



ALASKA DEPARTMENT OF TRANSPORTATION

Guardrail End Terminal Rating and Comparison Survey

Prepared by: Stephen P. Mattingly
Assistant Professor
Department of Civil and Environmental Engineering
Transportation Research Center
Institute of Northern Engineering
University of Fairbanks Alaska
PO Box 755900
Fairbanks AK 99775

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GUARDRAIL END TERMINAL
RATING AND COMPARISON SURVEY

FINAL REPORT

Prepared for
Alaska Department of Transportation & Public Facilities

Principal Investigator

Stephen P. Mattingly, Assistant Professor

Department of Civil and Environmental Engineering
Transportation Research Center
Institute of Northern Engineering
University of Alaska Fairbanks
P. O. Box 755900
Fairbanks, Alaska 99775

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ABSTRACT

This report presents an evaluation of guardrail end terminals for possible use in the State of Alaska, which has unique winter maintenance concerns. With significant snowfall levels and cold temperatures, Alaska needs to identify an end terminal that can withstand these conditions and can be readily repaired without having to deal with the frozen ground. The study collects product data from seven different vendors, and eight northern tier state Departments of Transportation. While the study tends to focus on winter repair and replacement, the study collects general information regarding the terminals cost and installation as well as product quality and compatibility. Although ease of replacement and terminal compatibility remains extremely important to the Alaska Department of Transportation and Public Facilities (DOT&PF), this report fails to provide significant insight to these issues.

Three different decision-making techniques are applied with similar results. In one, a decision-maker is interviewed and multi-attribute value function (MAVF) theory is applied to generate an additive value function for end terminal value. During the interview, some threshold values for criteria are established and those alternatives that fail to reach this value are eliminated from consideration. Through the application of MAVF, the alternatives are rank ordered. The second approach uses a linear relationship to rescale each attribute to generate a rank ordering of alternatives, and the third strategy simply combines the attribute ranks for each alternative to establish their rank order. Based on the limited data set (at most a sample size of eight and in two cases a sample size of one), a definitive selection of a single alternative is impossible but recommendations are made.

SUMMARY OF FINDINGS

This study identifies minimum acceptable levels over certain attributes that pertain directly to winter maintenance of guardrail end terminals. All terminals within the State of Alaska need to have an option of a steel or wood post and the Alaska Department of Transportation and Public Facilities (DOT&PF) may want to consider only stockpiling steel posts for use in winter replacements based on vendor recommendations. Additionally, those posts that cannot be sleeved in any particular terminal design are extremely difficult to replace during winter months. At this time, this study excludes terminal designs that have fewer than two posts that can be sleeved in its design; however, this study recommends that the Alaska DOT&PF exclude any tangential terminals that cannot have every post sleeved.

The study provides a preliminary ranking of the feasible alternatives based on three different ranking strategies, multiattribute value functions (MAVF), combined rankings and scaled criteria; however, a clearly optimal alternative, for either tangential or flared guardrail end terminals (GETs), fails to emerge during this study. The primary options for both tangential and flared terminals have generally similar characteristics where price is the only objective factor to separate the competing products. From the user's perspective, each state has their own preferences for the competing products, but the differences between the alternatives is not significant enough for a clear choice to emerge. Each of the products typically has a variety of options available for use in each specific application. These options must be carefully specified to meet the Alaska DOT&PF's need to repair and replace GETs above ground during the long winter season. Any GET specified for use in Alaska needs to meet the following criteria:

- (1) The terminal design must meet NCHRP Report 350 Test Level 3 standards.
- (2) All terminals within the State of Alaska need to have an option of steel or wood posts.
- (3) All posts for tangential terminals and the first two posts in flared terminals need to have the option of soil tube, hinge or similar strategy that facilitates above ground repair.

The Alaska DOT&PF needs to minimize maintenance training requirements, reduce stockpiling needs, and improve terminal and part compatibility. These needs can be partially met by lengthening the period of time that an agency is committed to a particular vendor for flared and tangential GETs. The Federal Highway Administration (FHWA) may permit the Alaska DOT&PF to award a five-year sole source contract that is fully competed; this report recommends that Alaska DOT&PF pursue such an award as long as the selected terminal meet the aforementioned specification requirements. Such an award will not eliminate all of the Alaska DOT&PF's maintenance concerns, but stockpiling and training needs will be reduced.

At this time, this study recommends that some terminals be excluded from further consideration as shown in Table I. These terminals must be eliminated because they currently fail to meet the previously discussed specification criteria.

Table I. Terminals Eliminated from Further Consideration

Vendor	Terminal Type	Reason
All Vendors	BRAKEMASTER	Concrete anchors/slab
All Vendors	REGENT	Only wood posts
Universal Industrial Sales, Utah	BEST	No sleeves/Only wood posts
Trinity Industries	CAT	Only wood posts

With the limited differentiation amongst the alternative end terminals across many of the alternatives, the identification of a single tangential and flared terminal for preferred usage statewide may require a demonstration program; additionally, a demonstration program may increase maintenance personnel confidence that the selected terminal design can usually be repaired during the winter season after it is damaged. A more extensive user survey effort may prove beneficial; however, it may fail to provide further insight because additional personnel with the requisite knowledge, specifically winter performance and above ground repairs, to participate may be difficult to identify. A new study that tracks the above ground track record of many terminal types and models across different environmental conditions and geographic locations may also provide a new level of understanding of one of the most critical attributes within this report's investigation. In order to select an optimal terminal, additional research will likely be required; however, the specification of appropriate end terminal attributes will improve the winter repair and replacement of Alaska's GETs.

CHAPTER 1 - INTRODUCTION AND RESEARCH APPROACH

1.1 Problem Statement and Research Objective

The W-beam guardrail has traditionally been the first choice for use in protecting the motoring public from serious roadside hazards. This wide usage results from its favorable safety record, ease of construction and repair, and low cost. One trouble spot for this system has been the difficulty in safely treating the end of the barrier. As a result, since the 1960s, research in guardrails has been focused on guardrail end treatment. Tests indicated that the standard terminal section (37 ½ ft. long) was extremely dangerous. A collision with untreated guardrail will have severe results for vehicle and its occupants. Safety improvements in terminal design have continued from these initial studies. The most recent advancement in terminal design focuses on new Federal Highway Administration (FHWA) requirements.

An important milestone in the development of the terminals is the FHWA requirement that all safety devices installed on federal-aid highways after September 1998 meet the new National Cooperative Highway Research Program (NCHRP) Report 350 standards (Ross *et al.*, 1993). To meet the new NCHRP 350 standards, several new terminals have developed, including the slotted rail terminal (SRT), the ET-2000, the beam-eating steel terminal (BEST), the sequential kinking terminal (SKT), and the flared W-beam guardrail terminal (FLEAT). The variety of new terminals that meet NCHRP 350 standards makes the identification of appropriate terminals for use in the State of Alaska difficult. Each of these terminals has its own design, installation, and repair procedures as well as parts that may or may not be interchangeable with other terminal designs. The State of Alaska has observed that the new guardrail end terminals (GETs) do not always withstand winter snow removal activities effectively. Ma and Mattingly (2000) provides anecdotal evidence of the causes of these failures, and some potential mitigation schemes. Ma and Mattingly (2000) identify marking strategies and increased operator care as two likely mitigation strategies. The State of Alaska Department of Transportation and Public Facilities (DOT&PF) would like to minimize maintenance costs by identifying the terminals that have performed well in other applications, are compatible with cold region snow removal activities and can share similar repair parts. Additionally, other institutional costs associated with each terminal need to be assessed to determine the actual costs for each terminal.

To minimize liability concerns and maintain a safe roadway environment, the Alaska DOT&PF need to be able to repair damaged end sections of guardrail in a timely manner. The Alaska DOT&PF needs to identify the safest, most reliable, tangential and flared end-terminals which can be repaired above ground during winter time months. An appropriate GET has the potential to greatly reduce repair, maintenance and training costs for the Alaska DOT&PF. Furthermore, the selection of a single alternative will greatly reduce the quantity of spare parts that the maintenance yards must stockpile, decrease the quantity of training required for maintenance personnel, and ease terminal replacement.

This study provides a matrix of key information for determining which guardrail end terminals are acceptable for use on state roads and makes an initial recommendation as to the best alternative.

1.2 Scope of Study

This project focused on guardrail end terminals that are currently manufactured and available for shipment to Alaska. This research used targeted surveys to obtain vendor descriptions of their products while targeting external agencies to obtain relatively unbiased assessments of the alternative GETs. The study includes seven GET vendors including, Bryson Products, Trinity Industries, Universal Industrial Sales, Gregory Highway Products, R.G Steel Corp., Road Systems, and Highway Safety Corp. All of the targeted external agencies experience significant snowfalls during the winter months. Only states that experience extensive snowfall events were considered as possible data sources and thus targeted as part of the survey. While fifteen state DOTs were considered and contacted as part of this survey, the study identified personnel in eight of the targeted states that had enough knowledge of the GETs to participate in the survey. Wyoming, Montana, Minnesota, Michigan, Utah, Oregon, Washington, and Idaho provided data for this study. These states represent a good data set because they experience similar winter conditions to Alaska.

1.3 Research Approach

During the preliminary study, the Alaska DOT&PF has identified many key concerns related to GET winter maintainability. Additionally, the Alaska DOT&PF has indicated some other general criteria for evaluating potential GETs. This project uses a vendor survey and external Department of Transportation (DOT) survey to gather two separate, relevant data sets, which include the aforementioned criteria, which are necessary for evaluating alternative GETs. Two separate data sets are used because the vendors are most likely to provide detailed product information; however, external agencies remain more likely to provide accurate, unbiased data regarding product performance criteria. The information obtained in these surveys populates two matrices for use in comparing the aforementioned criteria across alternatives. The rest of this section describes the potential evaluation criteria and the process for obtaining the data to complete the two matrices.

The vendor survey focuses on obtaining a detailed product description. The most important criterion for this study is that all alternatives must at least be compliant with the NCHRP 350 Test Level – 3. Most of the criteria focus on repairing and replacing GETs during winter conditions. Sleeved posts tend to be easier to replace during the winter as opposed to unsleeved posts that must be driven into frozen soil. This study identifies the number of sleeves for each of the products. As identified in the preliminary study (Ma and Mattingly, 2000), maintenance workers prefer steel posts to wood posts,

especially when unsleeved, because they can be driven into frozen ground more readily. For each of the products, the vendors identify if a steel post is available. Some of the vendors have innovative strategies to make replacing the GETs easier, such as hinged posts; the study seeks to obtain this information as well. The vendors provide their assessment of the viability of above ground and winter replacement for each of their products. While bias may exist, the vendors rate their products for ease of installation and complexity to maintain and repair on a scale of one to seven. This information can identify if some products may require more training than others and may result in greater maintenance costs. Finally, the study includes other general descriptive criteria, such as flare offset, cost, delivery time and compatibility. All of the data for these criteria must be obtained from the product vendors and can be collected by using the vendor websites and conducting brief telephone interviews with sales representatives.

In order to identify a large selection of alternatives, this study uses an Internet search to identify seven major end-terminal vendors that distribute to State DOT's. In the cases where companies did not have adequate web facilities, the study acquires the vendor contact information from other agencies. After examining a vendor's website and marketing materials, a researcher contacts the vendor for a phone interview, which may last between fifteen and thirty minutes. As much information as possible is gleaned from the Internet and marketing materials review, but all of this data is confirmed during the interview and any gaps filled. During the interview, the interviewer requests that the vendor identify agencies that currently use their product. Unfortunately, Sunbelt states, which the researchers deem unsuitable for inclusion in this investigation, seem to be the preferred references for most of the vendors. By using Internet research and DOT contacts, this study examines seven vendors: Bryson Products, Trinity Industries, Universal Industrial Sales, Gregory Highway Products, R.G Steel Corp., Road Systems, and Highway Safety Corp. This study examines the wide variety of GETs that the vendors produce including, FLEAT, SKT, REGENT, BRAKEMASTER, SRT 350, ET-2000, CAT, and BEST. The state of Wyoming has developed an end-terminal called the WYBET, which Trinity Industry distributes. The vendor matrix provides the essential descriptive information for each product and section 2.2 discusses the completed matrix in detail.

The DOT survey asks for an unbiased assessment of the alternative GETs over the criteria identified by the research team and Alaska DOT&PF. Once again, winter repair and replacement of the GETs figures prominently in the evaluation. The agencies provide their assessment of the viability of above ground and winter replacement for each of the GETs that they use. Beyond the previous criteria that closely mirror two similar criteria from the vendor survey, the DOTs assess the GETs' snow load resistance. The study also includes several general criteria for comparing GETs where many of these criteria are rated on a one to seven point scale. Firstly, the agencies give each terminal an overall rating and assess the product's quality and performance. Similarly, the survey participant rates the customer service associated with each of the products. More criteria attempt to explain the maintainability of the terminals. The agencies rate each terminal's overall maintainability and compatibility with other terminals. Another criterion describes the average repair cost in dollars per repair. In addition to cost, the man-hours

the amount of time required to complete the repair is important, and the length of time required to train maintenance workers to repair each type of terminal. As identified in the preliminary study (Ma and Mattingly, 2000), maintenance workers prefer older versions of the guardrail terminals where the posts may be reusable after the terminal is struck. The interviewer queries the DOTs to determine if any of the new terminals possess this characteristic. This data is collected using a phone survey.

The DOT matrix provides an unbiased assessment of each product's relevant criteria. The initial contact numbers for every state DOT can be found on the FHWA homepage on the Internet (<http://www.fhwa.dot.gov/webstate.htm>), but finding the proper contact within other state DOTs proves to be a difficult task. When the researchers are unable to locate an individual within a DOT to adequately complete the survey, the DOT must be eliminated from the study. The phone interview for this portion of the study tends to be a little longer (20-40 minutes) than the vendor survey because all of the necessary information must be obtained during the interview rather than merely confirmed. In addition to completing all of the appropriate matrix cells, the interviewer attempts to ascertain the other DOT's experiences with winter maintenance operations and the new GETs. Each of the DOT's guardrail marking strategies is particularly interesting. Section 2.3 discusses the completed matrix in detail while section 3.1 examines the implications of both surveys.

CHAPTER 2 - FINDINGS

2.1 State-of-the-Art Summary

Limited literature exists regarding GETs and most of the literature that does exist focuses on crash testing and product development as opposed to evaluating alternative end terminals. Denman and Welch (1999) describe the development and testing required to meet NCHRP Report 350 (Test Level 3) standards. They test the redirective and gating end terminal (REGENT) system attached to both wood and steel downstream guardrail posts. The report by Snyder (1995) describes a demonstration program of two end terminal treatment systems, the C-A-T and the BRAKEMASTER, conducted by the Pennsylvania Department of Transportation. This work appears quite interesting because it examines the installation procedures, costs, accident-related data and service and maintenance information for each system over a thirty-two month period. Unfortunately, this study has no direct impact on this research because it examines systems designed prior to NCHRP Report 350. This study's investigation did not find any more recent demonstration programs that look at the new treatment systems.

As indicated in Ma and Mattingly (2000), snow country states have experienced difficulties with the new GETs; however, only one of the seventeen agencies polled believes that their GETs may fail as a result of snow loads. Since significant failures due to snow loads seems unlikely, the most significant threat to GETs seems to be snow removal equipment striking the terminal. In the absence of any other supporting literature, this study must go forward with its own data collection effort.

2.2 Vendor Survey Results

The critical results from the vendor survey are displayed in Table 2.1 while the complete study results can be found in Appendix A. All of the GETs that this study examines meet the standards from NCHRP Report 350 (Test Level 3). During the survey, the vendors state that no special tools are required to install or repair any of the guardrail terminals that this report investigates; furthermore, any standard guardrail crew can be expected to install or repair these terminals. No terminals seem to be compatible with the existing SRT 350 and ET 2000 terminals that Alaska DOT&PF currently uses. The materials cost that the vendors identify is a delivered cost, and the variance that exists in some of these costs depends on the quantity ordered. The vendors generally lack knowledge regarding the installation costs of their products, and even if they possess some knowledge of these figures they may be loathe to provide a potential installation price. In the absence of installation costs, one vendor identifies the likely time required to install the company's products. The material prices for the end terminals vary widely between \$700 and \$2,800; however, when the CAT and BRAKEMASTER terminals are excluded, the price only varies between \$700 and \$1,400. None of the vendors have Alaska dealers, and the delivery times remain similar across all of the vendors with the expected delivery time ranging between seven and fourteen days. Many terminal types have steel posts available

while a few must be either steel or wood. While the vendors fail to provide installation costs, they provide a wealth of information regarding their product's specifications.

Table 2.1. Vendor Survey Results

Manufacturer	Terminal Name	Number of Sleeves	Actual Cost Materials	Steel Post?
Bryson Products, Mississippi	FLEAT	7 posts, 2 sleeved	\$1,200	Wood (steel option)
	SKT	8 posts, 2/4/8 sleeves	\$1,200	Wood (steel option)
	REGENT	11 posts, 2 sleeved	\$1,200	All Wood
	BRAKEMASTER	Concrete Slab	\$2,500	All Steel
Trinity Industries	SRT 350	6/8 posts, 2 sleeved ¹	\$900	Wood (steel option)
	ET 2000	8 posts, up to 8 sleeved ¹	\$1,200	Wood (steel option)
	CAT	6 posts, 6 sleeved	\$2,500	All Wood
Universal Industrial Sales, Utah	BEST	6 posts, 2 sleeved	N/A	All Wood
	FLEAT	7 posts, 2 sleeved	\$805	Wood (steel option)
	SKT	8 posts, 2/4/8 sleeves	\$1,015	Wood (steel option)
	REGENT	11 posts, 2 sleeved	\$800	All Wood
	BRAKEMASTER	Cemented Anchors	\$2,600-\$2,800	Wood and Steel
Gregory Highway Products, Ohio	SKT	8 posts, 2/4/8 sleeves	\$1,000-\$1,400	Wood (steel option)
	FLEAT	7 posts, 2 sleeved	\$900-\$1,000	Wood (steel option)
R.G. Steel Corp., Pennsylvania	FLEAT 350	7 posts, 2 sleeved	\$1,000-\$1,100	Wood (steel option)
	REGENT	11 posts, 2 sleeved	\$700-\$800	All Wood
	SKT 350	8 posts, 2/4/8 sleeves	\$1,300-\$1,400	Wood (steel option)
Road Systems	FLEAT	7 posts, 2 sleeved	\$1,000-\$1,100	Wood (steel option)
	SKT	8 posts, 2/4/8 sleeves	\$1,300-\$1,400	Wood (steel option)
Highway Safety Corp., Ohio	FLEAT 350	7 posts, 2 sleeved	\$1,000-\$1,100	Wood (steel option)
	SKT 350	8 posts, 2/4/8 sleeves	\$1,300-\$1,400	Wood (steel option)

1- Trinity Industry products can only use wooden posts in their sleeves; however, steel hinged posts are available instead

The vendors all identify the complexity of their products, especially in reference to installation and repair; these values range from four to seven on a seven point scale with seven being most complex. Most of the vendors also rate the ease of installation for their products on a seven point scale with values once again varying between four and seven. In all cases, the vendors have no reference with which to evaluate the resistance of their products to snow removal activities. Above ground repair seems possible with all of the terminals as long as the installation utilizes soil tubes. Similarly, all vendors state that steel posts are necessary for any wintertime removal or replacement. The wood posts on some end-terminals tend to break apart when driven into frozen ground. One vendor provides an example of this wintertime repair. The North Dakota DOT uses guardrail terminals with steel posts and soil tubes, and they can successfully execute winter repairs and replacements. While North Dakota winters may not be as severe as Alaskan winters, this provides valuable insight into possible strategies for the Alaska DOT&PF.

Table 2.1. Vendor Survey Results (cont'd)

Manufacturer	Terminal Name	Ease of Installation (1-7)	Complexity (1-7)	Hinged Posts
Bryson Products, Mississippi	FLEAT	N/A	7	No
	SKT	N/A	6	No
	REGENT	N/A	5	No
	BRAKEMASTER	N/A	4	No
Trinity Industries	SRT 350	5	5	Yes, 2 posts
	ET 2000	7	7	Yes, 8 posts
	CAT	4	4	No
Universal Industrial Sales, Utah	BEST	6	6	No
	FLEAT	7	7	No
	SKT	7	7	No
	REGENT	5	5	No
	BRAKEMASTER	4	4	No
Gregory Highway Products, Ohio	SKT	N/A	7	No
	FLEAT	N/A	7	No
R.G. Steel Corp., Pennsylvania	FLEAT 350	7	7	No
	REGENT	5	4	No
	SKT 350	5	7	No
Road Systems	FLEAT	6	6	No
	SKT	6	6	No
Highway Safety Corp., Ohio	FLEAT 350	6	6	No
	SKT 350	6	6	No

2.3 Northern Tier State DOT Survey Results

Although the researchers attempt to contact numerous northern tier states during this study, only eight state DOTs elect to participate. While these sample sizes appear to be small (even smaller with respect to individual terminal types), they actually represent a significant percentage of the population of northern tier states, where at most twenty states can be classified as northern tier states. In this context, the study has received responses from forty percent of the population with response rates for individual terminal types possibly being higher or lower than this value because the actual population of terminal usage remains unknown.

Table 2.2 provides summary data from the northern tier state DOT survey while the complete survey results can be found in Appendix A. Generally speaking, the external agencies do not identify an average cost for terminal repairs, but they all identify terminal

replacements as the same cost as new terminals. This study examines repair or replacement time for each terminal type, but it finds little difference within each DOT between different terminals with the exception of the BEST terminal, which requires on average forty percent more time to complete its repairs and replacements. The examination of training time requirements for maintenance crews fails to reveal many differences between terminal types with the exception of the BRAKEMASTER terminal, which requires forty percent more training time. This survey discovers that most agencies fail to observe much difference between terminal types when considering the human component of terminal maintenance; however, this trend may not hold true if actual maintenance crews provide the survey input.

Table 2.2. Northern Tier State DOT Survey Results

Terminal Type	Sample Size	Overall Rating (1-7)	Overall Maintainability (1-7)	Terminal Compatibility (1-7)
WYBET	3	6.67	3.67	6.00
SRT	7	6.14	3.43	6.57
FLEAT	8	6.13	3.63	6.38
CAT	5	5.60	3.00	7.00
BEST	5	5.20	4.00	5.60
REGENT	3	5.67	3.33	6.00
SKT	1	6.00	4.00	5.00
BRAKEMASTER	1	6.00	3.00	2.00
ET-2000	0	NR	NR	NR

NR – No responses

Table 2.2. Northern Tier State DOT Survey Results (cont'd)

Terminal Type	Product Quality & Performance (1-7)	Customer Service (1-7)	Resistance to Snow Load (1-7)	Prob. of Above Ground Repair (0-100%)
WYBET	5.67	6.00	5.00	60.00
SRT	6.00	5.57	5.00	61.43
FLEAT	5.25	5.25	5.25	62.50
CAT	5.60	5.40	5.60	64.00
BEST	5.40	5.60	4.60	64.00
REGENT	5.67	5.67	5.33	63.33
SKT	6.00	6.00	6.00	60.00
BRAKEMASTER	5.00	5.00	6.00	70.00
ET-2000	NR	NR	NR	NR

NR – No responses

The sample sizes for each terminal type vary widely with all eight states using the FLEAT terminal and only one using the SKT and BRAKEMASTER terminals. With the exception of the probability of above ground repair, the study rates all of the following criteria on a seven-point scale with seven being the best. The overall ratings for the

terminals range between 4.5 for the CRT and 6.67 for the WYBET terminals. The overall maintainability of the terminals seems relatively uniform with values ranging between three and four. Terminal compatibility shows a diverse range of values between two for the BRAKEMASTER and seven for the CAT terminals. The remainder of the criteria seems relatively uniform across terminal types with the typical values ranging between five and six. The probability of above ground repair varies between sixty and seventy percent. Fifty percent of the agencies indicate that winter replacement of the terminals is possible for all terminal types as long as the posts are sleeved. Three of eight surveyed DOTs use a guardrail delineator, New Century Northwest distributes one for \$8.95/each, for marking their guardrails while another fifty percent use a standard flexible marker. In both cases, these simply identify the agency’s standard practices, and not any specific special marking strategies. In the opinion of the DOTs, there seem to be little difference between the different terminal types over many of the criteria. These findings appear discouraging because the guardrail end-terminal vendors and state DOTs possess limited knowledge of the winter replacement of GETs.

2.4 Decision-Maker Interview Results

This study gathers decision-maker information from a single decision-maker within Alaska DOT&PF. The purpose of this interview is to identify the screening criteria and any appropriate thresholds for these criteria being. Additionally, the decision-maker provides his opinions regarding the values and weights attributable to each criterion. Prior to the conducting the interview the researchers develop a hierarchy of the criteria. This hierarchy is verified with the decision-maker at the time of the interview. The hierarchy is presented in figures 2.1, 2.2 and 2.3. All of these figures display the local weights identified by the decision-maker during the interview.

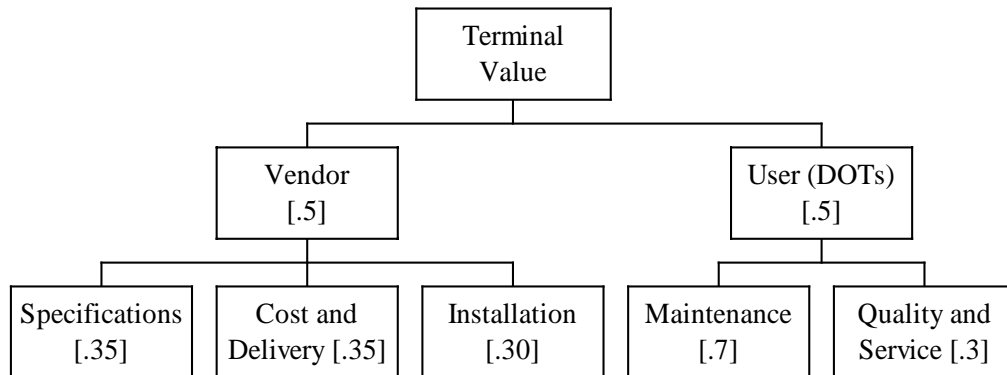


Figure 2.1. Terminal Value Hierarchy with Decision-Maker Weights

The hierarchy has two main branches; one addresses the vendor matrix while the other addresses the DOT matrix. Although this study examines many vendor criteria, only five vendor criteria impact the decision-making process quantitatively. Since delivery time does not seem to fluctuate significantly across vendors, the hierarchy currently excludes

it. While the decision-maker shows little preference across the upper level of this branch, he exhibits distinct opinions at the lowest level. Some vendor criteria also serve to eliminate infeasible alternatives. The first and most critical screening criterion is the NCHRP Report 350 Test Level; however, all of the alternatives that this study identifies meet NCHRP Report 350 Test Level 3. Additionally, the decision-maker establishes a minimum threshold of two posts within a terminal being sleeved to facilitate winter replacement. The two BRAKEMASTER products fail to meet this standard. The decision-maker fails to identify any more threshold criteria at this time.

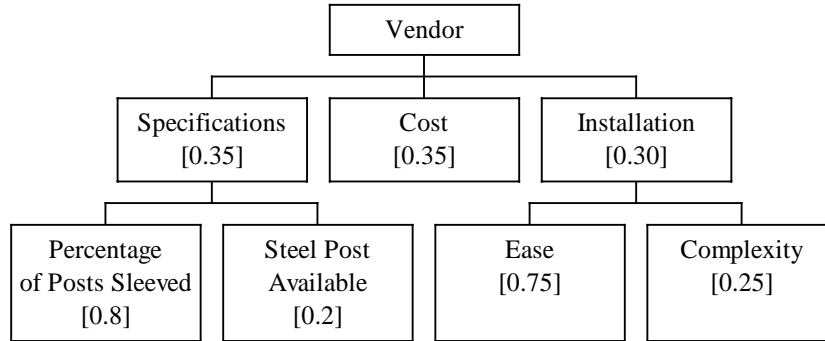


Figure 2.2. Vendor Branch with Decision-Maker Weights

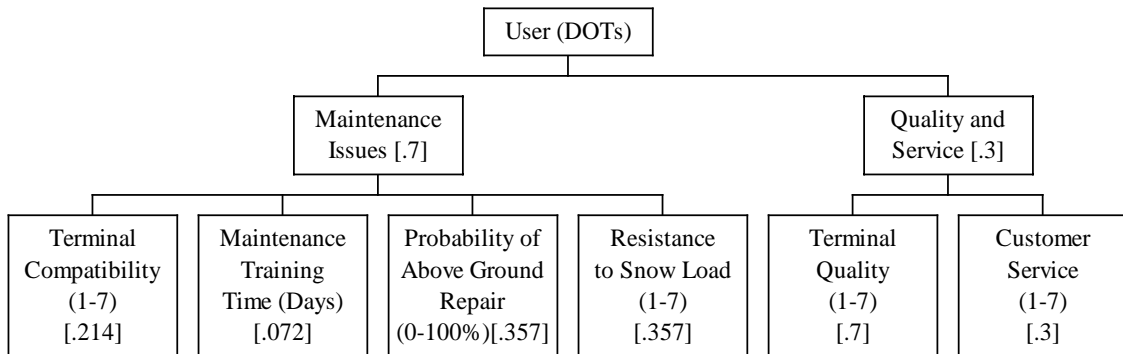


Figure 2.3. User (DOT) Branch with Decision-Maker Weights

The other branch, the DOT branch, retains six criteria for inclusion in the decision analysis process. Currently, the time to replace a terminal is not included in the final assessment because the collected values did not seem to vary across terminal types; instead they vary across agencies with each agency declaring similar repair times for all terminals. For the user branch, the decision-maker gives two criteria each twenty-five percent of the overall value for DOT input. Appendix B lists all of the criteria that this study considered for inclusion in the hierarchy and provides the general curve shape for each criterion. Additionally, Appendix B displays the value functions that result from the interview process.

2.5 Decision Analysis

This report explores three different decision analysis techniques in order to rank the alternative GETs. The first two techniques combined rankings and scaled criteria do not require any decision-maker input. The third MAVF requires decision-maker input to arrive at the rank order of the alternative GETs. In all of the analyses, all Bryson and Gregory Highway Products use an assumed value (.5) for ease of installation because the vendor did not provide a value for these cells. For cold region implementation, the two highest-ranking tangential terminals both lack user feedback. For this analysis, the user value for the ET-2000 is given by an average of all user values because no external agencies using it responded to this study, and the SKT has only a single user response. The absence of user information makes selecting a single alternative for the tangential case challenging and perhaps counter-productive. Nevertheless, based on vendor scores a recommendation can be made. None of the flared terminals provide the option of sleeving all posts for easing winter replacement. If one of the flared terminals can meet this requirement in the future it will greatly enhance their desirability. The following sections describe the evaluation techniques and make a recommendation for the preferred tangential and flared terminal according to each technique.

2.5.1 Combined Rankings

In this technique (Papacostas and Prevedouros, 2001), the alternatives are ranked according to each criterion from worst to first. The combination of the rankings from each criterion provides a composite score for the alternatives that can be rank ordered. Its formulation is given by the following equation:

$$S_i = \sum_j R_{ij} \quad (1)$$

where

S_i = score of alternative i

R_{ij} = rank of alternative i with respect to criterion j

Table 2.3 displays the overall values that are determined by the combined rankings for this decision. The values are sorted from the highest to lowest values where a lower composite score is better. The SKT and the CAT both receive the highest user rankings. The SKT that Universal Industrial Sales in Pleasant Grove, Utah, distributes receives the highest vendor value as well; however, the vendor values for many of the other SKT distributors do not fare as well and their ranking as a result is lower. The ET-2000 presents a strong case as a viable alternative for the tangential case with the second best vendor score and overall ranking. The FLEAT terminal dominates the flared rankings with all six distributors ranking above its chief competition, the SRT-350.

Table 2.3. Combined Ranking Guardrail End Terminal Values

Vendor	Terminal Type	Vendor Value	User (DOT) Value	Overall Value
Universal Industrial Sales, Utah	SKT	10.00	10.00 ³	20.00
Trinity Industries	ET 2000	14.00	12.37 ²	26.37
Universal Industrial Sales, Utah	FLEAT	16.00	11.88	27.88
R.G. Steel Corp., Pennsylvania	FLEAT 350	20.00	11.88	31.88
R.G. Steel Corp., Pennsylvania	SKT 350	27.00	10.00 ³	37.00
Road Systems	SKT	30.00	10.00 ³	40.00
Highway Safety Corp., Ohio	SKT 350	30.00	10.00 ³	40.00
Gregory Highway Products, Ohio	SKT	32.00 ¹	10.00 ³	42.00
Gregory Highway Products, Ohio	FLEAT	32.00 ¹	11.88	43.88
Road Systems	FLEAT	32.00	11.88	43.88
Highway Safety Corp., Ohio	FLEAT 350	32.00	11.88	43.88
Bryson Products, Mississippi	SKT	36.00 ¹	10.00 ³	46.00
Bryson Products, Mississippi	FLEAT	37.00 ¹	11.88	48.88
Trinity Industries	SRT 350	39.00	12.00	51.00
Universal Industrial Sales, Utah	REGENT	59.00	12.00	71.00
R.G. Steel Corp., Pennsylvania	REGENT	62.00	12.00	74.00
Universal Industrial Sales, Utah	BEST	64.00	15.00	79.00
Trinity Industries	CAT	70.00	10.00	80.00
Bryson Products, Mississippi	REGENT	73.00 ¹	12.00	85.00
Bryson Products, Mississippi	BRAKEMASTER	72.00 ¹	14.00	86.00
Universal Industrial Sales, Utah	BRAKEMASTER	74.00	14.00	88.00

- 1 – All Bryson and Gregory Highway Products use an assumed value (.5) for ease of installation
- 2 – No State DOTs responded; the user value is found as an average of all user values
- 3 – Only one state DOT responded for the user value

2.5.2 *Scaled Criteria*

In this technique (Papacostas and Prevedouros, 2001), every individual criterion is mapped onto a common scale between zero and one. In this case, the value “zero” represents the lowest value that any alternative takes or a theoretical minimum value, and the value “one” represents the highest value that any alternative takes or a theoretical maximum value. The rescaled criterion can be summed to find the composite score for each alternative. After mapping each criterion to the common scale, the alternatives composite score is given by the following formulation:

$$S_i = \sum_j M_{ij} \quad (2)$$

where

S_i = score of alternative i

M_{ij} = the mapped value of alternative i with respect to criterion j

Table 2.4 displays the overall values that are determined by the scaled criteria for this decision. The values are sorted from the highest to lowest values where a higher composite score is better. The CAT followed by the SRT-350 receive the highest user rankings while the SKT that Universal Industrial Sales in Pleasant Grove, Utah, distributes receives the highest vendor value. The ET-2000 presents a strong case as a viable alternative for the tangential case with the second best vendor score and second highest overall value, which remains well ahead the other SKT distributors. Although the SRT-350 has a better user ranking, its chief competition, the FLEAT, dominates the overall flared rankings with five of the six distributors ranking it above the SRT-350.

Table 2.4. Scaled Criteria Guardrail End Terminal Values

Vendor	Terminal Type	Vendor Value	User (DOT) Value	Overall Value
Universal Industrial Sales, Utah	SKT	4.893	5.167 ³	10.059
Trinity Industries	ET 2000	4.800	5.164 ²	9.964
Universal Industrial Sales, Utah	FLEAT	4.283	5.171	9.454
R.G. Steel Corp., Pennsylvania	FLEAT 350	4.136	5.171	9.307
R.G. Steel Corp., Pennsylvania	SKT 350	4.033	5.167 ³	9.200
Road Systems	SKT	4.033	5.167 ³	9.200
Highway Safety Corp., Ohio	SKT 350	4.033	5.167 ³	9.200
Gregory Highway Products, Ohio	SKT	3.700 ¹	5.167 ³	8.867
Road Systems	FLEAT	3.469	5.171	8.640
Highway Safety Corp., Ohio	FLEAT 350	3.469	5.171	8.640
Bryson Products, Mississippi	SKT	3.467 ¹	5.167 ³	8.633
Gregory Highway Products, Ohio	FLEAT	3.186 ¹	5.171	8.357
Trinity Industries	SRT 350	2.947	5.324	8.270
Bryson Products, Mississippi	FLEAT	3.086 ¹	5.171	8.257
Universal Industrial Sales, Utah	BEST	2.033	4.927	6.960
Universal Industrial Sales, Utah	REGENT	1.848	5.067	6.915
R.G. Steel Corp., Pennsylvania	REGENT	1.515	5.067	6.582
Trinity Industries	CAT	1.150	5.390	6.540
Bryson Products, Mississippi	REGENT	1.315 ¹	5.067	6.382
Bryson Products, Mississippi	BRAKEMASTER	1.150 ¹	4.067	5.217
Universal Industrial Sales, Utah	BRAKEMASTER	1.000	4.067	5.067

1 – All Bryson and Gregory Highway Products use an assumed value (.5) for ease of installation

2 – No State DOTs responded; the user value is found as an average of all user values

3 – Only one state DOT responded for the user value

2.5.3 Multi-Attribute Value Function

MAVF Theory develops a value function that provides the worth for every i attribute, $v_i(x)$. Beinat (1997) presents the axiomatic foundation for value function theory in detail. This reference is used to present many key points in conjunction with Keeney and Raiffa (1993) and French (1986). Dyer and Sarin (1979) use the difference independence property to define their measurable additive value functions. This report offers a short summary of MAVF's application to this decision. This report creates a hierarchical structure to simplify this problem. Mattingly *et al.* (2001) presents a detailed example of the use of a hierarchy in conjunction with MAVF. Based on fundamental principles that the previous references describe, this project creates an additive value function that incorporates all of the criteria within the hierarchy that figures 2.1, 2.2 and 2.3 display. This value additive value function takes the following formulation:

$$V = \sum_{j=1}^J \alpha_j \sum_{i=a_j}^{b_j} w_i v_i(x_i) \quad (3)$$

Where:

- α_j = the weights for each grouping within the hierarchy,
- J = number of groupings or branches,
- a_j and b_j = the node locations (taken from a vector N of all nodes) within a given j th branch,
- w_i = priority weight for each individual attribute i ,
- v_i = the value function for the i th attribute ($i = 1$ to 4 for the maintenance issues branch in Figure 2.3),
- x_i = the level of attribute present in the system, and
- V = the sum of all values for the system.

This research slightly modifies standard practices to simplify the decision-maker's effort in the creation of the necessary weights and value functions; however, these modifications do not affect the underlying theoretical foundations of this technique. In this application, the value functions are assessed using a blend of the mid-value splitting (Keeney and Raiffa, 1993) and curve selection (Beinat, 1997). This study uses a 100-point weight rating technique to assess the weights throughout the hierarchy. All of the value functions that this study uses are displayed in Appendix B while the attribute and hierarchical weights can be found in figures 2.1, 2.2 and 2.3. Table 2.5 displays the overall values that are determined by the additive value function for this decision. Each alternative takes a value between zero and one with one representing the greatest preference. The values are sorted from the highest to lowest values.

Two Trinity Industries products, the CAT and SRT-350, emerge with the highest user values while the third Trinity Industry product, the ET-2000, did not receive any user responses. The SKT that Universal Industrial Sales in Pleasant Grove, Utah, distributes receives the highest vendor value and ranks first overall. The ET-2000 continues to present a strong case as a viable alternative for the tangential case with the second best

vendor score and second highest overall value; however, three other SKT distributors immediately follow it in the overall rankings. In contrast to the previous analysis techniques, the SRT-350 performs reasonably well when compared to the FLEAT; only two of the six FLEAT distributors rank above the SRT-350

Table 2.5. MAVF Guardrail End Terminal Values

Vendor	Terminal Type	Vendor Value	User (DOT) Value	Overall Value
Universal Industrial Sales, Utah	SKT	0.963	0.471 ³	0.717
Trinity Industries	ET 2000	0.930	0.450 ²	0.690
Road Systems	SKT	0.795	0.471 ³	0.633
Highway Safety Corp., Ohio	SKT 350	0.795	0.471 ³	0.633
R.G. Steel Corp., Pennsylvania	SKT 350	0.745	0.471 ³	0.608
Universal Industrial Sales, Utah	FLEAT	0.750	0.436	0.593
Bryson Products, Mississippi	SKT	0.680 ¹	0.471 ³	0.575
Gregory Highway Products, Ohio	SKT	0.670 ¹	0.471 ³	0.570
R.G. Steel Corp., Pennsylvania	FLEAT 350	0.698	0.436	0.567
Trinity Industries	SRT 350	0.542	0.497	0.520
Road Systems	FLEAT	0.598	0.436	0.517
Highway Safety Corp., Ohio	FLEAT 350	0.598	0.436	0.517
Universal Industrial Sales, Utah	REGENT	0.534	0.433	0.483
R.G. Steel Corp., Pennsylvania	REGENT	0.509	0.433	0.471
Gregory Highway Products, Ohio	FLEAT	0.491 ¹	0.436	0.463
Universal Industrial Sales, Utah	BEST	0.515	0.406	0.460
Trinity Industries	CAT	0.403	0.510	0.456
Bryson Products, Mississippi	FLEAT	0.456 ¹	0.436	0.446
Bryson Products, Mississippi	REGENT	0.389 ¹	0.433	0.411
Bryson Products, Mississippi	BRAKEMASTER	0.123 ¹	0.338	0.230
Universal Industrial Sales, Utah	BRAKEMASTER	0.070	0.338	0.204

1 – All Bryson and Gregory Highway Products use an assumed value (.5) for ease of installation

2 – No State DOTs responded; the user value is found as an average of all user values

3 – Only one state DOT responded for the user value

While this decision analysis cannot be considered definitive, it provides valuable insight into the products by combining their disparate attributes into a single overall value. Of particular concern in this evaluation is the similarity in raw attribute scores across alternatives. This similarity makes the selection of a definitive alternative more challenging. An examination of the attributes in Tables 2.1 and 2.2 identifies the shortcomings of each terminal system. For example, the CAT terminal receives solid support from the user community, but its high cost, difficulty in installing and complexity make it difficult to recommend as the only alternative. Chapter 3 investigates these issues and makes some initial recommendations.

CHAPTER 3 - INTERPRETATION, APPRAISAL, AND APPLICATIONS

3.1 Implications of Survey and Analysis

Decision-maker priorities can be included in both the combined rankings and scaled criteria analysis; however, neither analysis is performed in this manner to show the baseline cases without any decision-maker influence. While the SRT-350 performs poorly when compared to the FLEAT in the two techniques that do not include decision-maker weights, it performs markedly better after including decision-maker priorities. The SRT-350's strong performance with respect to user responses make it a significant challenger to the FLEAT, especially because the vendors self-assessed the only attributes where the FLEAT outperformed the SRT-350. If decision-maker priorities seem reasonable to the Alaska DOT&PF, then it should pay particular attention to the analysis reported in section 2.5.3.

This study's limited sample size may degrade the final results; however, within each DOT, the number of respondents that seem qualified to address the larger picture appears small. In this respect, the data set may be adequate; however, the large variation that exists between some agencies reduces the confidence in the final results. If a significantly larger number of qualified respondents can be identified, a larger more in depth survey may yield more reliable results. In a similar manner, the use of a single decision-maker for Alaska DOT&PF in the MAVF analysis may be questioned; however, the selected decision-maker survey in a statewide role for the Alaska DOT&PF and the decision analysis techniques that this report utilizes can be difficult for a group of decision-makers to use together unless they are all present for the value function specification. The weights are easier to integrate in a group decision-making context, but this project did not undertake this effort because a single decision-maker seems to be the most reasonable approach when attempting a new technique within the Alaska DOT&PF.

For many of the attributes, most of the alternatives receive similar scores. This lack of differentiation amongst alternatives implies either a lack of knowledge or similar performance. The use of MAVF becomes more challenging as the ranges in attribute values tighten because the decision-maker must do an extremely good job of recognizing this limited variation and distribute the attribute weights accordingly.

Throughout both surveys, this project measures many attributes over a seven-point scale. The use of the seven-point scale is widely accepted; however, it still carries the inherent difficulty that the scale is not standardized across different respondents. For example, one respondent may believe that the overall maintainability of a given terminal is a five while another respondent from the same agency may believe that its maintainability is only a three. The small sample sizes coupled with these inherent difficulties make the development of specific recommendations difficult.

3.2 General Recommendations

A clearly defined best choice, for either tangential or flared GETs, fails to emerge during this study. The primary options for both tangential and flared terminals have generally similar characteristics where price is the only objective factor to separate the competing products. From the user's perspective, each state has their own preferences for the competing products, but the differences between the alternatives is not significant enough for a clear choice to emerge. Each of the products typically has a variety of options available for use in each specific application. These options must be carefully specified to meet the Alaska DOT&PF's need to repair and replace GETs above ground during the long winter season. Any GET specified for use in Alaska needs to meet criteria one through three, and vendors should make an effort to meet criteria four:

- (1) The terminal design must meet NCHRP Report 350 Test Level 3 standards.

This is a requirement to meet FHWA standards.

- (2) All terminals within the State of Alaska need to have an option of steel or wood posts.

The vendors unanimously advocate the use of steel posts with soil tubes, or hinged steel posts for facilitating winter replacements. The agencies do not seem to require the use of steel posts, just soil tubes; however, the vendors' support for steel posts is difficult to ignore.

- (3) All posts for tangential terminals and the first two posts in flared terminals need to have the option of soil tube, hinge or similar strategy that facilitates above ground repair.

Frozen ground poses a significant obstacle to GET repair. The use of soil tube, hinge or similar strategy eliminates the need to excavate frozen soil during the winter and drive posts into frozen ground. For the flared case, a fewer number of posts appears desirable as well, which reduces the number of posts unprepared for above ground repair.

