back-up plate bolted to block only.

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

Figure 1B
VERTICAL CONCRETE BRIDGE RAIL END
W-BEAM WITH RUBRAIL
STEEL POSTS
December 1987

ITEM A.

ITEM B.1a.

Add 2 Posts

Post No.

Add Rubrail TS 6x2x.1875

15

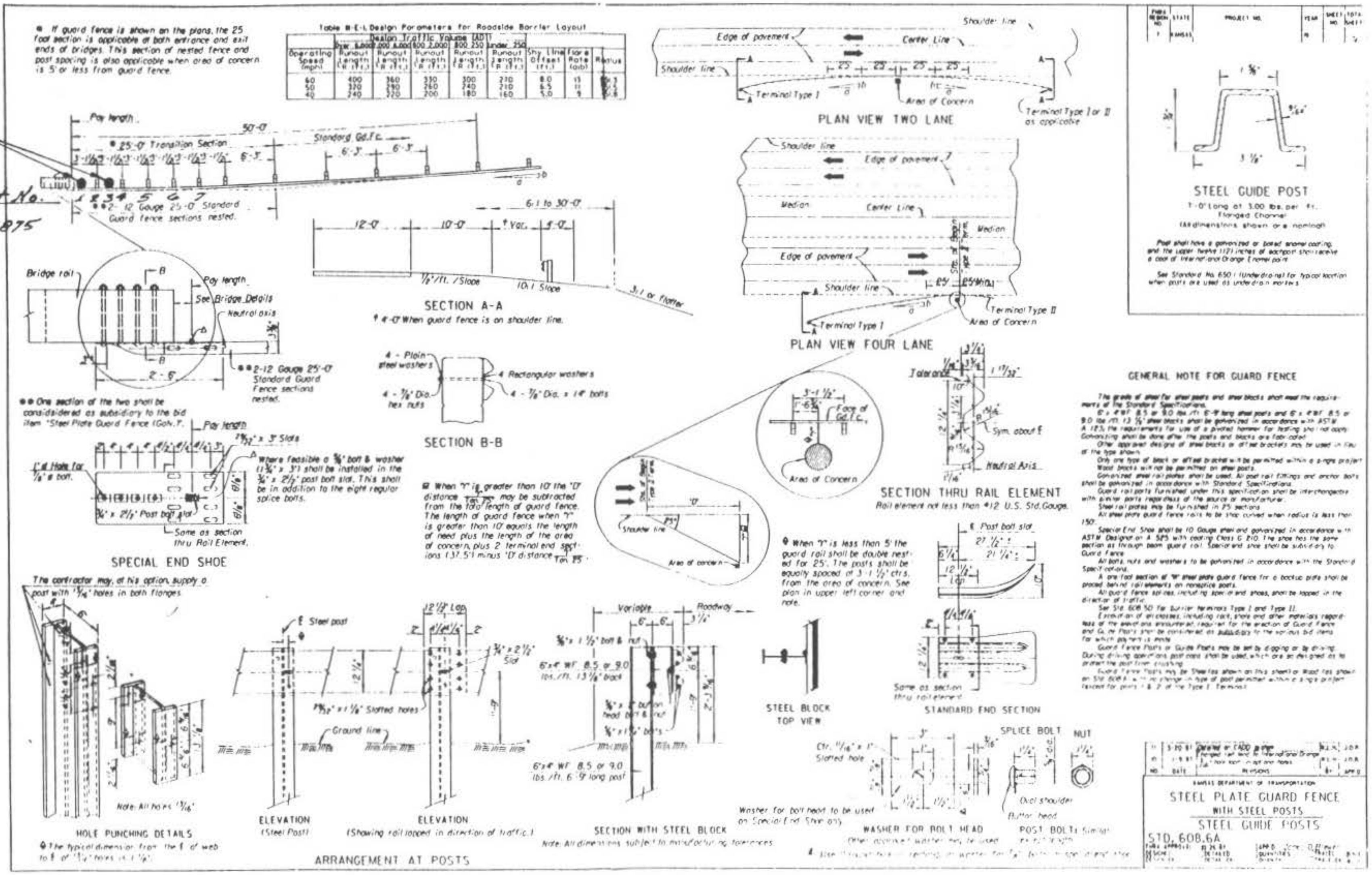
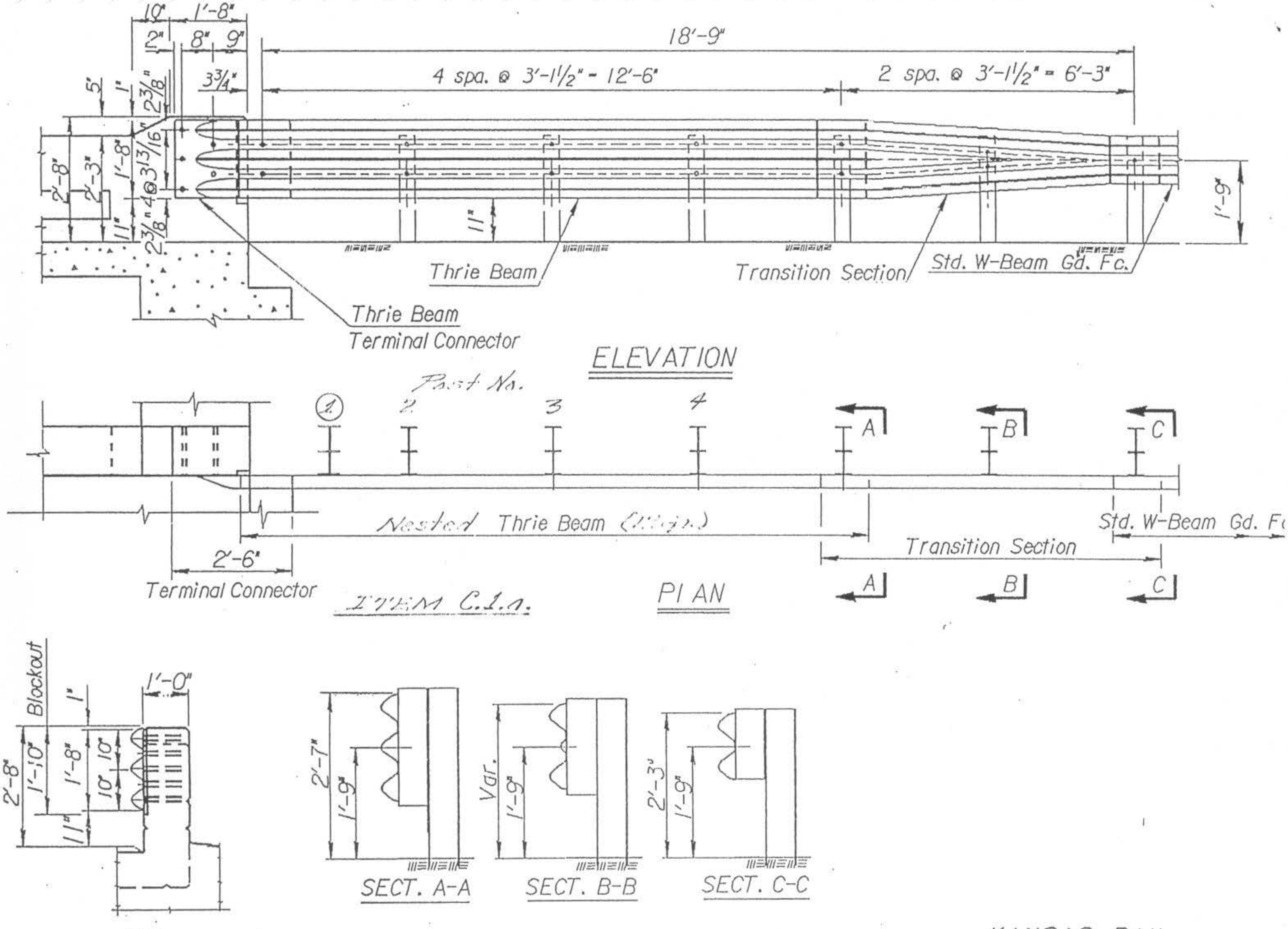