- (4) Every effort should be made to make a particular terminal design compatible with other terminal designs to reduce stockpiling requirements.

This reduction in GET styles minimizes maintenance training requirements, reduces stockpiling needs, and improves terminal and part compatibility.

The Alaska DOT&PF's compatibility requirement (number 4) cannot be met in the short-term based on current terminal designs; however, an alternative approach may exist to help mitigate these concerns. The FHWA may permit the Alaska DOT&PF to award a five-year sole source contract that is fully competed; this report recommends that Alaska

DOT&PF pursue such an award as long as the selected terminal meet the aforementioned specification requirements. Such an award will not eliminate compatibility concerns, but stockpiling and training needs will be reduced.

The REGENT, CAT and BEST terminals are added to the list infeasible alternatives because they require the use of wooden posts. This seems especially appropriate because their overall value ranked near the bottom of the alternatives. At this time, only the CAT, BEST, BRAKEMASTER and REGENT families are recommended for immediate exclusion. Further investigation is required to determine if an optimal end terminal exists because many end terminals appear to possess the desirable specifications for the State of Alaska.

CHAPTER 4 - SUGGESTED RESEARCH

With the limited differentiation amongst the alternative end terminals across many of the alternatives, a demonstration program may prove the most effective approach for identifying a single terminal for preferred usage statewide or simply a terminal that design and maintenance has confidence that it can usually be repaired during the winter season after it is damaged. The demonstration program can supplement or supercede the data that this study identifies. This new evaluation needs to investigate installation procedures, costs, accident-related data, snow load survivability and maintenance for each selected system over at least two winters. While a more aggressive and detailed survey effort may prove beneficial, the researchers believe that further data collection may be unlikely to provide further insight because detailed knowledge about end terminals seems lacking. Furthermore, knowledge seems lacking specifically about winter performance and above ground repairs. A thorough investigation into above ground repairs may also prove beneficial because this represents one of the most critical attributes under investigation and the results from the user survey show limited differentiation amongst alternatives. In order to obtain a definitive answer, additional research will likely be required; however, a selection of viable end terminal alternatives may already be identifiable based on the existing data.

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APPENDIX A – COMPLETE STUDY RESULTS

Table A.1. Complete Vendor Survey Results

Manufacturer	Terminal Name	Number of Sleeves	Flare Offset	Compatibility with	
				SRT-350	ET-2000
Bryson Products, Mississippi 1-800-482-4559 Representative: Chad	FLEAT	7 posts, 2 sleeved	2'-4'	No	No
	SKT	8 posts, 2/4/8 sleeves	Tangent	No	No
	REGENT	11 posts, 2 sleeved	4' Parallel	No	No
	BRAKEMASTER	Concrete Slab	Tangent, 0'	No	No
Trinity Industries 1-800-772-7976 Representative: Randy Olsen	SRT 350	6/8 posts, 2 sleeved	3'-4'	Yes	No
	ET 2000	8 posts, up to 8 sleeved	Tangential 1'-2'	No	Yes
	CAT	6 posts, 6 sleeved	Tangential	No	No
Universal Industrial Sales, Utah (801) 785-0505 Representative: Delane	BEST	6 posts, 2 sleeved	50:1 Flare rate	No	No
	FLEAT	7 posts, 2 sleeved	2'-4'	No	No
	SKT	8 posts, 2/4/8 sleeves	Tangent	No	No
	REGENT	11 posts, 2 sleeved	4'	No	No
	BRAKEMASTER	Cemented Anchors	Only Median Usage	No	No
Gregory Highway Products, Ohio (330) 477-4800 Representative: Steve	SKT	8 posts, 2/4/8 sleeves	Tangent	No	No
	FLEAT	7 posts, 2 sleeved	2'-4'	No	No
R.G. Steel Corp., Pennsylvania (724) 656-1722 Representative: David Price	FLEAT 350	7 posts, 2 sleeved	2'-6" to 4'	No	No
	REGENT	11 posts, 2 sleeved	4'	No	No
	SKT 350	8 posts, 2/4/8 sleeves	Tangent	No	No
Road Systems (815) 464-5917 Representative: John	FLEAT	7 posts, 2 sleeved	2'-6" to 4'	No	No
	SKT	8 posts, 2/4/8 sleeves	Tangent	No	No
Highway Safety Corp., Ohio (877) 866-7997 Representative: Kevin	FLEAT 350	7 posts, 2 sleeved	2'-6" to 4'	No	No
	SKT 350	8 posts, 2/4/8 sleeves	Tangent	No	No

Table A.1. Complete Vendor Survey Results (cont'd)

Manufacturer	Terminal Name	Actual Cost		Steel Post?	Ease of Installation (1-7)
		Materials	Installed		
Bryson Products, Mississippi	FLEAT	\$1,200	N/A	Wood (steel option)	N/A
	SKT	\$1,200	N/A	Wood (steel option)	N/A
	REGENT	\$1,200	N/A	All Wood	N/A
	BRAKEMASTER	\$2,500	N/A	All Steel	N/A
Trinity Industries	SRT 350	\$900	2 hr	Wood (steel option)	5
	ET 2000	\$1,200	2 hr	Wood (steel option)	7
	CAT	\$2,500	4 hr	All Wood	4
Universal Industrial Sales, Utah	BEST	N/A	N/A	All Wood	6
	FLEAT	\$805	N/A	Wood (steel option)	7
	SKT	\$1,015	N/A	Wood (steel option)	7
	REGENT	\$800	N/A	All Wood	5
	BRAKEMASTER	\$2,600-\$2,800	N/A	Wood and Steel	4
Gregory Highway Products, Ohio	SKT	\$1,000-\$1,400	N/A	Wood (steel option)	N/A
	FLEAT	\$900-\$1,000	N/A	Wood (steel option)	N/A
R.G. Steel Corp., Pennsylvania	FLEAT 350	\$1,000-\$1,100	N/A	Wood (steel option)	7
	REGENT	\$700-\$800	N/A	All Wood	5
	SKT 350	\$1,300-\$1,400	N/A	Wood (steel option)	5
Road Systems	FLEAT	\$1,000-\$1,100	N/A	Wood (steel option)	6
	SKT	\$1,300-\$1,400	N/A	Wood (steel option)	6
Highway Safety Corp., Ohio	FLEAT 350	\$1,000-\$1,100	N/A	Wood (steel option)	6
	SKT 350	\$1,300-\$1,400	N/A	Wood (steel option)	6

Table A.1. Complete Vendor Survey Results (cont'd)

Manufacturer	Terminal Name	Complexity (1-7)	Time to Deliver (days)	Alaska Dealer?	Above Ground Replacement	Hinged Posts
Bryson Products, Mississippi	FLEAT	7	14 Day Maximum	None	yes	No
	SKT				yes	No
	REGENT				yes	No
	BRAKEMASTER				yes	No
4						
Trinity Industries	SRT 350	5	10 - 14 Days	None	yes w/ soil tubes	Yes, 2 posts
	ET 2000				yes w/ soil tubes	Yes, 8 posts
	CAT				yes w/ soil tubes	No
4						
Universal Industrial Sales, Utah	BEST	6	7 Days to Seattle	None	N/A	No
	FLEAT				N/A	No
	SKT				N/A	No
	REGENT				N/A	No
	BRAKEMASTER				N/A	No
4						
Gregory Highway Products, Ohio	SKT	7	7-10 Days	None	yes w/ soil tubes	No
	FLEAT				yes w/ soil tubes	No
7						
R.G. Steel Corp., Pennsylvania	FLEAT 350	7	7-14 Days	None	yes w/ soil tubes	No
	REGENT				yes w/ soil tubes	No
	SKT 350				yes w/ soil tubes	No
7						
Road Systems	FLEAT	6	7-14 Days	None	yes w/ soil tubes	No
	SKT				yes w/ soil tubes	No
6						
Highway Safety Corp., Ohio	FLEAT 350	6	7-14 Days	None	yes w/ soil tubes	No
	SKT 350				yes w/ soil tubes	No
6						

Table A.2. Complete Northern Tier State DOT Survey Results

State DOT	Terminal Used	Overall Rating (1-7)	Overall Maintainability (1-7)	Terminal Compatibility (1-7)	Time to Replace/Repair (Man-hours)
Wyoming DOT (307) 777-4216	WYBET	7	2	7	3 weeks total
	SRT	7	3	7	3 weeks total
	FLEAT	6	3	7	3 weeks total
	CAT	6	3	7	3 weeks total
Montana DOT (460) 444-6158	FLEAT	6	4	6	2-3 weeks
	SRT	6	3	7	2-3 weeks
	CAT	5	3	7	2-3 weeks
	BEST	4	4	5	3-4 weeks
	CRT	3	2	5	3-4 weeks
Utah DOT (801) 965-4242	SRT	6	4	6	3-4 weeks
	FLEAT	6	3	7	3-4 weeks
	CAT	6	3	7	3-4 weeks
	BEST	6	3	6	3-4 weeks
Minnesota DOT (651) 296-3036	SRT	6	4	6	4 weeks
	FLEAT	7	4	7	4 weeks
	WYBET	7	4	6	4 weeks
	CRT	6	4	6	4 weeks
	BEST	6	4	6	4 weeks
	REGENT	5	4	7	4 weeks
Michigan DOT (517) 373-0746	FLEAT	6	3	6	3 weeks total
	SKT	6	4	5	3 weeks total
	REGENT	6	3	5	3 weeks total
	BRAKEMASTER	6	3	2	3 weeks total
OREGON DOT (503) 986-4000	REGENT	6	3	6	3 weeks total
	SRT	6	2	7	3 weeks total
	FLEAT	6	3	6	3 weeks total
	CAT	6	3	7	3 weeks total
Washington DOT (360) 705-9269	FLEAT	6	4	6	2-3 weeks
	SRT	6	3	7	2-3 weeks
	CAT	5	3	7	2-3 weeks
	BEST	4	4	5	3-4 weeks
IDAHO DOT (801) 965-4242	SRT	6	5	6	4 weeks
	FLEAT	6	5	6	4 weeks
	WYBET	6	5	5	4 weeks
	BEST	6	5	6	4 weeks

Table A.2. Complete Northern Tier State DOT Survey Results (cont'd)

State DOT	Terminal Used	Maintenance Training Time (days)	Avg. Maint. Cost (\$/repair)	Product Quality & Performance (1-7)	Customer Service (1-7)
Wyoming	WYBET	Already Capable	New installed (\$)	6	5
	SRT	Already Capable	New installed (\$)	6	5
	FLEAT	Already Capable	New installed (\$)	6	5
	CAT	Already Capable	New installed (\$)	6	5
Montana	FLEAT	5	New Cost	5	4
	SRT	5	New Cost	6	5
	CAT	5	New Cost	5	5
	BEST	5	New Cost	4	6
	CRT	5	New Cost	5	5
Utah	SRT	3-4 days	Replace/ new cost	6	6
	FLEAT	3-4 days	Replace/ new cost	6	5
	CAT	3-4 days	Replace/ new cost	6	6
	BEST	3-4 days	Replace/ new cost	6	5
Minnesota	SRT	n/a	None, Replacement	5	6
	FLEAT	n/a	None, Replacement	5	6
	WYBET	n/a	None, Replacement	6	6
	CRT	n/a	None, Replacement	5	6
	BEST	n/a	None, Replacement	6	6
	REGENT	n/a	None, Replacement	6	6
Michigan	FLEAT	5	New Cost	5	5
	SKT	5	New Cost	6	6
	REGENT	5	New Cost	6	5
	BRAKEMASTER	7	New Cost	5	5
Oregon	REGENT	Already Capable	New installed (\$)	5	6
	SRT	Already Capable	New installed (\$)	6	6
	FLEAT	Already Capable	New installed (\$)	5	6
	CAT	Already Capable	New installed (\$)	6	6
Washington	FLEAT	5	New Cost	5	6
	SRT	5	New Cost	6	5
	CAT	5	New Cost	5	5
	BEST	5	New Cost	4	6
Idaho	SRT	2-5 days	Replace/ new cost	7	6
	FLEAT	2-5 days	Replace/ new cost	5	5
	WYBET	2-5 days	Replace/ new cost	5	7
	BEST	2-5 days	Replace/ new cost	7	5

Table A.2. Complete Northern Tier State DOT Survey Results (cont'd)

State DOT	Terminal Used	Resistance to Snow Load (1-7)	Replace Post During Winter	Winter Replacement	Above ground Repair (0-100%)	Marking Strategy
Wyoming	WYBET	6	Yes	Yes	50	Guard rail Delineator
	SRT	5	No	No	60	
	FLEAT	5	No	No	50	
	CAT	5	No	No	50	
Montana	FLEAT	6	If Sleeved, Yes	If Sleeved, Yes	70	N/A
	SRT	6	If Sleeved, Yes	If Sleeved, Yes	70	
	CAT	6	If Sleeved, Yes	If Sleeved, Yes	80	
	BEST	5	If Sleeved, Yes	If Sleeved, Yes	70	
	CRT	5	If Sleeved, Yes	If Sleeved, Yes	70	
Utah	SRT	5	No	No	70	Standard Flexible Markers
	FLEAT	5	No	No	70	
	CAT	5	No	No	80	
	BEST	5	No	No	60	
Minnesota	SRT	3	Yes	Yes	50	Standard Flexible Markers
	FLEAT	4	Yes	Yes	60	
	WYBET	4	Yes	Yes	60	
	CRT	4	Yes	Yes	60	
	BEST	3	Yes	Yes	70	
	REGENT	4	Yes	Yes	50	
Michigan	FLEAT	6	Yes	Yes	60	Standard Flexible Markers
	SKT	6	Yes	Yes	60	
	REGENT	5	Yes	Yes	70	
	BRAKEMASTER	6	Yes	Yes	70	
Oregon	REGENT	7	Yes	Yes	70	Guard rail Delineator New Century Northwest 541-342-4500
	SRT	7	Yes	Yes	70	
	FLEAT	7	Yes	Yes	60	
	CAT	7	Yes	Yes	60	
Washington	FLEAT	3	No	No	60	Guard rail Delineator
	SRT	4	No	No	40	
	CAT	5	No	No	50	
	BEST	5	No	No	50	
Idaho	SRT	5	No	No	70	Standard Flexible Markers
	FLEAT	6	No	No	70	
	WYBET	5	No	No	70	
	BEST	5	No	No	70	

APPENDIX B – DECISION-MAKER DETAILS

Table B.1. Decision-Maker Input

Criteria	Screening Only	Acceptable Threshold	Curve Shape
Flare	*		
NCHRP Test Level	*		
Steel Post		No	Option
Sleeve/Hinge/Slip Base	*	2 Minimum	
Cost		No	Linear
Delivery Time		No	Linear
Pct. of Posts (Winter Replaceable)		No	Power
Installation ease		No	Linear
Installation complexity		No	Linear
Terminal compatibility		No	Power
Time to replace/repair		No	Inverse Power
Maintenance training time		No	Inverse Power
Terminal quality		No	Linear
Customer service		No	Linear
Resistance to Snow Load		No	Power
Above Ground repair		No	Power

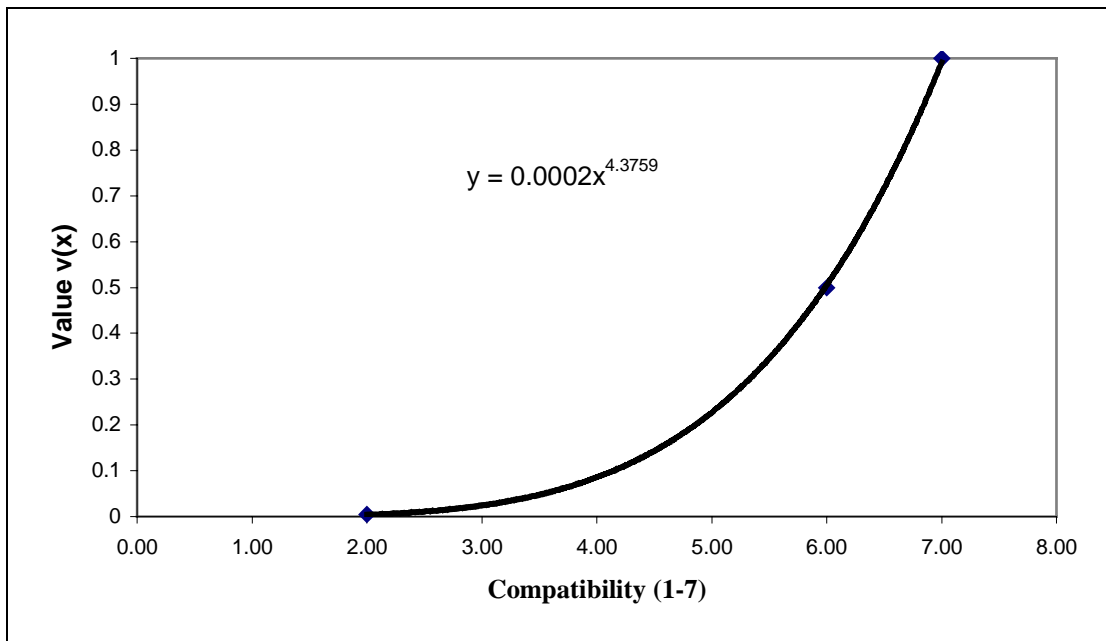


Figure B.1. Terminal compatibility value function

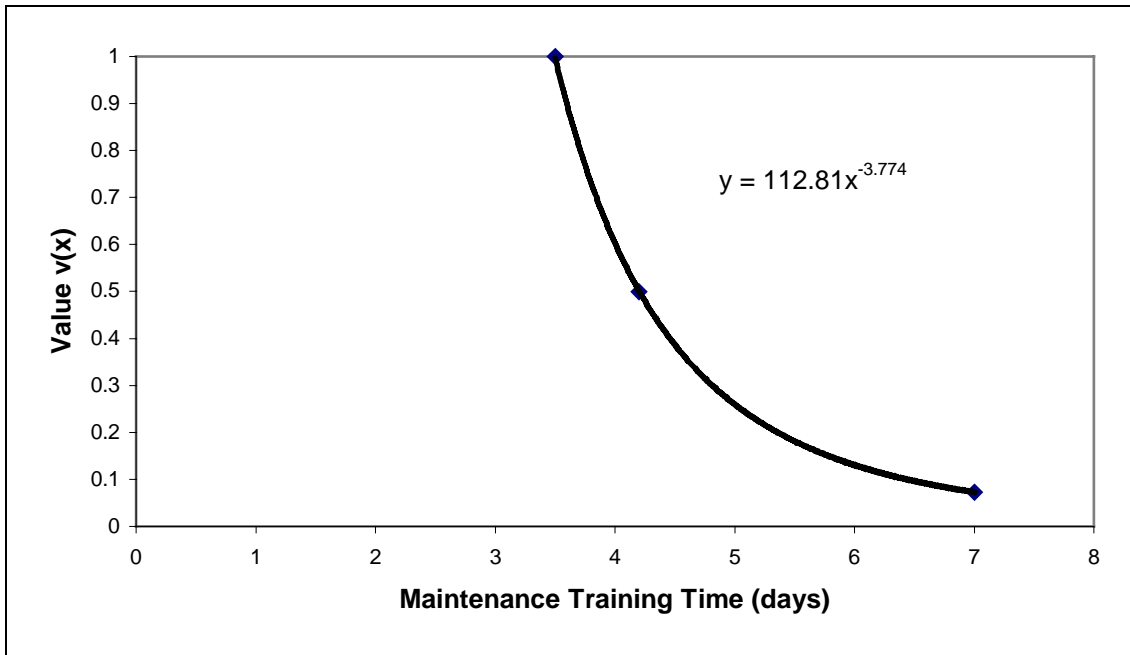


Figure B.2. Maintenance training time value function



Figure B.3. Terminal quality and performance value function

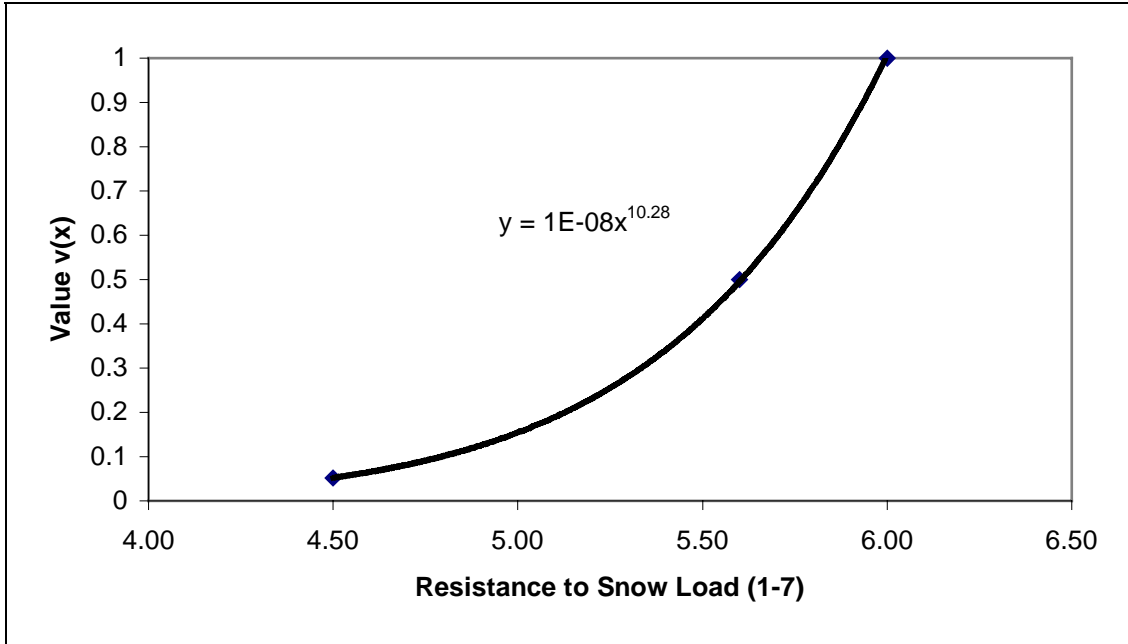


Figure B.4. Terminal resistance to snow load value function

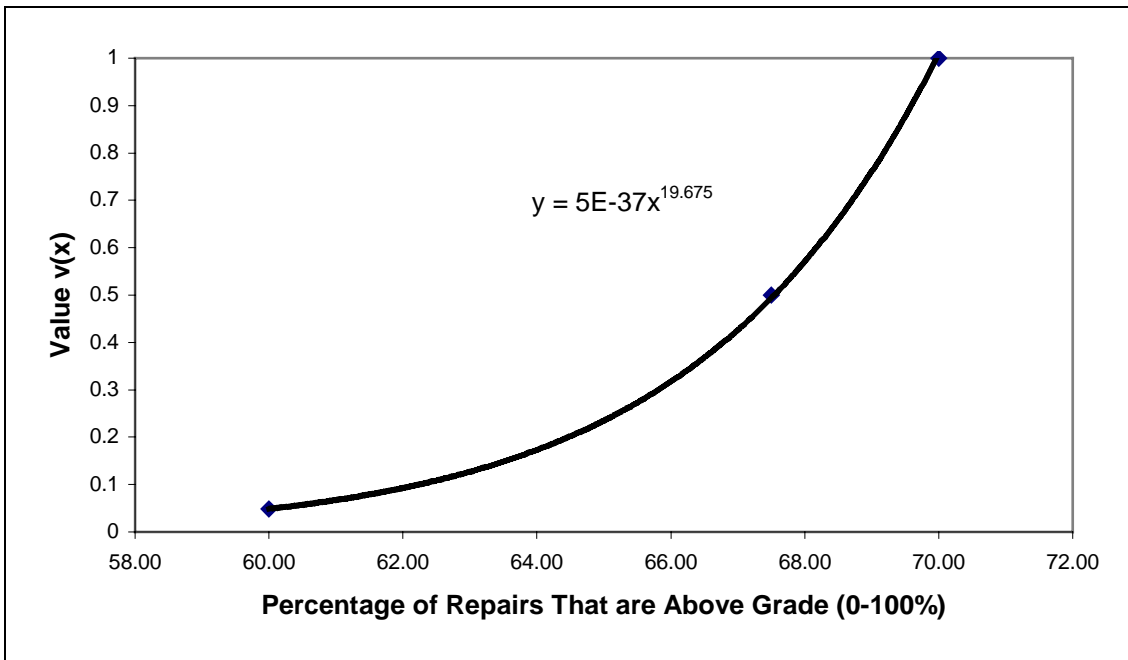


Figure B.5. Percentage of terminal repairs that are above ground repairs value function

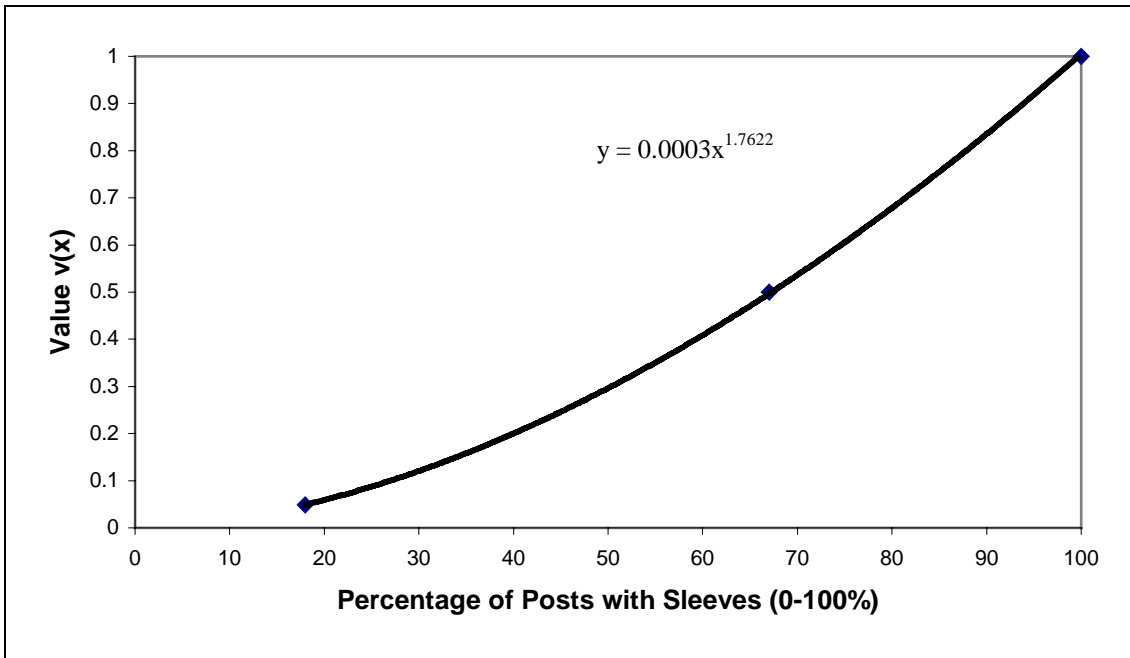


Figure B.6. Percentage of terminal posts with sleeves value function

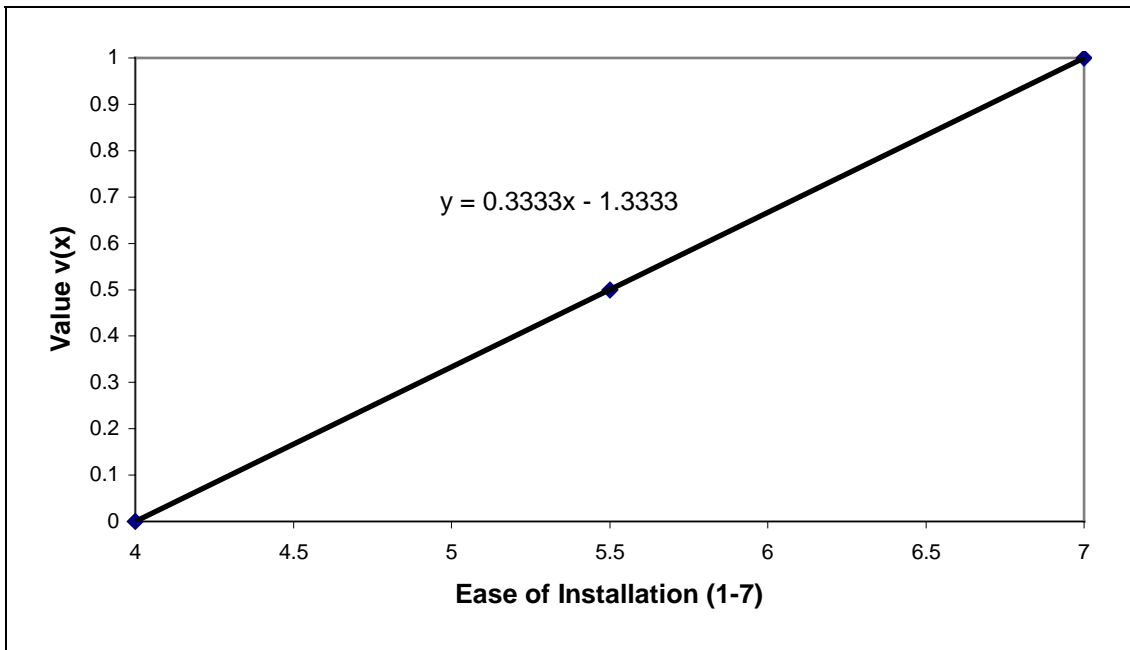


Figure B.7. Ease of terminal installation value function

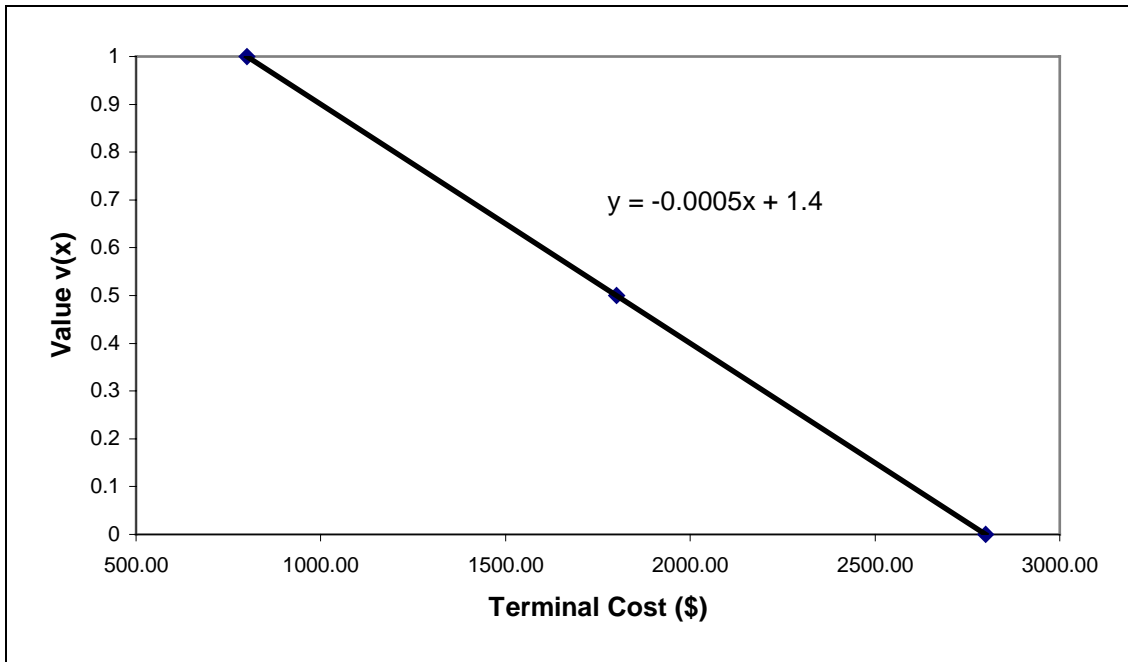


Figure B.8. Terminal cost value function

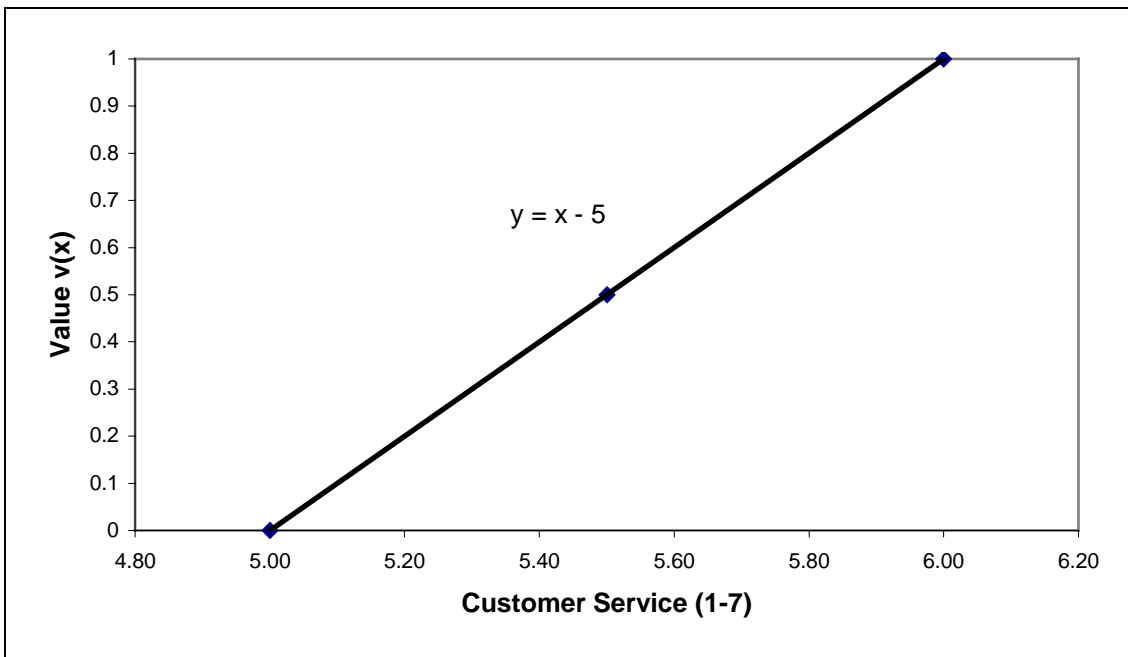


Figure B.9. Customer service value function

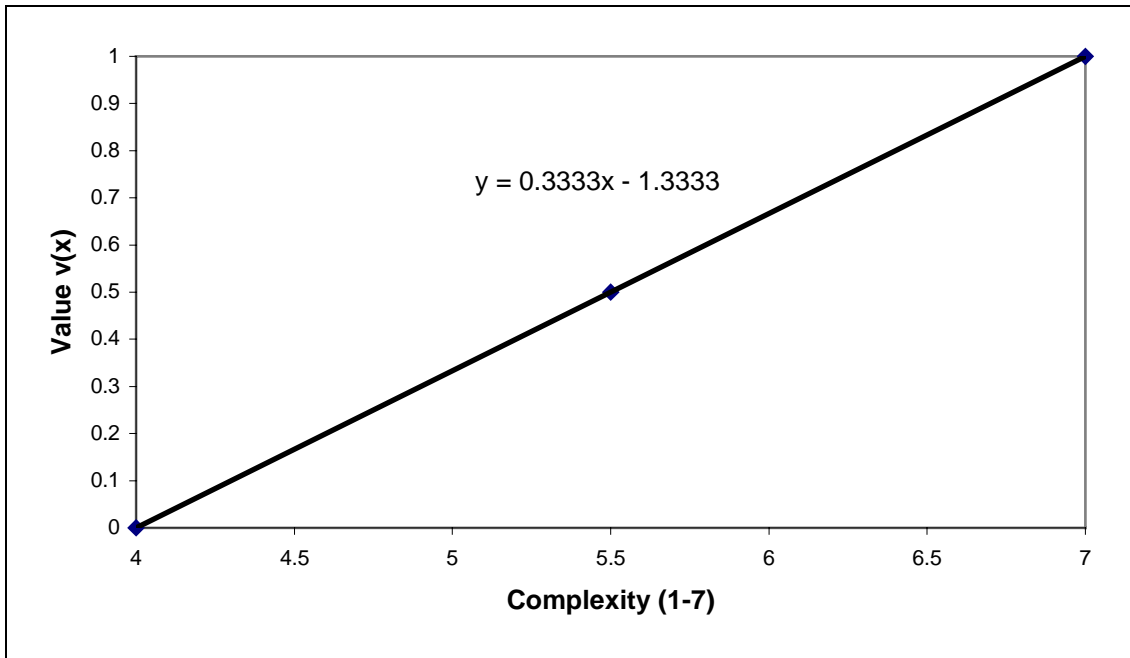


Figure B.10. Terminal complexity value function

APPENDIX C – ET-2000 APPROVAL LETTERS

The FHWA approval letters can be found on their web site at:

http://safety.fhwa.dot.gov/fourthlevel/hardware/term_cush.htm



U.S. Department
of Transportation

**Federal Highway
Administration**

AUG 22 1995

400 Seventh St. S.W.
Washington, D.C. 20590

Refer to: HNG-14

Mr. Don H. Johnson
President
Syro Steel, Inc.
2525 Stemmons Freeway
Dallas, Texas 75207

Dear Mr. Johnson:

Your August 9 letter to Mr. William A. Weseman requested the Federal Highway Administration (FHWA) to concur in your assertion that the ET-2000 guardrail terminal has satisfied the National Cooperative Highway Research Program (NCHRP) Report 350 evaluation criteria for a test level 3 (TL-3) terminal. To support this request, you provided copies of appropriate test reports, drawings, photographs, and videotapes of the full-scale crash tests. The summary results of the NCHRP Report 350 certification tests are enclosed for ready reference. In response to questions raised by my staff, you submitted supplemental information with your letter dated August 14 and identified three specific ET-2000 designs for which you sought FHWA acceptance under the NCHRP Report 350 criteria. This second letter also stated that you were not seeking acceptance of the ET-2000 as modified per Mr. Jerry L. Poston's April 26 letter (copy enclosed) as an NCHRP Report 350 terminal at this time.

Based on our review of the information presented, we have concluded that the ET-2000 designs designated as Option A and Option B (drawings enclosed) satisfy the NCHRP Report 350 evaluation criteria for a TL-3 terminal and that either or both of these designs may continue to be used on the National Highway System (NHS) when selected by a highway agency. These two designs are identical except that posts five through eight are shortened wood posts in steel tubes in Option A, whereas these posts are full-length CRT posts in Option B. Since the ET-2000 is proprietary, all regulations regarding its use on Federal-aid projects (except non-NHS projects) remain applicable.

You will note we have not accepted the modified Option B design (Texas Department of Transportation version) which uses weakened round wood posts in lieu of CRT posts at post positions five through eight. Based on our review of Test 9429A-2 (NCHRP Report 230 test number 40) which was conducted with a 2,000-kg passenger car, we have concerns that this particular design would not pass the NCHRP Report 350 test 3-35. These concerns are based on the facts that the rear wheel of the passenger car in test 9429A-2 contacted and rode up on a post, creating some instability, the round wood posts are approximately half as strong as the CRT posts and deflect considerably more on impact, increasing the likelihood of pocketing and the 2000-kg pickup truck has proven

relatively unstable in several recent length-of-need and strength tests. If you chose to conduct test 3-35, or have additional information to offer, we will be please to review our current position.

We also noted that in test 3-39 (reverse direction hit), the extruder head was detached from the w-beam and slid 64 m from its original location and 3.5 m nearer the traffic lane. While such a trajectory might pose a hazard to other vehicles, we agree with your analysis that such an event is unlikely. Nonetheless, user agencies should be made aware of this occurrence so that each can make an objective assessment of the appropriateness of the ET-2000 at a specific location.

A copy of this letter and enclosures will be sent to the FHWA field offices for information.

Sincerely yours,



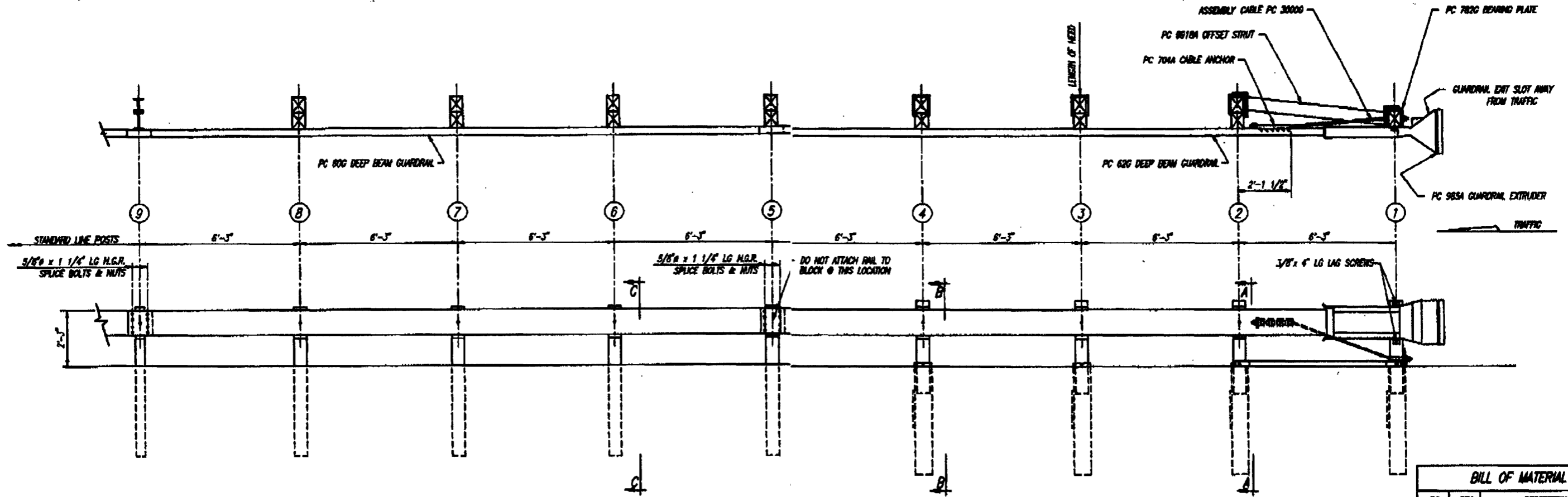
for Jerry L. Poston, Chief
Federal-Aid and Design Division

3 Enclosures

Supplement to Geometric and Roadside Design Acceptance Letter CC-12

SUMMARY OF ET-2000 COMPLIANCE TESTS FOR TEST LEVEL 3 OF NCHRP REPORT 350

NCHRP 350 Test No.	Description	TTI Test No.	Test Report and Test Article Description	Max OIV (m/sec)	Max RA (G's)	Results Meet All Report 350 Requirements?
3-30	820C head-on on nose w/15° offset, 0° approach	6001-1	See Ref 1 and drawing SS 215	9.3	17.3	Yes
3-31	2000P head-on on nose, 0° approach	220510- 5	See Ref 2 and drawing SS 241T	8.1	13.0	Yes
3-32	820C head-on on nose, 15° approach	220510- 3	See Ref 2 and drawing SS 241T	9.0	7.4	Yes
3-33	2000P head-on on nose, 15° approach	220510- 4	See Ref 2 and drawing SS 241T	5.5	4.0	Yes
3-34	820C between nose and beginning of LON, 15° approach (at post #2)	9429A-1	See Ref 3 and drawing SS 230	5.2	10.3	Yes
3-35	2000P at beginning of LON, 20° approach (at post #3)	220510- 2	See Ref 2 and drawing SS 241T	7.6	8.2	Yes
3-39	2000P reverse hit midway along length of terminal, 20° approach (at post #5)	220537- 6	See Ref 2 and drawing SS 241T	6.0	10.5	Yes

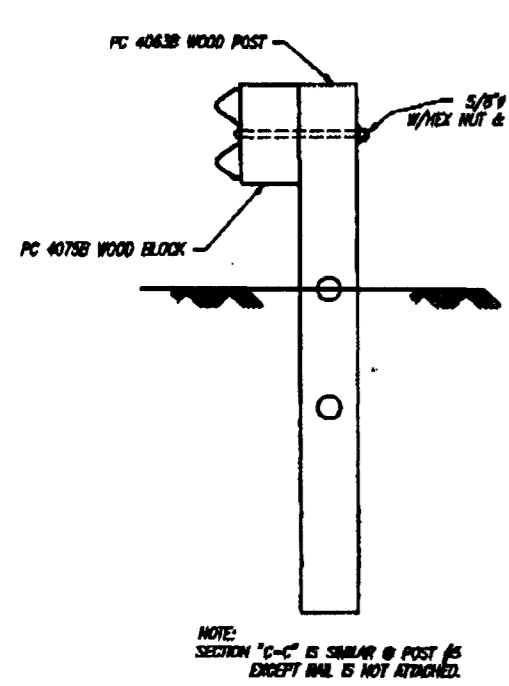


BILL OF MATERIAL

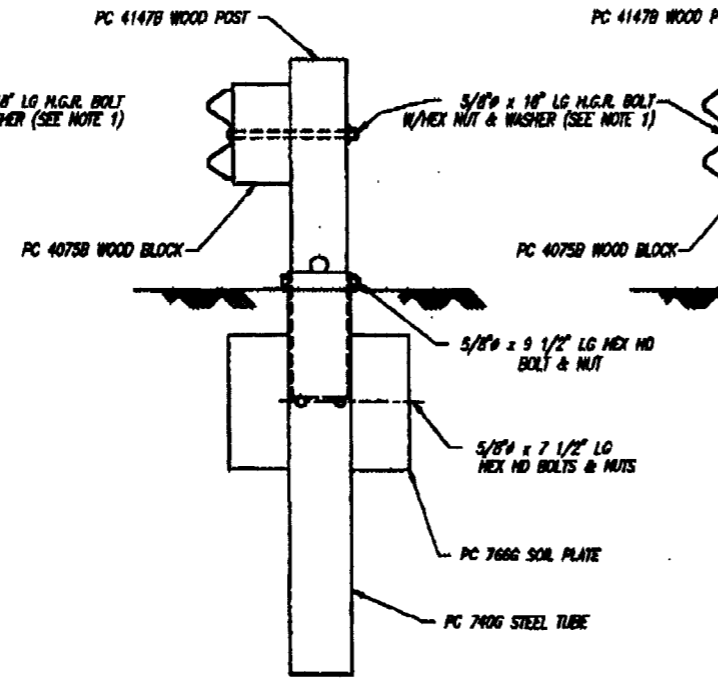
PC	QTY	DESCRIPTION
806	7	12/25/63/S (GUARDRAIL)
826	1	12/25/63/S ANG (GUARDRAIL)
704A	1	CABLE ANCHOR BRACKET
702G	1	2" x 3 1/2" PIPE
740G	4	4" TUBE SLEEVE
788G	4	1/2" x 18" x 24" SOL PLATE
782G	1	8/8" x 8" x 8" BEARING PLATE
905A	1	ET-2000 EXTRUDER
3000G	1	CABLE 3/4" x 6'8"
3300G	11	3/8" WASHER
3340G	35	5/8" HEX NUT
3300G	16	5/8" x 1 1/4" SPLICE BOLT
3478G	4	5/8" x 7 1/2" HEX HD BOLT
3407G	4	5/8" x 9 1/2" HEX HD BOLT
3500G	7	5/8" x 18" POST BOLT
3800G	2	1" WASHER
3810G	2	1" HEX NUT
4063B	4	NO 60 POST 8 x 8
4075B	7	NO BLOCK 12" 6" x 6" BR
4147B	4	NO 39 POST 5 1/2" x 7 1/2"
4220G	2	3/8" x 6" LAG SCREW
8018A	1	6J STRUT

- NOTES:**
- 1.) THE 5/8" FLAT WASHER IS USED UNDER THE NUT, BEHIND THE POST ONLY. NO WASHER IS USED AT THE RAIL.
 - 2.) THE BREAKAWAY POSTS @ LOCATIONS #5, 6, 7 & 8 MAY BE AS SHOWN OR MAY UTILIZE POSTS AS SHOWN IN OPTION "A" WITH FOUNDATION TUBES. (SEE DRAWING NO SS 240). POSTS @ LOCATIONS #1, 2, 3 & 4 MUST USE FOUNDATION TUBES.
 - 3.) THE ET-2000 WAS TESTED ON FLAT & LEVEL TERRAIN. IT IS NOT RECOMMENDED ON SLOPES.
 - 4.) MANUFACTURER SUGGESTS CUSTOMER TO PROVIDE REFLECTION/DEFLECTION OF TERMINAL.

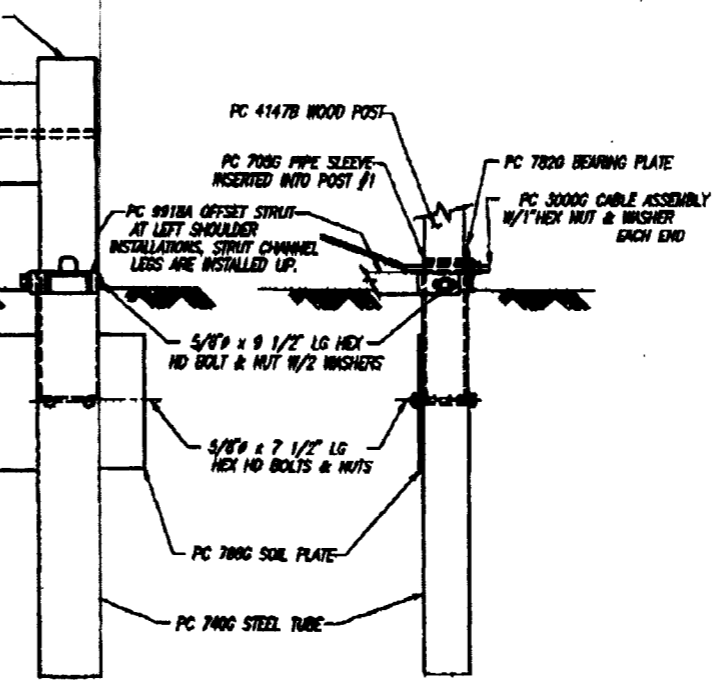
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SECTION "C-C"
(TYP @ POSTS #6, 7 & 8)



SECTION "B-B"
(TYP @ POSTS #3 & 4)



SECTION "A-A"
(@ POST #1) **PARTIAL VIEW @ POST #1**

2	BT	5-3-88	CHE PC 4148 TO 4075
1	TP	6-8-85	CHE PC 3204 TO 4228, UPDATED BILL OF MATL
REV	CHG	BY	DATE

ET-2000

**ET-2000
PLAN, ELEVATION & SECTIONS
OPTION "B"**

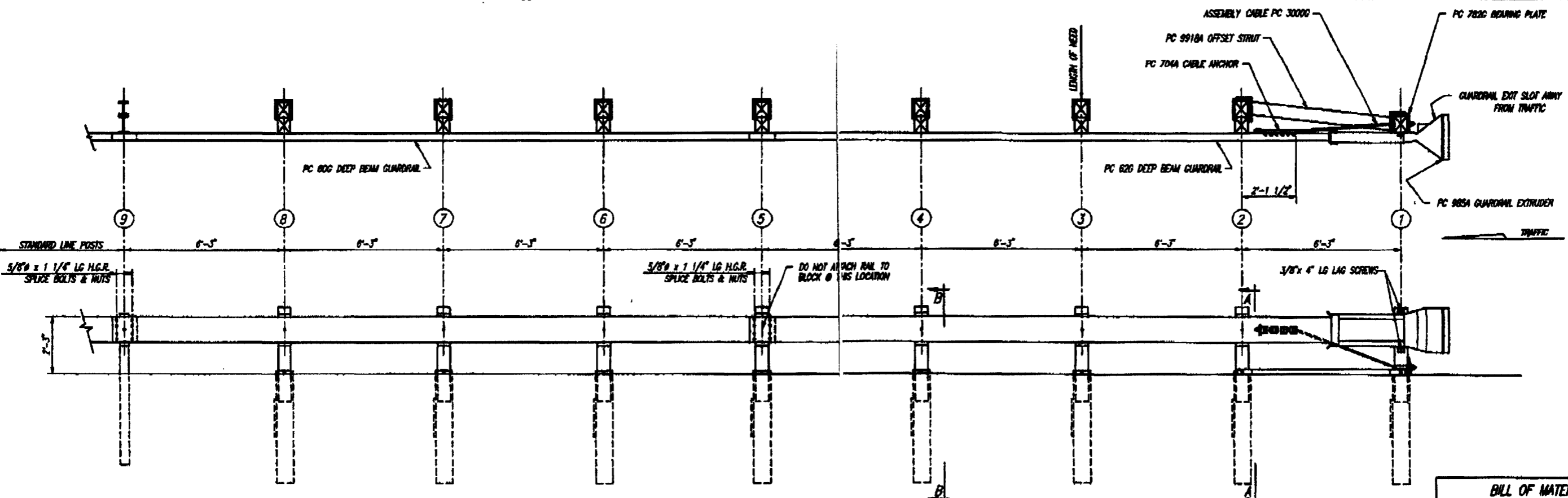
1984 EDITION

CUSTOMER: _____ P.O. No. _____

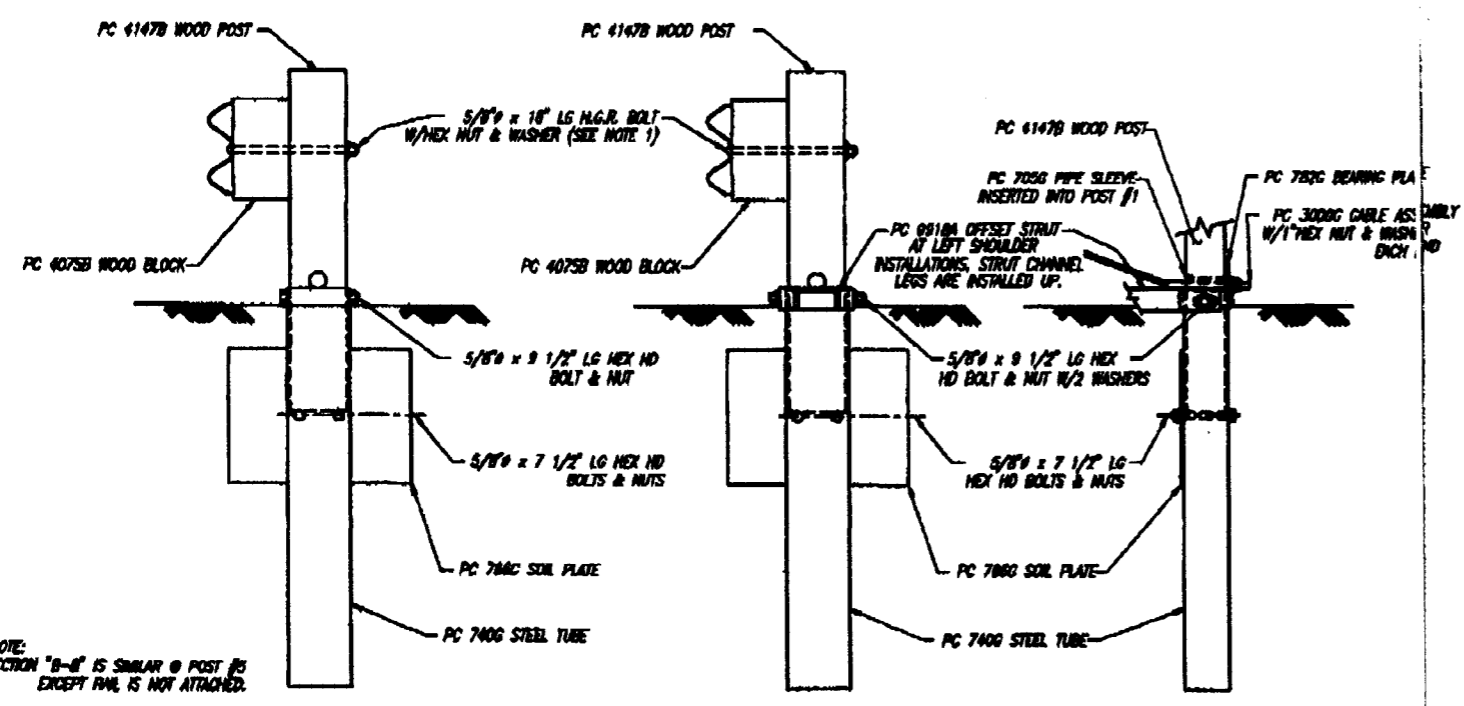
DATE: 4-12-88
SHEET NO.: SS241
TOTAL SHEETS: 67 OF

SS 241





BILL OF MATERIAL		
PC	QTY	DESCRIPTION
600	1	12/25/63/5 (GUARDRAIL)
620	1	12/25/63/5 A&C (GUARDRAIL)
704A	1	CABLE ANCHOR BRACKET
7082	1	2" x 3 1/2" PIPE
7406	8	4" TUBE SLEEVE
782C	8	1/4" x 18" x 24" SOIL PLATE
782C	1	5/8" x 8" x 8" BEARING PLATE
985A	1	ET-2000 EXTRUDER
3000G	1	CABLE 3/4" x 6'6"
3300G	11	5/8" WASHER
3340G	47	5/8" HEX NUT
3380G	18	5/8" x 1 1/2" SPLICE BOLT
3478G	18	5/8" x 7 1/2" HEX HD BOLT
3497G	8	5/8" x 9 1/2" HEX HD BOLT
3500G	7	5/8" x 18" POST BOLT
3800G	2	1" WASHER
3812G	2	1" HEX NUT
4075B	7	NO BLOCK 12" x 6" x 8" OR
4147B	8	NO 3" POST 5 1/2" x 7 1/2"
4220G	2	3/8" x 4" LAG SCREW
9910A	1	6" STRUT



- NOTES:
- 1.) THE 5/8" FLAT WASHER IS USED UNDER THE NUT, BEHIND THE POST ONLY. NO WASHER IS USED AT THE RAIL.
 - 2.) THE BRACKETRY POSTS @ LOCATIONS #6, 7 & 8 MAY BE AS SHOWN OR MAY UTILIZE POSTS AS SHOWN IN OPTION "B" WITHOUT FOUNDATION TUBES. (SEE LEARNING NO SS 241.) POSTS @ LOCATIONS #1, 2, 3 & 4 MUST USE FOUNDATION TUBES.
 - 3.) THE ET-2000 WAS TESTED ON FLAT & LEVEL TERRAIN. IT IS NOT RECOMMENDED ON SLOPES.
 - 4.) MANUFACTURER SUGGESTS CUSTOMER TO PROVIDE REFLECTORIZATION OF TERMINAL.

2	DT	5-3-89	CHG PC 4148 TO 4075
1	TP	6-6-89	CHG PC 3204 TO 4220, UPDATED BILL OF MATL
REV.	CHG	BY	DATE
ET-2000			
ET-2000 PLAN, ELEVATION & SECTIONS OPTION "A"			
DESIGNED	PA. NO.	DATE	4-12-84
DRAWN	BY	DATE	4-12-84
CHECKED	BY	DATE	4-12-84
APPROVED	BY	DATE	4-12-84
TRINITY INDUSTRIES, INC. BELLAR, NY BRIDGE, NY FORT MONROE, VA GUNTERVILLE, NY HARTFORD, CT WASHINGTON, DC			SHEET NO. SS 240 OF 1

NOTE: SECTION "B-B" IS SIMILAR @ POST #5 EXCEPT RAIL IS NOT ATTACHED.

SECTION "B-B"
(TP @ POSTS #5, 6, 7 & 8)

SECTION "A-A"
(@ POST #1)

PARTIAL VIEW @ POST #1

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December 20, 1996

Refer to: HNG-14

Hayes E. Ross, Jr., P.E., Ph.D.
Professor, Civil Engineer Department
Head, Structural Systems Division, TTI
The Texas A&M University System
Texas Transportation Institute
College Station, Texas 77843-3135

Dear Dr. Ross:

Your November 22 letter to Mr. Gerald L. Eller requested the Federal Highway Administration's acceptance of three changes to the ET-2000 guardrail terminal. These are:

1. Use of 1980-mm (6'- 6") soil tubes without soil plates for posts 1 and 2.
2. Use of standard CRT posts for posts 3 through 7. This results in replacing the shortened, tube-supported posts 3 and 4 with full length CRT posts and in replacing the original CRT post 8 with a standard line post.
3. Elimination of the offset block at post 2, permitting the use of an in-line strut at ground level.

A review of our files indicated that these same modifications were requested for the NCHRP Report 230 ET-2000 in an April 19, 1995, letter from Mr. David R. Lewis to Mr. Jerry L. Poston and were accepted via our return correspondence dated April 25, 1995. However, the ET-2000 design you submitted and we recognized, with Mr. Jerry L. Poston's August 22, 1995, letter to Mr. Don H. Johnson of Syro, Inc., as an acceptable Report 350 design was unchanged from the original Report 230 ET-2000 design. In your letter you cite a Report 350 test on a terminal very similar to the ET-2000 that incorporates approximately the same features we had accepted as modifications to the Report 230 design and for which you are now requesting acceptance as meeting Report 350 guidelines. We concur that the results of that test support acceptance of the modified ET-2000 as meeting the acceptance guidelines in NCHRP Report 350.

Enclosed is a drawing showing the modified ET-2000, which is named the LET. Thus, the LET is acceptable for use on the National Highway System if proposed by a highway agency. Since it is a proprietary feature, the provisions of Title 23, Code of Federal Regulations, Section 635.411, are applicable.

Please send us a complete set of the final drawings for our files.

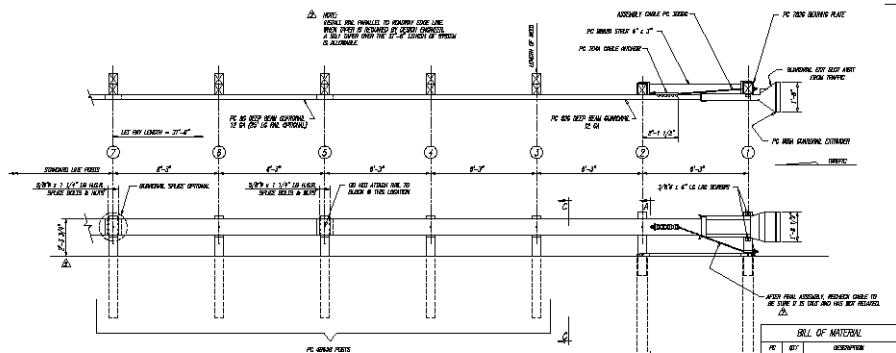
Sincerely yours,

(original signed by Dwight A. Horne)

Dwight A. Horne, Chief
Federal-Aid and Design Division

Enclosure

Acceptance letter CC-12D

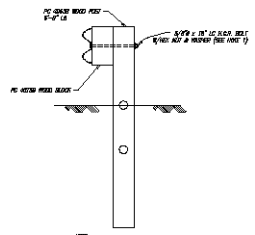


BILL OF MATERIAL

PC	QTY	DESCRIPTION
PC	1	12/12 W 8"x5" (SUBSTRATE)
PC	1	12/12 W 8"x5" (SUBSTRATE)
2000	1	CABLE TRAYING DISTRICT
2000	1	2" x 5 1/2" PIPE
2000	2	#12 TRAY SLUITS
2000	1	5/8" x 8" x 1/2" BEARING PLATE
2000	1	12" COVER DISTRICT
2000	1	COVER 1/2" x 8"
2000	10	5/8" POSTS
2000	50	5/8" HEX NUT
2000	10	5/8" x 7 1/2" SPLIT BEZEL
2000	2	5/8" x 7 1/2" POST (NO BODY)
2000	1	5/8" x 10" POST BEZEL
2000	5	5/8" x 10" POST BEZEL
2000	2	1" WIPPER
2000	2	1" HEX NUT
4000	6	NO. 10 POST 8" x 8"
4000	2	NO. 10 POST 12" x 8" x 8"
4000	2	NO. 10 POST 8" x 12" x 1/2"
4000	2	NO. 10 POST 8" x 12" x 1/2"
4000	1	5/8" x 4" LAG SCREW
4000	1	SPLIT & NUT

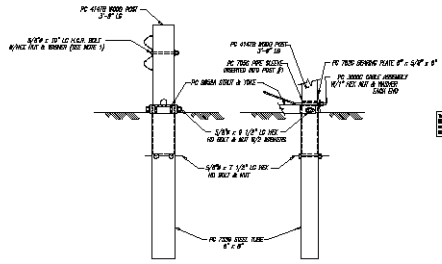
- NOTE:
- THE 6" x 6" PLATE WASHER IS LOOSER UNDER THE NUT, BEHIND THE POST ONLY. NO WASHER IS USED AT THE END.
 - APPROXIMATELY SUGGEST DISTRICTS TO PROVIDE REINFORCEMENT OF TRAYING.

All drawings and the information shown therein is the sole property of TRINITY INDUSTRIES, INC. and is to be used for the project and location specified. It is to be used for no other purpose other than that for which it was specifically intended by TRINITY INDUSTRIES, INC. and is not to be reproduced, altered, or used without written permission.



NOTE: SECTION "C-C" IS SHOWN @ POST AS SHOWN AND IS NOT ATTACHED.

SECTION "C-C"
(TOP @ POSTS 4, 5, 6 & 7)



SECTION "7-1"
(@ POST #1)

PARTIAL VIEW OF POST #1

#	BY	DATE	REVISION
1	BY	DATE	REVISION
REV	BY	DATE	REVISION
ET2000-LET			
ET2000 - LET PLAN, ELEVATION & SECTIONS			
DESIGNER	SCALE	DATE	DATE
DRAWN	SCALE	DATE	DATE
CHECKED	SCALE	DATE	DATE
APPROVED	SCALE	DATE	DATE
TRINITY INDUSTRIES, INC.		SHEET NO. 260	
1000 W. MAIN ST. CENTRALIA, UT		1000 W. MAIN ST. CENTRALIA, UT	

September 22, 1998

Refer to: HNG-14

Dr. Hayes E. Ross, Jr.
Professor and Research Engineer
Texas Transportation Institute
Structural Research Division
The Texas A&M University System
College Station, Texas 77843-3135

Dear Dr. Ross:

In your September 3 letter to Mr. Henry H. Rentz, you requested the Federal Highway Administration to approve the use of two 3810-mm long w-beam panels as an alternative to the single 7625 mm panel that was originally tested and accepted for use with the ET-2000 guardrail terminal. The use of two shorter panels would result in the bolted splice at post 3 being forced through the extruder head in an end-on impact with the 2000-kg pickup truck (test 3-31), but not with the 820-kg car (test 3-30) which was stopped at that point in the original certification test.

To support this request, you ran test 3-31 into an ET-2000 installation which used the shorter rail lengths. Test results were given in your report entitled "Testing and Evaluation of the ET-2000 with 3.8 m W-Beam Sections," by Hayes E. Ross, Jr., Wanda L. Menges, and Barbara G. Baker, Project/Report No. 520201-1, August 1998. The results of this test and the earlier test with the single 7625 mm panel were essentially the same, with 7600 mm of rail being extruded in both instances and with all NCHRP Report 350 evaluation criteria being met in both cases.

Based on these results, we agree that the ET-2000 can be used with either length rail element.

Sincerely yours,

(original signed by Dwight A. Horne)

Dwight A. Horne
Chief, Federal-Aid and Design Division

Acceptance letter CC12E



U.S. Department
of Transportation
**Federal Highway
Administration**

January 18, 2000

400 Seventh St., S.W.
Washington, D.C. 20590

Refer to: HMHS-CC12G

Dr. Hayes E. Ross, Jr.
Professor and Research Engineer
Texas Transportation Institute
The Texas A&M University System
College Station, Texas 77843-3135

Dear Dr. Ross:

In your December 17, 1999 letter, you requested the Federal Highway Administration's acceptance of a modified extruder head for use with any all of the previously-accepted terminal designs which used the ET-2000 extruder head. The new head, called the "ET-PLUS", differs from the original head in the size and shape of its face plate and in the omission or reduction in size of several of its non-structural components. The ET-PLUS is almost 100 pounds lighter than the original ET-2000 head. A comparison of the two designs is shown on Enclosure 1.

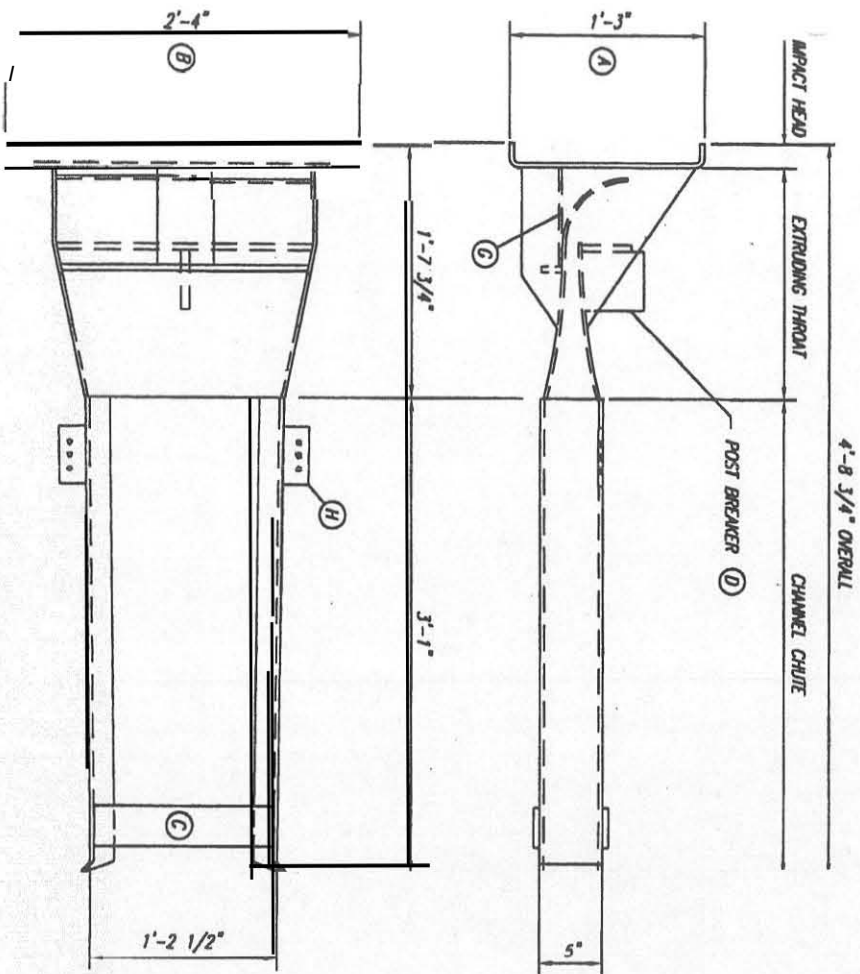
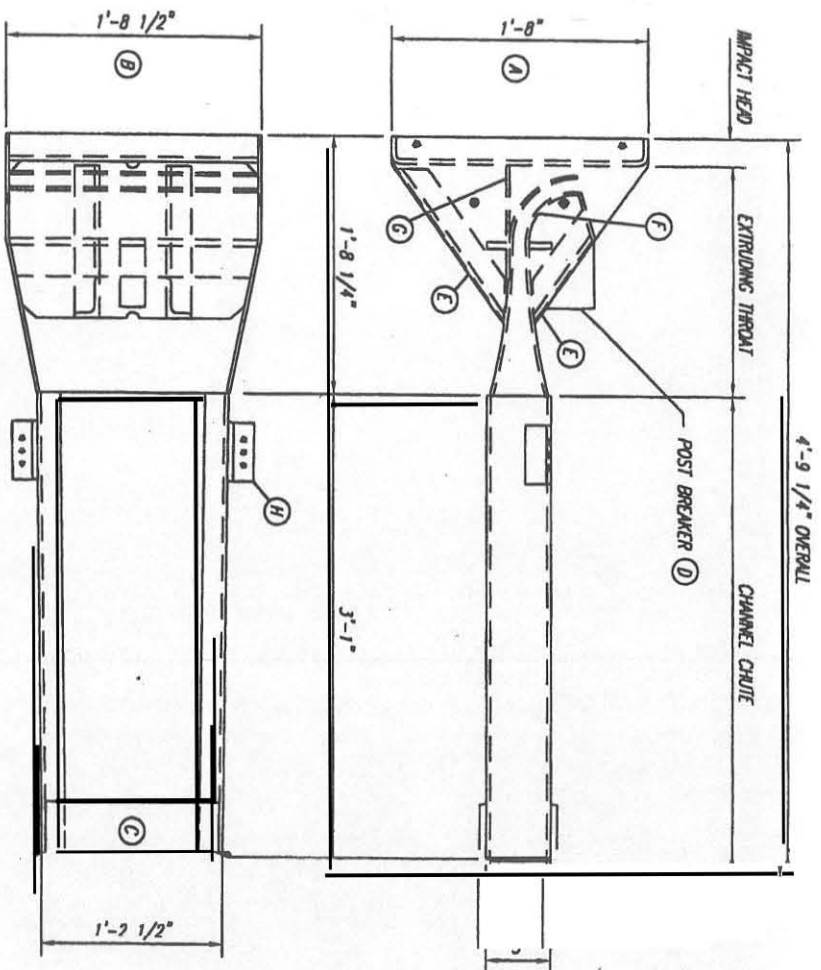
In support of your request, you sent me copies of a Texas Transportation Institute test report, dated December 1999, entitled "NCHRP REPORT 350 TEST 3-31 OF THE ET-2000 PLUS", by Menges, Buth, Ross, and Schoeneman, and copies of a videotape of that test. You stated that this end-on test with a 2000-kg pickup truck was the most critical to demonstrate acceptable performance of the modified extruder head, and that additional impacts at the end were not needed. You also stated that since no other changes were made in the terminal anchor design, none of the side impacts in the Report 350 test matrix were necessary. We agree with your conclusions.

Based on staff review of the results of test 3-31, as summarized in Enclosure 2, we agree that the ET-PLUS can be used in lieu of the original ET-2000 extruder head on any of the ET-2000 systems previously accepted for use on the National Highway System.

Sincerely yours,

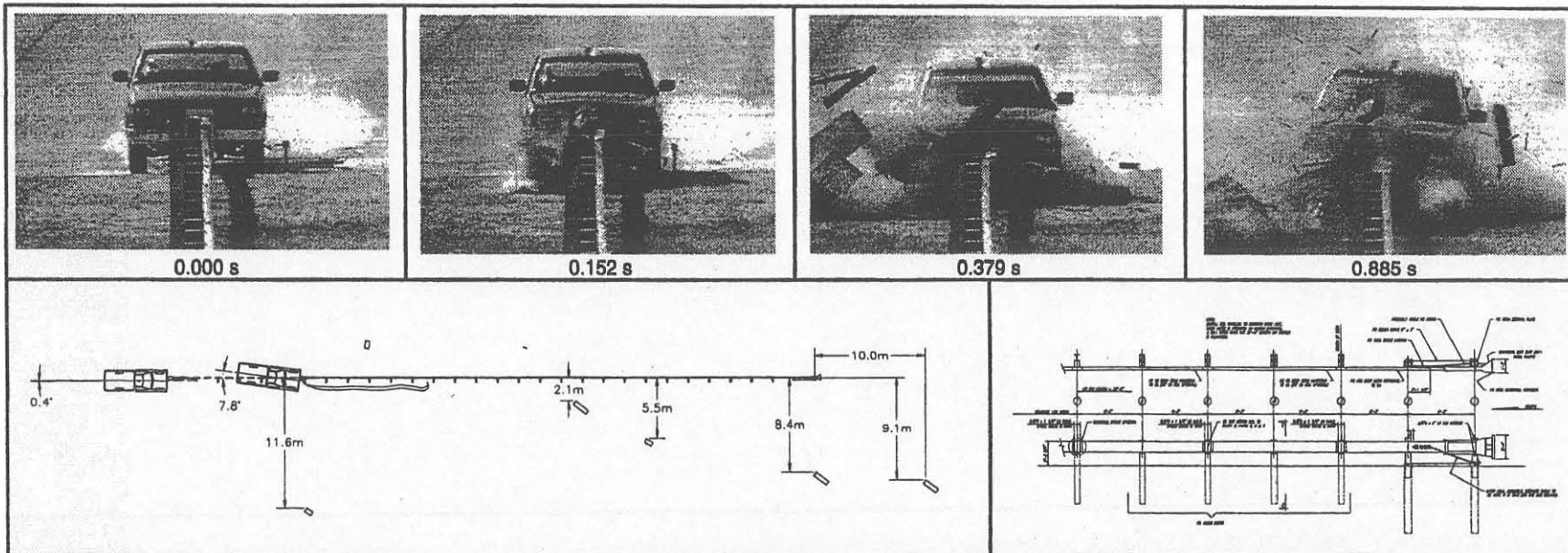
Dwight A. Home
Director, Office of Highway Safety Infrastructure

2 Enclosures



MATERIAL DIFFERENCE

	ET-2000	ET-PLUS
(A)	1'-8	1'-3
(B)	1'-8 1/2	2'-4
(C)	1/2 x 3	1/2 x 1 1/2
(D)	2	5/8
(E)		OMITTED
(F)		SHORTENED
(G)	9 x 1/4 x 20	6 x 1/4 x 8
(H)	12 x 2 x 4 1/2	PL 2 x 4 1/2
WT	268#	175#



General Information

Test Agency Texas Transportation Institute
 Test No. 400001-LET1
 Date 10/05/99

Test Article

Type Terminal
 Name ET-2000 PLUS
 Installation Length (m) 57.2
 Material or Key Elements ... ET-2000 PLUS Guardrail Extruder
 Terminal on Wood CRT Posts

Soil Type and Condition

Standard Soil, Dry

Test Vehicle

Type Production
 Designation 2000P
 Model 1994 Chevrolet 2500 Pickup Truck
 Mass (kg)
 Curb 1896
 Test Inertial 2000
 Dummy No Dummy
 Gross Static 2000

Impact Conditions

Speed (km/h) 100.3
 Angle (deg) 0.4

Exit Conditions

Speed (km/h) Stopped
 Angle (deg) N/A

Occupant Risk Values

Impact Velocity (m/s)
 x-direction 6.2
 y-direction 0.1
 THIV (km/h) 22.3
 Ridedown Accelerations (g's)
 x-direction -6.9
 y-direction 2.8
 PHD (g's) 7.3
 ASI 0.52
 Max. 0.050-s Average (g's)
 x-direction -6.1
 y-direction 1.0
 z-direction 3.4

Test Article Deflections (m)

Dynamic N/A
 Permanent 11.6

Vehicle Damage

Exterior
 VDS 12FC5
 CDC 12FCEW1
 Maximum Exterior
 Vehicle Crush (mm) 460
 Interior
 OCDI FS0000000
 Max. Occ. Compart.
 Deformation (mm) 0

Post-impact Behavior

(during 1.0 s after impact)
 Max. Yaw Angle (deg) 5
 Max. Pitch Angle (deg) -8
 Max. Roll Angle (deg) -6

Figure 14. Summary of results for test 400001-LET1, NCHRP Report 350 test 3-31.



U.S. Department
of Transportation
Federal **Highway**
Administration

400 Seventh St., S.W.
Washington, D.C. 20590

February 18, 2000

Refer to: HMHS-CC12H

Mr. Don Johnson
Trinity Industries, Inc.
2525 Stemmons Freeway
Dallas, Texas 75207

Dear Mr. Johnson:

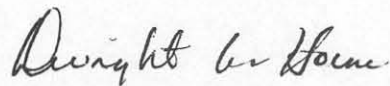
In your February 15 letter to Mr. Richard Powers of my staff, you requested a formal Federal Highway Administration (FHWA) acceptance of a modified ET-2000 Plus guardrail terminal at NCHRP Report 350 test level 2 (TL-2). The original ET-2000 Plus design was accepted as a test level 3 (TL-3) w-beam terminal in my January 18 letter to Dr. Hayes E. Ross, Jr.

As stated in your request, the difference between the proposed TL-2 design and the current TL-3 design is the total number of breakaway posts used in the terminal. Whereas the TL-3 terminal had a total of six breakaway posts, the TL-2 design has only four, the last two breakaway posts in the original design being replaced with standard line posts. The post spacing for all posts remains the same for both designs at 1905 mm (6' 3"). When the ET-2000 Plus was impacted head-on at 100 km/h with the 2000-kg pickup truck, 11.6 m (38 feet) of rail was extruded. The modified design will allow approximately 7.6 m (25 feet) of rail to extrude in advance of the first standard line post (wood or steel). Since the kinetic energy of a vehicle impacting at 70 km/h is less than half of the TL-3 impact speed of 100 km/h and the expected amount of system stroke is proportional to impact severity, less than 6 m (20 feet) of rail can be expected to be forced through the extruder head in a 70 km/h impact. Therefore, a vehicle will be stopped before reaching the first non-breakaway post. In the 820-kg vehicle head-on test of the original ET-2000 at 100 km/h, approximately 4 m (13 feet) of rail was extruded. Thus, for a small car impacting head-on with at a 38-mm (1.5 inch) lateral offset, the TL-2 design would be expected to satisfy even the TL-3 evaluation criteria. Since there are no changes in your anchorage design, and the angle tests required on the nose would be unaffected by the reduced number of breakaway posts, we agree that no additional tests are needed to verify acceptable TL-2 performance.

Based on the above, we consider the modified ET-2000 Plus as described herein to be acceptable for use on the National Highway System as a TL-2 terminal when such use is requested by a transportation agency. This acceptance includes the use of any of the current breakaway post options, i.e., breakaway wood posts in 1.8 m (6 foot) tube sleeves without soil

plates or in 1.37 m (4.5 foot) tube sleeves with soil plates, or steel hinged breakaway posts; (HBA posts). Users should be advised that, as with all TL-2 terminals, the TL-2 ET-2000 Plus should be used only at locations where impact speeds are expected to be at or below the TL-2 speed of 70km/h (approximately 45 mph).

Sincerely yours,

A handwritten signature in cursive script that reads "Dwight A. Horne".

Dwight A. Horne
Director, Office of Highway Safety Infrastructure



U.S. Department
of Transportation
**Federal Highway
Administration**

400 Seventh St., S.W.
Washington, D.C. 20590

Refer to: HSA-CC12I

April 10, 2000

Mr. Rodney Boyd
Trinity Industries, Inc.
2525 Stemmons Freeway
Dallas, TX 75207

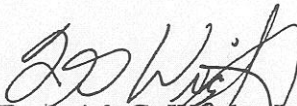
Dear Mr. Boyd:

Mr. James R. Albritten of Exodyne Technologies, Inc., in his capacity as a consultant to Trinity Industries, Inc., sent me two separate letters, both dated March 16, requesting that my response be sent directly to you. One of these letters requested acceptance of the 3" x 3" x 1/4" (76mm x 76mm x 6.4mm) steel ground strut that was used in the certification testing for the Hinged Breakaway (HBA) post ET-2000 as an alternative to the original channel strut for use with any of the previously accepted ET-2000 combinations of wood breakaway posts and tube sleeves. The second letter requested confirmation that the Federal Highway Administration considered the HBA posts to be a direct substitute for the weakened wood posts in any of the previously accepted versions of the ET-2000.

The angle strut described above performed satisfactorily in the strength test you ran using your HBA posts and it has a greater moment of inertia than the steel channel strut currently in use. Therefore, when this galvanized steel angle is attached to the first two wood post/soil tube assemblies with 3/4" (19mm) high strength bolts as described in your letter and shown on Enclosure 1, it may be considered an alternative to the original channel strut design.

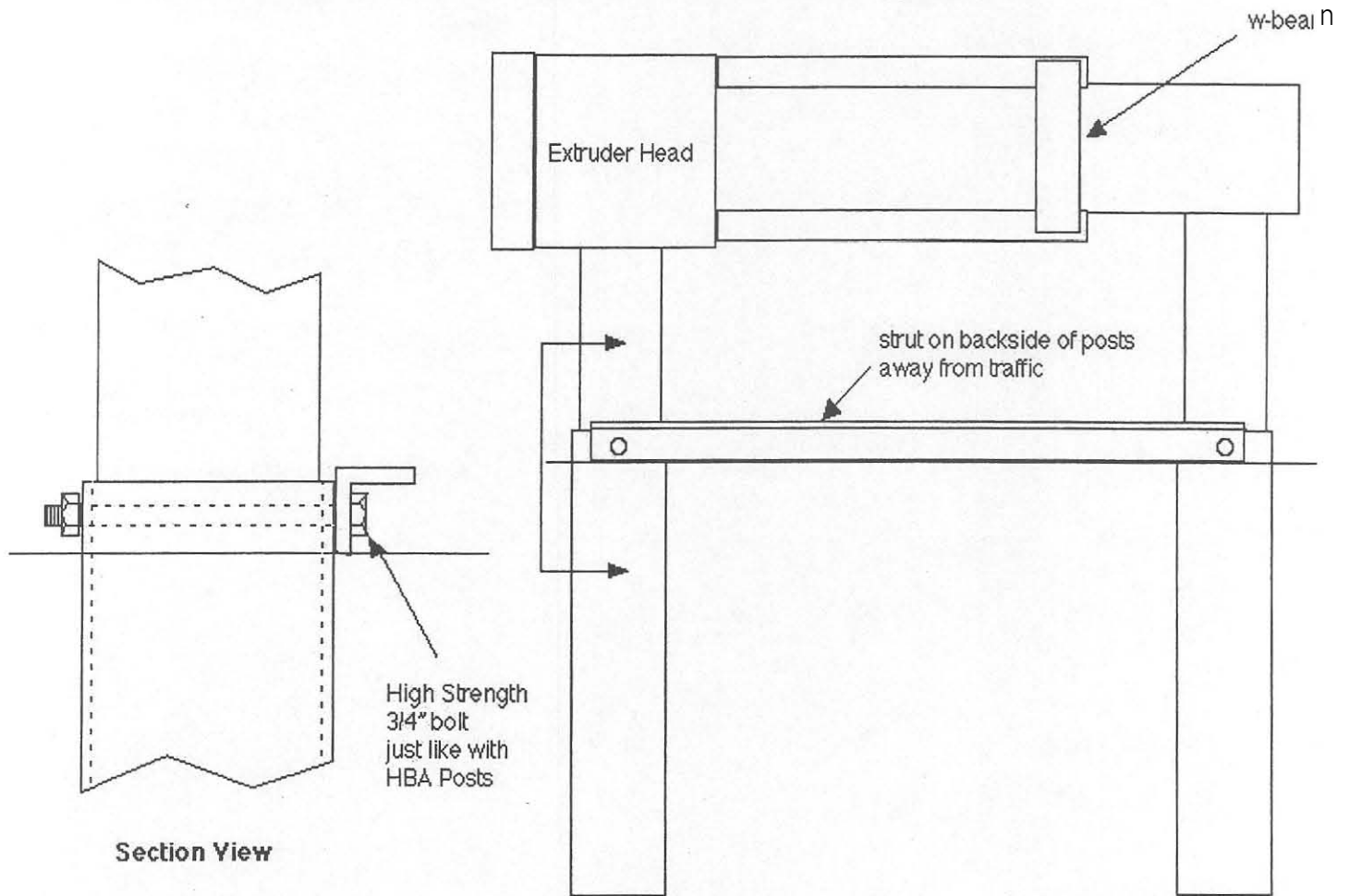
We also confirm that the HBA posts may be used as a direct substitute for the original weakened wood posts in any of the ET-2000 configurations previously accepted as meeting Report 350 evaluation criteria.

Sincerely yours,


Frederick G. Wright, Jr.
Program Manager, Safety

Enclosure

Use of 3x3x1/4 Strut with Wood Posts on ET-2000 System



Sketch Not to Scale

J. R. Albritton, P.E.
Exodyne Technologies, Inc.
Trinity Industries, Inc.
817-560-1459

APPENDIX D – SRT-350 APPROVAL LETTERS

The FHWA approval letters can be found on their web site at:

http://safety.fhwa.dot.gov/fourthlevel/hardware/term_cush.htm



US Department
of Transportation
**Federal Highway
Administration**

DEC 4 1995

400 Seventh St., S.W.
Washington, D.C. 20590

Refer to: HNG-14

Dr. Hayes E. Ross, Jr.
Research Engineer
The Texas A&M University System
Texas Transportation Institute
College Station, Texas 77843-3135

Dear Dr. Ross:

Your November 6 letter to Mr. William A. Weseman provided videotape and test reports indicating that the Slotted Rail Terminal (SRT) successfully met the National Cooperative Highway Research Program (NCHRP) Report 350 evaluation criteria as a test level 3 (TL-3) guardrail terminal. This letter also requested the Federal Highway Administration's (FHWA) concurrence in this determination.

In reviewing this material, we noted that the final NCHRP Report 350 terminal differed from the 230 tested design in the following ways:

1. The 305-mm long slots at post number 2 have been eliminated.
2. The w-beam rail element spanning posts 3 through 11 is a single section 76 20~~0~~ mm in length. The 230 design used two 38 10~~0~~-mm sections of w-beam in this area.
3. In lieu of a shelf angle to hold the rail in place, the 350 design uses standard 305-mm long w-beam backup plates at post 2 and at posts 4 through 10.
4. The 350 design uses a total of eight CRT posts (posts 3 through 10).

The final SRT design is shown in enclosure 1. Enclosure 2 summarizes the results of the full-scale tests that were conducted during the compliance testing for the SRT. We concur with the researchers' opinion that tests 3-30 and 3-34

need not be rerun on the modified design and that tests 3-32 and 3-33 may be waived for this terminal. In all tests the occupant impact velocities and subsequent ride down accelerations were below the maximum allowable values given in the NCHRP Report 350 evaluation criteria.

The FHWA concurs that the SRT is an acceptable TL-3 terminal for strong-post w-beam barrier and may be used on projects on the National Highway System when selected by a State highway agency.

Since the SRT is a proprietary design, its use on Federal-aid highway projects is subject to the conditions in Title 23, Code of Federal Regulations, Section 635.411, a copy of which is enclosed for your ready reference.

As with all gating terminals, the SRT must be installed on a relatively level site and have a reasonably clear and traversable area behind it for optimal performance in the field. We assume that, as with the BCT and the MELT terminals, the barrier length of need begins at post number 3 for the SRT.

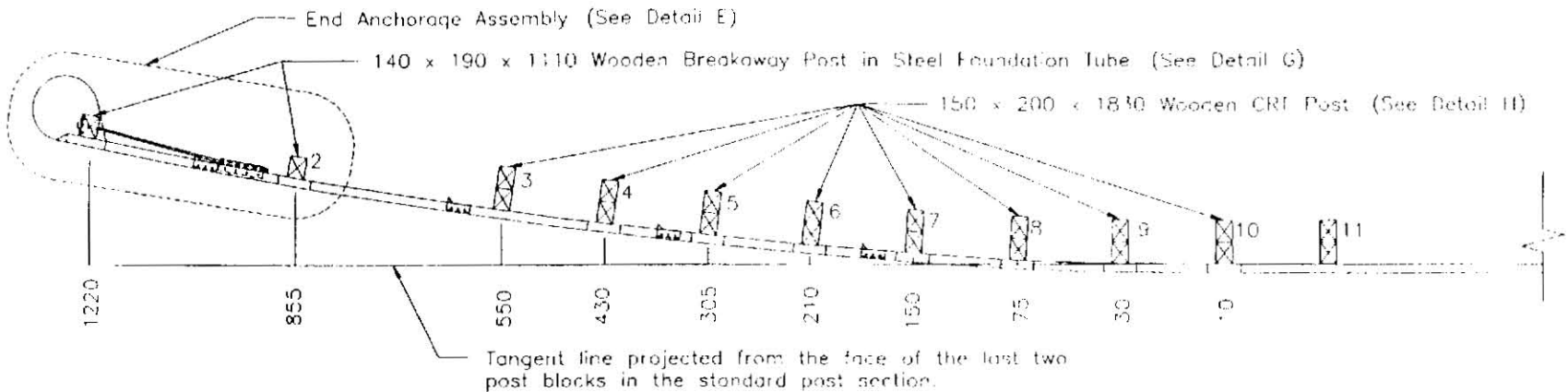
A copy of this letter with enclosures will be sent to all FHWA field offices for information. Questions concerning this terminal should be addressed to Mr. Richard Powers of my staff at (202) 366-1320.