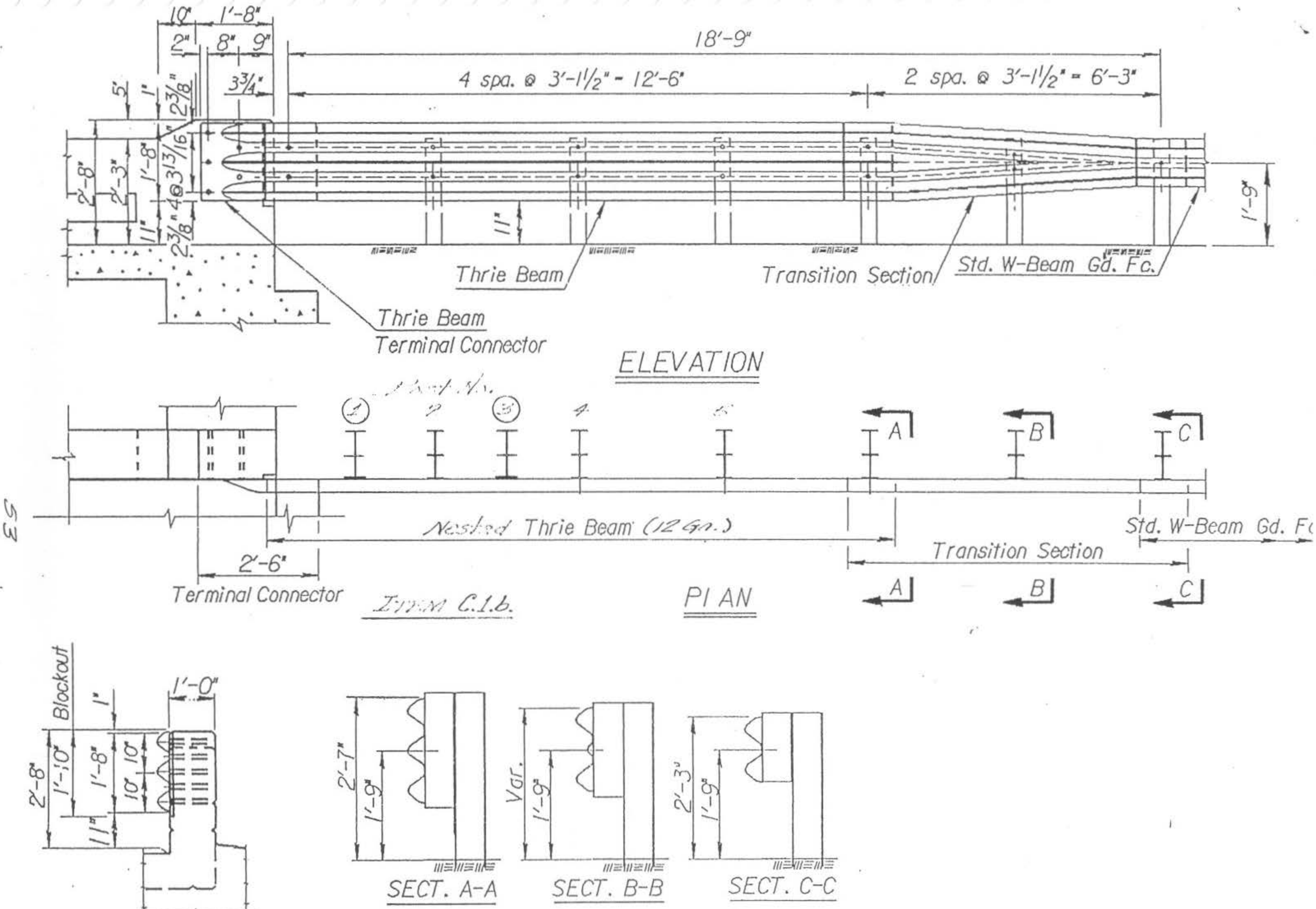
Table III-E-1, Design Parameters for Roadside Barrier Layout