Sincerely yours,

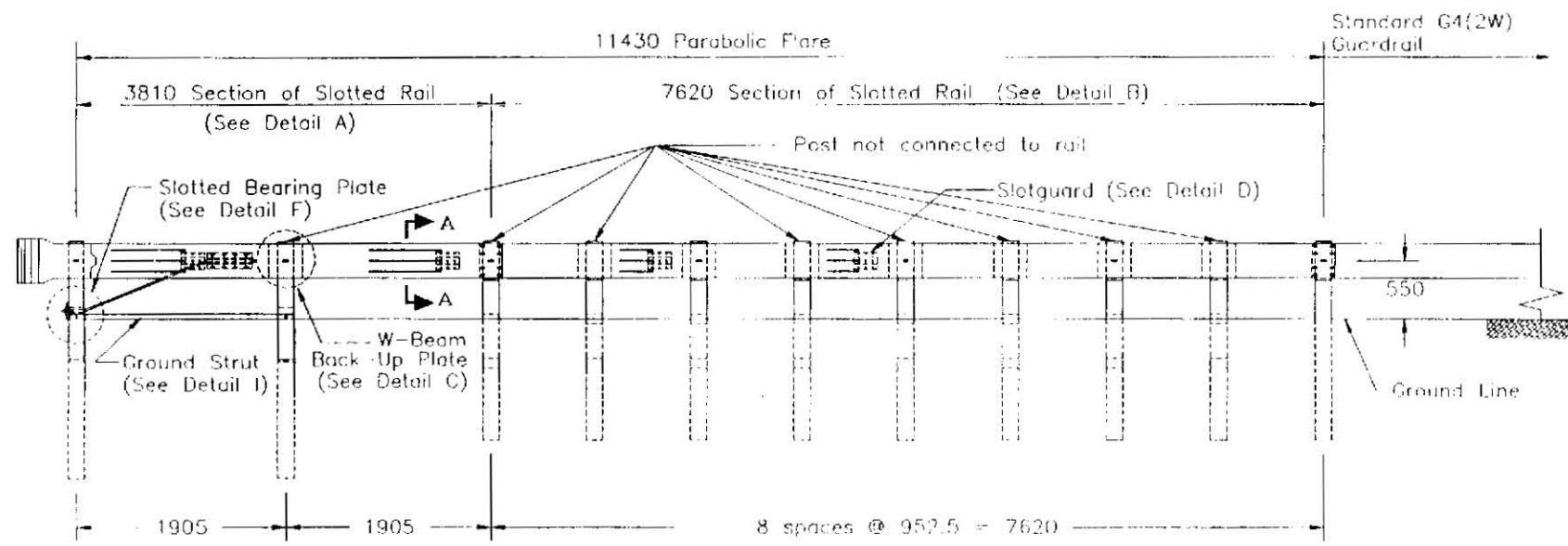


for Jerry L. Poston, Chief
Federal-Aid and Design Division

3 Enclosures



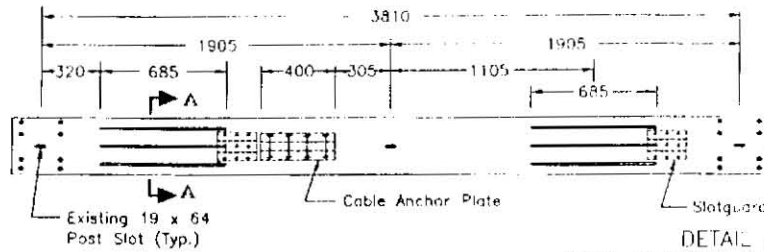
Plan



Elevation

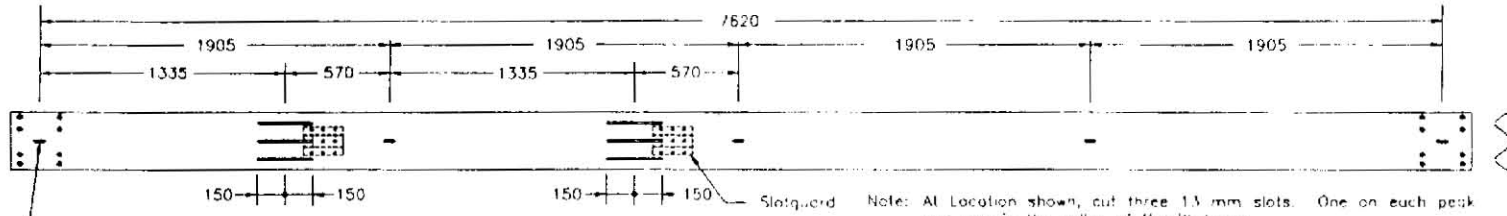
Notes. posts 3 through 10 are CRT posts
 posts 2, 3, 4, 6, 7, 8, 9, 10 not connected to rail
 backup plates at posts 2, 4, 5, 6, 7, 8, 9, 10

100 KM/H SLOTTED RAIL TERMINAL.



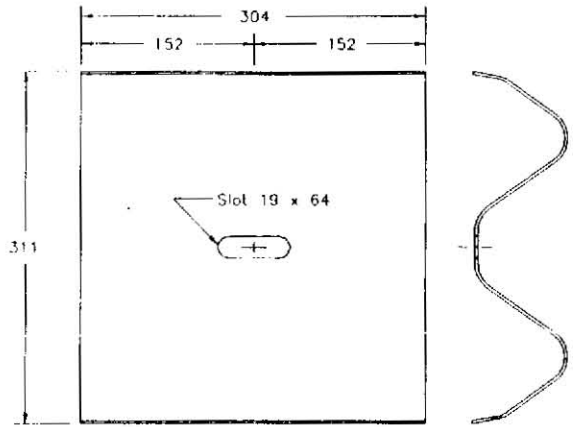
DETAIL A
3810 SLOTTED RAIL ELEMENT

Note: At location shown, cut three 13 mm slots. One on each peak and one in the valley of the W-beam.

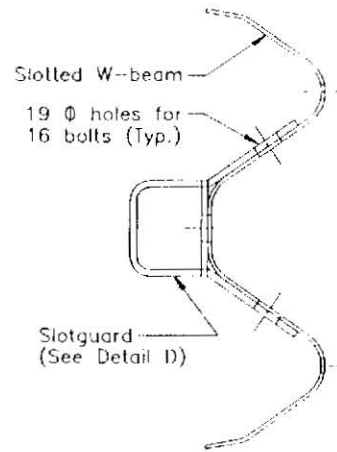


DETAIL B
7620 SLOTTED RAIL ELEMENT

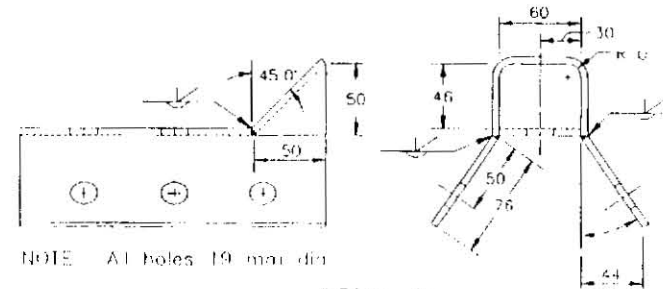
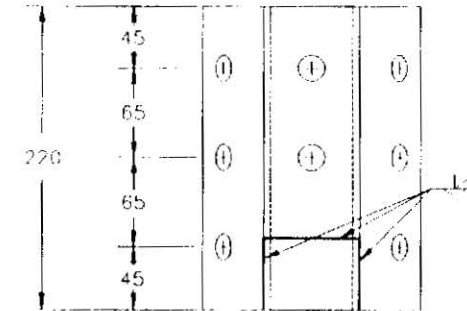
Note: At location shown, cut three 13 mm slots. One on each peak and one in the valley of the W-beam.



DETAIL C
W-BEAM BACK-UP PLATE

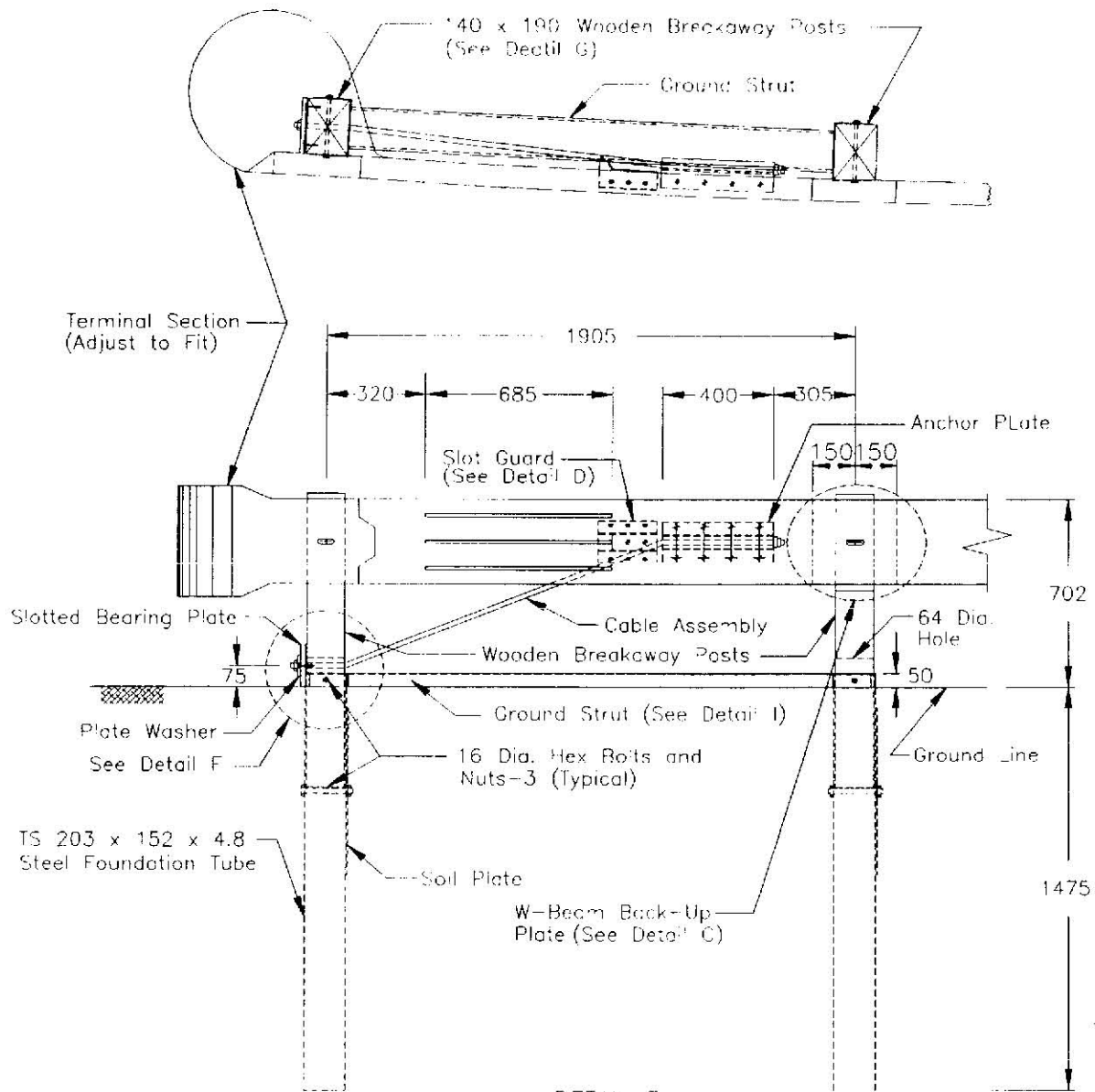


SECTION A A

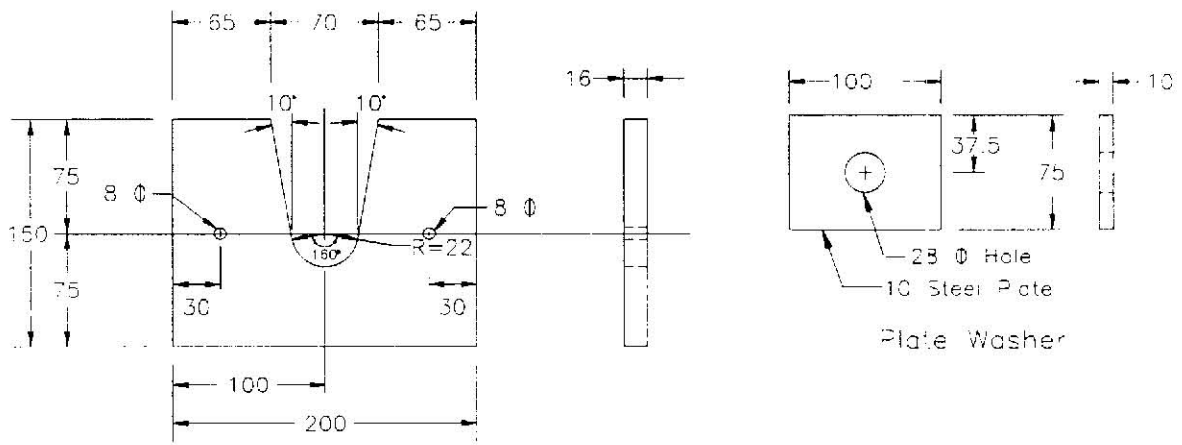
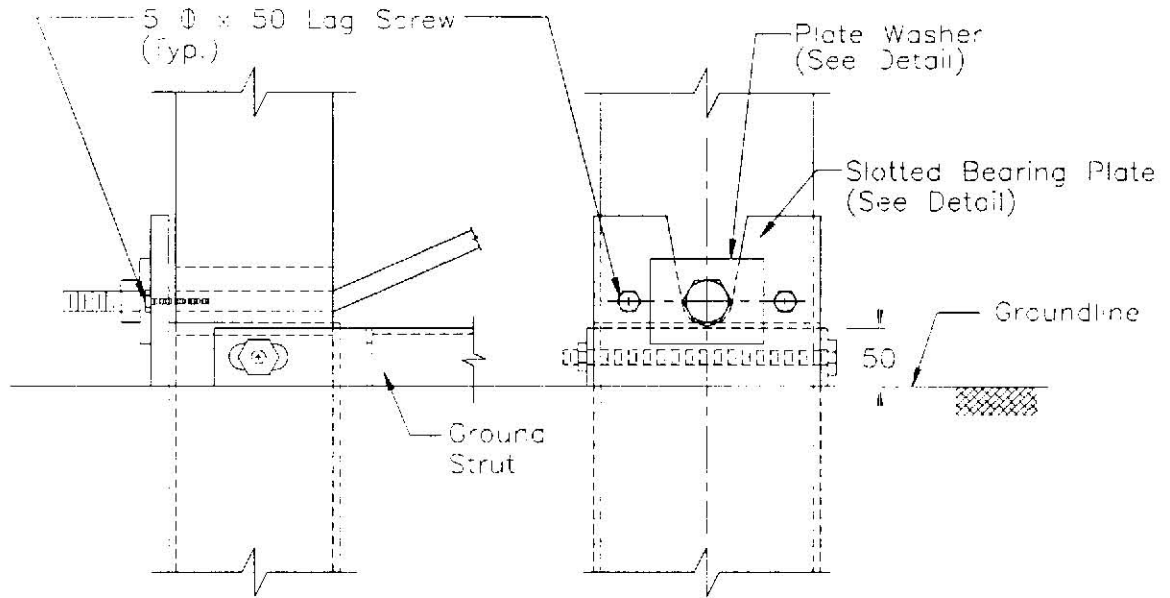


NOTE: All holes 19 mm dia

DETAIL D
SLOTGUARD

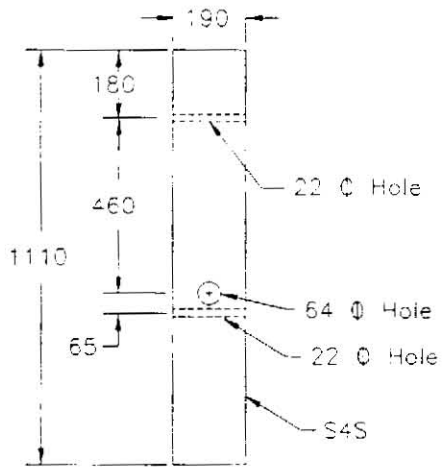


DETAIL E
END ANCHORAGE ASSEMBLY

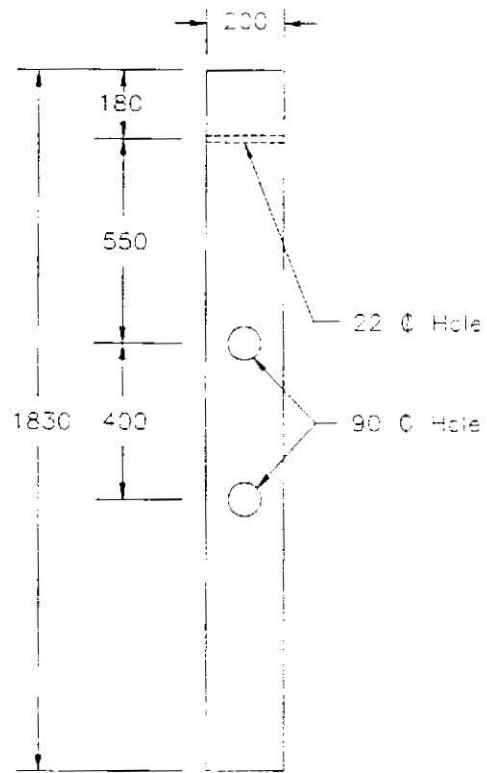


Slotted Bearing Plate

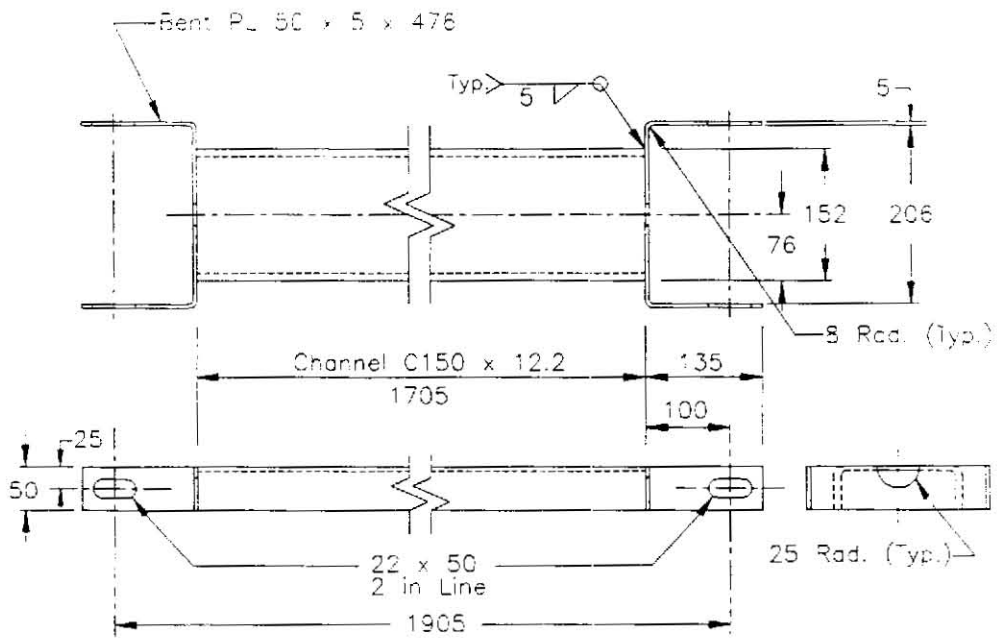
DETAIL F
SLOTTED BEARING PLATE



DETAIL G
SHORT BREAKAWAY WOODEN POST



DETAIL H
WOODEN CRT POST



DETAIL I
GROUND STRUT

Table 1. Summary of performance evaluation of compliance tests for 350 SRT terminal.

NCHRP 350 Test No.	Description	TTI Test No.	Impact Conditions		Occupant Impact Velocity		Ridedown Acceleration		Results Meet NCHRP 350 Requirements
			Speed	Angle	Long.	Lateral	Long.	Lateral	
3-30	Small Car Head-On	220530-5 ^(a)	99.4 km/h (61.8 mi/h)	0 deg.	8.4 m/s (26.7 ft/s)	2.6 m/s (8.6 ft/s)	-9.4 g	13.5 g	Yes
3-31	Pickup Truck Head-On	220530-10	101.4 km/h (63.0 mi/h)	0 deg.	5.4 m/s (17.8 ft/s)	3.2 m/s (10.5 ft/s)	-7.0 g	-8.2 g	Yes
3-34	Small Car Redirection	2404SR-5 ^(b)	101.8 km/h (63.3 mi/h)	15 deg.	5.9 m/s (19.2 ft/s)	7.2 m/s (23.7 ft/s)	-1.8 g	-13.8 g	Yes
3-35	Pickup Truck Redirection	220536-13	99.2 km/h (61.6 mi/h)	20.9 deg.	8.6 m/s (28.3 ft/s)	0.8 m/s (2.6 ft/s)	-6.5 g	10.5 g	Yes
3-39	Pickup Truck Reverse Direction	220536-14	100.9 km/h (62.7 mi/h)	21.0 deg.	3.9 m/s (12.8 ft/s)	1.6 m/s (5.4 ft/s)	-2.8 g	6.0 g	Yes

^(a) Reference 2. 230 SRT Terminal Compliance Test.

^(b) Reference 7. Split Rail End Terminal Compliance Test.

§ 635.411 Material or product selection.

(a) Federal funds shall not participate, directly or indirectly, in payment for any premium or royalty on any patented or proprietary material, specification, or process specifically set forth in the plans and specifications for a project, unless:

(1) Such patented or proprietary item is purchased or obtained through competitive bidding with equally suitable unpatented items; or

(2) The State highway agency certifies either that such patented or proprietary item is essential for synchronization with existing highway facilities, or that no equally suitable alternate exists; or

(3) Such patented or proprietary item is used for research or for a dis-

tinctive type of construction on relatively short sections of road for experimental purposes.

(b) When there is available for purchase more than one nonpatented, nonproprietary material, semifinished or finished article or product that will fulfill the requirements for an item of work of a project and these available materials or products are judged to be of satisfactory quality and equally acceptable on the basis of engineering analysis and the anticipated prices for the related item(s) of work are estimated to be approximately the same, the PS&E for the project shall either contain or include by reference the specifications for each such material or product that is considered acceptable for incorporation in the work. If the State highway agency wishes to substitute some other acceptable material or product for the material or product designated by the successful bidder or bid as the lowest alternate, and such substitution results in an increase in costs, there will not be Federal-aid participation in any increase in costs.

(c) A State highway agency may require a specific material or product when there are other acceptable materials and products, when such specific choice is approved by the Division Administrator as being in the public interest. When the Division Administrator's approval is not obtained, the item will be nonparticipating unless bidding procedures are used that establish the unit price of each acceptable alternative. In this case Federal-aid participation will be based on the lowest price so established.

(d) Appendix A sets forth the FHWA requirements regarding (1) the specification of alternative types of culvert pipes, and (2) the number and types of such alternatives which must be set forth in the specifications for various types of drainage installations.

(e) Reference in specifications and on plans to single trade name materials will not be approved on Federal-aid contracts.

LINE 1000000



U.S. Department
of Transportation

**Federal Highway
Administration**

400 Seventh St. S.W.
Washington, D.C. 20590

January 27, 1998

Refer to: HNG-14

King K. Mak, P.E.
Research Engineer
The Texas A&M University System
Texas Transportation Institute
College Station, Texas 77843-3135

Dear Mr. Mak:

In your December 11, 1997, letter you requested the Federal Highway Administration's acceptance of proposed design changes to the Slotted Rail Terminal (SRT) as an alternative to the current design. Briefly, these modifications consist of the elimination of the ground-level strut between the first two posts in the terminal (and the use of a reinforced concrete footing at the first post with either a concrete footing or a 2177-mm long steel foundation tube with a soil plate at the second post) and the substitution of a rounded W-beam end section (*Guide for Standardized Highway Barrier Hardware Designation RWE03a*) for the current one-piece, wrap-around buffered W-beam end section. You provided an analysis of numerous crash tests of the Breakaway Cable Terminal (BCT) and early developmental designs of the SRT to support your assertion that the changes would not affect the performance of the SRT and that additional full-scale testing was not needed.

We concur with your proposal to replace the current end section with the standard RWE03a end section. However, we need additional information on the more significant changes in the anchorage design. We do not believe tests of the BCT are directly applicable to the SRT because the BCT is a much stiffer system, having only two weakened posts and an intact W-beam rail element (i.e., no cut-outs/slots) that is bolted to each post. Consequently, the tensile forces transmitted through the rail to the cable end-anchor in a downstream impact would be less with the BCT than would occur in a similar impact with the SRT. In addition, even though the calculated impact severity is higher in the 25-degree National Cooperative Highway Research Program (NCHRP) Report 230 test with a 4500-pound sedan than in the 20-degree Report 350 test with a 2000-kg pickup truck, recent experience with the NCHRP Report 350 testing has shown conclusively that a successful NCHRP Report 230 test with a passenger car does not guarantee similar performance with the 2000-kg pickup truck. On the other hand, more information on Test No. 220536-13 (NCHRP Report test 3-35), which was run to qualify the current design as a NCHRP Report 350 terminal, might be persuasive if it reveals no movement in the first and second posts. Some details on this test were included in

your October 1995 report, "NCHRP Report 350 Compliance Testing of the W-beam Slotted Rail Terminal," but no information on end-anchorage movement was included. Our review of the crash test video tape submitted with the report failed to shed any light on this aspect of the test. If you can provide a more detailed analysis of this test, we may be able to conclude that the proposed modified anchorage is acceptable without rerunning Test 3-35. We would point out, however, that the NCHRP Report 350 strength test of the original MELT design resulted in the end post pivoting on the strut and pulling several inches out of the ground. This indicates to us that the strut is essential in the current anchorage design, and that its elimination and the subsequent use of a concrete footing at post No. 1 must be conclusively justified.

A second concern we have is the effect that a different foundation design at the second post might have on Test 3-34, the critical impact point (CIP) test. In reviewing the test you originally submitted to us for acceptance of the SRT under the NCHRP Report 350 guidelines, we noted that the second post (a weakened wood post set only in soil) showed significant lateral deflection. With your proposed modified anchorage design, this second post can be set in a concrete foundation and, in this less yielding foundation, may fail in the CIP test, resulting in unacceptable performance. Thus, we believe that test 3-34 is necessary to show that this change will not degrade system performance. If test 3-34 is passed with the second post set in concrete, we will accept a steel tube with a soil plate at post No. 2 as an alternate design without additional testing.

As a general comment, members of my staff have observed numerous problems in the past when concrete footings were used with BCT installations. Since relatively small volumes of concrete are required, installation costs tend to be significantly higher than tube foundations, particularly in remote or isolated locations. Also, if the reinforcing is omitted or the excavation for the footing is conical rather than cylindrical or the existing soil is weak or saturated, the anchor is likely to fail if the guardrail is hit just downstream from the end. For these reasons, we believe it is essential that acceptable soil and foundation details for posts 1 and 2 be determined and clearly specified if your proposed changes prove to be otherwise acceptable.

Please do not hesitate to call Mr. Richard Powers at (202) 366-1320, or Mr. James Hatton at (202) 366-1329, if you wish to discuss this response in detail.

Sincerely yours,



Dwight A. Horne
Chief, Federal-Aid and Design Division

FHWA:HNG-14:RPowers:366-1320:rp:1-22-98:KMAK
copies to:
HNG-1 HNG-10 HNG-14 Reader, 3128 File, 3128

June 18, 1998

Refer to: HNG-14

King K. Mak, P.E.
Research Engineer
The Texas A&M University System
Texas Transportation Institute
College Station, Texas 77843-3135

Dear Mr. Mak:

On June 9 you wrote to Mr. Henry Rentz, Director, Office of Engineering, requesting the Federal Highway Administration's (FHWA) acceptance of modifications to the Slotted Rail Terminal (SRT) design that was first approved as an National Cooperative Highway Report Program (NCHRP) Report 350 Test Level 3 (TL-3) terminal on December 4, 1995. Included with your request were copies of the Texas Transportation Institute report, "Optimization of the W-Beam Slotted Rail Terminal," dated May 1998, a composite video tape of the crash tests conducted, and drawings of the modified design.

This modified design, called the Improved Slotted Rail Terminal (ISRT-3), included a reduction in the end offset from 1.22 m to 0.91 m, a reduction in the length of the parabolic flare from 11.4 m to 8.9 m, an increase in the spacing between posts 3 to 9 from 0.95 m to 1.27 m, and the addition of a third set of 305-mm long slots in the second 3.81-m section of w-beam. In addition to these changes, the ISRT-3 uses redesigned slot guards, eliminates the w-beam backup plates, and specifies that the w-beam rail element be bolted to all posts except posts 7 and 8. Enclosure 1 shows the design and layout of the ISRT-3.

To support your request, you ran four full-scale crash tests: NCHRP Report 350 tests 3-30, 3-31, 3-34, and 3-35. All tests were run on the ISRT-3 design except 3-34 which was run on a similar design (called ISRT-4) having the original SRT-350 four-foot flare over its full 11.4-m length. Enclosure 2 contains the summaries of each of the four tests.

Based on our review of the information you sent, we agree that the ISRT-3, as tested, meets the evaluation criteria for an NCHRP Report 350 TL-3 terminal. Therefore, it may be used on the National Highway System (NHS) when it is specified by, or acceptable to, the responsible transportation agency. Because it remains a proprietary device, use of the ISRT-3 on Federal-aid projects, except exempt, non-NHS projects, is still subject to the conditions listed in Title 23, Code of Federal Regulations, Section 635.411.

You also requested that the ISRT-3 be accepted for use with any one of four different foundation tubes: 1.82-m or 1.98-m long steel tubes without soil plates, and 1.52-m or 1.37-m long steel tubes with soil plates. We agree that any one of these combinations may be used.

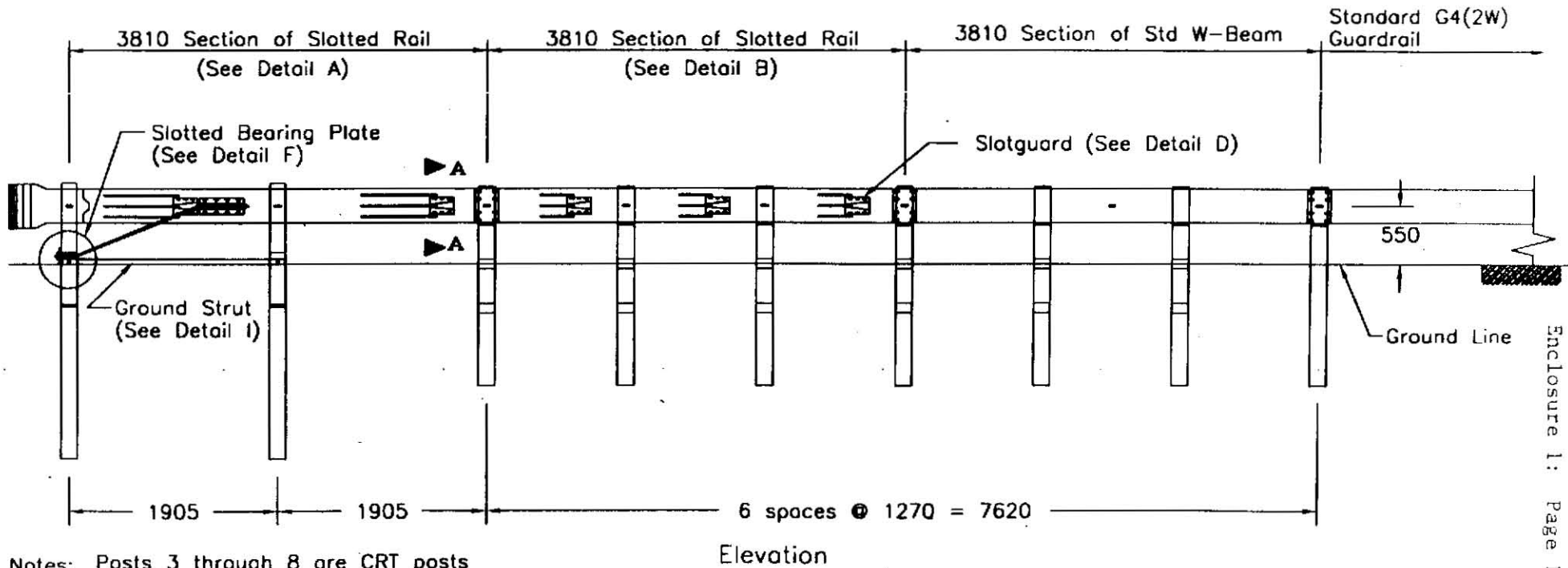
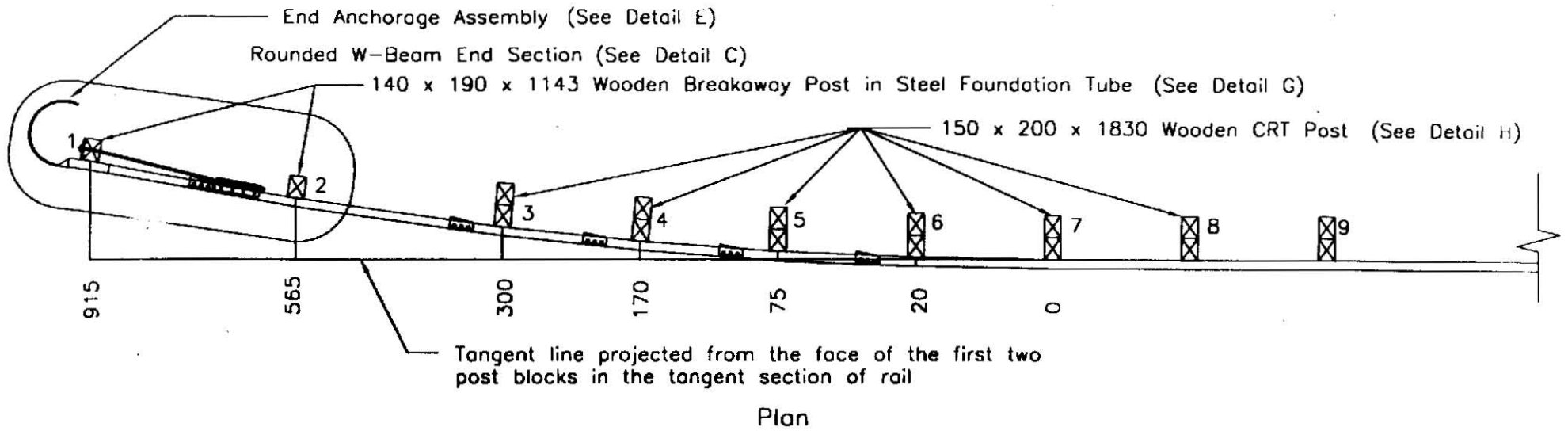
Please call Mr. Richard Powers at (202) 366-1320 if you have any questions on this action or if you wish to discuss any of the above in more detail.

Sincerely yours,

(original signed by Seppo I. Sillan)

for Dwight A. Horne
Chief, Federal-Aid and Design Division

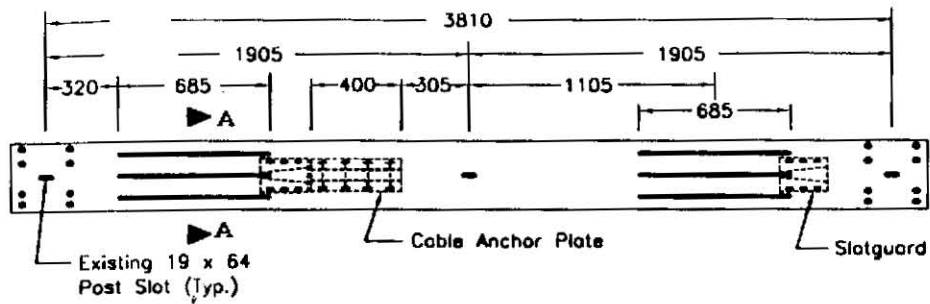
2 Enclosures
Acceptance Letter CC-51



Notes: Posts 3 through 8 are CRT posts
 Posts 7 and 8 not connected to rail

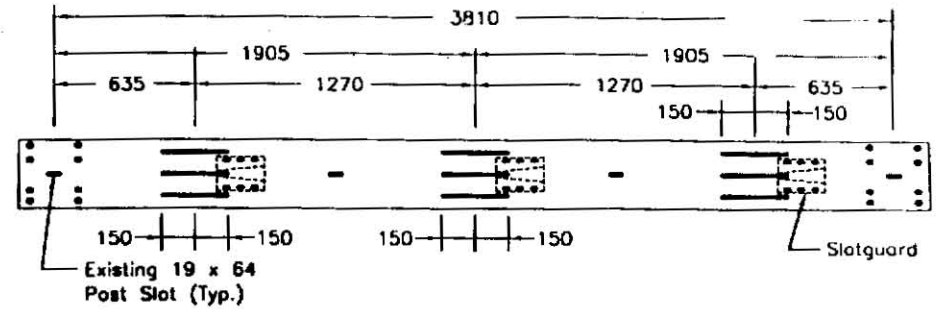
Modified SRT w/ 0.9m Offset

Revised on 5/4/98.



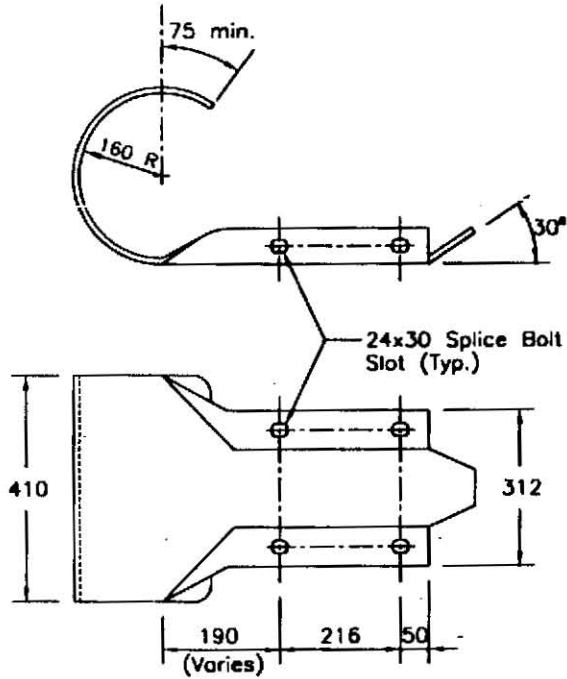
Note: At Location shown, cut three 13 mm slots. One on each peak and one in the valley of the W-beam.

DETAIL A
3810 SLOTTED RAIL ELEMENT

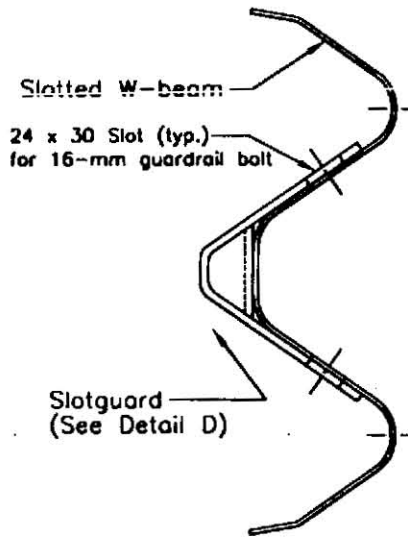


Note: At Location shown, cut three 13 mm slots. One on each peak and one in the valley of the W-beam.

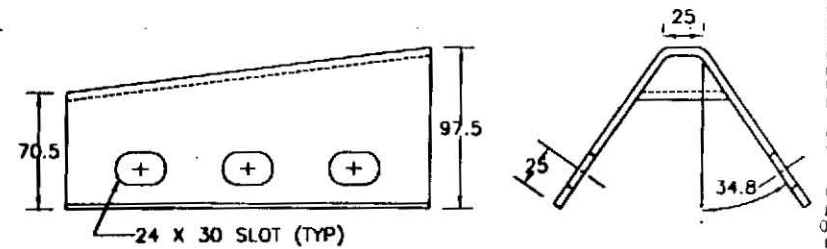
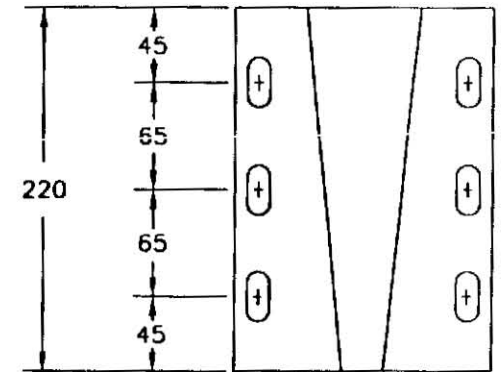
DETAIL B
3810 SLOTTED RAIL ELEMENT



DETAIL C
ROUNDED W-BEAM END SECTION

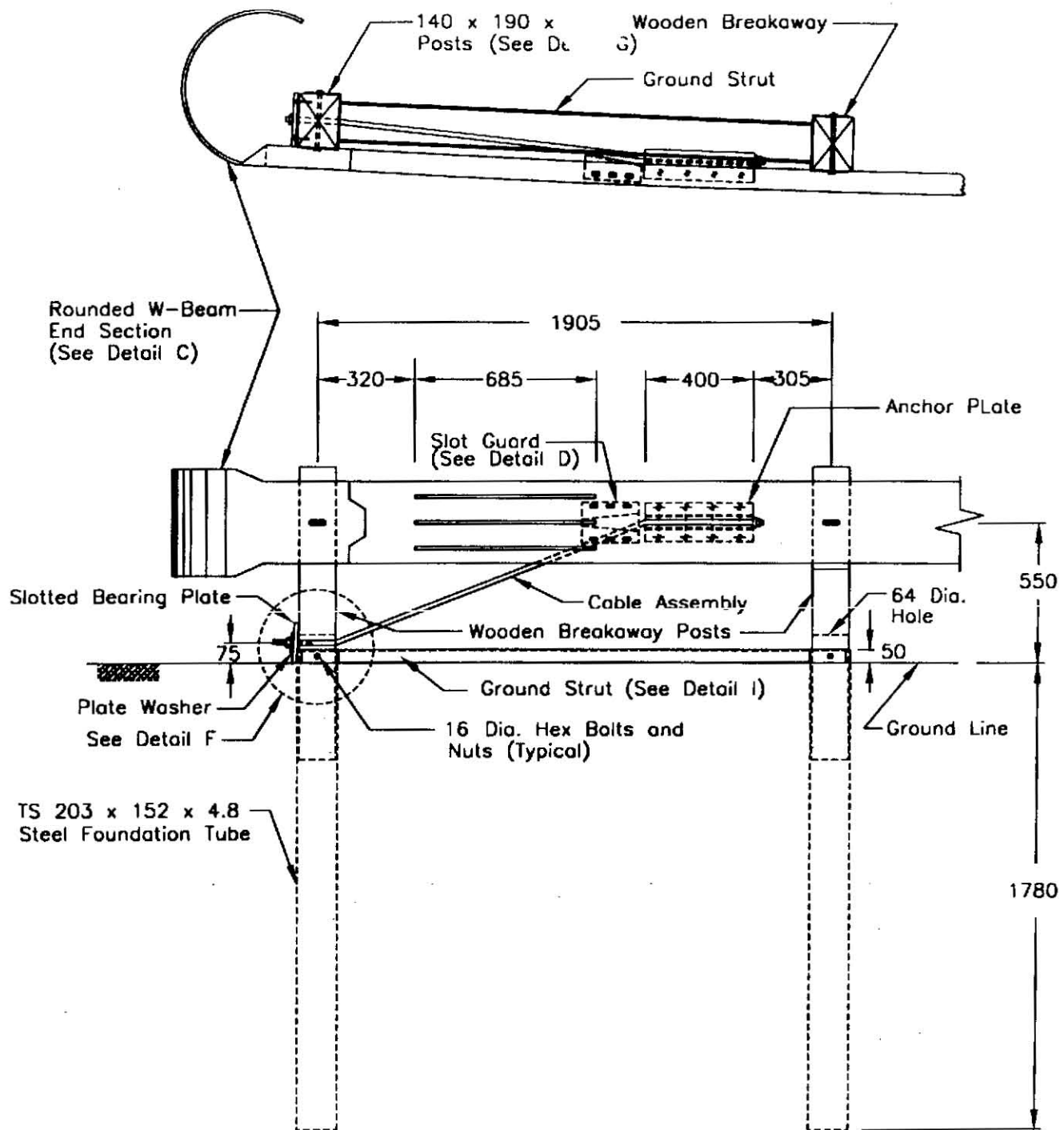


SECTION A-A



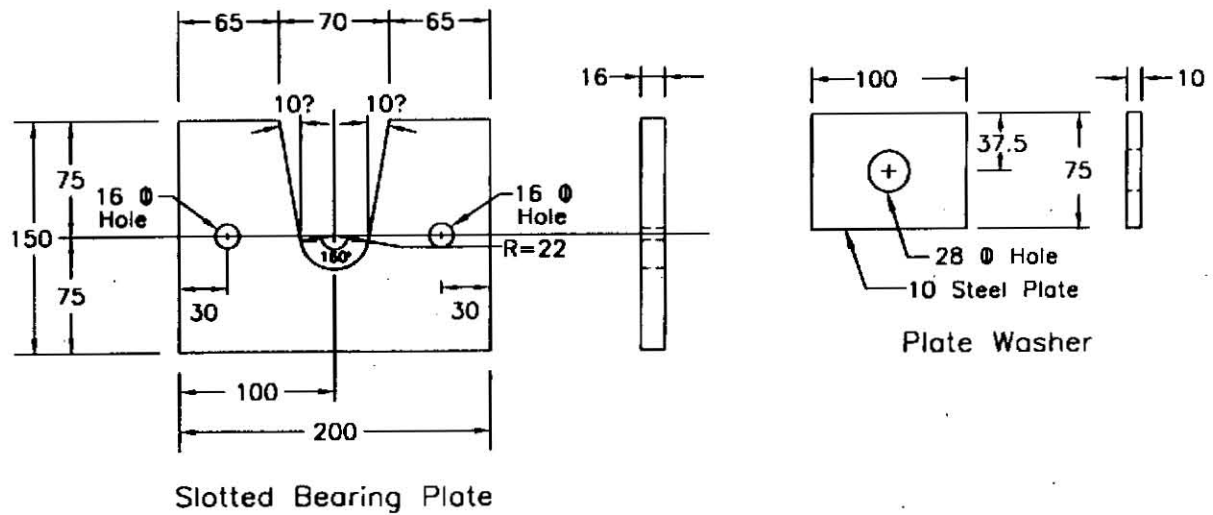
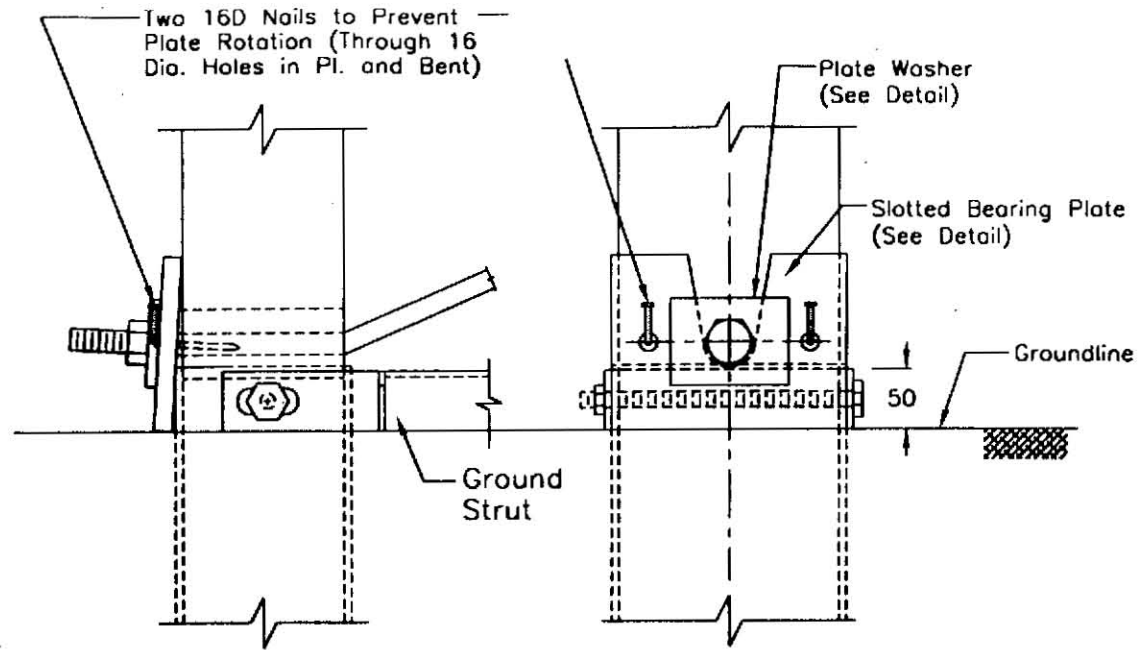
DETAIL D
SLOTGUARD

Revised on 5/4/98



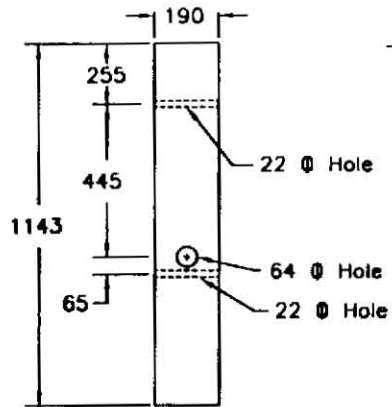
DETAIL E
END ANCHORAGE ASSEMBLY

Revised on 5/4/98

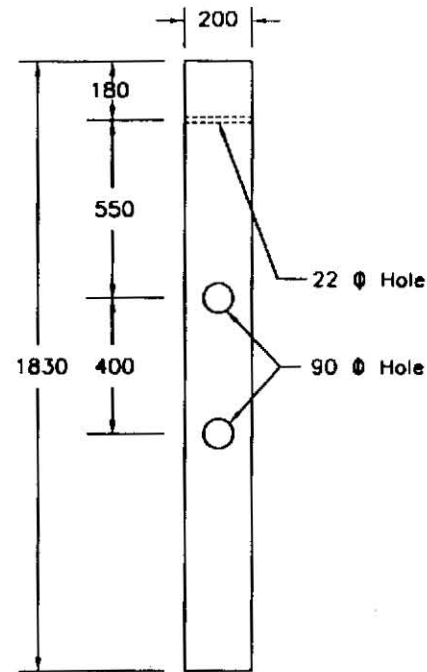


DETAIL F
SLOTTED BEARING PLATE

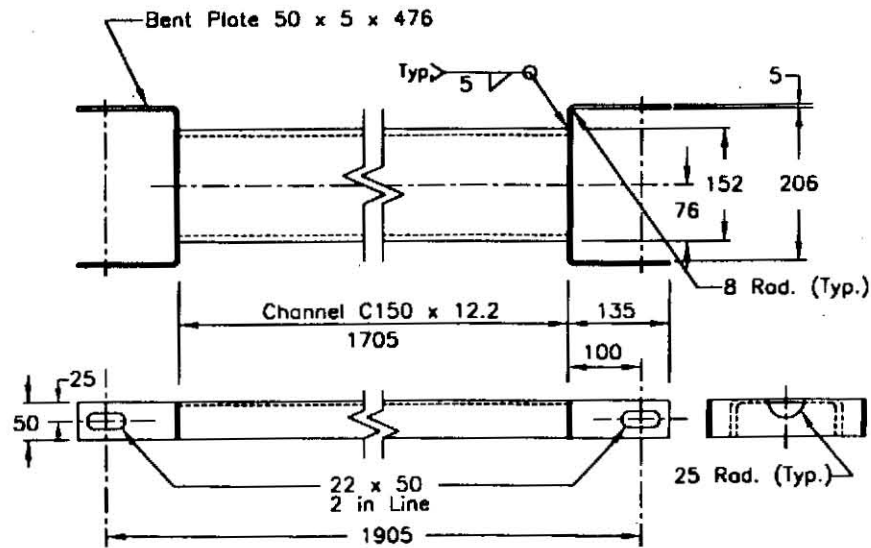
REVISED ON 5/4/98



DETAIL G
SHORT BREAKAWAY WOODEN POST

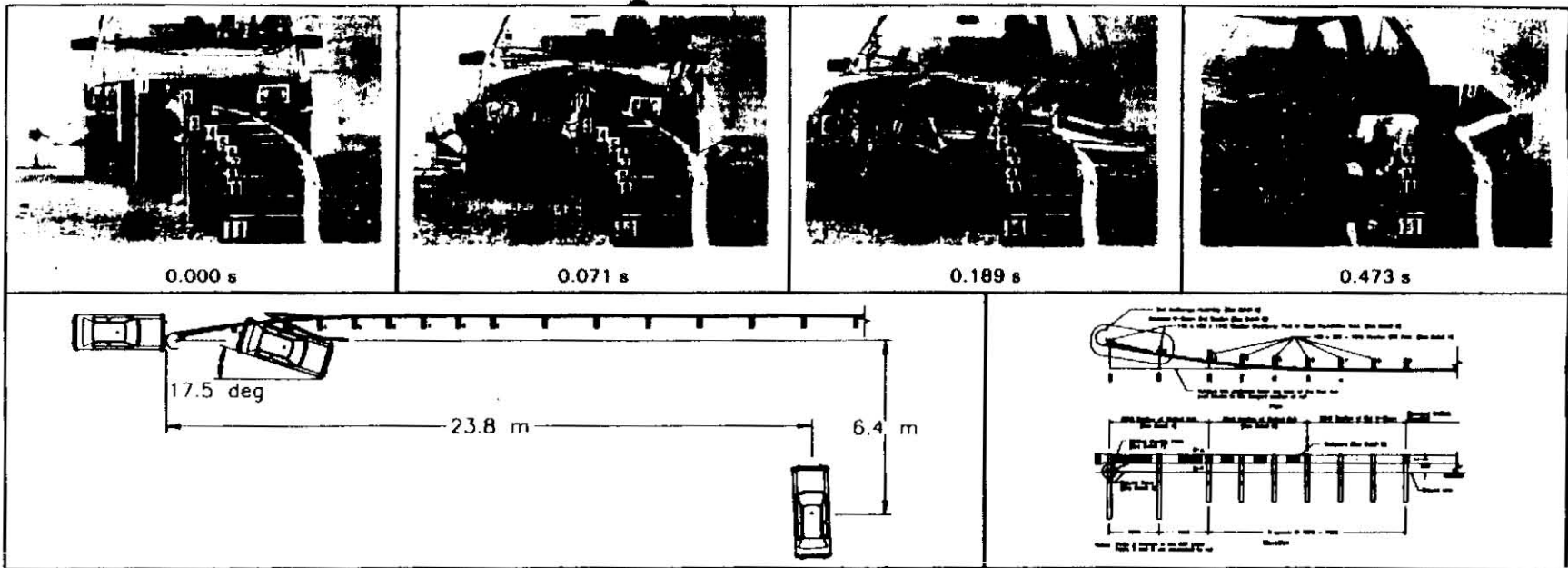


DETAIL H
WOODEN CRT POST



DETAIL I
GROUND STRUT

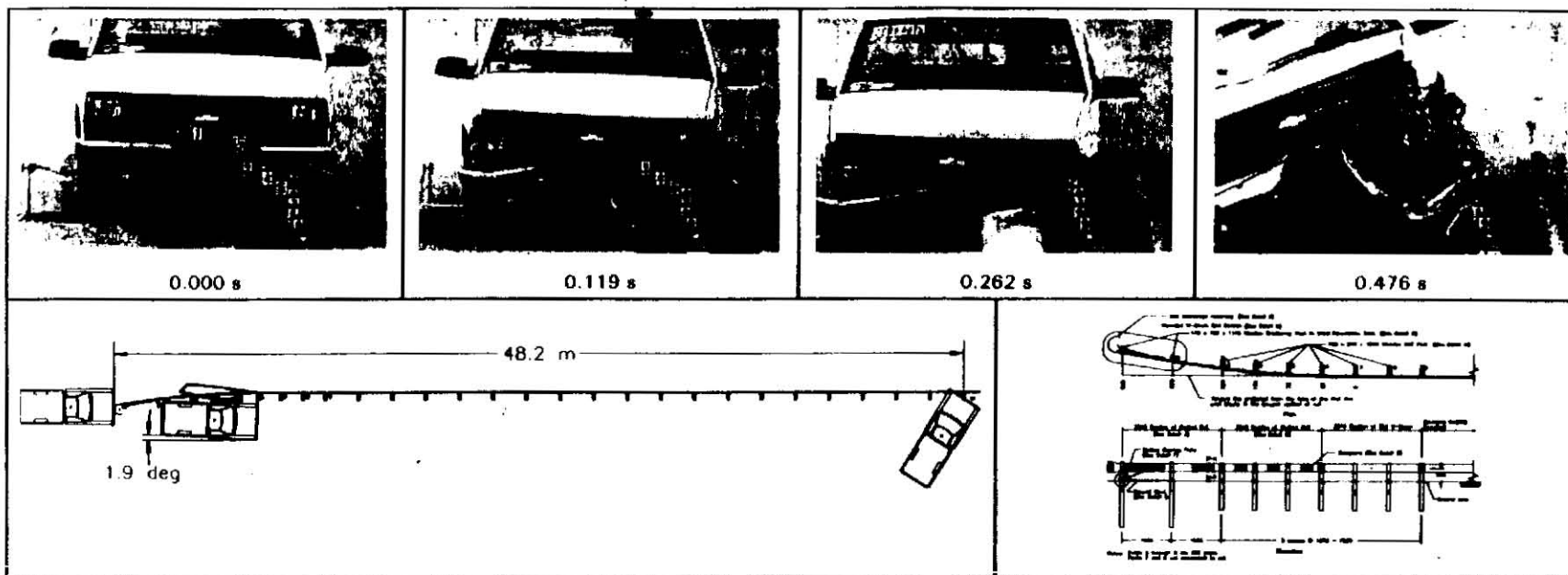
Revised on 5/4/98



37

General Information		Impact Conditions		Test Article Deflections (m)	
Test Agency	Texas Transportation Institute	Speed (km/h)	99.4	Dynamic	7.01
Test No.	220546-6	Angle (deg)	0.0	Permanent	3.80
Date	04/08/98	Exit Conditions		Vehicle Damage	
Test Article		Speed (km/h)	43.6	Exterior	
Type	Terminal	Angle (deg)	17.5	VDS	12FL4
Name	Improved SRT	Occupant Risk Values		CDC	12YZEW3
Installation Length (m)	53.3	Impact Velocity (m/s)		Maximum Exterior	
Material or Key Elements	Slotted W-beam guardrail with 915 mm flare	x-direction	6.8	Vehicle Crush (mm)	300
Soil Type and Condition	Standard Soil, Dry	y-direction	3.4	Interior	
Test Vehicle		THIV (km/h)	24.8	OCDI	LS0000000
Type	Production	Ridedown Accelerations (g's)		Max. Occ. Compartment	
Designation	820C	x-direction	-13.5	Deformation (mm)	17
Model	1993 Ford Festiva	y-direction	11.8	Post-Impact Behavior	
Mass (kg) Curb	856	PHD (g's)	15.3	(during 1.0 s after impact)	
Test Inertial	820	ASI	0.8	Max. Yaw Angle (deg)	27
Dummy	76	Max. 0.050 s Average (g's)		Max. Pitch Angle (deg)	-2
Gross Static	896	x-direction	-7.7	Max. Roll Angle (deg)	7
		y-direction	6.3		
		z-direction	-1.5		

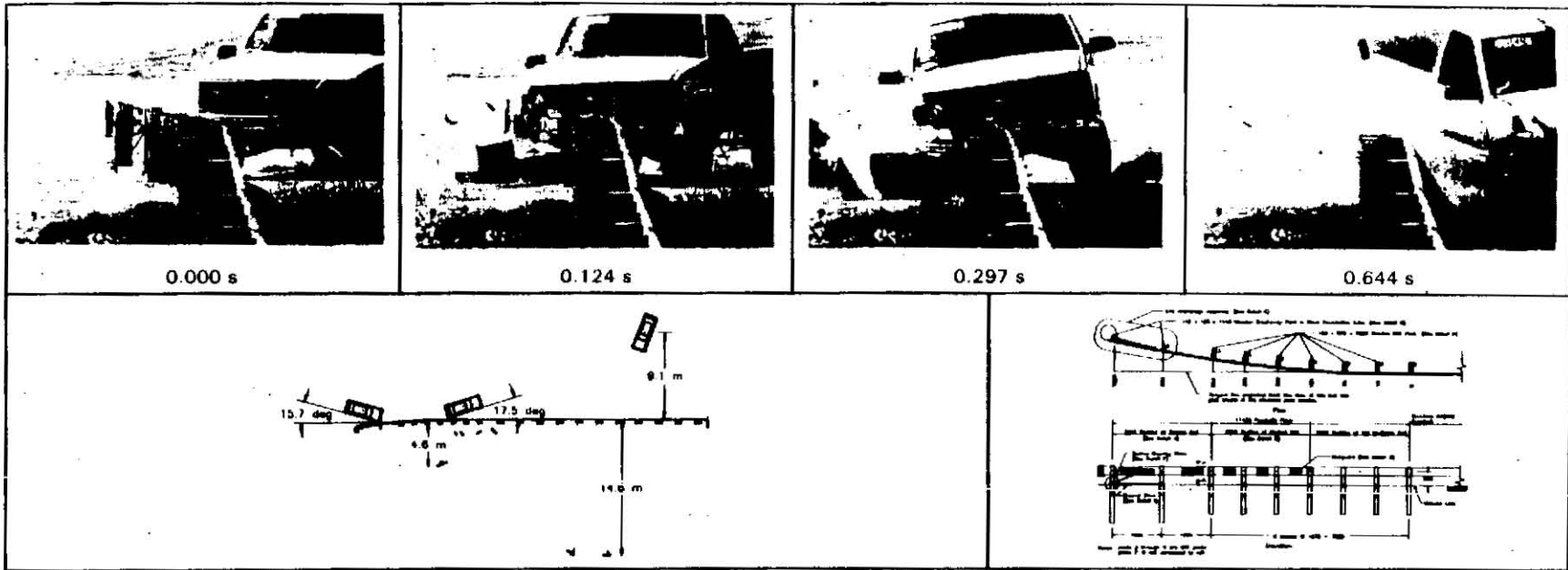
Figure 19. Summary of results for test 220546-6, NCHRP Report 350 test 3-30.



27

General Information		Impact Conditions		Test Article Deflections (m)	
Test Agency	Texas Transportation Institute	Speed (km/h)	100.6	Dynamic	7.23
Test No.	220546-5	Angle (deg)	0.0	Permanent	3.94
Date	04/02/98	Exit Conditions		Vehicle Damage	
Test Article		Speed (km/h)	77.1	Exterior	
Type	Terminal	Angle (deg)	1.9	VDS	12FD2
Name	Improved SRT	Occupant Risk Values		CDC	12FDEW2
Installation Length (m)	53.3	Impact Velocity (m/s)		Maximum Exterior	
Material or Key Elements	Slotted W-beam guardrail with 915 mm flare	x-direction	5.0	Vehicle Crush (mm)	270
Soil Type and Condition	Standard Soil, Dry	y-direction	1.5	Interior	
Test Vehicle		THIV (km/h)	18.2	OCDI	FS0000000
Type	Production	Ridedown Accelerations (g's)		Max. Occ. Compart.	
Designation	2000P	x-direction	-4.4	Deformation (mm)	25
Model	1995 Chevrolet 2500 pickup truck	y-direction	-2.8	Post-Impact Behavior	
Mass (kg) Curb	1898	PHD (g's)	5.1	(during 1.0 s after impact)	
Test Inertial	2000	ASI	0.4	Max. Yaw Angle (deg)	-12
Dummy	No dummy	Max. 0.050-s Average (g's)		Max. Pitch Angle (deg)	-6
Gross Static	2000	x-direction	-4.6	Max. Roll Angle (deg)	34
		y-direction	-1.6		
		z-direction	-1.9		

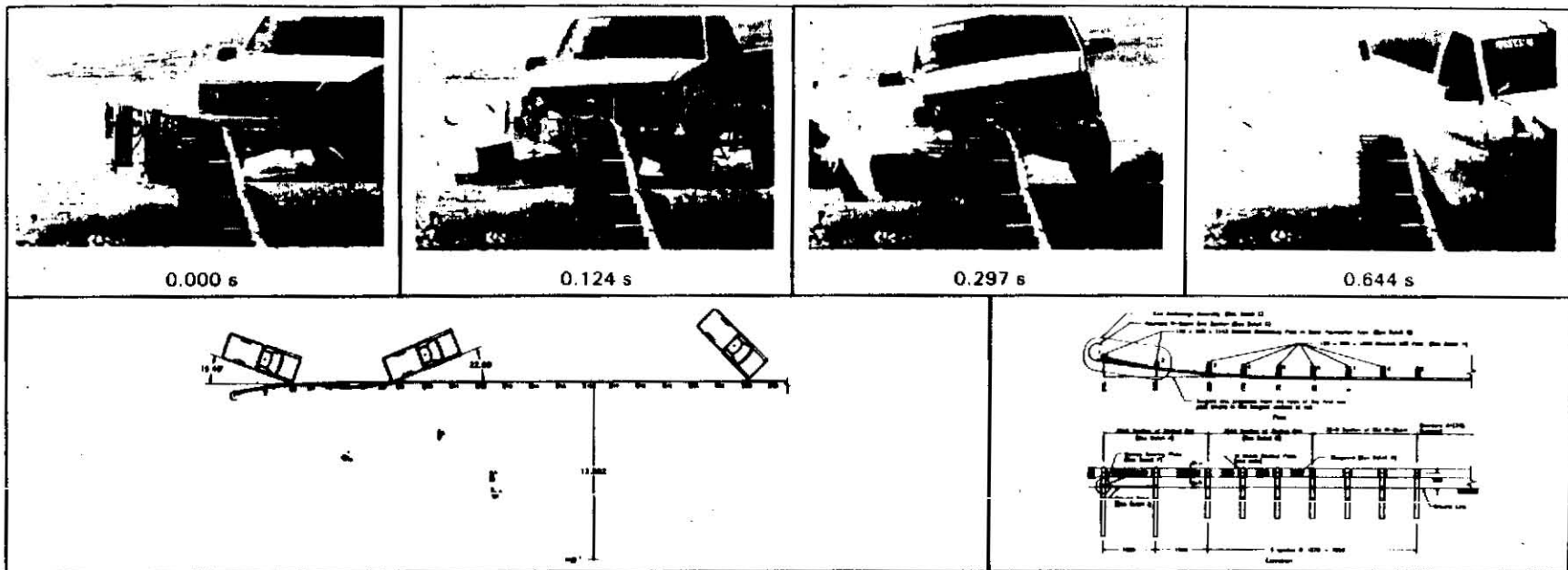
Figure 11. Summary of results for test 220546-5, NCHRP Report 350 test 3-31.



58

General Information		Impact Conditions		Test Article Deflections (m)	
Test Agency	Texas Transportation Institute	Speed (km/h)	101.1	Dynamic	0.94
Test No.	220546-8	Angle (deg)	15.7	Permanent	0.52
Date	05/19/98	Exit Conditions		Vehicle Damage	
Test Article		Speed (km/h)	57.4	Exterior	
Type	Terminal	Angle (deg)	17.5	VDS	01FR4
Name	Improved SRT	Occupant Risk Values		CDC	01FZEW4
Installation Length (m)	53.3	Impact Velocity (m/s)		Maximum Exterior	
Material or Key Elements	Slotted W-beam guardrail with 1220 mm flare	x-direction	8.3	Vehicle Crush (mm)	
Soil Type and Condition		y-direction	4.7	320	
Standard Soil, Dry		THIV (km/h)	26.0	Interior	
Test Vehicle		Ridedown Accelerations (g's)		OCDI	
Type	Production	x-direction	-9.1	RS0010000	
Designation	2000P-820C	y-direction	-10.9	Max. Occ. Compart.	
Model	1994 Geo Metro	PHD (g's)	13.8	Deformation (mm)	
Mass (kg) Curb	770	ASI	0.8	40	
Test Inertial	820	Max. 0.050-s Average (g's)		Post-Impact Behavior	
Dummy	75	x-direction	-6.8	(during 1.0 s after impact)	
Gross Static	895	y-direction	-5.0	Max. Yaw Angle (deg)	-35
		z-direction	-2.7	Max. Pitch Angle (deg)	-2
				Max. Roll Angle (deg)	-8

Figure 35. Summary of results for test 220546-8, NCHRP Report 350 test 3-34.



48

General Information		Impact Conditions		Test Article Deflections (m)	
Test Agency	Texas Transportation Institute	Speed (km/h)	99.2	Dynamic	1.01
Test No.	220546-7	Angle (deg)	19.5	Permanent	0.71
Date	04/24/98	Exit Conditions		Vehicle Damage	
Test Article		Speed (km/h)	28.3	Exterior	
Type	Terminal	Angle (deg)	22.1	VDS	01FL4
Name	Improved SRT	Occupant Risk Values		CDC	01ZYEW3
Installation Length (m)	53.3	Impact Velocity (m/s)		Maximum Exterior	
Material or Key Elements	Slotted W-beam guardrail with 915 mm flare	x-direction	6.6	Vehicle Crush (mm)	585
Soil Type and Condition		y-direction	4.5	Interior	
Standard Soil, Dry		THIV (km/h)	23.0	OCDI	
Test Vehicle		Ridedown Accelerations (g's)		Max. Occ. Compart.	
Type	Production	x-direction	-7.6	Deformation (mm)	
Designation	2000P	y-direction	-6.9	10	
Model	1995 Chevrolet 2500 pickup truck	PHD (g's)	10.6	Post Impact Behavior	
Mass (kg) Curb	2062	ASI	0.8	(during 1.0 s after impact)	
Test Inertial	2000	Max. 0.050 s Average (g's)		Max. Yaw Angle (deg)	-40
Dummy	No dummy	x-direction	-5.3	Max. Pitch Angle (deg)	-5
Gross Static	2000	y-direction	-5.6	Max. Roll Angle (deg)	8
		z-direction	4.1		

Figure 27. Summary of results for test 220546-7, NCHRP Report 350 test 3-35.

June 4, 1999

Refer to: HMHS-

CC51A

Mr. King K. Mak
Research Engineer
Safety & Structural Systems Division
Texas Transportation Institute
College Station, TX 77843-3135

Dear Mr. Mak:

In your April 26 letter to me you requested the Federal Highway Administration's acceptance at the National Cooperative Highway Research Program (NCHRP) Report 350 test level 3 (TL-3) of an Improved Slotted Rail Terminal having a 1.22-m end offset. I have previously accepted a similar design with a 0.9-m end offset (initially called the Improved Slotted Rail Terminal or ISRT and subsequently marketed as the ROSS - Reduced Offset Slotted System) in my June 18, 1998 letter to you. The primary difference in the new 1.22-m offset design from the original Slotted Rail Terminal (SRT) design is an increase in the post spacing, which reduced the number of CRT posts from eight to six, as was done with the ROSS, and the addition of a steel strap below the post bolt holes on the first two posts.

To support your request, you sent me copies of two reports prepared at the Texas Transportation Institute by K. K. Mak, H. E. Ross, Jr., R. P. Bligh, and W. C. Menges: "Improved W-Beam Slotted Rail Terminal With 1.22-M End Offset," dated December 1998, and "Improved W-Beam Slotted Rail Terminal with 1.22-m End Offset and Steel Line Posts," dated April 1999. You also sent video tapes showing the tests that you ran on each design. A summary of each test is enclosed as Enclosure 1. Enclosure 2 shows the design details of the Improved Slotted Rail Terminal with a 1.22-m offset. A 19-mm wide, 0.38-mm thick steel strap was added approximately 25 mm below the post bolt hole in posts 1 and 2 to lessen the likelihood of these posts splitting under tensile loading.

Based on staff review of the material you submitted, the Improved Slotted Rail Terminal with a 1.22-m offset is acceptable for use on the National Highway System when installed with either steel or wood line posts. Since I have previously accepted this terminal with a 0.9-m offset, an intermediate offset design of 1.07 m can also be considered acceptable, as you requested. The appropriate post offsets for each of the three variations are shown in Table 1 (Enclosure 3). The 19 mm steel strap must be used on posts 1 and 2 when the 1.07-m offset layout is used.

Finally, you also asked to standardize the slot pattern in the second w-beam panel with two sets of 305-mm long slots and stated that such standardization would have no adverse effect on system performance. Since our review of tests previously conducted with the three-slot panel showed that the middle set of slots did not activate in either end-on test, you may also consider

2

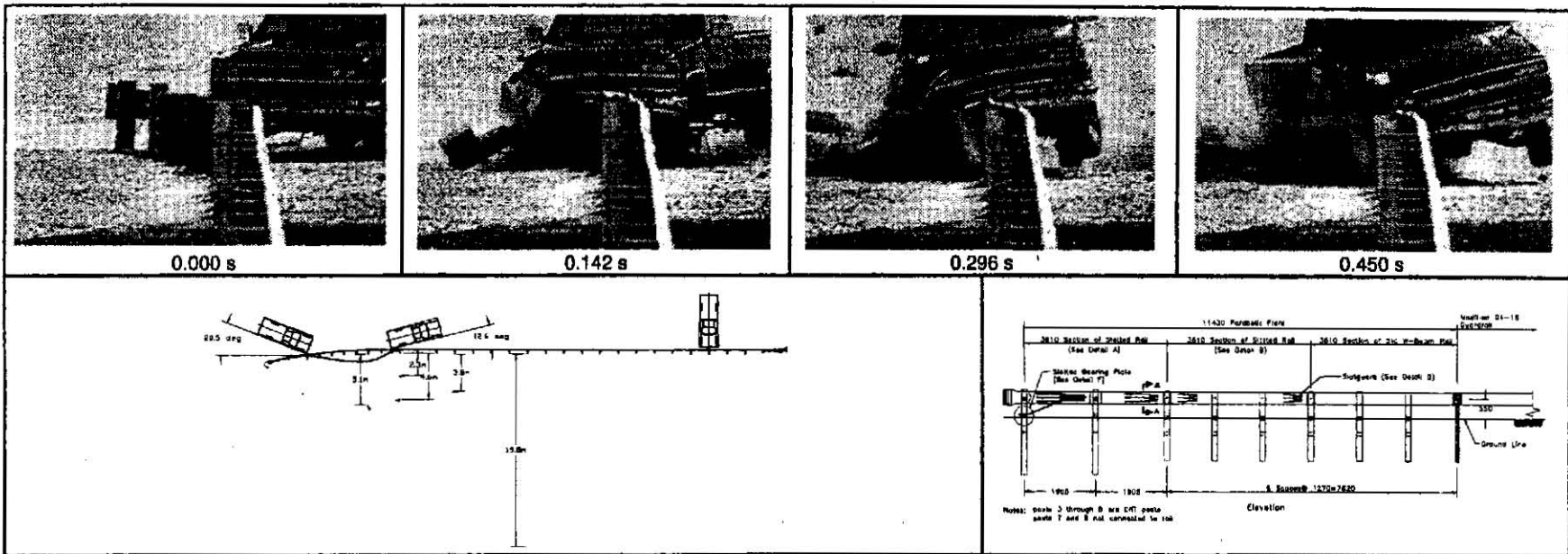
this change acceptable. The standard panel, which can be used with all previous and current slotted Rail terminals, is as shown on page 2 of Enclosure 2. The steel-tube, soil plate alternatives listed in my June 18, 1998 letter for the first two posts of the ISRT/ROSS remain acceptable for use with the 1.07-m offset and the 1.22-m offset ISRT.

Sincerely yours,

(original signed by Dwight A. Horne)

Dwight A. Horne
Director, Office of Highway Safety Infrastructure

3 Enclosures



30

General Information

Test Agency Texas Transportation Institute
 Test No. 220546-14
 Date 03/09/99

Test Article

Type Terminal
 Name or Manufacturer Improved SRT w/ 1.2 m flare
 Installation Length (m) 53.3
 Material or Key Elements Slotted W-beam guardrail

Soil Type and Condition Standard soil, dry

Test Vehicle

Type Production
 Designation 2000P
 Model 1993 Chevrolet 2500 pickup truck
 Mass (kg)
 Curb 2083
 Test Inertial 2000
 Dummy No dummy
 Gross Static 2000

Impact Conditions

Speed (km/h) 100.6
 Angle (deg) 20.5

Exit Conditions

Speed (km/h) 48.5
 Angle (deg) 12.6

Occupant Risk Values

Impact Velocity (m/s)
 x-direction 4.6
 y-direction 4.3
 THIV (km/h) 20.4
 Ridedown Accelerations (g's)
 x-direction -8.0
 y-direction -10.8
 PHD (g's) 12.6
 ASI 0.68
 Max. 0.050-s Average (g's)
 x-direction -5.6
 y-direction -4.8
 z-direction 3.9

Test Article Deflections (m)

Dynamic 1.37
 Permanent 1.05

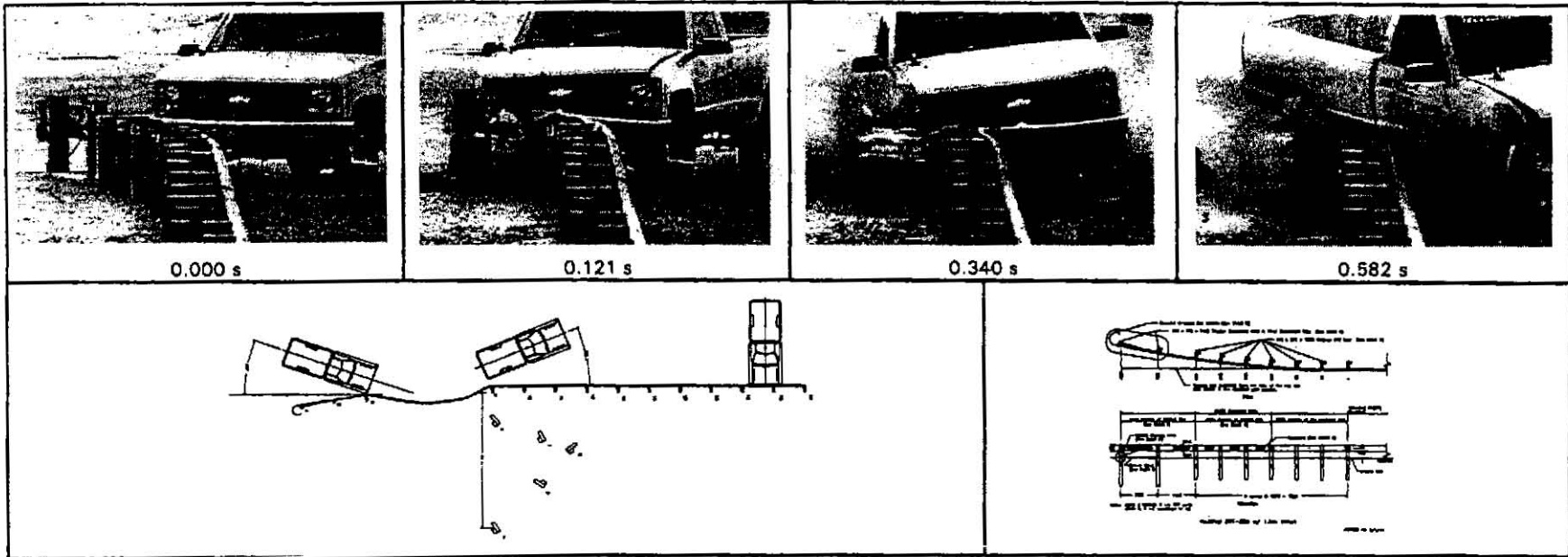
Vehicle Damage

Exterior
 VDS 01FL3
 CDC 01FREW3
 Maximum Exterior
 Vehicle Crush (mm) 400
 Interior
 OCDI FS0002000
 Max. Occ. Compart.
 Deformation (mm) 15

Post-Impact Behavior

(during 1.0 s after impact)
 Max. Yaw Angle (deg) -29
 Max. Pitch Angle (deg) -6
 Max. Roll Angle (deg) 20

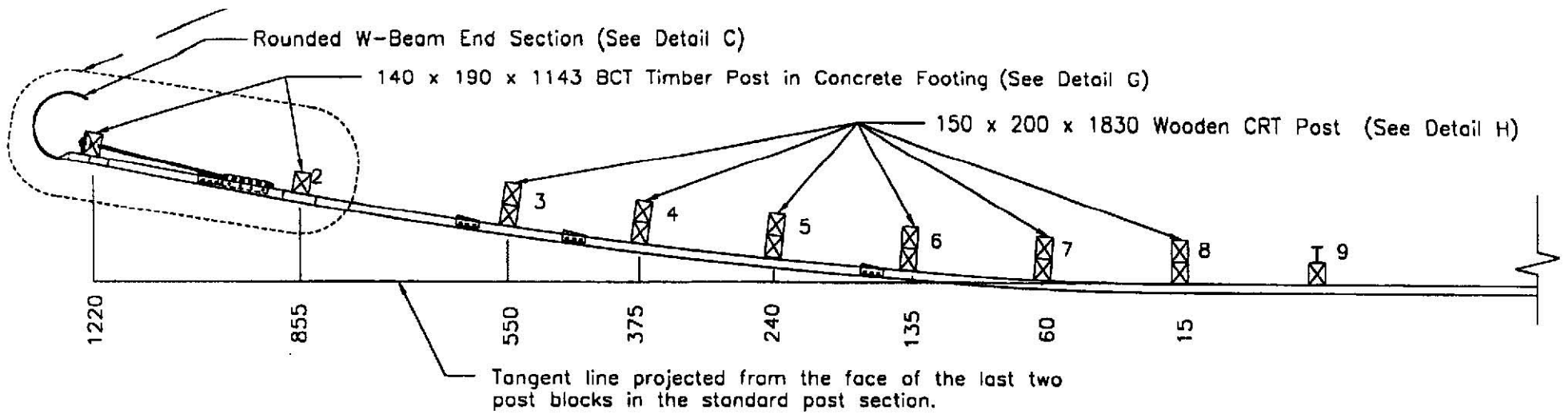
Figure 13. Summary of Results for test 220546-14, NCHRP Report 350 test 3-35.



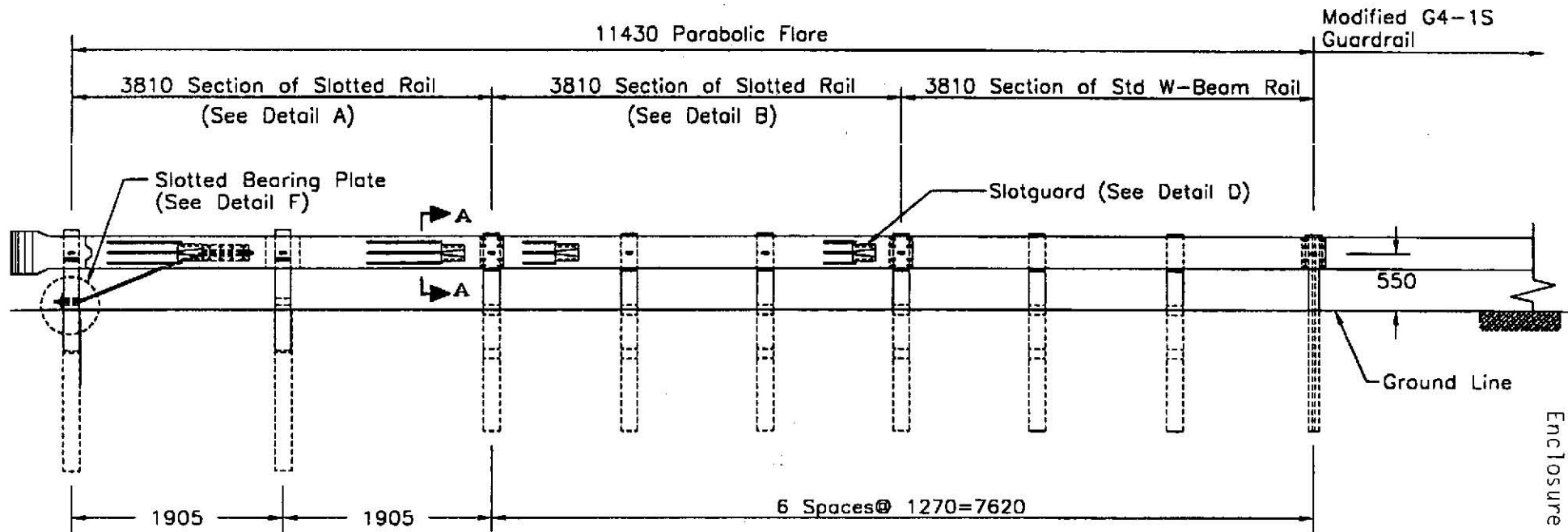
38

General Information		Impact Conditions		Test Article Deflections (m)	
Test Agency	Texas Transportation Institute	Speed (km/h)	100.5	Dynamic	1.03
Test No.	220546-10	Angle (deg)	20.4	Permanent	0.18
Date	11/24/98	Exit Conditions		Vehicle Damage	
Test Article		Speed (km/h)	39.9	Exterior	
Type	Terminal	Angle (deg)	22.7	VDS	01FL3
Name or Manufacturer	Improved SRT with 1.2 m offset	Occupant Risk Values		CDC	01FREW3
Installation Length (m)	53.3	Impact Velocity (m/s)		Maximum Exterior	
Material or Key Elements	Slotted W-beam guardrail	x-direction	7.2	Vehicle Crush (mm)	290
Soil Type and Condition		y-direction	4.4	Interior	
Standard soil, dry		THIV (km/h)	25.0	OCDI	RS0000000
Test Vehicle		Ridedown Accelerations (g's)		Max. Occ. Compart.	
Type	Production	x-direction	-8.2	Deformation (mm)	
Designation	2000P	y-direction	-8.2	nil	
Model	1995 Chevrolet 2500 pickup truck	PHD (g's)	10.9	Post-Impact Behavior	
Mass (kg)		ASI	0.70	(during 1.0 s after impact)	
Curb	2145	Max. 0.050-s Average (g's)		Max. Yaw Angle (deg)	-45
Test Inertial	2000	x-direction	-6.5	Max. Pitch Angle (deg)	-8
Dummy	No dummy	y-direction	-5.1	Max. Roll Angle (deg)	18
Gross Static	2000	z-direction	3.3		

Figure 15. Summary of results for test 220546-10, NCHRP Report 350 test 3-35.



Plan

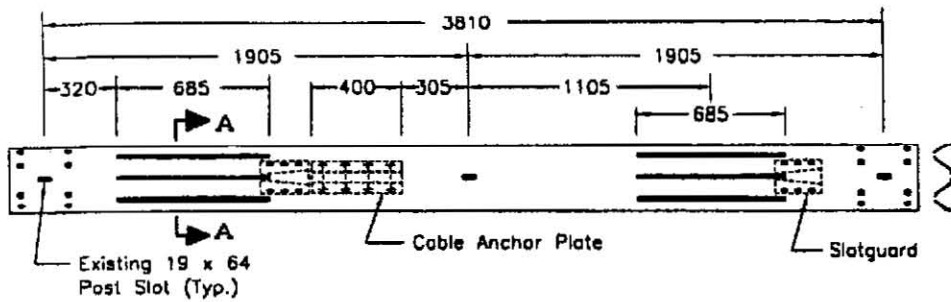


Elevation

Notes: posts 3 through 8 are CRT posts
posts 7 and 8 not connected to rail

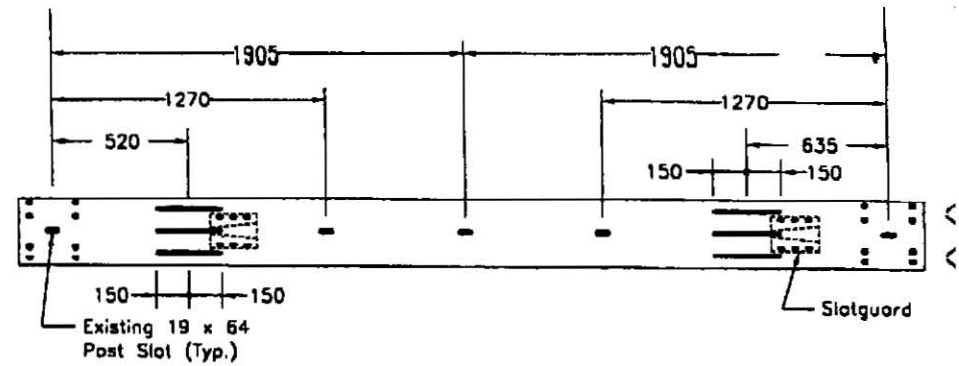
MODIFIED SRT-350

REVISED ON 1/15/99



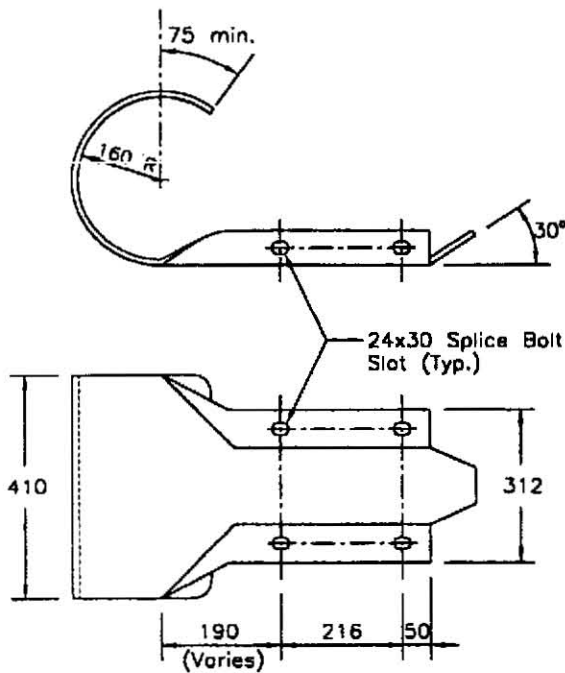
Note: At Location shown, cut three 13 mm slots. One on each peak and one in the valley of the W-beam.