Operating Speed (mph)	Over 6,000 Runout Length (R (ft.))	2,000-6,000 Runout Length (R (ft.))	800-2,000 Runout Length (R (ft.))	800-250 Runout Length (R (ft.))	Under 250 Runout Length (R (ft.))	Shy Line Offset (ft.)	Flare Rate (a:b)	Radius
60	400	360	330	300	270	8.0	15	[illegible]
50	320	290	260	240	210	6.5	11	[illegible]
40	240	220	200	180	160	5.0	9	[illegible]



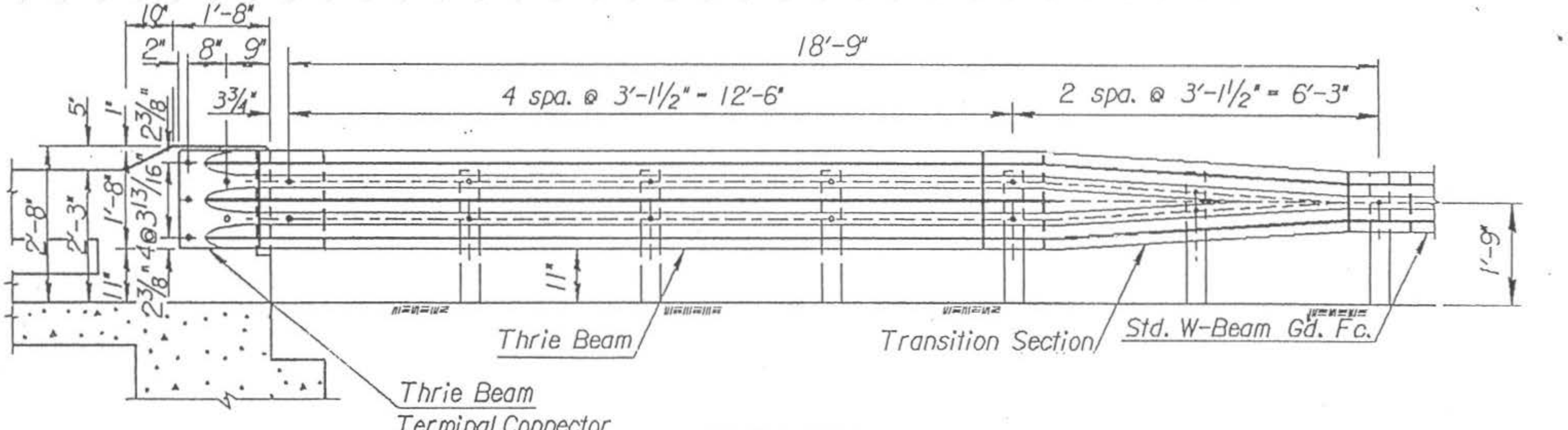
TYPICAL SECTION
END BLOCK

KANSAS RAIL
GUARD FENCE ATTACHMENT
THRIE BEAM