DETAIL A
3810 SLOTTED RAIL ELEMENT

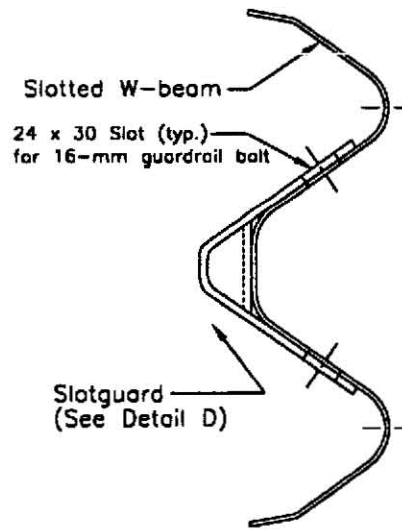


Note: At Location shown, cut three 13 mm slots. One on each peak and one in the valley of the W-beam.

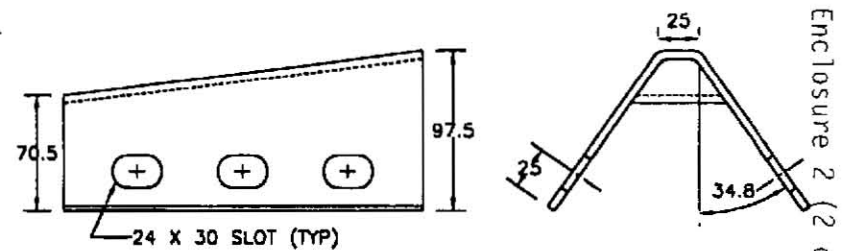
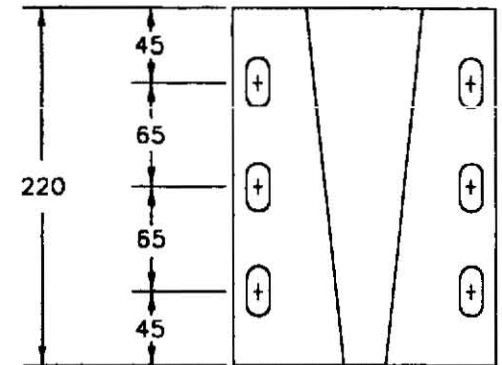
DETAIL B
3810 SLOTTED RAIL ELEMENT



DETAIL C
ROUNDED W-BEAM END SECTION

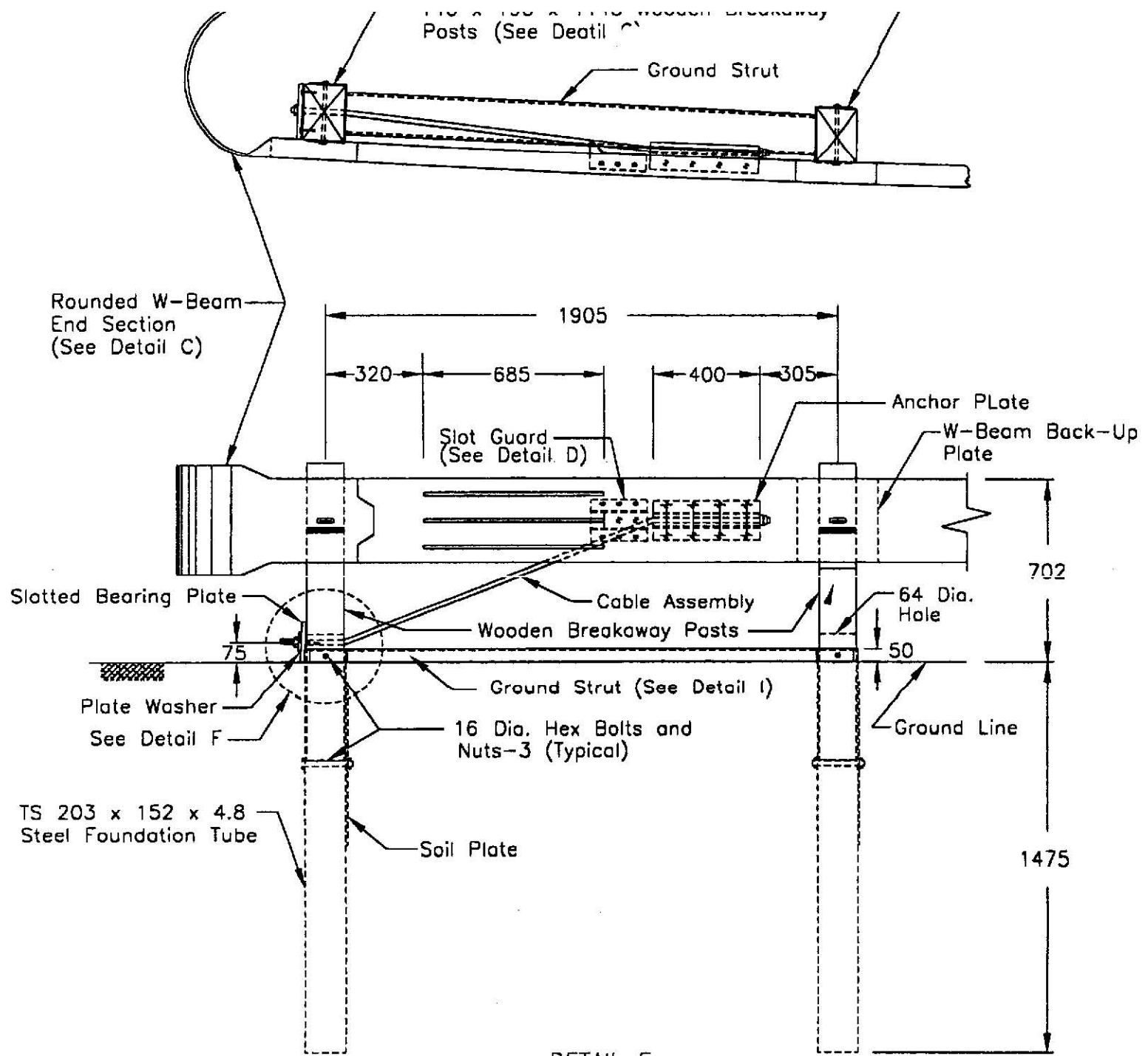


SECTION A-A



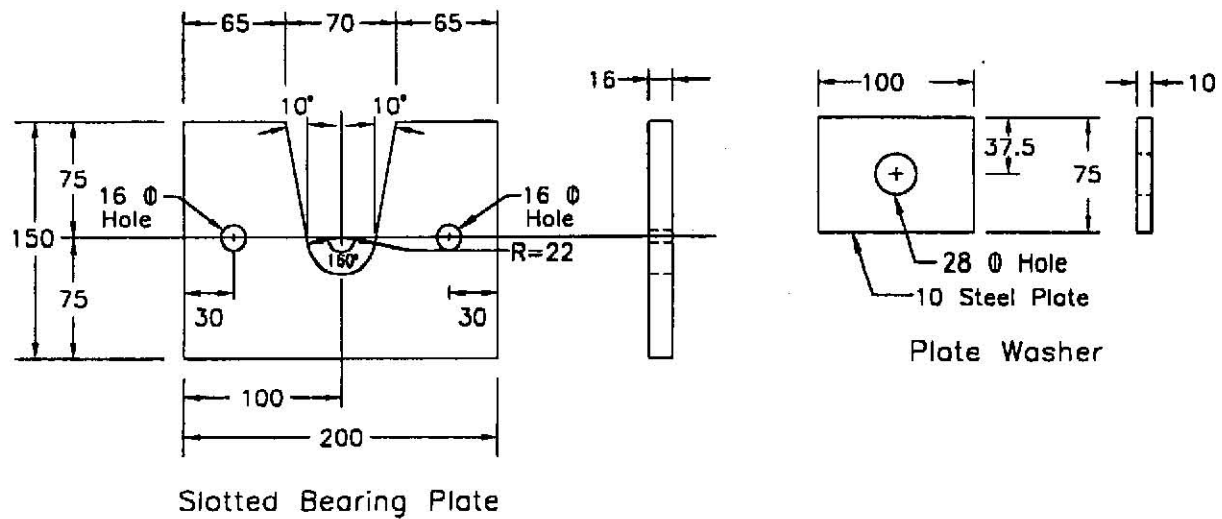
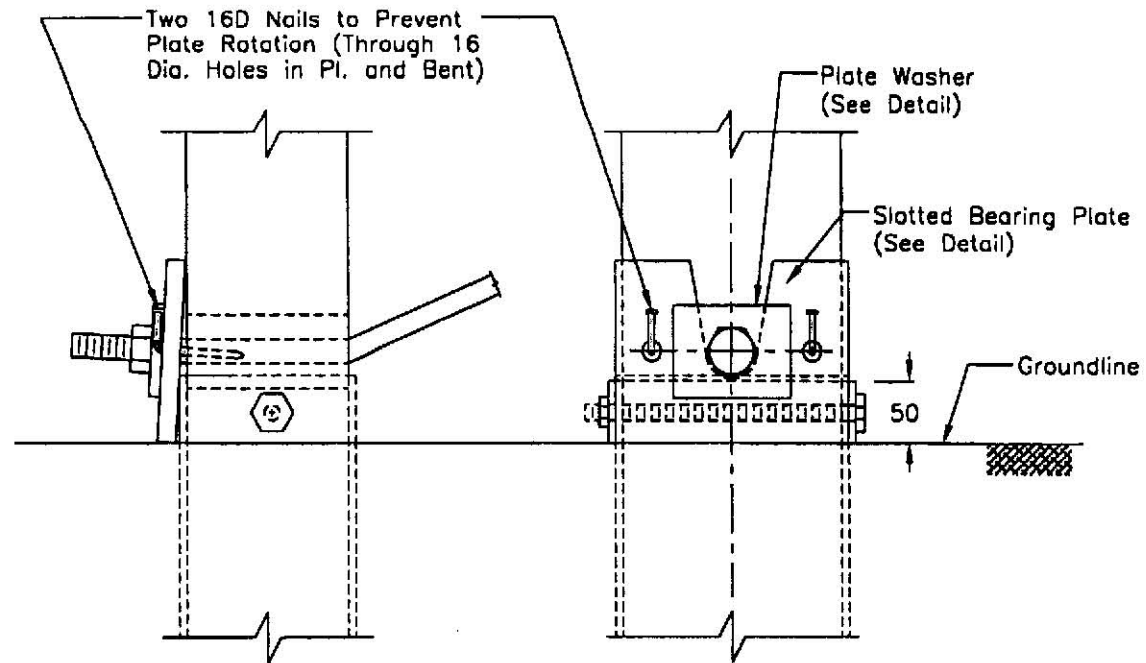
DETAIL D
SLOTGUARD

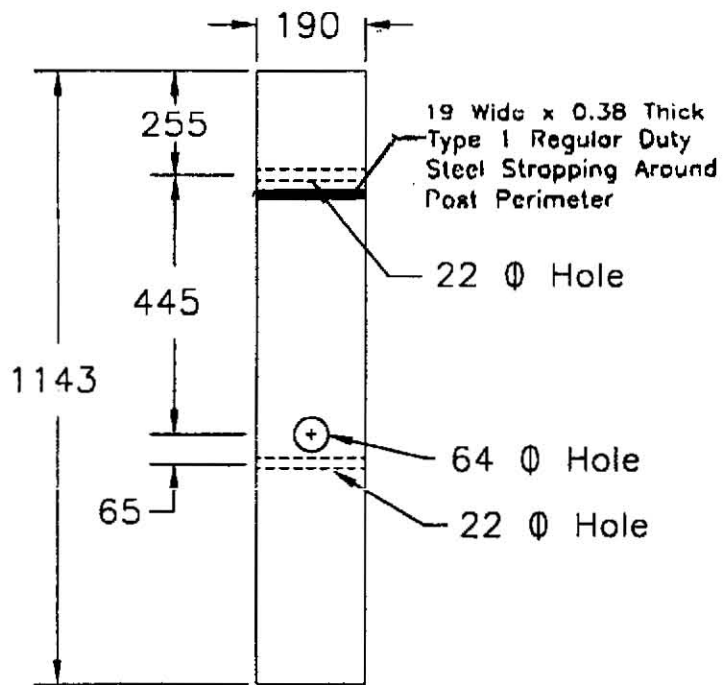
Enclosure 2 (2 of 5)



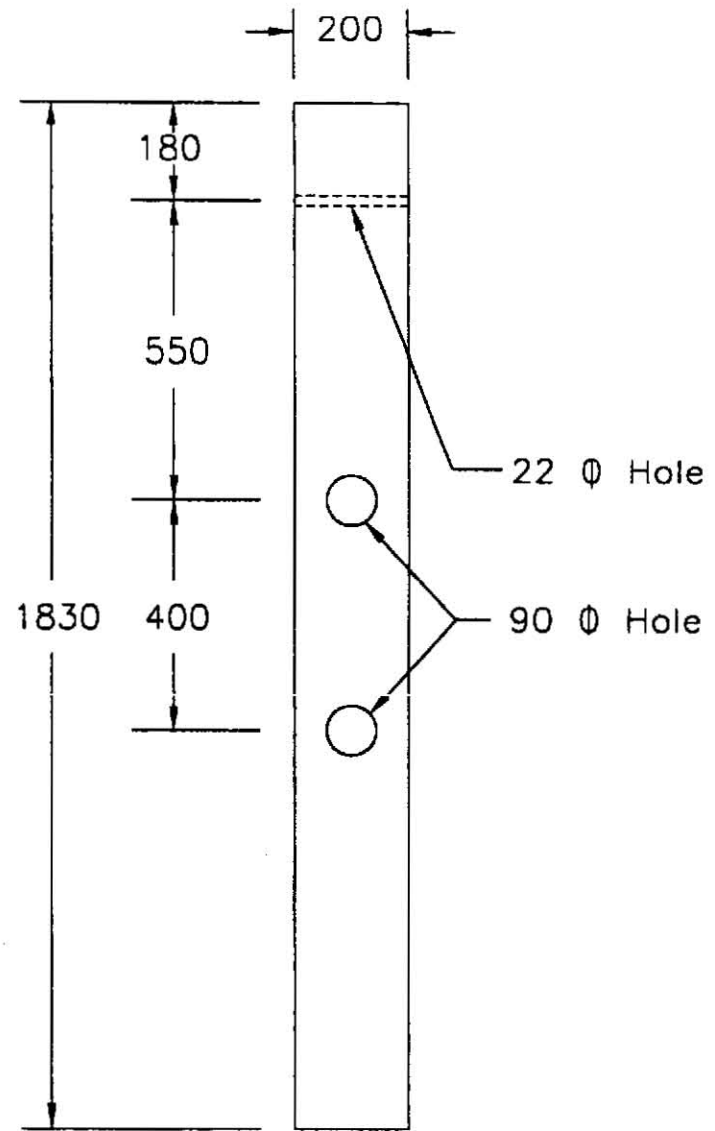
DETAIL E
 END ANCHORAGE ASSEMBLY

REVISED ON 1/15/99





DETAIL G
SHORT BREAKAWAY WOODEN POST



DETAIL H
WOODEN CRT POST

Table 1. Lateral Post Offset for End Offsets of 915, 1070 and 1220 mm

Post No.	Long. Distance (mm)	End Offset		
		915 mm	1070 mm	1220 mm
1	0	915	1070	1220
2	1905	565	705	850
3	3810	300	420	540
4	5080	170	270	375
5	6350	75	150	240
6	7620	20	70	135
7	8890	0	20	60
8	10160		0	15
9	11430			0

December 18, 2000

Mr. Rodney A. Boyd
Trinity Industries, Inc.
2525 Stemmons Freeway
Post Office Box 568887
Dallas, Texas 75356-8887

Refer to : HSA-1/CC72

Dear Mr. Boyd:

In his November 21 letter to Mr. Richard Powers of my staff, your consultant, Mr. James Albritton, requested the Federal Highway Administration's (FHWA) acceptance of a modified Slotted Rail Terminal (SRT) as an National Cooperative Highway Research Program (NCHRP) Report 350 test level 3 (TL-3) terminal for w-beam guardrail. To support this request, he also sent the Texas Transportation Institute (TTI) final report entitled "Testing and Evaluation of the Linear SRT with Steel HBA Posts," dated November 2000, and copies of the test video tapes.

The tested design consisted of an 11.4-m (37.5-foot) straight flare with the first post offset 1.2 m (4 feet) from the downstream guardrail. The two anchor posts were steel Hinged Breakaway (HBA) posts while the remaining posts were standard 1830-mm (6-foot) long CRT posts. The HBA posts were modified slightly from the design accepted for use with the ET-2000 terminal. These modifications included the use of 102 x 152 x 5 mm (4 x 6 x 3/16 in) soil tubes in lieu of W150 x 13 (W6 x 8.5) steel stub posts, and two parallel ground struts between post no. 1 and post no. 2. To prevent premature failure of the end post in a downstream hit, the rail to post attachment hole at post no. 1 was slotted to the end of the beam element. Enclosure 1 shows these and other design details.

You conducted three tests on your proposed design. These were NCHRP Report 350 tests 3-30, 3-31, and 3-35. Test 3-32, an 820-kg car impacting the terminal nose at 100 km/h and at a 15 degree angle, was conducted when the HBA posts were developed and tested with the tangent ET-2000. Satisfactory performance with these similar posts on the flared SRT can be safely assumed. Test 3-33, the test with a 2000-kg pickup truck under the same impact conditions as test 3-32, can also be waived. Test 3-34, a 20 degree impact at post no. 2 with the small car, was conducted under earlier tests of the original SRT design which has a more critical parabolic flare, rather than the straight flare of the linear SRT.

The design that you actually tested used four CRT posts. In reviewing the tests, all of which met Report 350 evaluation criteria, it was noted that the use of a standard line post at post no. 7 contributed to a relatively high roll angle in test 3-31 and to a higher than expected pitch angle in test 3-35. These results can be directly related to the vehicle striking post no 7 in both tests. After discussions between Mr. Richard Powers of my staff and Mr. Albritton, you agreed to specify a fifth CRT post at post position no. 7. This change from the tested design is reflected in drawing no. SS 351 dated December 12, 2000 (Enclosure 1). The summary results of the three tests you conducted are enclosed (Enclosure

2). Based on the results of test 3-35, the beginning length-of-need of the linear SRT is at post no. 3, approximately 3.8 m (12.5 feet) from the end.

Considering the above, the modified linear SRT terminal with an offset of 1.2 m (4 feet), two steel HBA posts, and five CRT posts may be considered acceptable for use on the National Highway System as a TL-3 w-beam terminal when such use is requested by a State or local transportation agency. As with all gating, non-energy absorbing terminals, it should not be used in locations where there is inadequate run out distance immediately behind and parallel to the railing itself. Based on the final position of the pickup truck in test 3-31, approximately 53 m (175 feet) of barrier proper should be used in advance of a fixed object hazard when a non-energy absorbing design like the SRT is used to terminate the barrier.

Sincerely yours,

(original signed by Rudolph M. Umbs)

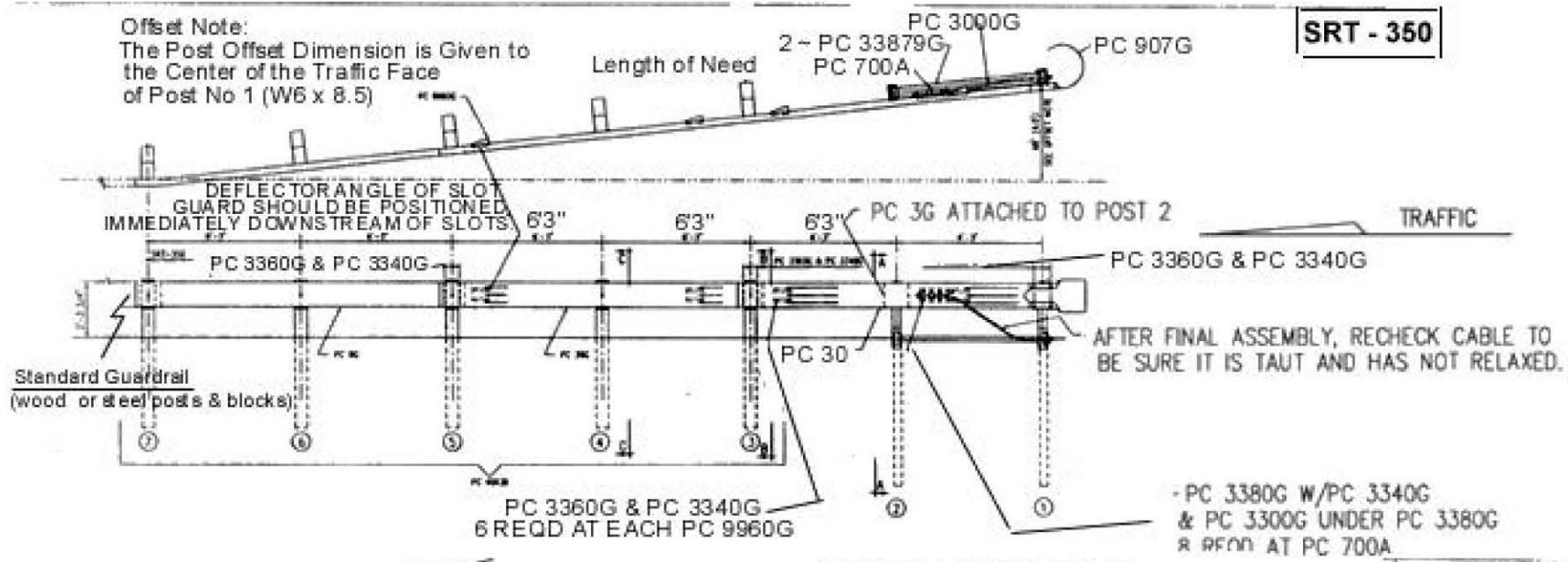
for

Frederick G. Wright, Jr.
Program Manager, Safety

2 Enclosures

SRT - 350

Offset Note:
The Post Offset Dimension is Given to the Center of the Traffic Face of Post No 1 (W6 x 8.5)



PC6718 W/ PC4258, PC4254 & PC6405
INSTALL WITH HEAD ON STRUT SIDE
W/WASHER & LOCKWASHER UNDER HEX NUT

PC 33879G

PC5355 W/ PC3701, PC4699 & PC3704
INSTALL WITH HEAD ON STRUT SIDE
W/WASHER & LOCKWASHER UNDER HEX NUT

DETAIL "G"
(● POST #1)

STACK 2-3 WASHERS ON 3/4" BOLT BETWEEN POST PLATE & STRUT TO ALLOW STRUT TO PASS OVER 3/8" BOLT HEAD.

PC 33879G

TRAFFIC

VIEW "H-H"
(● POST #2)

PC5156 W/ PC3701, PC4699 & PC3704 -
INSTALL WITH HEAD ON STRUT SIDE
W/WASHER & LOCKWASHER UNDER HEX NUT

DETAIL "H"
(● POST #2)

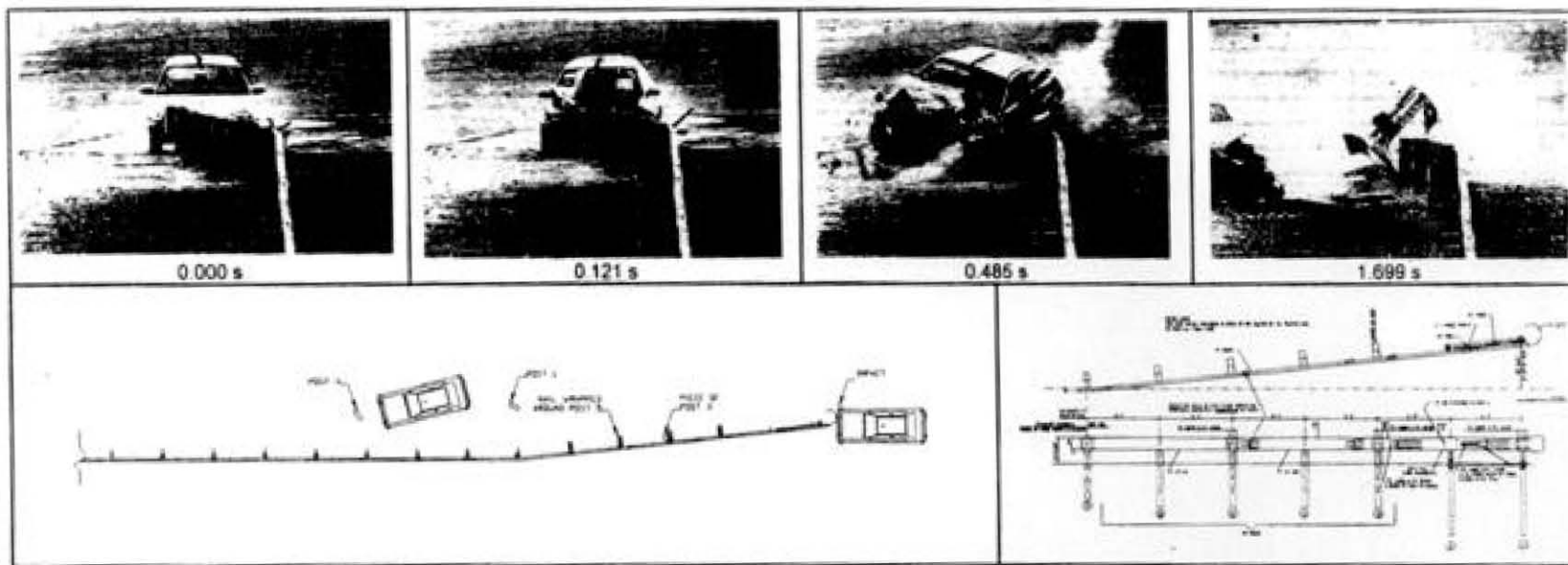
TRAFFIC SIDE

H

H

BILL OF MATERIAL

QTY	UNITS	DESCRIPTION
1	PC	PC 3000G
1	PC	PC 907G
2	PC	PC 33879G
1	PC	PC 700A
1	PC	PC 3380G
1	PC	PC 3340G
1	PC	PC 3360G
1	PC	PC 3G
1	PC	PC 30
1	PC	PC 3300G
1	PC	PC 9960G
1	PC	PC 6718
1	PC	PC 4258
1	PC	PC 4254
1	PC	PC 6405
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1	PC	



General Information

Test Agency Texas Transportation Institute
 Test No. 400001-SRT5
 Date 10/06/00

Test Article

Type Terminal
 Name Linear SRT with Steel HBA Posts
 Installation Length (m) 53.3
 Material or Key Elements Slotted Rail Panels with 1220 mm Linear Flare and Steel HBA Posts

Soil Type and Condition

..... Standard Soil, Dry

Test Vehicle

Type Production
 Designation 820C
 Model 1995 Geo Metro
 Mass (kg)
 Curb 868
 Test Inertial 820
 Dummy 76
 Gross Static 896

Impact Conditions

Speed (km/h) 102.0
 Angle (deg) 0.4

Exit Conditions

Speed (km/h) 25.4
 Angle (deg) 26.4

Occupant Risk Values

Impact Velocity (m/s)
 x-direction 7.3
 y-direction -0.2
 THIV (km/h) 26.6
 Ridedown Accelerations (g's)
 x-direction -12.1
 y-direction 7.4
 PHD (g's) 13.0
 ASI 0.70
 Max. 0.050-s Average (g's)
 x-direction -8.2
 y-direction 2.8
 z-direction -4.1

Test Article Deflections (m)

Dynamic 7.60
 Permanent 7.60

Vehicle Damage

Exterior
 VDS 12FD7
 CDC 12FDEW7
 Maximum Exterior
 Vehicle Crush (mm) 320
 Interior
 OCDI FS0010000

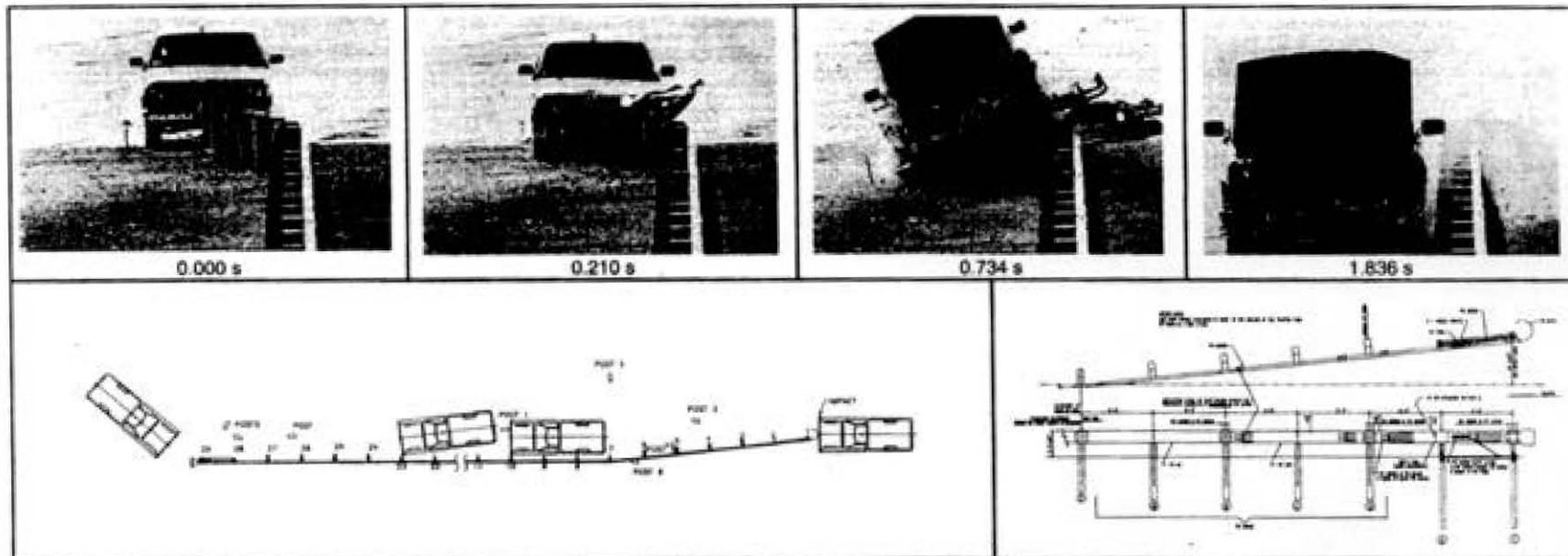
Max. Occ. Compart.

Deformation (mm) 431

Post-Impact Behavior

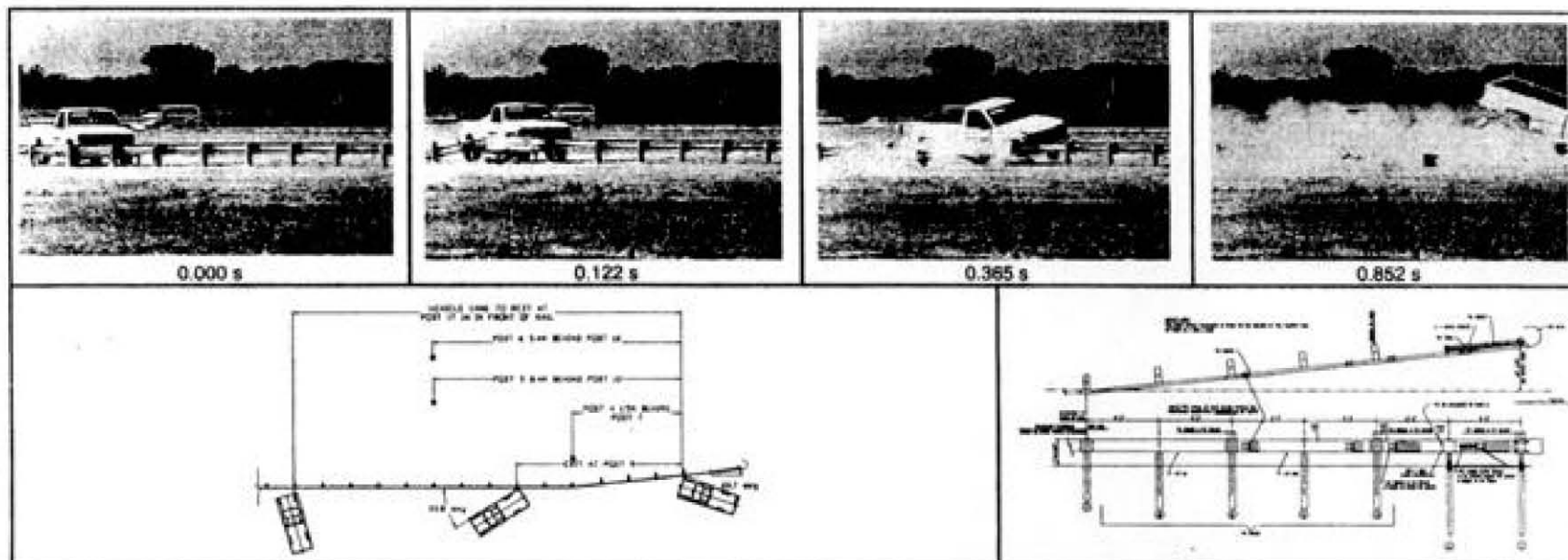
(during 1.0 s after impact)
 Max. Yaw Angle (deg) 25
 Max. Pitch Angle (deg) -12
 Max. Roll Angle (deg) -19

Figure 30. Summary of results for test 400001-SRT5, NCHRP Report 350 test 3-30.



General Information		Impact Conditions		Test Article Deflections (m)	
Test Agency	Texas Transportation Institute	Speed (km/h)	102.2	Dynamic	11.4
Test No.	220546-19	Angle (deg)	0	Permanent	11.4
Date	01/14/00	Exit Conditions		Vehicle Damage	
Test Article		Speed (km/h)	N/A	Exterior	
Type	Terminal	Angle (deg)	0	VDS	12FD2
Name	Linear SRT with Steel HBA Posts	Occupant Risk Values		CDC	12FDEW2
Installation Length (m)	53.3	Impact Velocity (m/s)		Maximum Exterior	
Material or Key Elements	Slotted Rail Panels with 1220 mm Linear Flare and Steel HBA Posts	x-direction	5.7	Vehicle Crush (mm)	490
Soil Type and Condition		y-direction	No contact	Interior	
Standard Soil, Dry		THIV (km/h)	20.6	OCDI	FS0000000
Test Vehicle		Ridedown Accelerations (g's)		Max. Occ. Compart.	
Type	Production	x-direction	-4.7	Deformation (mm)	
Designation	2000P	y-direction	3.0	nil	
Model	1994 Chevrolet 2500 Pickup Truck	PHD (g's)	6.6	Post-Impact Behavior	
Mass (kg)		ASI	0.46	(during 1.0 s after impact)	
Curb	1989	Max. 0.050-s Average (g's)		Max. Yaw Angle (deg)	-6
Test Inertial	2000	x-direction	-5.6	Max. Pitch Angle (deg)	6
Dummy	No dummy	y-direction	-1.3	Max. Roll Angle (deg)	26
Gross Static	2000	z-direction	2.8		

Figure 16. Summary of results for test 220546-19, NCHRP Report 350 test 3-31.



General Information

Test Agency Texas Transportation Institute
 Test No 400001-SRT2
 Date 07/11/00

Test Article

Type Terminal
 Name Linear SRT with Steel HBA Posts
 Installation Length (m) 53.3
 Material or Key Elements Slotted Rail Panels with 1220 mm Linear Flare and Steel HBA Posts

Soil Type and Condition

Standard Soil, Dry

Test Vehicle

Type Production
 Designation 2000P
 Model 1995 Chevrolet 2500 Pickup Truck
 Mass (kg)
 Curb 2153
 Test Inertial 2000
 Dummy No dummy
 Gross Static 2000

Impact Conditions

Speed (km/h) 100.2
 Angle (deg) 20.7

Exit Conditions

Speed (km/h) 50.7
 Angle (deg) 33.8

Occupant Risk Values

Impact Velocity (m/s)
 x-direction 4.7
 y-direction 3.8
 THIV (km/h) 21.1
 Ridedown Accelerations (g's)
 x-direction -6.9
 y-direction -7.4
 PHD (g's) 9.7
 ASI 0.60
 Max. 0.050-s Average (g's)
 x-direction -4.6
 y-direction -4.5
 z-direction 4.7

Test Article Deflections (m)

Dynamic 1.28
 Permanent 0.70

Vehicle Damage

Exterior
 VDS 01RFQ3
 CDC 01FREK3
 & 01RYEW3
 Maximum Exterior
 Vehicle Crush (mm) 360
 Interior
 OCCI FS0000000
 Max. Occ. Compart.
 Deformation (mm) 5
Post-impact Behavior
 (during 1.0 s after impact)
 Max. Yaw Angle (deg) -50
 Max. Pitch Angle (deg) -24
 Max. Roll Angle (deg) 17

Figure 23. Summary of results for test 400001-SRT2, NCHRP Report 350 test 3-35.

APPENDIX E – SKT APPROVAL LETTERS

The FHWA approval letters can be found on their web site at:

http://safety.fhwa.dot.gov/fourthlevel/hardware/term_cush.htm

April 2, 1997

Refer to: HNG-14

Mr. Kaddo Kothmann
President
Road Systems, Inc.
P.O. Box 2163
Big Spring, Texas 79721

Dear Mr. Kothmann:

Your March 4 letter to Mr. Gerald L. Eller provided the Federal Highway Administration (FHWA) information on the design and the crash-test performance of a new w-beam guardrail terminal named the Sequential Kinking Terminal (SKT-350). Design and performance details were contained in a March 1997 report from Southwest Research Institute entitled "Full-Scale Crash Evaluation of a Sequential Kinking Terminal (SKT-350)".

The SKT-350 is 15.2 m long and can be installed parallel to the roadway or with a 50:1 flare. Its major components include a 3.81-m w-beam rail section (modified by punching three 102-mm x 12.6-mm long slots in the "valley" of the rail centered at 267 mm, 546 mm, and 825 mm from the upstream end of the rail), an impact head assembly, a guide tube and guide rail assembly, and a breakaway cable anchorage assembly. Details for each of these components are included in the enclosed drawings SKT-1 through SKT-5.

When the SKT-350 is struck head-on, the impact head is forced rearward, bending the w-beam rail against the deflector plate which, in conjunction with a "kinker" beam in the head, causes short segments of rail to kink sequentially, and bend away from the impacting vehicle. For hits at and downstream from post 3 (the beginning of the length of need), the cable attachment transmits the tensile forces in the rail to the anchorage system to contain and redirect the impacting vehicle.

NCHRP Report 350 requires up to seven crash tests to determine the adequacy of a traffic barrier terminal/crash cushion at test level 3 (TL-3). Enclosure 2 is a summary of the results of the tests actually run on the SKT-350. We have noted that tests 3-34 and 3-39 were not run. Test 3-34 is a 100 km/h, 15 degree impact with an 820-kg car at the "critical impact point" which is approximately mid-way between the end of the terminal and the beginning of the length of need, i.e., at post number 2 for the SKT-350. Test 3-39 is a 100 km/h, 20 degree impact with a 2000-kg pickup truck at the mid-point of the terminal in a reverse direction. You stated that both tests were run previously on the ET-2000 and/or BEST terminals and that, because of the similarity of the three designs at the impact points specified for tests 3-34 and 3-39, these tests would be redundant, and hence, unnecessary for certification of the SKT-350. After reviewing the earlier tests and the details of the SKT-350 design, we agree that tests 3-34 and 3-39 are not needed. However, we note that in the reverse direction tests (test 3-39) with both the ET-2000 and the BEST, the impact heads were dislodged from the w-beam rail and were propelled approximately 60 m downstream in a line that was essentially parallel to the barrier installation. Under some site

and roadway alignment conditions this head could become a hazard to other motorists. We assume that the SKT-350 head would act the same, and that users be advised accordingly. Based on our analysis of the information you provided, we conclude that the SKT-350 terminal meets the appropriate evaluation criteria contained in NCHRP Report 350 and may be considered acceptable for use on projects on the National Highway System (NHS) when selected by a State highway agency. In addition to the design tested, we also agree that the post/foundation tube combinations shown in Enclosure 3 are acceptable for use with the SKT-350 without additional testing.

Since your product is proprietary, its use on Federal-aid highway projects, except exempt, non-NHS projects, is subject to the conditions stated in Title 23, Code of Federal Regulations, Section 635.411. If you have any questions, please call Mr. Hatton at (202) 366-1329 or Mr. Richard Powers at (202) 399-1320.

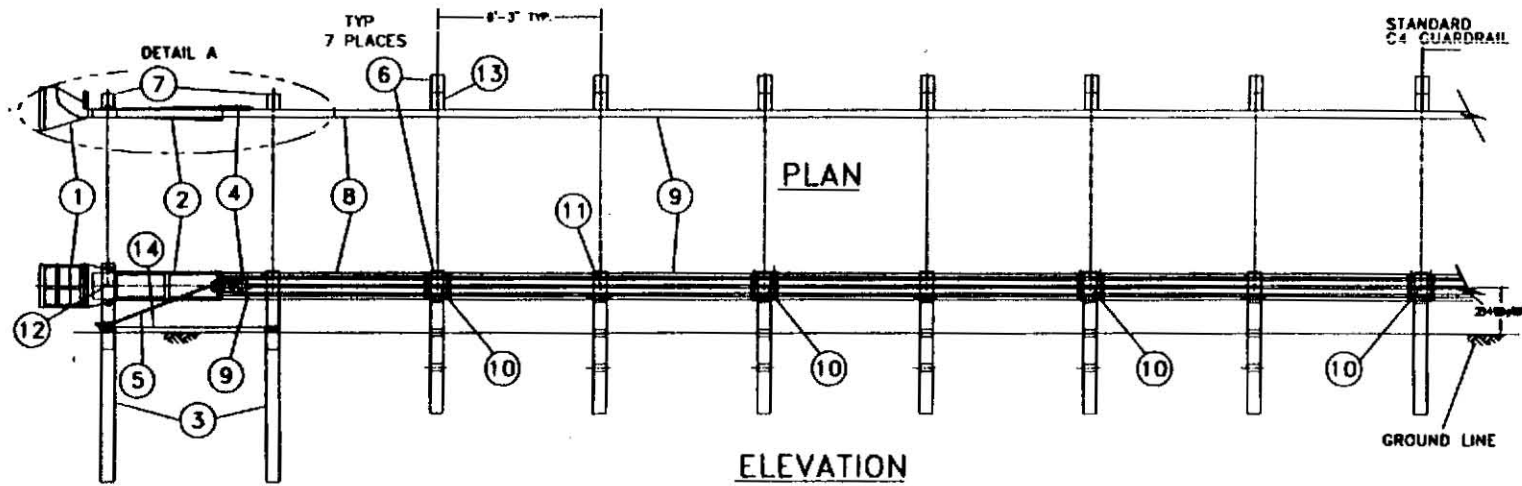
Sincerely yours,

(original James H. Hatton, Jr.)

for Dwight A. Horne, Chief
Federal-Aid and Design Division

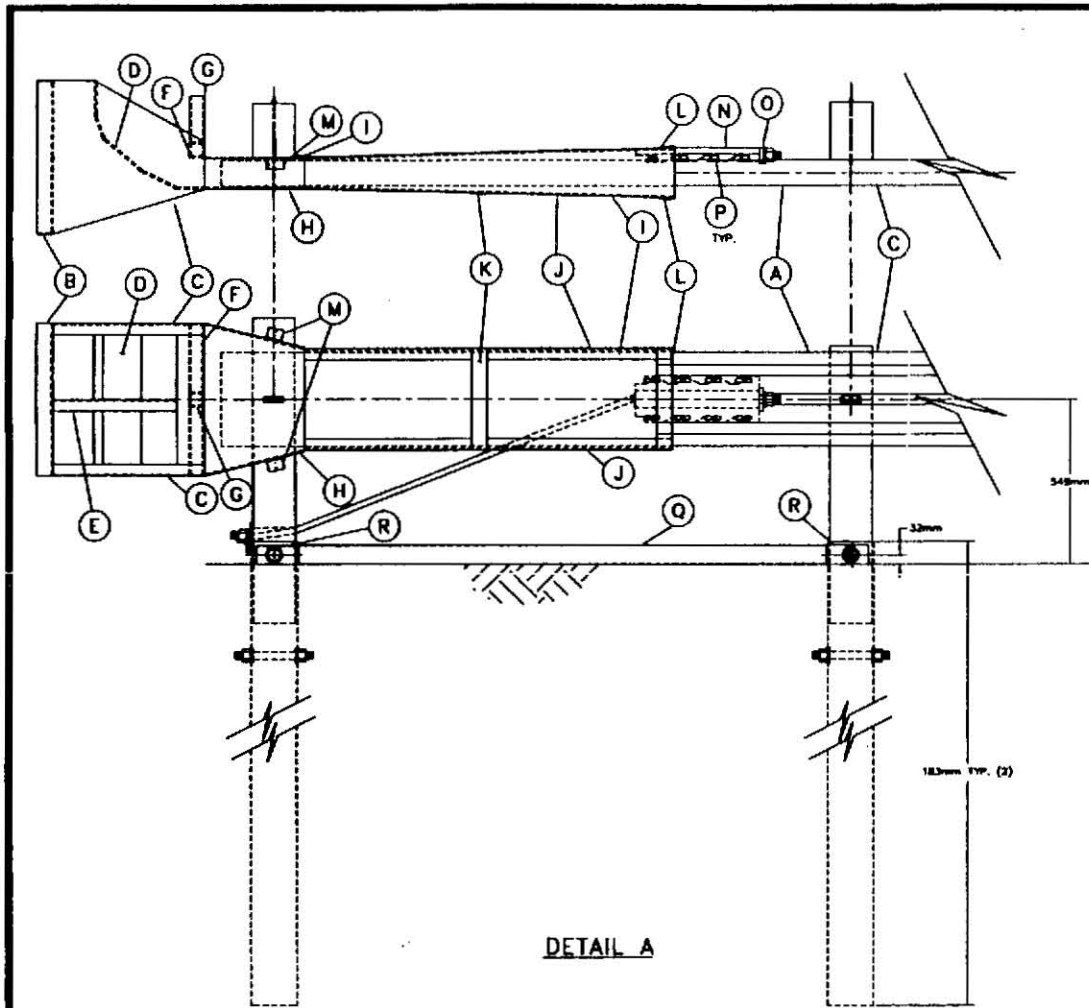
3 Enclosures
Acceptance Letter CC-40

ITEM NO.	QTY	DESCRIPTION	DWG NO. AND PART NO
1	1	IMPACT HEAD ASSY	SKT-1: B,C SKT-2: D,E,F,G
2	1	GUIDE RAIL AND GUIDE TUBE ASSY	SKT-3: H,I,J,K,L,M
3	2	FOUNDATION SLEEVE (B-4)	SKT-4
4	1	CABLE RELEASE BRACKET ASSY	SKT-5: N,O,P
5	1	BCT CABLE ANCHOR ASSEMBLY	-
6	6	PDE09 6" x 8" x 6'-0" CRT TIMBER POST (POSTS 3 THRU 8)	-
7	2	PDF01 5.5" x 7.5" x 42.5" BCT TIMBER POST (POSTS 1 & 2)	-
8	1	W-BEAM TERMINAL RAIL SECTION (12'-6")	SKT-1: A
9	3	2-SPACE OR 4 SPACE W-BEAM GUARDRAIL (12'-6" SECTION)	-
10	32	FBB01 GUARDRAIL SPLICE BOLT & RECESSED NUT	-
11	7	FBB04 GUARDRAIL BOLT AND RECESSED NUT (POSTS 2 THRU 8)	-
12	1 ea	1/2" ALL THREAD BOLT w/WASHER & NUT (POST 1)	-
13	6	PDB01 W-BEAM TIMBER BLOCKOUT (POSTS 3 THRU 8)	-
14	1	GROUND LINE STRUT ASSY	SKT-5: Q, R



**SEQUENTIAL KINKING TERMINAL
(SKT-350) ASSEMBLY**

DESIGNED BY	DATE	DWG NO.	PK. OF
LS	11/22/06	ASSY	1 2
REVISIONS			



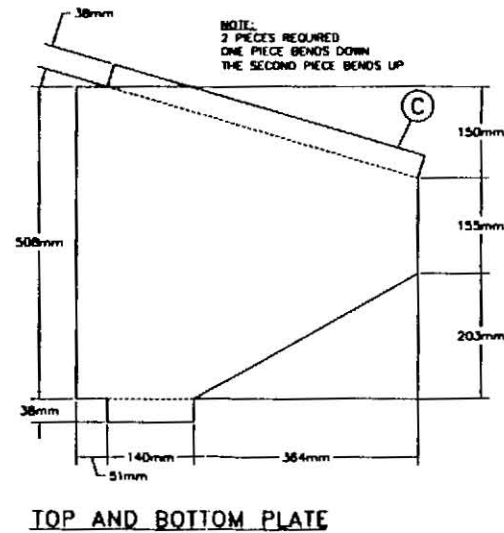
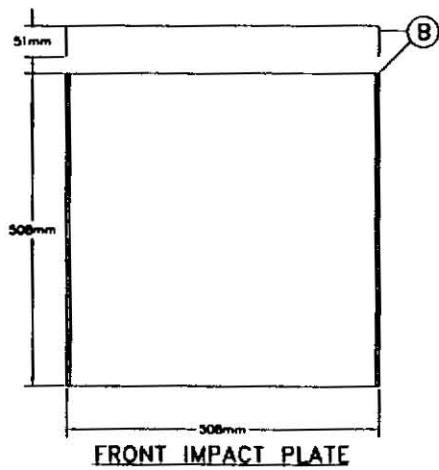
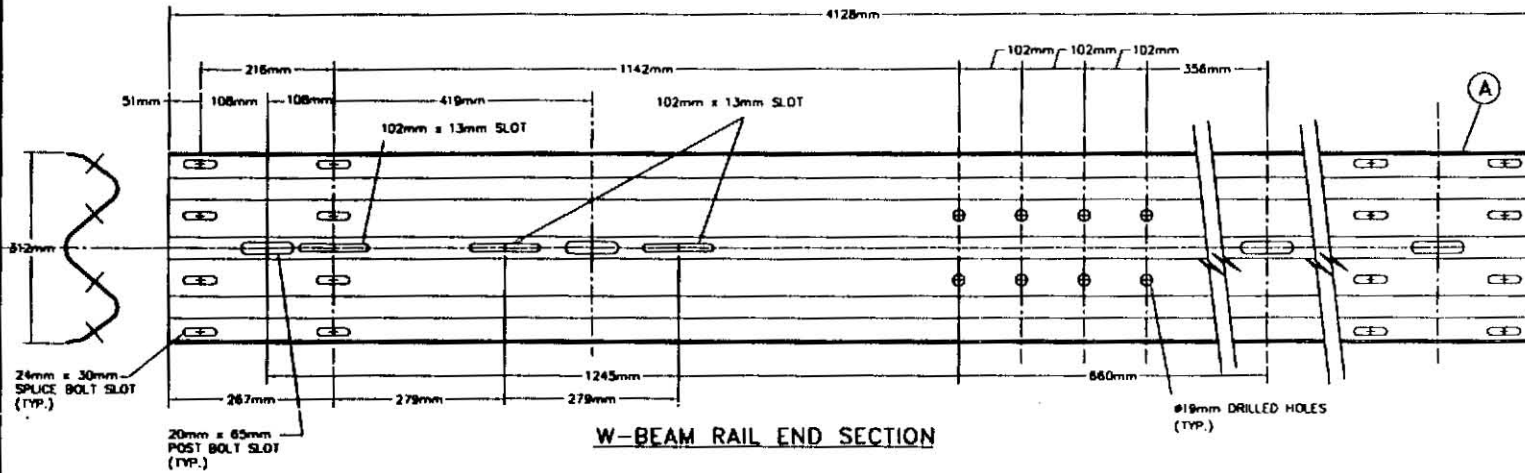
ITEM NO.	DESC. NO.	QTY	DESCRIPTION
A	SKT-1	1	W-BEAM TERMINAL RAIL SECTION (REF)
B	SKT-1	1	FRONT IMPACT PLATE
C	SKT-1	2	TOP AND BOTTOM PLATES
D	SKT-2	1	DEFLECTOR PLATE
E	SKT-2	1	GUSSET PLATE
F	SKT-2	1	KINKER BEAM
G	SKT-2	1	POST BREAKER BEAM
H	SKT-3	1	GUIDE TUBE
I	SKT-3	1	GUIDE TUBE STRAP
J	SKT-3	2	GUIDE RAIL CHANNELS
K	SKT-3	1	CENTER GUIDE RAIL STRAP
L	SKT-3	2	END GUIDE RAIL STRAPS
M	SKT-3	2	POST ANGLES
N	SKT-5	1	CABLE RELEASE BRACKET
O	SKT-5	1	CABLE RELEASE PLATE
P	SKT-5	8	SLEEVED BOLTS
Q	SKT-5	1	GROUND STRUT
R	SKT-5	2	YOKES
	SKT-6	-	WELDING SPECIFICATIONS

DETAIL A

SEQUENTIAL KINKING TERMINAL
(SKT-350) ASSEMBLY

DESIGNED BY	DATE	REV. NO.	REV. OF
LS	11/22/06	ASSY2	2 2

ITEM NO.	QTY	DESCRIPTION	MATERIAL
A	1	RAIL END SECTION	12 GA. W-BEAM
B	1	FRONT IMPACT PLATE	10 GA. 50 ksi PLATE
C	2	TOP AND BOTTOM PLATES	10 GA. 50 ksi PLATE

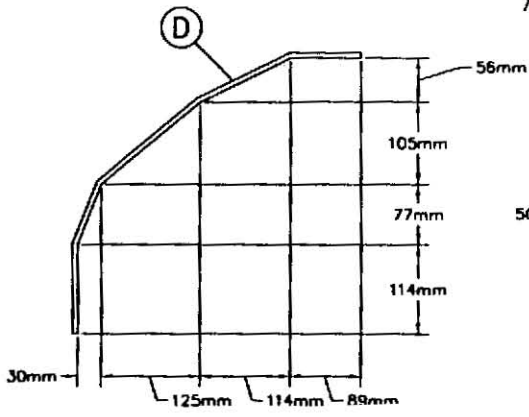


SEQUENTIAL KINKING TERMINAL (SKT-350)			
W-BEAM RAIL END SECTION			
FRONT IMPACT PLATE			
TOP AND BOTTOM PLATES			
DESIGNED BY	DATE	REV. NO.	REV. BY
LS	11/22/98	SKT-1	1 1
DRAWN BY			

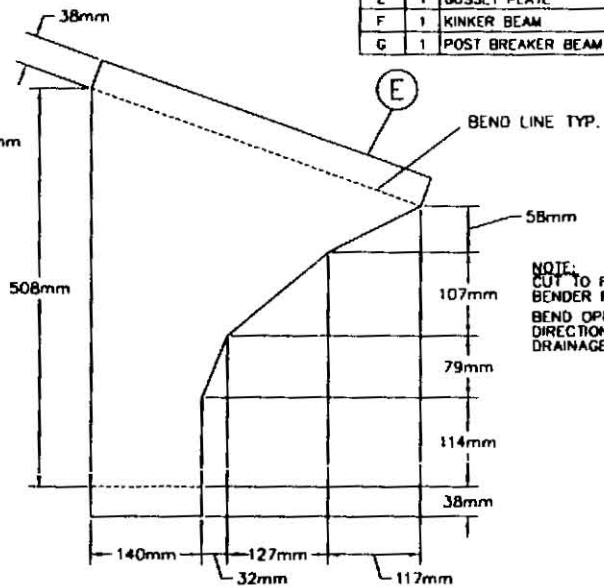
7 10 C 12311C



ITEM NO.	QTY	DESCRIPTION	MATERIAL
D	1	DEFLECTOR PLATE	A36 1/4" PLATE
E	1	GUSSET PLATE	10 GA. 50 ksi PLATE
F	1	KINKER BEAM	51mm x 51mm x 1/4" A500 GRADE B
G	1	POST BREAKER BEAM	51mm x 51mm x 1/4" A500 GRADE B

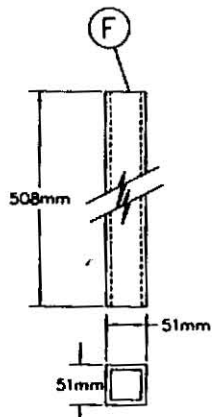


DEFLECTOR PLATE

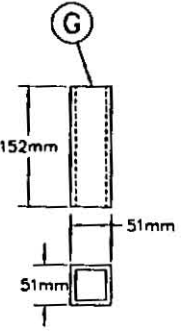


GUSSET PLATE

NOTE:
CUT TO FIT BACK OF
BENDER PLATE
BEND OPPOSITE
DIRECTIONS FOR
DRAINAGE

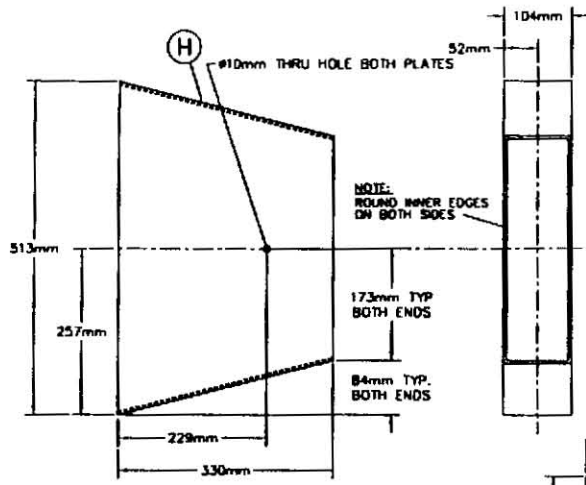


KINKER BEAM

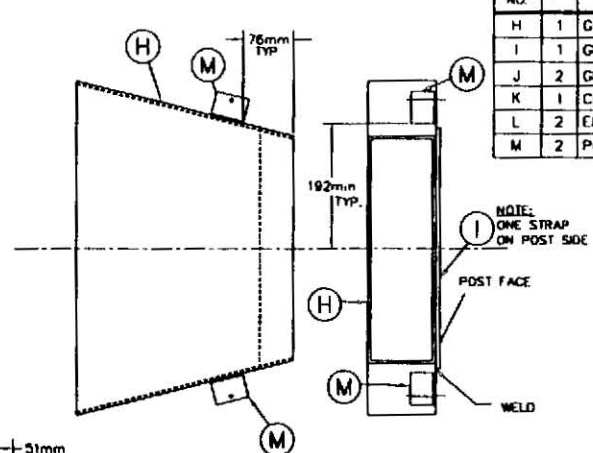


POST BREAKER BEAM

SEQUENTIAL KINKING TERMINAL (SKT-350)			
DEFLECTOR PLATE			
GUSSET PLATE			
KINKER BEAM			
POST BREAKER BEAM			
Drawn by	DATE	REV. NO.	REV. DATE
LS	11/22/96	SKT-2	1 1

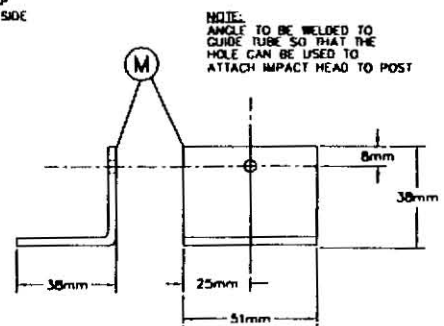


GUIDE TUBE

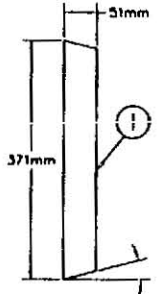


**GUIDE TUBE,
POST ANGLE AND
GUIDE TUBE STRAP ASSEMBLY**

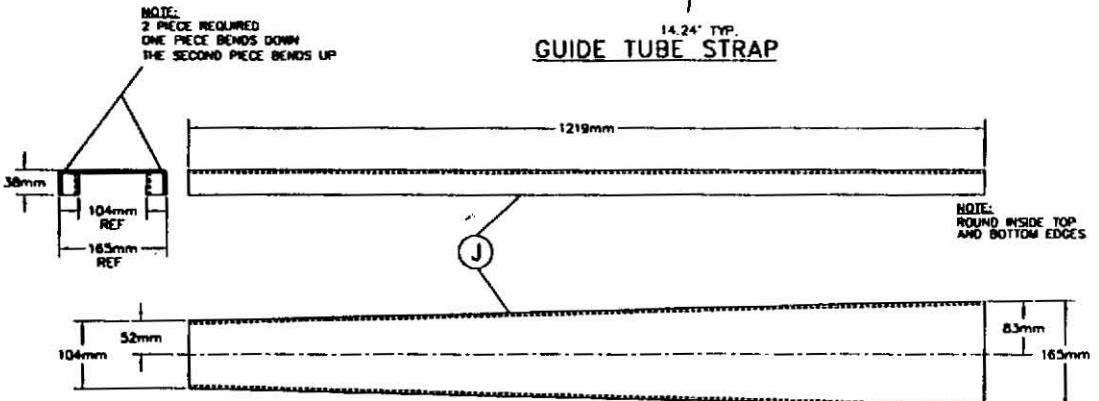
ITEM NO.	QTY	DESCRIPTION	MATERIAL
H	1	GUIDE TUBE	10 GA. 50 ksi PLATE
I	1	GUIDE TUBE STRAP	6mm 50 ksi PLATE
J	2	GUIDE RAIL CHANNELS	10 GA. 50 ksi PLATE
K	1	CENTER GUIDE RAIL STRAP	10 GA. 50 ksi PLATE
L	2	END GUIDE RAIL STRAPS	12.7mm 50 ksi PLATE
M	2	POST ANGLES	A36 3mm PLATE



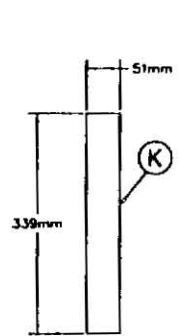
POST ANGLE



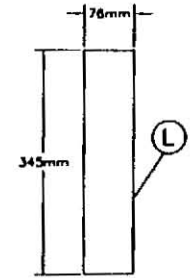
GUIDE TUBE STRAP



GUIDE RAIL CHANNEL



**CENTER GUIDE
RAIL STRAP**

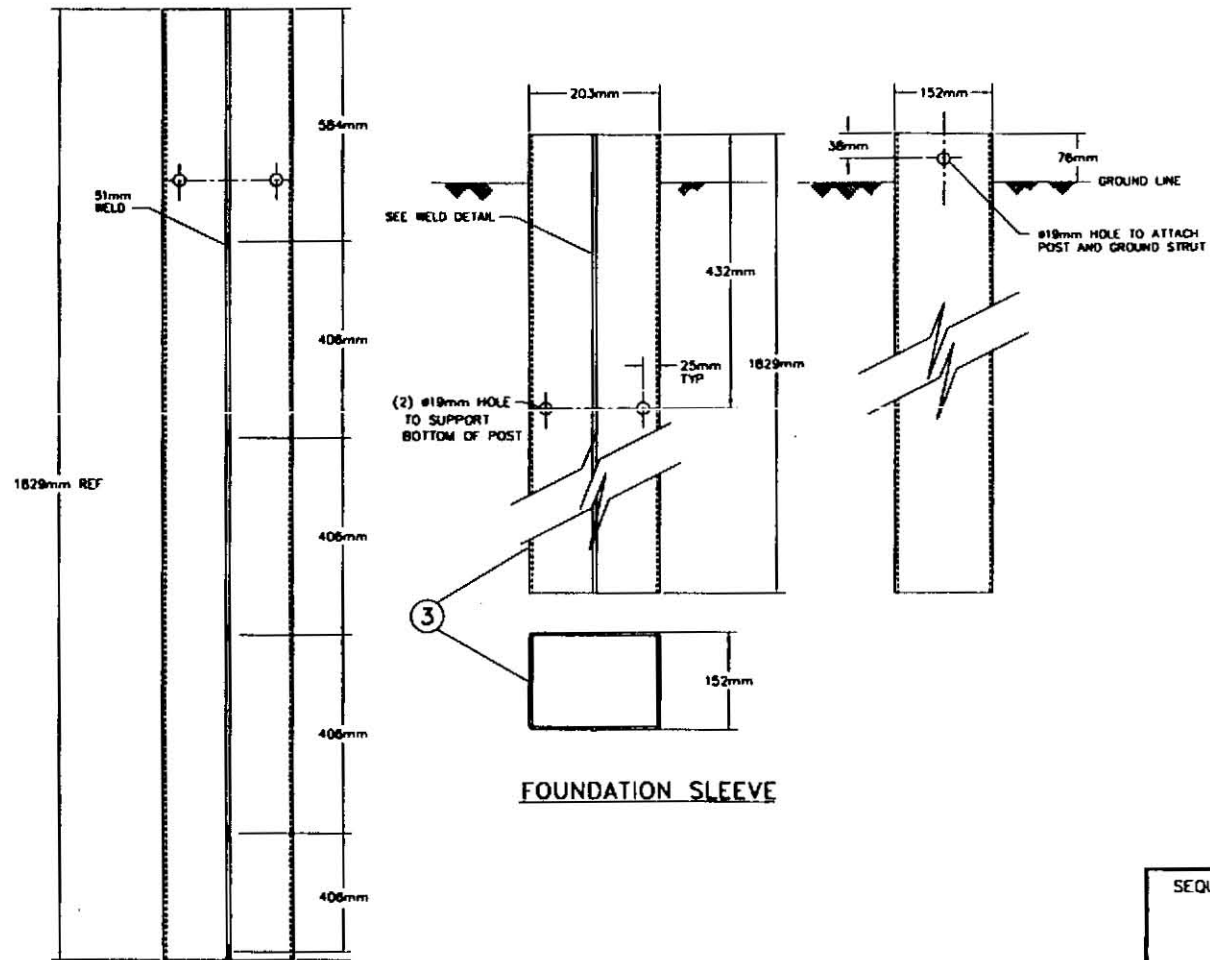


**END GUIDE
RAIL STRAP**

SEQUENTIAL KINKING TERMINAL (SKT-350)			
GUIDE TUBE			
GUIDE TUBE STRAP			
GUIDE RAIL CHANNELS			
CENTER GUIDE RAIL STRAP			
END GUIDE RAIL STRAPS			
POST ANGLES			
DESIGNED BY	DATE	REVISED BY	REVISED DATE
LS	11/22/96	SKT-3	1 1



ITEM NO.	QTY	DESCRIPTION	MATERIAL
3	2	FOUNDATION SLEEVE	50 ksi 3mm PLATE

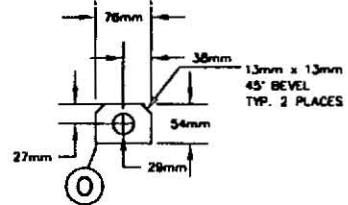
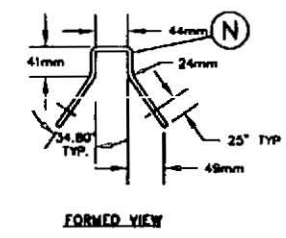
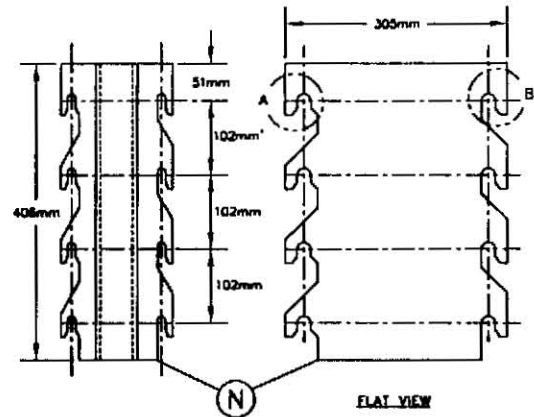
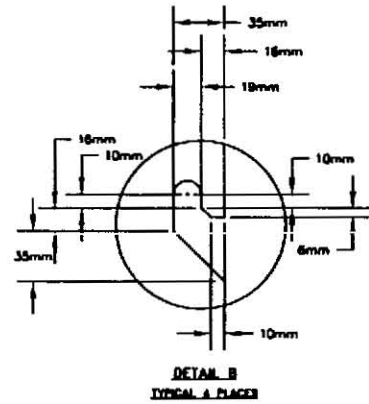
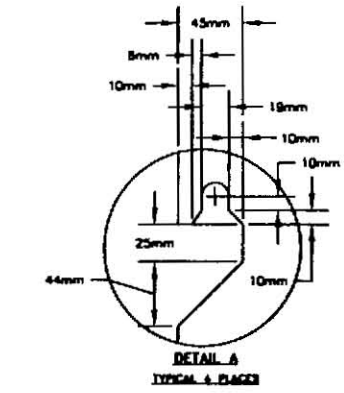


WELD DETAIL
NOT TO SCALE

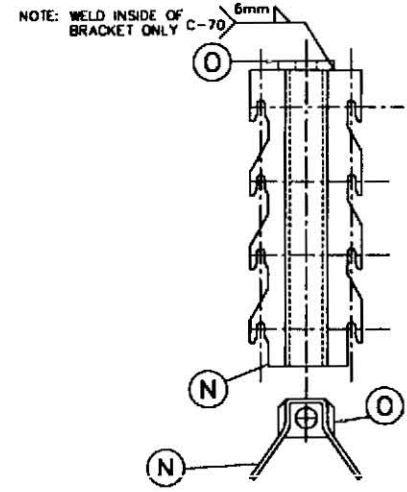
FOUNDATION SLEEVE

SEQUENTIAL KINKING TERMINAL (SKT-350)			
FOUNDATION SLEEVE			
Drawn BY	DATE	ISSUED BY	PG. OF
LS	11/22/00	SKT-4	1 1
REVISION DATE			

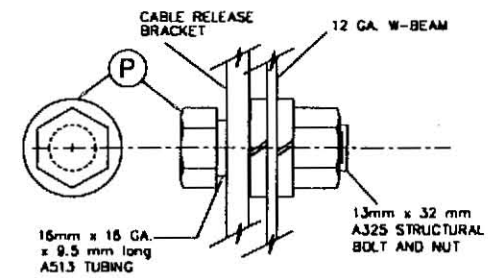
ITEM NO.	QTY	DESCRIPTION	MATERIAL
N	1	CABLE RELEASE BRACKET	A36 3mm PLATE
O	1	CABLE RELEASE PLATE	A36 13mm PLATE
P	8	QUICK RELEASE BOLTS	A325
Q	1	GROUND STRUT	54mm x 54mm x 14 GA TUBING
R	2	YOKES	A36 5mm PLATE



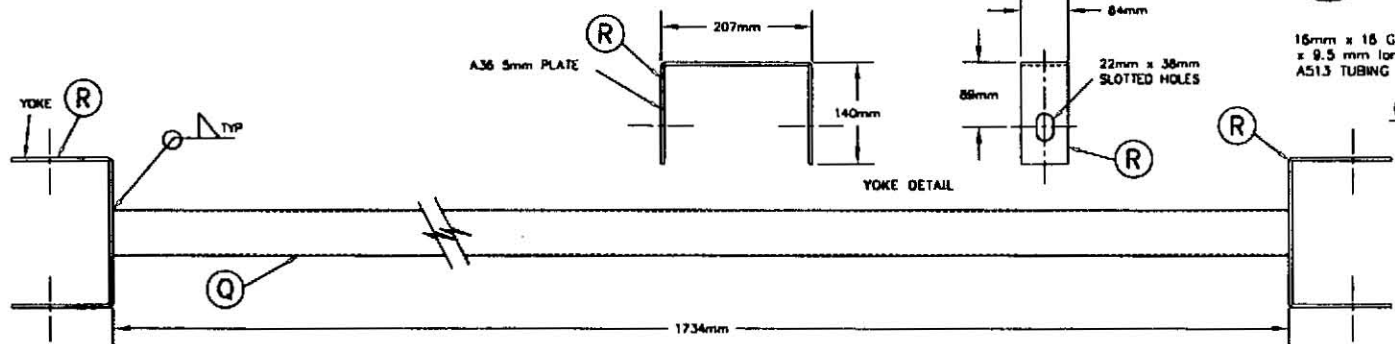
CABLE RELEASE BRACKET CABLE RELEASE PLATE



CABLE RELEASE ASSEMBLY



QUICK RELEASE BOLT



GROUND STRUT ASSEMBLY

SEQUENTIAL KINKING TERMINAL (SKT-350)			
CABLE RELEASE BRACKET			
CABLE RELEASE PLATE			
SLEEVED BOLT			
GROUND STRUT			
YOKES			
DRAWN BY	DATE	REV. NO.	PC. OF
LS	11/22/96	SKT-5	1 1
REVISION DATE			

TABLE 1. SUMMARY OF CRASH TEST RESULTS

Test No.	Test Designation and Description	Actual Impact Conditions		Occupant Risk				Comments	Assessment
		Speed (km/h)	Angle (Deg.)	OIV (m/s)		RA (g's)			
				Long.	Lat.	Long.	Lat.		
SBD-1	Test 3-35 - Pickup truck redirection.	99.8 (62.0 mph)	20.0	5.7	1.7	-4.2	8.4	Maximum deflection = 0.8 m (31.5 in.). Length of contact = 7.6 m (24.9 ft). Posts 3 through 8 fractured.	PASS
SBD-2	Test 3-31 - Pickup truck end-on.	100.1 (62.2 mph)	0	4.3	2.0	-21.4	-16.3	Deformed bumper blocked exit of kinked rail and limited kinking to approx. 1.3 m (4 ft). Posts 1 through 7 broken off. Test judged unsatisfactory due to excessive long, ridedown acceleration.	FAIL
SBD-3	Test 3-31 - Pickup truck end-on.	100.1 (62.2 mph)	0	5.9	1.5	-7.6	5.4	Repeat of test SBD-2 with modified impact head. Posts 1 through 9 broken off. Approx. 15 m (50 ft) of rail fed through impact head.	PASS
SBD-4	Test 3-30 - Small car end-on.	98.5 (61.2 mph)	0	6.4	3.6	-5.6	3.9	Actual point of impact on front of vehicle was offset 584 mm (23 in.) instead of the nominal 381 mm (15 in.). Posts 1 through 4 broken off and approx. 4.5 m (15 ft) of the rail fed through impact head prior to the vehicle exiting. Vehicle yawed clockwise a total of 360 degrees.	PASS
SBD-5	Test 3-32 - Small car end-on at an angle.	100.1 (62.2 mph)	15.0	7.4	1.5	-9.6	-3.1	Posts 1 through 3 broken off with approx. 2.5 m (8 ft) of rail fed through impact head. Vehicle bent rail at post 4 and exited behind guardrail.	PASS
SBD-6	Test 3-33 - Pickup truck end-on at an angle.	100.1 (62.2 mph)	15.0	5.1	1.8	-13.9	13.3	Posts 1 through 3 broken off with approx. 1.5 m (5 ft) of rail fed through impact head. Vehicle bent rail at post 4 and exited behind guardrail.	PASS

TABLE 2. PROPOSED SKT-350 POST OPTIONS

SKT-350 Design Options	No. Of New 1.9 m (6 ft) Long, 3.2 mm (1/8 in.) Thick Foundation Tubes	No. of PTE05 Foundation Tubes with PLS03 Soil Plates	No. of CRT Posts
A	2	0	6
B	2	2	4
C	2	6	0
D	0	4	4
C	0	8	0



US Department
of Transportation
**Federal Highway
Administration**

400 Seventh St., S.W.
Washington, D.C. 20590

August 27, 1999

Refer to: HMHS-CC61

Mr. Kaddo Kothmann
President
ROAD SYSTEMS, INC.
P.O. Box 2163
Big Spring, Texas 79721

Dear Mr. Kothmann:

In your July 30 letter, you requested the Federal Highway Administration's (FHWA) acceptance of a steel breakaway post as an alternative to the weakened timber posts that are currently used in your SKT-350 and FLEAT-350 w-beam guardrail terminals. These breakaway posts are comprised of a lower stub post connected to an upper post by splice plates welded to the flanges of the stub post along the bottom and sides of the plates and connected to the upper post with two 31-mm diameter plug welds. This design causes the plug welds to yield at relatively low loads when the posts are struck head on and the welds are loaded in torsion, but the connection can sustain loads as high as 89 KN when loaded laterally in shear. Enclosure 1 shows the breakaway end posts, the breakaway line posts, and the splice weld details. All other features of the SKT-350 and the FLEAT-350 remain unchanged from the original designs.

To show that the steel breakaway posts functioned as desired, you ran three tests on the alternative design, and provided me with copies of the test reports for staff review. Summaries of each of the tests are shown in Enclosure 2.

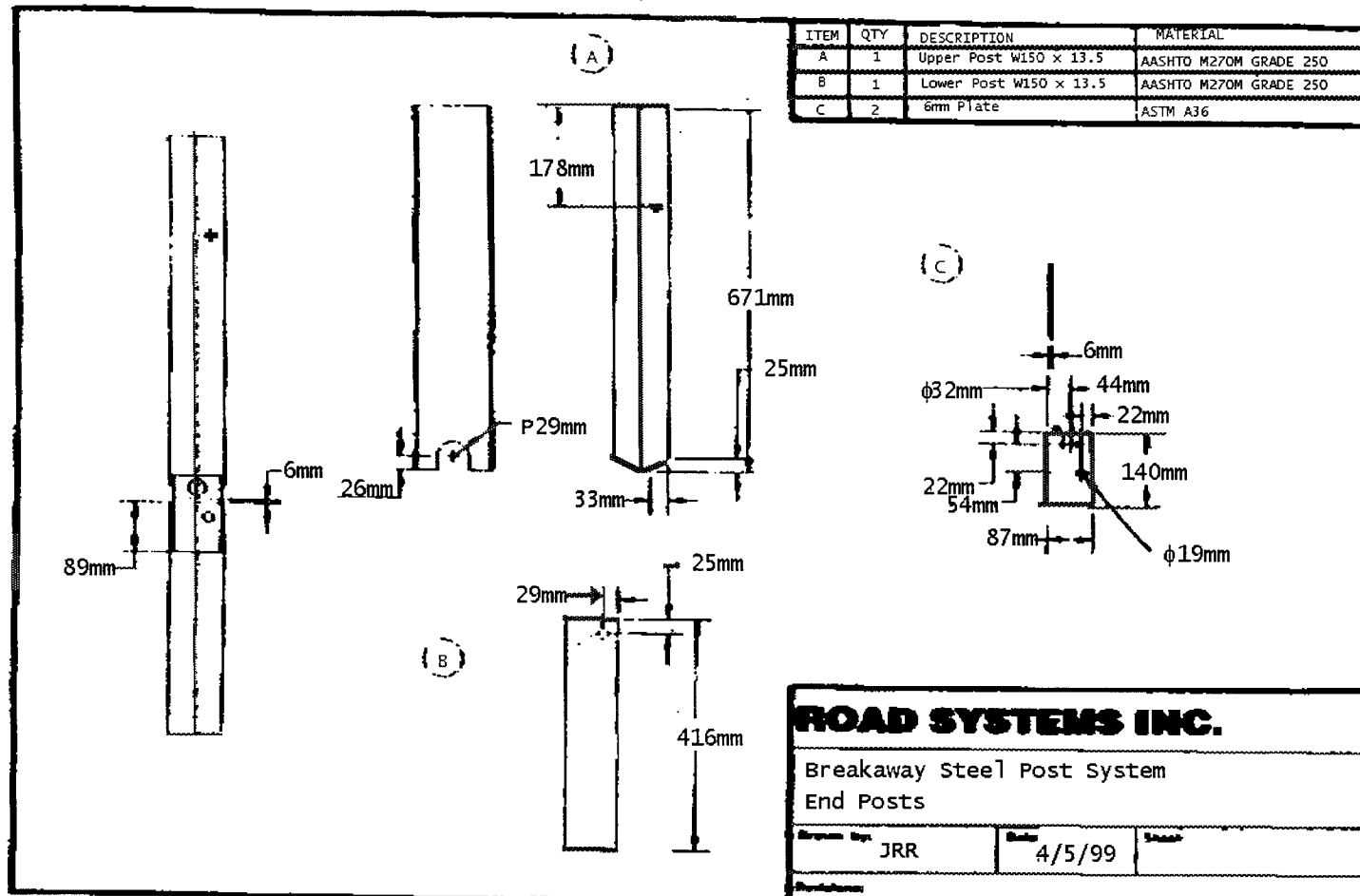
We believe that the tests you ran satisfactorily demonstrate that the steel breakaway posts are an acceptable alternative to the original wood post designs for the SKT-350 and the FLEAT-350 and may be used as such on the National Highway System when requested by a transportation agency.

Sincerely yours,

Dwight A. Horne
Director, Office of Highway Safety Infrastructure

2 Enclosures

Figure 9. Steel Breakaway End Post



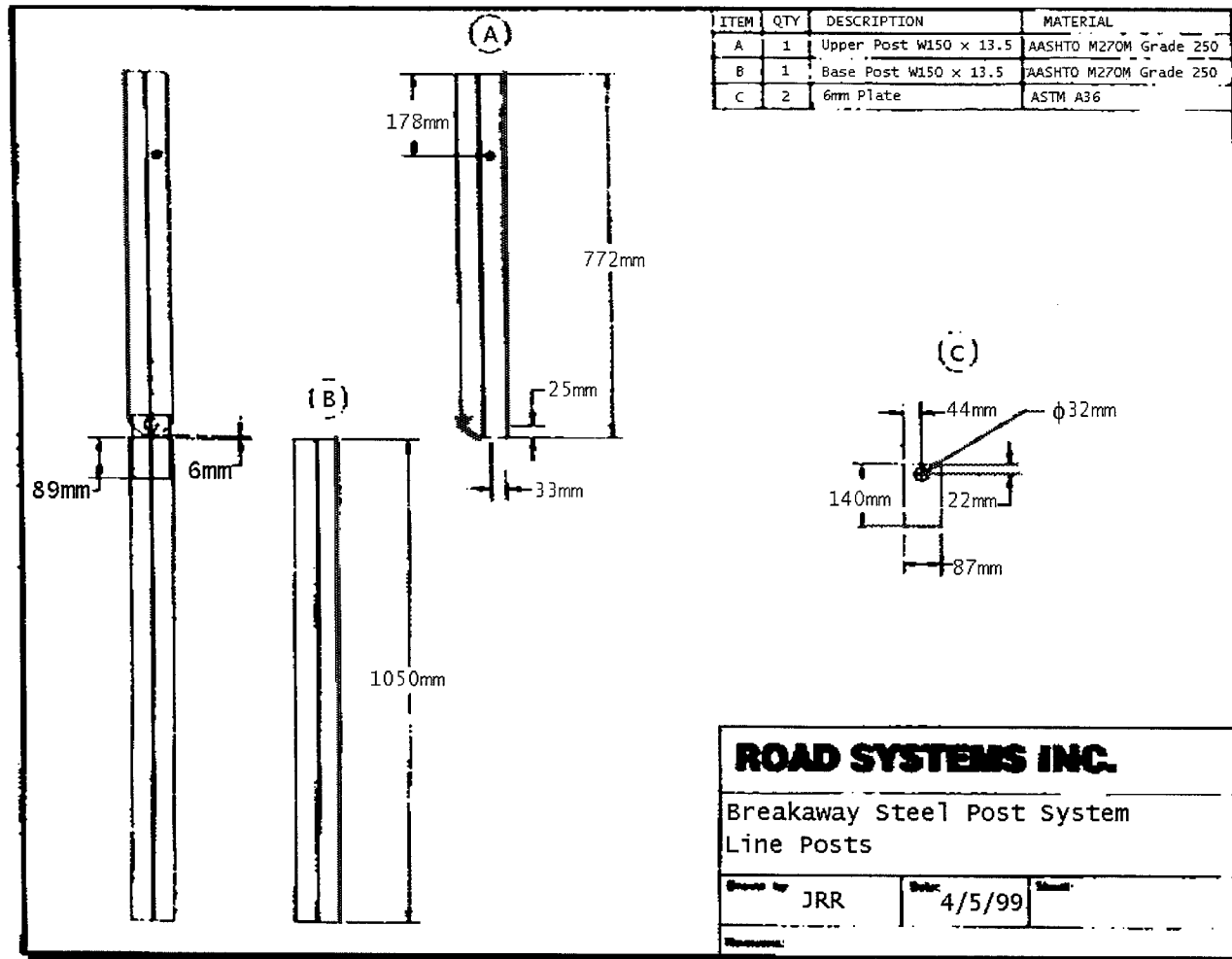
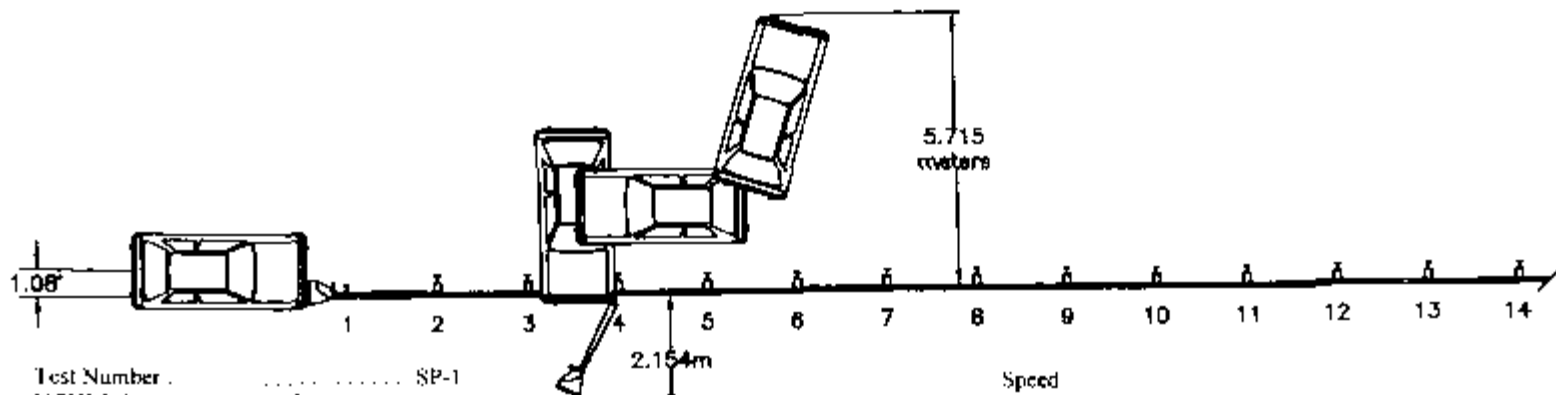
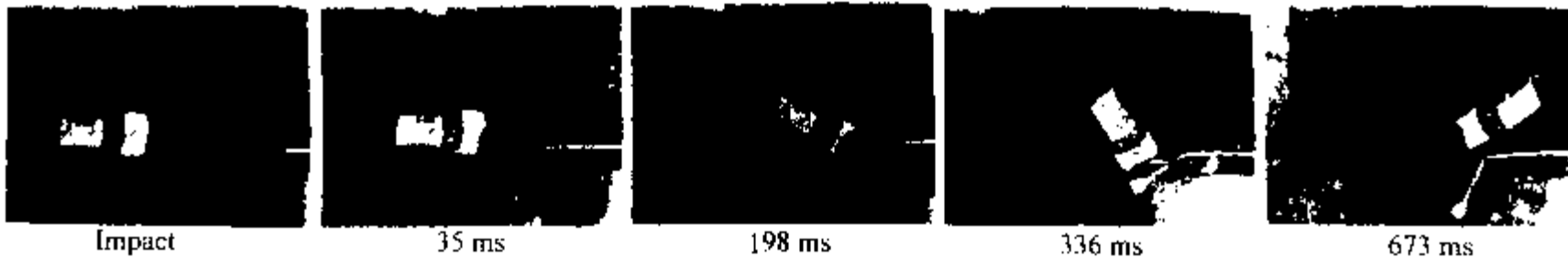


Figure 11. Steel Breakaway Line Post

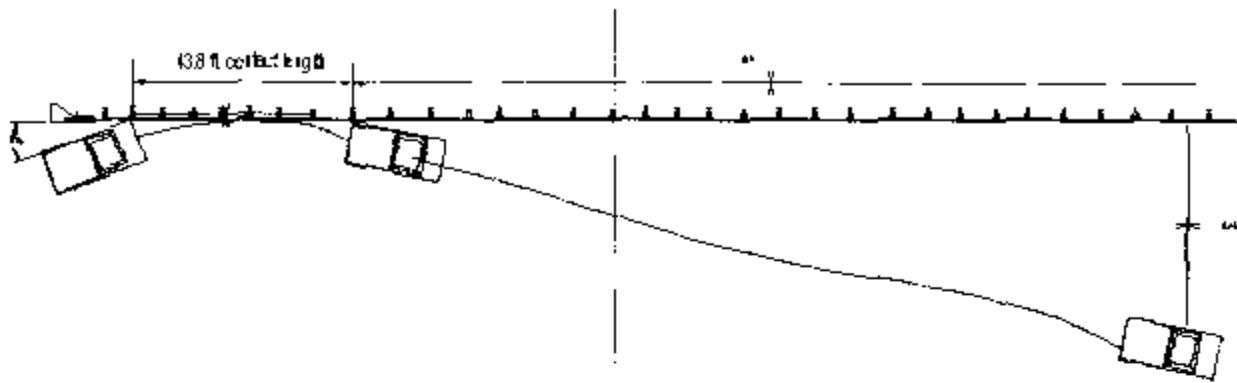


Test Number	SP-1
NCHRP 350 Test Designation	3-31
Date	2/2/98
Installation	Sequential Kinking Terminal
System length	41.91 m
Head Dimensions (LxWxH)	2104 mm x 508 mm x 508 mm
Face Angle	0.0 degrees
Guardrail	12-gauge W-beam
End Terminal Posts	
Number 1	W150x13.5 BCT steel post, 1080 mm long in SKT foundation tube w/ modified groundline strut to post 2
Number 2	W150x13.5 BCT steel post, 1830 mm long in SKT foundation tube w/ modified groundline strut and 200x150x360 mm routed timber block
Numbers 3-8	W150x13.5 CRT steel posts, 1830 mm long w/ 200x150x360 mm routed timber block
Vehicle Model	1993 Ford Festiva Compact Car
Vehicle Weight	
Curb	795 kg
Test Inertia	819 kg
Gross Static	894 kg

Speed	
Impact	98.64 km/h
Exit	N.A.
Angle	
Impact	1.08 deg (on head)
Exit	N.A.
Occupant Impact Velocity	
Longitudinal	8.40 m/s
Lateral	3.51 m/s
Occupant Ridedown Deceleration	
Longitudinal	12.12 g/s
Lateral	10.81 g/s
Vehicle Damage	
TAD	12-FR-3
VDI	12FREN2
Vehicle Rebound Distance	5.7 meters (approx)

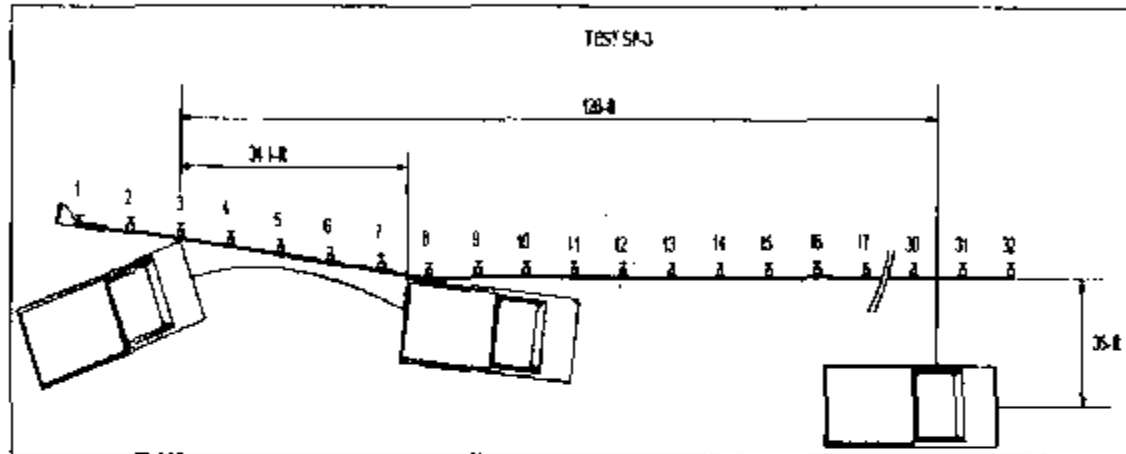
Conversion Factors: 1 in. = 2.54 cm, 1 lb = 0.454 kg

Figure 17. Summary of Test SP-1



General Information		Test Vehicle (continued)		Ridedown Accelerations (g's)	
Test Agency	Southwest Research Institute	Mass (kg) Dummy(s)	75.0	Y-direction	12.6
Test Number	SP-2	Mass (kg) Gross Strain	2030.0	Test Article Deflection (mm)	
Test Date	Feb. 18, 1999	Impact Conditions		Dynamic	1189
Test Article	Guardrail End Terminal	Speed (km/h)	100.1	Permanent	935
Type	Sequential Kinking Terminal	Angle (deg)	20.0	Vehicle Damage	
Installation Length (m)	61	Exit Conditions		Exterior	
Barrier	W-beam	Speed (km/h)	64.9	VDS	11FQ
Soil Type and Condition	S1 Dry	Angle (deg)	15.8	DCDC	11FNEN
Test Vehicle		Occupant Risk Values		Interior	
Type	Standard Pickup	Impact Velocity (m/s)		OCCI	LF000000
Designation	2000P	X-direction	3.8	Post-Impact Vehicular Behavior	
Model	1993 Chevrolet C-20	Y direction	3.5	Maximum Roll Angle (deg)	7.3
Mass (kg) Curb	1925	Ridedown Accelerations (g's)		Maximum Pitch Angle (deg)	4.5
Mass (kg) Test Inertial	1925	X-direction	10.6	Maximum Yaw Angle (deg)	Not Available

Figure 13. Impact Description and Summary of Results, Test SP-2



General Information		Test Vehicle (continued)		Ridedown Accelerations (g's)	
Test Agency	Southwest Research Institute	Mass (kg) Dummy(s)	75.0	Y-direction	7.8
Test Number	SP-3	Mass (kg) Gross Static	2020.0	Test Article Deflection (mm)	
Test Date	13-Apr-99	Impact Conditions		Dynamic	1217
Test Article	4-ft Offset Guardrail End Terminal	Speed (km/h)	104.5	Permanent	1080
Type	Sequential Kinking Terminal	Angle (deg)	20.4	Vehicle Damage	
Installation Length (m)	61	Exit Conditions		Exterior	
Barrier	W-beam	Speed (km/h)	55.1	VDS	11FQ-2
Soil Type and Condition	S1-Dry	Angle (deg)	16.0	DCDC	11FNEN
Test Vehicle		Occupant Risk Values		Interior	
Type	Standard Pickup	Impact Velocity (m/s)		OCDI	LF000000
Designation	2000P	X-direction	5.5	Post-Impact Vehicular Behavior	
Model	1993 Chevrolet C-20	Y-direction	3.6	Maximum Roll Angle (deg)	5
Mass (kg) Curb	1945	Ridedown Accelerations (g's)		Maximum Pitch Angle (deg)	9.4
Mass (kg) Test Inertial	1945	X-direction	7.5	Maximum Yaw Angle (deg)	Not Available

Figure 14. Impact Description and Summary of Results, Test SP-3

February 4, 2000

Dean L. Sicking, Ph.D, P.E.
Director, Midwest Roadside Safety Facility
University of Nebraska - Lincoln
W348 Nebraska Hall
P.O. Box 880531
Lincoln, NE 68588-0531

HMHS-CC40A

Dear Dr. Sicking:

Your January 21 letter to Mr. Richard Powers of my staff requested formal Federal Highway Administration acceptance of a modified Sequential Kinking Terminal (SKT) at NCHRP Report 350 test level 2 (TL-2). The original SKT-350 was accepted as a test level 3 (TL-3) w-beam terminal in my April 2, 1997, letter to Mr. Kaddo Kothmann.