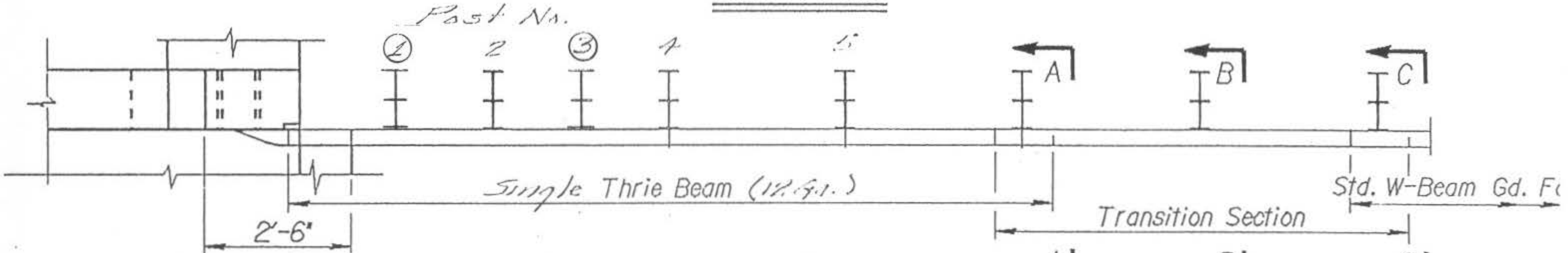


TYPICAL SECTION
END BLOCK

KANSAS RAIL
GUARD FENCE ATTACHMENT
THRIE BEAM

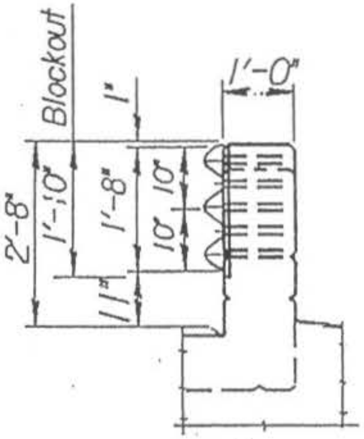


ELEVATION

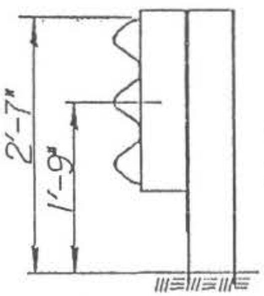


PLAN

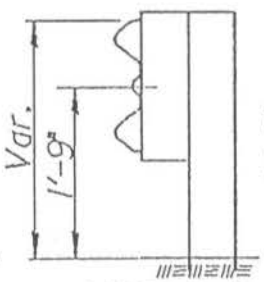
45



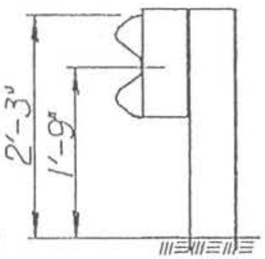
TYPICAL SECTION
END BLOCK



SECT. A-A

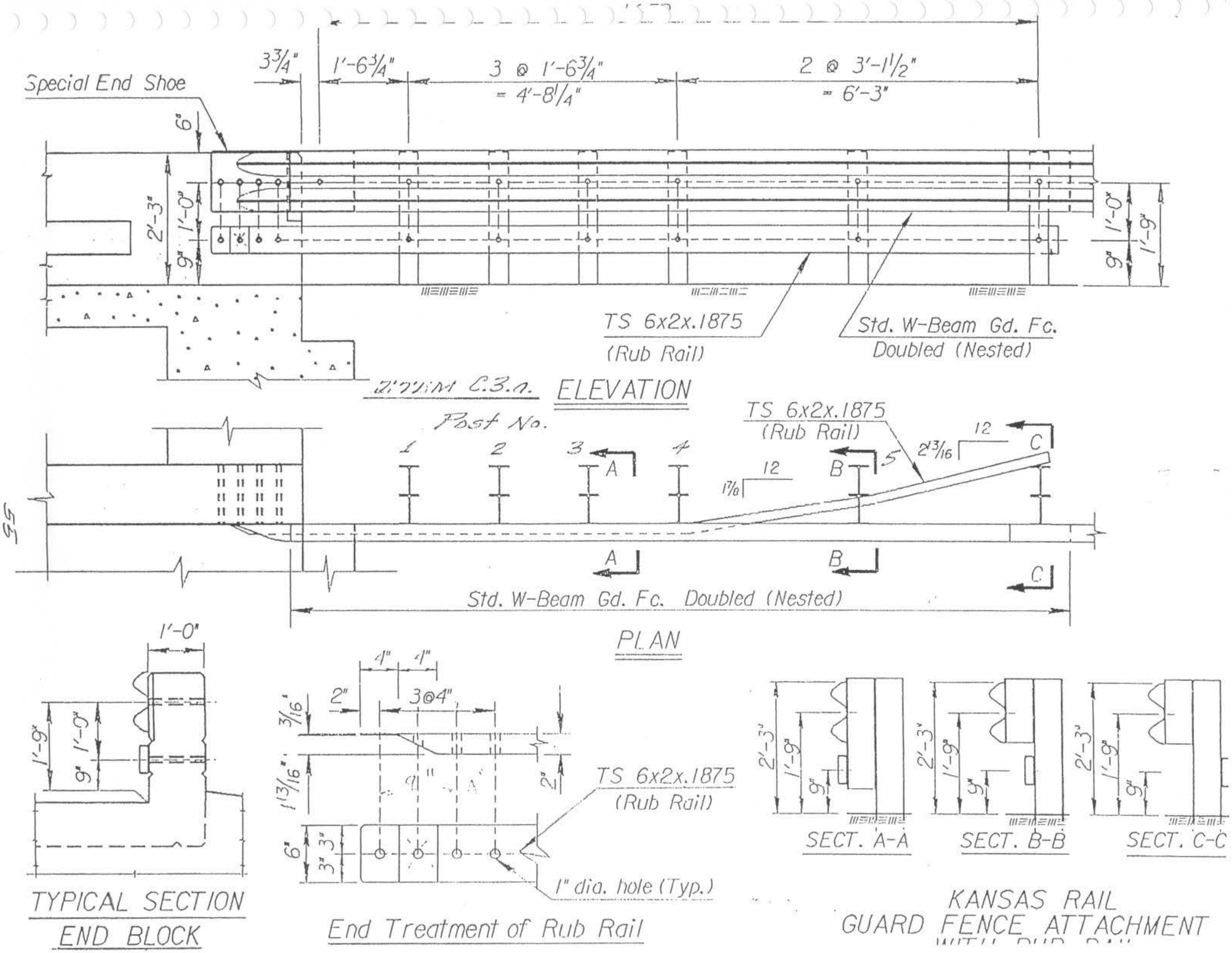


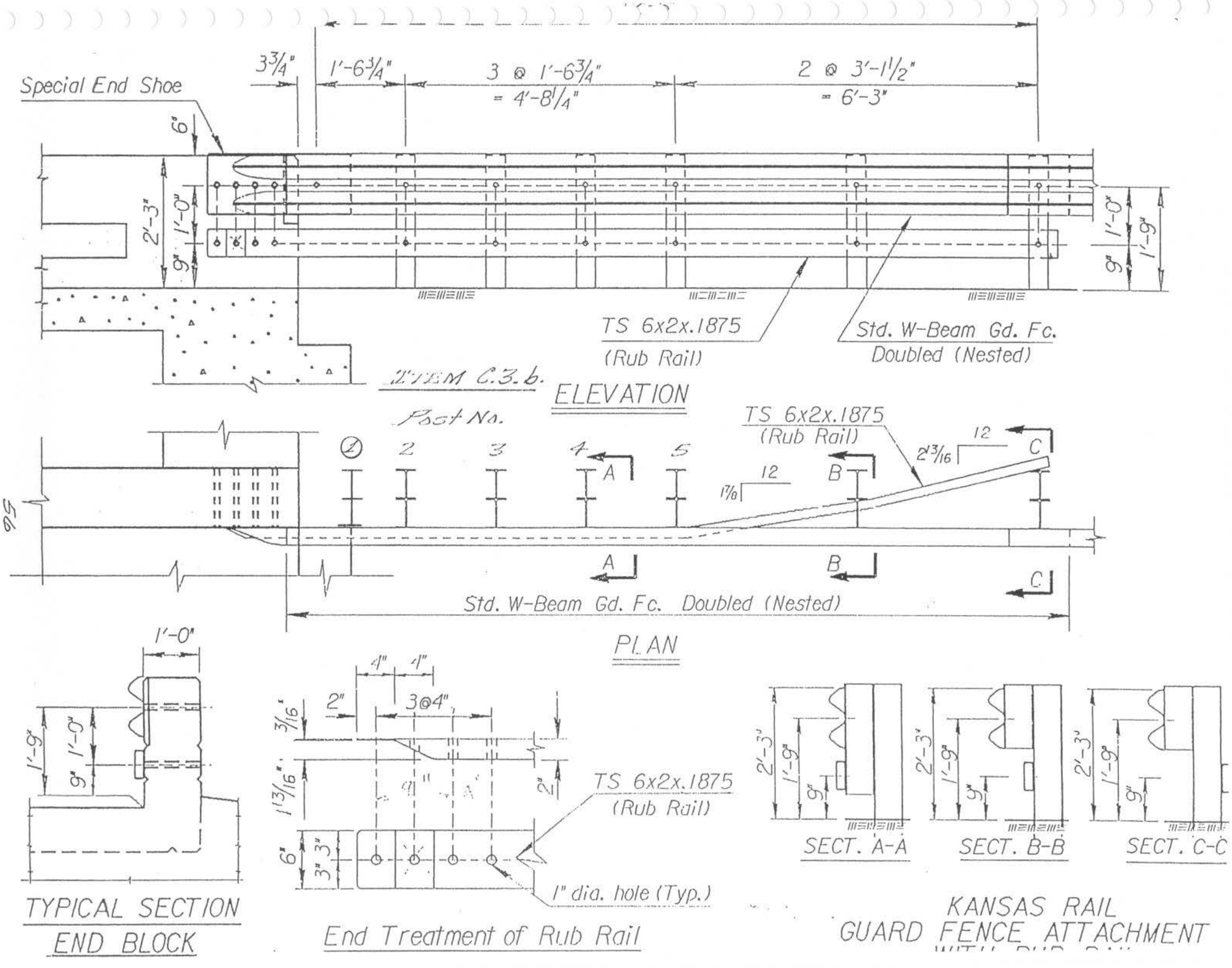
SECT. B-B



SECT. C-C

KANSAS RAIL
GUARD FENCE ATTACHMENT
THRIE BEAM


Special End Shoe
3¾"
1'-6¾"
3 @ 1'-6¾" = 4'-8¼"
2 @ 3'-1½" = 6'-3"
6"
2'-3"
1'-0"
9"
1'-9"
TS 6x2x.1875 (Rub Rail)
Std. W-Beam Gd. Fc. Doubled (Nested)
ELEVATION
Post No.
1
2
3
4
5
A
B
C
12
1⅞
2 13/16
Std. W-Beam Gd. Fc. Doubled (Nested)
PLAN
1'-0"
TYPICAL SECTION
END BLOCK
4"
2"
3@4"
3/16"
1 13/16"
3"
TS 6x2x.1875 (Rub Rail)
1" dia. hole (Typ.)
End Treatment of Rub Rail
SECT. A-A
SECT. B-B
SECT. C-C
KANSAS RAIL
GUARD FENCE ATTACHMENT



Special End Shoe
3 3/4"
1'-6 3/4"
3 @ 1'-6 3/4"
= 4'-8 1/4"
2 @ 3'-1 1/2"
= 6'-3"
6"
2'-3"
1'-0"
9"
1'-9"
TS 6x2x.1875
(Rub Rail)
Std. W-Beam Gd. Fc.
Doubled (Nested)
ITEM C.3.b.
ELEVATION
Post No.
1
2
3
4
5
TS 6x2x.1875
(Rub Rail)
12
2 13/16
1 7/8
A
B
C
Std. W-Beam Gd. Fc. Doubled (Nested)
PLAN
1'-0"
1'-9"
1'-0"
9"
TYPICAL SECTION
END BLOCK
4"
4"
2"
3@4"
3/16"
1 13/16"
2"
6"
3"
3"
TS 6x2x.1875
(Rub Rail)
1" dia. hole (Typ.)
End Treatment of Rub Rail
2'-3"
1'-9"
9"
SECT. A-A
SECT. B-B
SECT. C-C
KANSAS RAIL
GUARD FENCE ATTACHMENT