As stated in your request, the only difference between the proposed TL-2 design and the current TL-3 design is the total number of breakaway posts used in the terminal. Whereas the TL-3 terminal had eight breakaway posts, the TL-2 design has only five breakaway posts, the last three breakaway posts in the original design being replaced with standard line posts. The post spacing for all posts remains the same for both designs at 1905 mm. When the original SKT-350 was impacted head-on at 100 km/h with an 820-kg car, less than 7600 mm of rail was extruded. Since the modified design will allow this much w-beam rail to be extruded before a vehicle reaches the non-breakaway line posts, the proposed TL-2 design actually meets TL-3 evaluation criteria for this particular test. In the 100 km/h, head-on pickup truck test, the SKT-350 extruded approximately 15.25 m of rail. You stated that the SKT-350 absorbs energy at a relatively constant rate. Therefore, at the TL-2 impact speed of 70 km/h, slightly less than half of the impact energy would result in about half of that amount of rail being deformed. Again, this would result in the truck coming to a stop prior to reaching the standard line posts. Based on the results of the redirection test with the pickup truck that was conducted on the *flared* TL-2 FLEAT terminal, we also conclude that this test can be waived for the *tangent* TL-2 SKT-350.

Based on the above, we consider the modified SKT-350, as described above, to be acceptable for use on the National Highway System as a TL-2 terminal when such use is requested by a transportation agency. Users should be advised that, as with all test level 2 terminals, the TL-2 SKT-350 is most appropriate for use at locations where operating speeds are expected to be at or below the TL-2 speed of 70km/h.

Sincerely yours,

(original signed by Dwight A. Horne)

Director, Office of Highway Safety Infrastructure

APPENDIX F – FLEAT APPROVAL LETTERS

The FHWA approval letters can be found on their web site at:

http://safety.fhwa.dot.gov/fourthlevel/hardware/term_cush.htm

April 2, 1998

Refer to: HNG-14

Mr. Kaddo Kothmann:
President
Road Systems, Inc.
P.O. Box 2163
Big Spring, Texas 79721

Dear Mr. Kothmann:

In your March 19, 1998, letter to Mr. Henry H. Rentz, you requested FHWA review of information you enclosed on your Flared Energy Absorbing Terminal (FLEAT) and acceptance of this w-beam guardrail terminal as a NCHRP Report 350 test level 3 (TL-3) device. To support your request, you also included a description of the FLEAT-350, a summary of crash test results, a composite crash test video tape, drawings, photographs, and a March 1998 test report for the certification test which was run at the Midwest Roadside Safety Facility. A second report (also dated March 1998) prepared by the Southwest Research Institute, entitled "FULL-SCALE CRASH EVALUATION OF A FLARED ENERGY ABSORBING TERMINAL" included information on the three additional tests that were run at that testing facility. We received a copy of this report with your March 27 letter to Mr. Rentz.

The FLEAT-350 is a w-beam guardrail terminal that is linearly offset from the line of rail by 1200 mm over its 11400-mm length. Its main components include an impact head and guide tube assembly, a modified w-beam rail section, a breakaway anchor assembly, and a series of seven weakened timber posts, the first two being 140 mm x 190 mm x 1080 mm long set in 1830-mm steel tubes and the next five being 150 mm x 200 mm x 1830 mm long set directly into the ground. Design details are shown in Enclosure 1. The FLEAT-350 dissipates impact energy in end-on hits by bending and flattening the w-beam rail element as the extruder head is forced back along the rail. For downstream hits, the tension in the rail is transmitted to the anchorage system, resulting in containment and re-direction of an impacting vehicle.

A total of four tests were conducted to certify the FLEAT-350 as meeting the evaluation criteria of NCHRP Report 350. These included the 820-kg car and the 2000-kg pickup truck at zero degrees on the end of the terminal (Report 350 tests 3-30 and 3-31, respectively), the car at post 2 at 15 degrees (critical impact point, test 3-34), and the pickup truck at the beginning of the barrier length of need at post 3 at 20 degrees (test 3-35). The summary sheets for each of these tests are attached as Enclosure 2. We noted that the occupant impact velocities and the subsequent ridedown accelerations were below the preferred Report 350 evaluation criteria for both end-on hits. We noted also that the 820-kg car was smoothly stopped in only 5.48 meters. After initial impact, the 2000-kg truck continued 32 meters behind the rail before stopping. Although the energy absorbing nature of this terminal significantly reduced the distance traveled behind the terminal after impact (compared to non-energy absorbing terminals), the post-crash trajectory seen in test 3-31 re-emphasizes the need for a clear, relatively traversable runout area behind all guardrail terminals.

We agree with your assessment that a reverse-direction impact test (test 3-39) is not necessary based on earlier tests on similar systems. Tests 3-32 and 3-33 (15 degree angle hits on the nose of the terminal with the 820-kg and 2000-kg vehicles) can also be waived because these tests are demonstrably less severe than tests 3-30 and 3-31 for gating terminals with designs similar to the FLEAT-350.

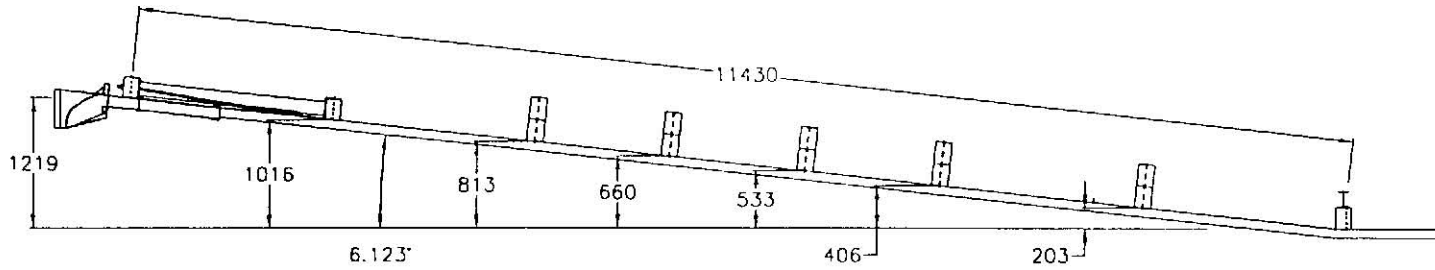
Based on our review of the information you submitted, we consider the FLEAT-350 to meet appropriate Report 350 evaluation criteria at test level 3 (TL-3). Therefore, it may be used on the National Highway System (NHS) when such use is requested by a transportation agency. Since the FLEAT-350 is a proprietary terminal, its use on Federal-aid projects, except exempt non-NHS projects, is subject to the conditions noted in Title 23, Code of Federal Regulations, Section 635.411, a copy of which is attached for your ready reference as Enclosure 3.

Sincerely yours,

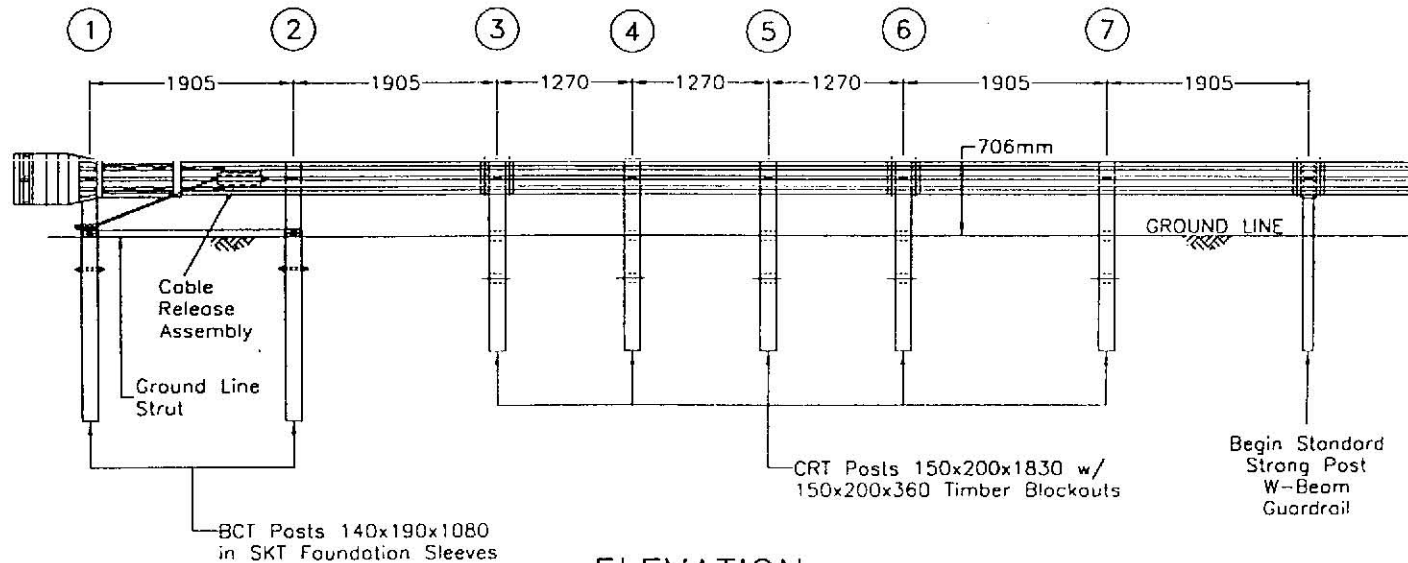
(original signed by Dwight A. Horne)

Dwight A. Horne
Chief, Federal-Aid and Design Division

3 Enclosures
Acceptance letter CC-46



PLAN



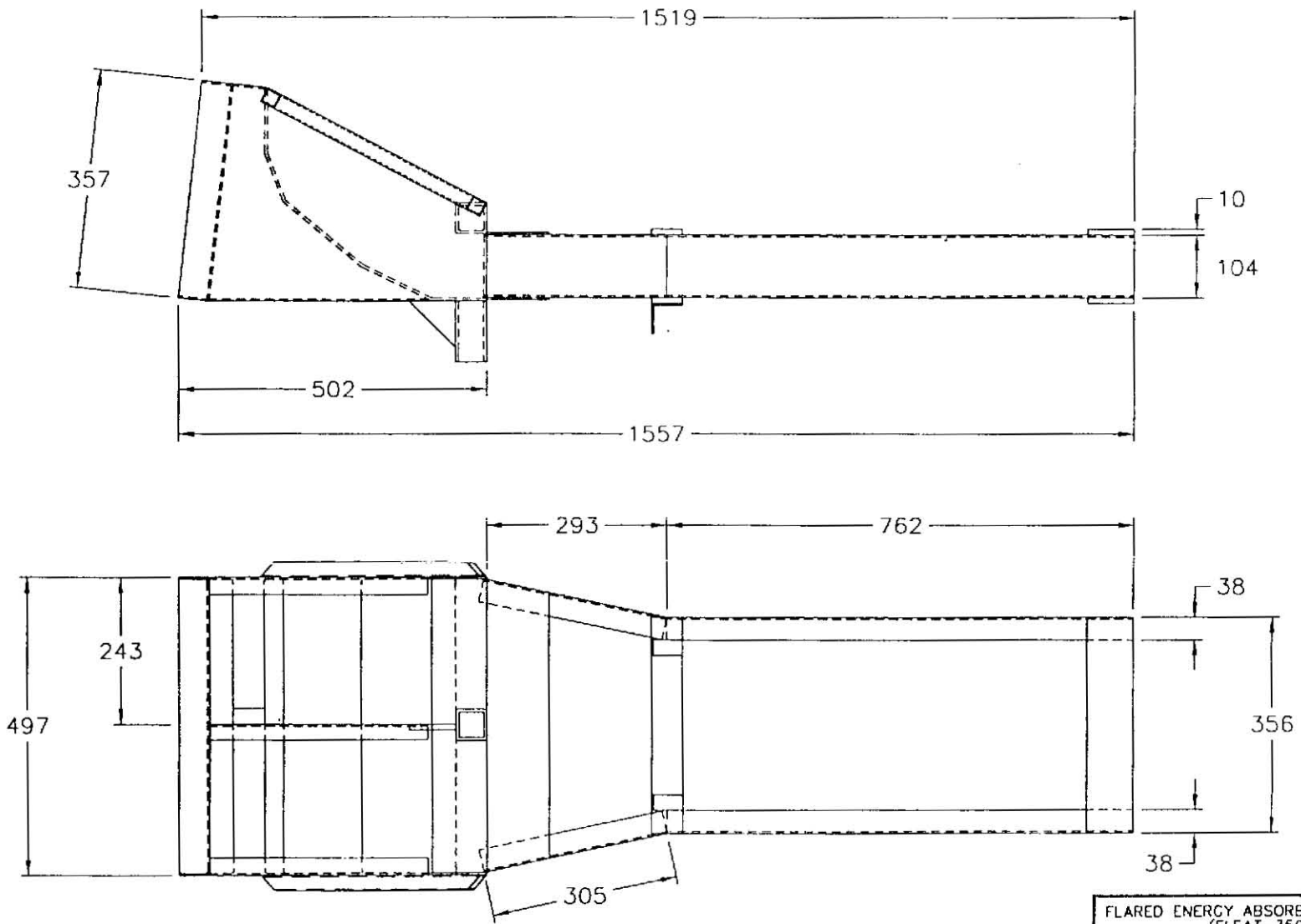
ELEVATION

FLARED ENERGY ABSORBING TERMINAL (FLEAT-350)			
DRAWN BY EAK	DATE 3/20/98	SHEET NO. SYSTEM	PC. OF 1 5
REVISION DATE			

3

ENCLOSURE 1

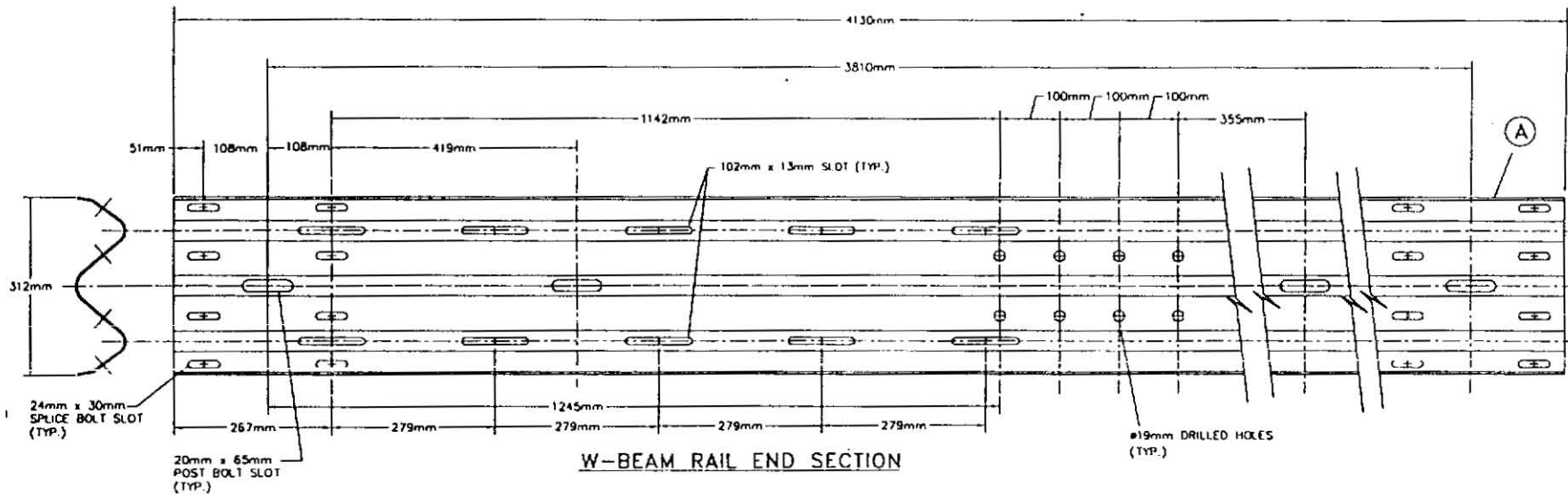
Figure 1: FLEAT Assembly and Component Drawings



FLARED ENERGY ABSORBING TERMINAL (FLEAT-350)			
FLEAT HEAD			
DRAWN BY	DATE	CHK'D BY	PG. OF
EAK	3/20/98	SYSTEM	2 5
REVISION	DATE		
1	3/20/98		

Figure 1 con't: FLEAT Assembly and Component Drawings

ITEM NO.	QTY	DESCRIPTION	MATERIAL
A	1	RAIL END SECTION	12 GA. W-BEAM

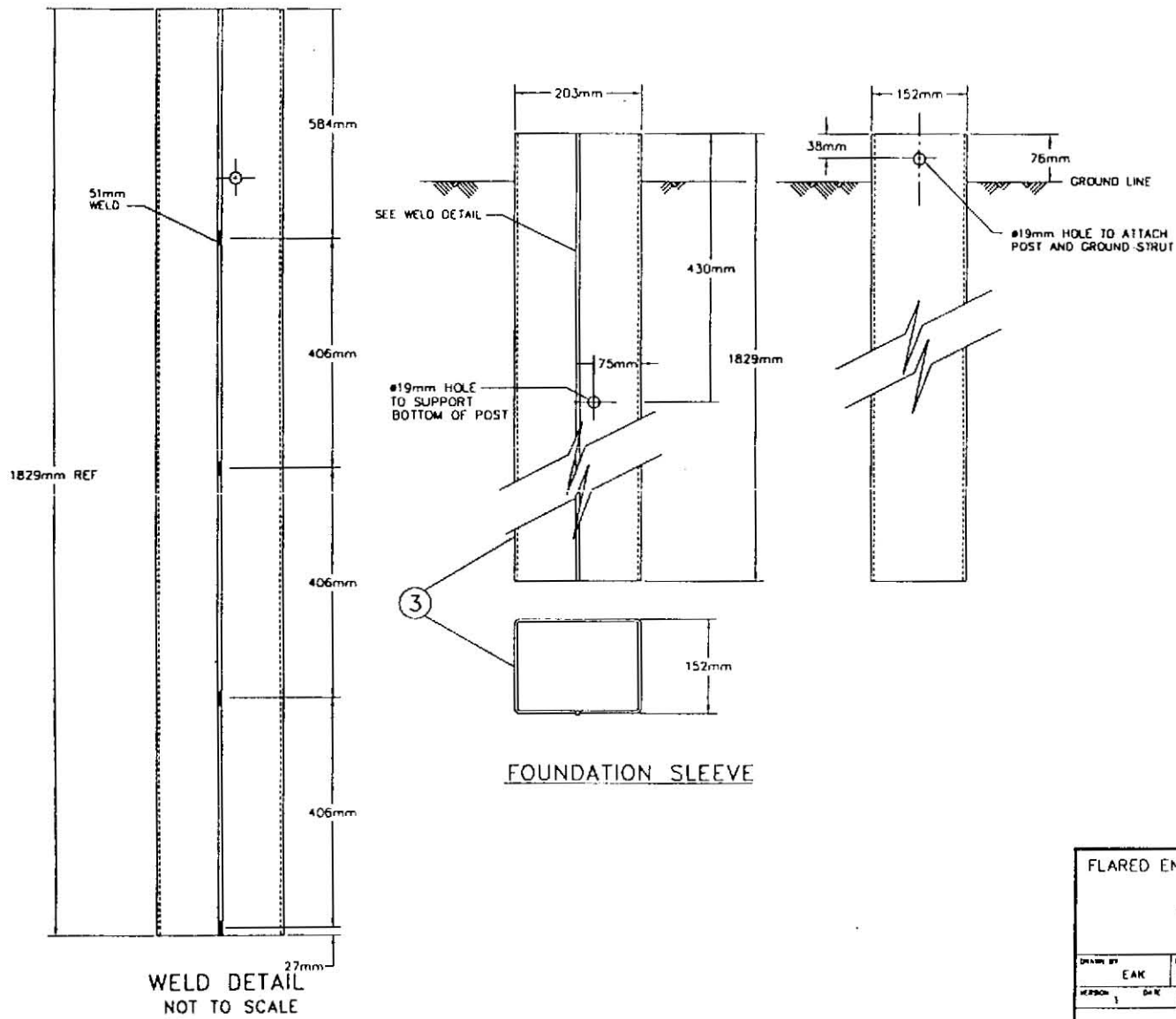


FLARED ENERGY ABSORBING TERMINAL (FLEAT-350)			
W-BEAM RAIL END SECTION			
DESIGNED BY	DATE	CHK. SET	PC. OF
EAK	3/20/98	SYSTEM	3 5
REVISION	DATE		
1	3/20/98		

DRAWING NO. 1: 3 OF 5

Figure 1 con't: FLEAT Assembly and Component Drawings

ITEM NO.	QTY	DESCRIPTION	MATERIAL
3	2	FOUNDATION SLEEVE	50 ksi 3mm PLATE



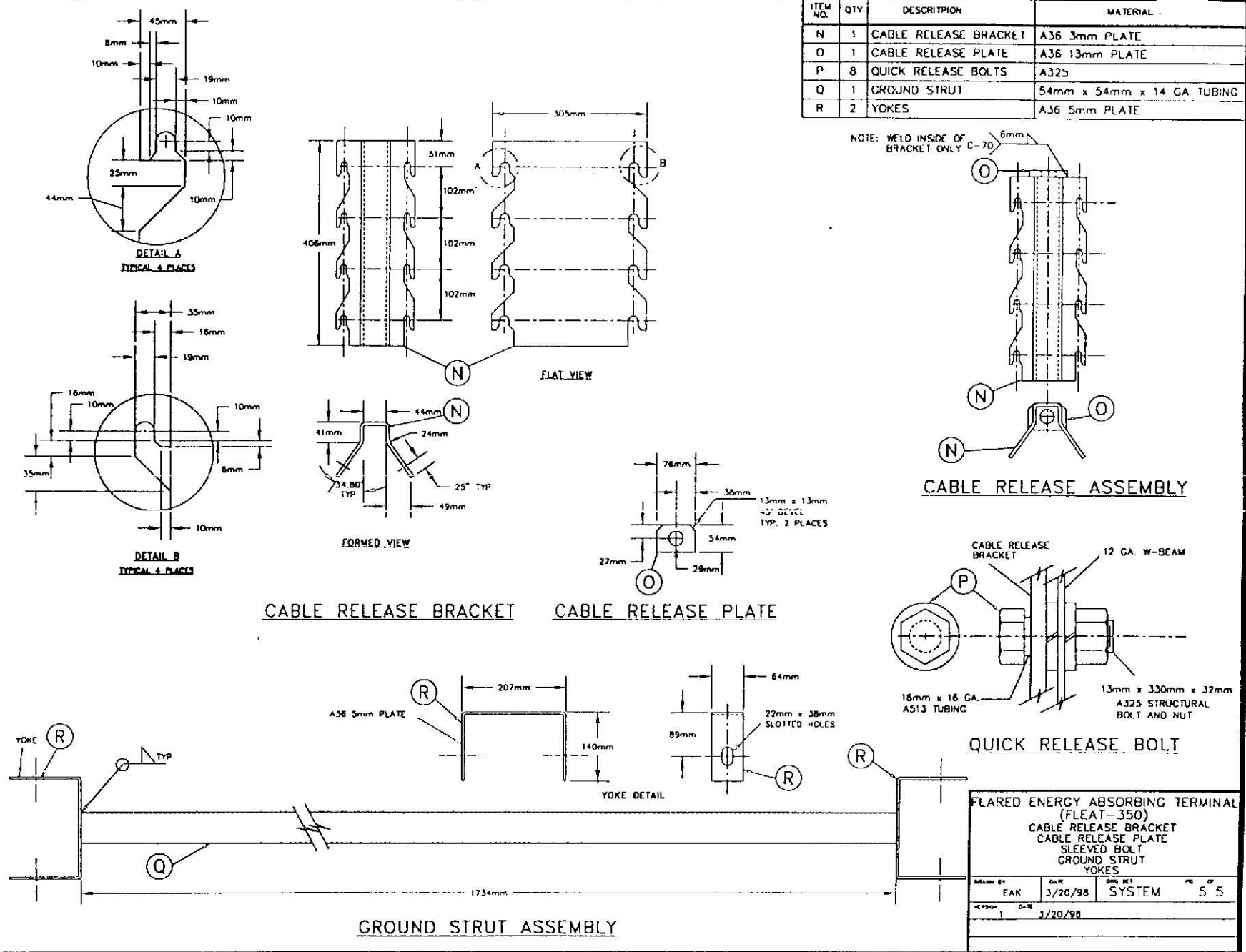
FLARED ENERGY ABSORBING TERMINAL (FLEAT-350)			
FOUNDATION SLEEVE			
DRAWN BY	DATE	CHK. BY	PC. OF
EAK	3/20/98	SYSTEM	4 5
REVISION	DATE		
1	3/20/98		

Figure 1 con't: FLEAT Assembly and Component Drawings

7

ITEM NO.	QTY	DESCRIPTION	MATERIAL
N	1	CABLE RELEASE BRACKET	A36 3mm PLATE
O	1	CABLE RELEASE PLATE	A36 13mm PLATE
P	8	QUICK RELEASE BOLTS	A325
Q	1	GROUND STRUT	54mm x 54mm x 14 GA TUBING
R	2	YOKES	A36 5mm PLATE

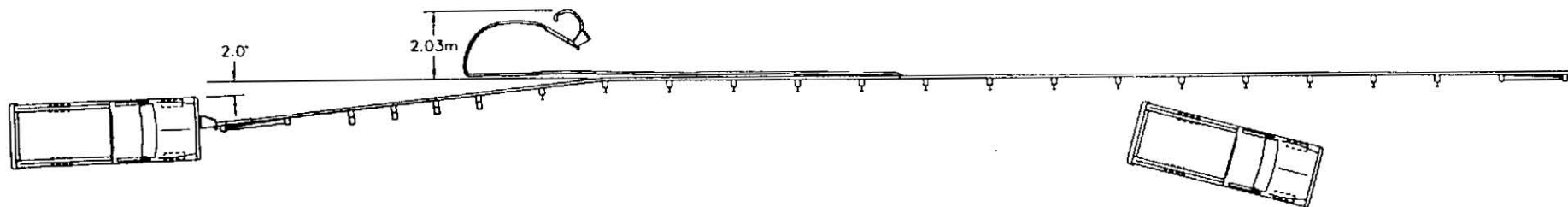
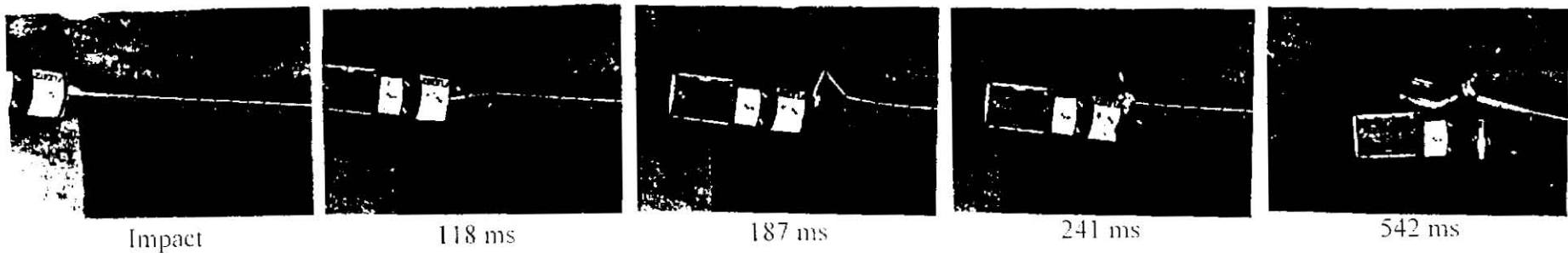
NOTE: WELD INSIDE OF BRACKET ONLY



ENCLOSURE 1: 5 OF 5

FLARED ENERGY ABSORBING TERMINAL (FLEAT-350) CABLE RELEASE BRACKET CABLE RELEASE PLATE SLEEVED BOLT GROUND STRUT YOKES			
DRAWN BY EAK	DATE 3/20/98	DES. SET SYSTEM	NO. OF 5 5
REVISION 1	DATE 3/20/98		

Figure 1 con't: FLEAT Assembly and Component Drawings



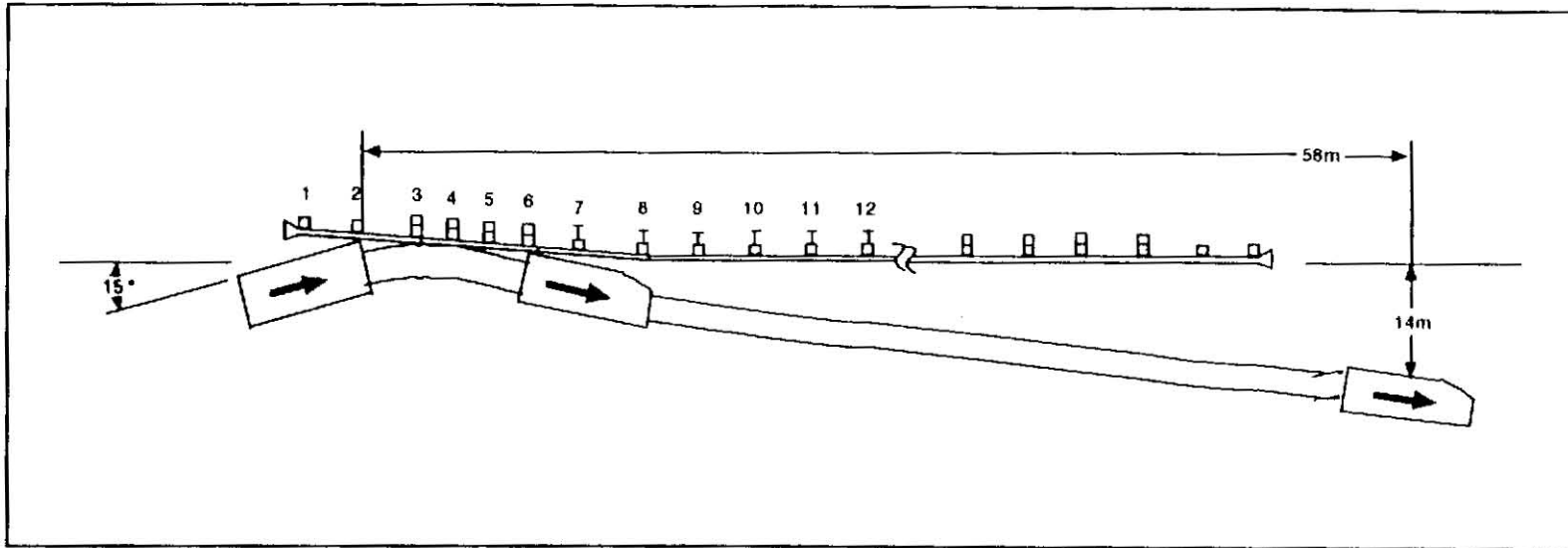
25

Test Number	FLEAT-2
NCHRP 350 Test Designation	3-31
Date	2/24/98
Installation	Flared Energy Absorbing Terminal
System length	40.0 m
Head Dimensions (LxWxH)	1557 mm x 356 mm x 490 mm
Face Angle	6.0 degrees
Flare Details	
Length	11.43 m
Offset	1.22 m
Angle	6.123 degrees
Guardrail	12-gauge W-beam
End Terminal Posts	
Numbers 1-2	BCT timber posts 140x190x1080 long in foundation tubes with groundline strut
Numbers 3-6	CRT timber posts 150x200x1830 long
Numbers 7-8	W150x13.5 steel posts, 1830 long
Vehicle Model	1993 GMC 2500 3/4-Ton Pickup
Vehicle Weight	
Curb	1,877 kg
Test Inertia	1,982 kg
Gross Static	1,982 kg

Speed	
Impact	97.2 km/h
Exit	N.A.
Angle	
Impact	-2.0 deg
Exit	N.A.
Occupant Impact Velocity	
Longitudinal	6.2 m/s
Lateral	1.7 m/s
Occupant Ridedown Deceleration	
Longitudinal	10.4 g's
Lateral	4.2 g's
Vehicle Damage	
TAD	12-FD-5
VDI	12FDI:W2
Vehicle Rebound Distance	N.A.

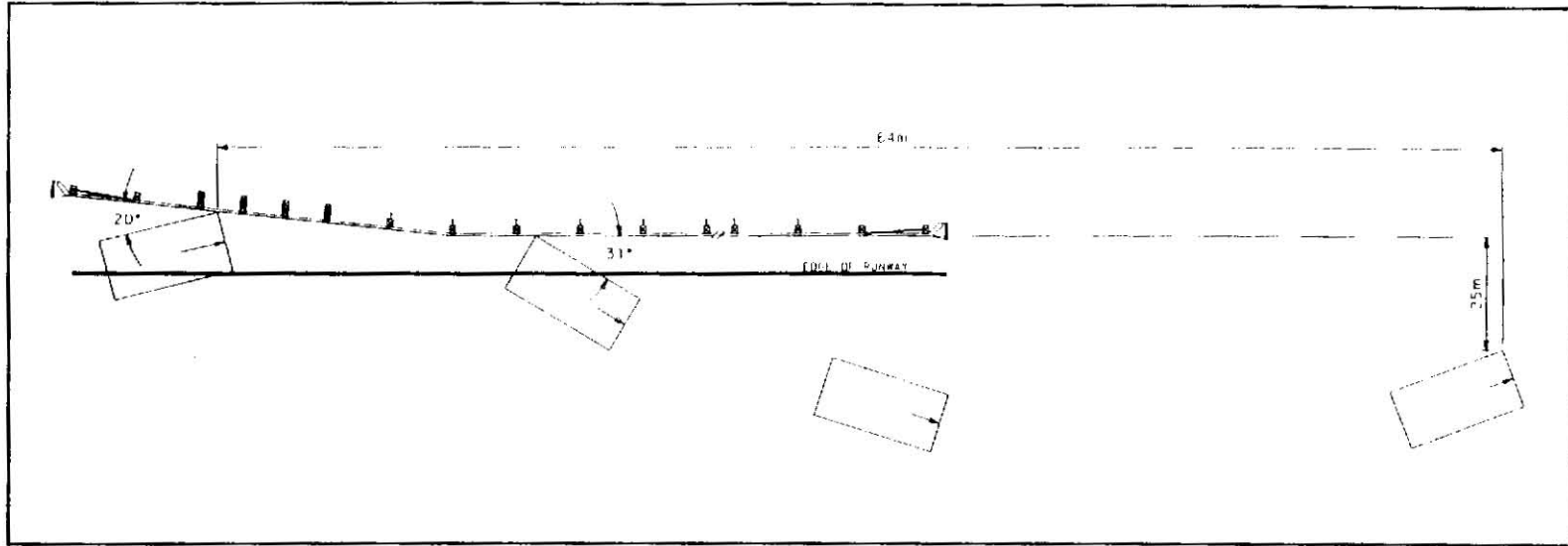
Conversion Factors: 1 in. = 2.54 cm; 1 lb = 0.454 kg

Figure 9. Summary of Test FLEAT-2.



4. General Information		7. Test Vehicle (Continued)		10. Ridedown Acceleration (g's)	
Test Agency	Southwest Research Institute	Mass (kg) Dummy(s)	75	y-direction	12.6
Test Number	FLEAT-2	Mass (kg) Gross Static	904	11. Test Article Deflection (m)	
Test Date	03/03/98	8. Impact Conditions		Dynamic	0.67
5. Test Article		Speed (km/h)	100.0	Permanent	0.38
Type	End Terminal	Angle (deg)	15.0	12. Vehicle Damage	
Installation Length (m)	57.1	9. Exit Conditions		Exterior	
Barrier		Speed (km/h)	45.7	VDS	11-LFQ-3
6. Soil Type and Condition	Standard Soil, Dry Compacted	Angle (deg)	6	CDC	11FLEE2
7. Test Vehicle		10. Occupant Risk Values		Interior	
Type	Production	Impact Velocity (m/s)		OCDI	LF0000000
Designation	820C	x-direction	7.0	13. Post-Impact Vehicular Behavior	
Model	1992 Ford Festiva	y-direction	7.6	Maximum Roll Angle (deg)	10 Approximate
Mass (kg) Curb	829	Ridedown Acceleration (g's)		Maximum Pitch Angle (deg)	5 Approximate
Mass (kg) Test Inertial	829	X-direction	-7.1	Maximum Yaw Angle (deg)	0 Approximate

Figure 6. Impact Sequence and Summary of Test Conditions and Results - Test FLEAT-2



4. General Information		7. Test Vehicle (Continued)		10. Ridedown Acceleration (g's)	
Test Agency	Southwest Research Institute	Mass (kg) Dummy(s)	75	y-direction	-9.36
Test Number	SBD-1A	Mass (kg) Gross Static	2,043	11. Test Article Deflection (m)	
Test Date	10/30/97	8. Impact Conditions		Dynamic	1.0
5. Test Article		Speed (km/h)	100.0	Permanent	0.84
Type	End Terminal	Angle (deg)	20.0	12. Vehicle Damage	
Installation Length (m)	57.1	9. Exit Conditions		Exterior	
Barrier		Speed (km/h)	36	VDS	11-LFQ-3
6. Soil Type and Condition	Standard Soil, Dry Compacted	Angle (deg)	31	CDC	11FLEE2
7. Test Vehicle		10. Occupant Risk Values		Interior	
Type	Production	Impact Velocity (m/s)		OCIDI	LF0000000
Designation	2000P	x-direction	6.74	13. Post-Impact Vehicular Behavior	
Model	1991 Chevrolet C2500	y-direction	2.20	Maximum Roll Angle (deg)	27 Approximate
Mass (kg) Curb	1,968	Ridedown Acceleration (g's)		Maximum Pitch Angle (deg)	21 Approximate
Mass (kg) Test Inertial	1,968	X-direction	-3.86	Maximum Yaw Angle (deg)	N/A

Figure 6. Impact Sequence and Summary of Test Conditions and Results - Test SBD-1A

these materials must occur in the United States.

(2) The State has standard contract provisions that require the use of domestic materials and products, including steel materials, to the same or greater extent as the provisions set forth in this section.

(3) The State elects to include alternate bid provisions for foreign and domestic steel materials which comply with the following requirements. Any procedure for obtaining alternate bids based on furnishing foreign steel materials which is acceptable to the Division Administrator may be used. The contract provisions must (i) require all bidders to submit a bid based on furnishing domestic steel materials, and (ii) clearly state that the contract will be awarded to the bidder who submits the lowest total bid based on furnishing domestic steel materials unless such total bid exceeds the lowest total bid based on furnishing foreign steel materials by more than 25 percent.

(4) When steel materials are used in a project, the requirements of this section do not prevent a minimal use of foreign steel materials, if the cost of such materials used does not exceed one-tenth of one percent (0.1 percent) of the total contract cost or \$2,500, whichever is greater. For purposes of this paragraph, the cost is that shown to be the value of the steel products as they are delivered to the project.

(c)(1) A State may request a waiver of the provisions of this section if:

(i) The application of those provisions would be inconsistent with the public interest; or

(ii) Steel materials/products are not produced in the United States in sufficient and reasonably available quantities which are of a satisfactory quality.

(2) A request for waiver, accompanied by supporting information, must be submitted in writing to the Regional Federal Highway Administrator (RFHWA) through the FHWA Division Administrator. A request must be submitted sufficiently in advance of the need for the waiver in order to allow time for proper review and action on the request. The RFHWA will have approval authority on the request.

(3) Requests for waivers may be made for specific projects, or for certain materials or products in specific geographic areas, or for combinations of both, depending on the circumstances.

(4) The denial of the request by the RFHWA may be appealed by the State to the Federal Highway Administrator (Administrator), whose action on the request shall be considered administratively final.

(5) A request for a waiver which involves nationwide public interest or availability issues or more than one FHWA region may be submitted by the RFHWA to the Administrator for action.

(6) A request for waiver and an appeal from a denial of a request must include facts and justification to support the granting of the waiver. The FHWA response to a request or appeal will be in writing and made available to the public upon request. Any request for a nationwide waiver and FHWA's action on such a request may be published in the FEDERAL REGISTER for public comment.

(7) In determining whether the waivers described in paragraph (c)(1) of this section will be granted, the FHWA will consider all appropriate factors including, but not limited to, cost, administrative burden, and delay that would be imposed if the provision were not waived.

(d) Standard State and Federal-aid contract procedures may be used to assure compliance with the requirements of this section.

(23 U.S.C. 315, sec. 10 of Pub. L. 98-229, 98 Stat. 55, sec. 165 of Pub. L. 97-424, 96 Stat. 2136 and 49 CFR 1.48(b))

(48 FR 53104, Nov. 25, 1983, as amended at 49 FR 18821, May 3, 1984)

§ 635.411 Material or product selection.

(a) Federal funds shall not participate, directly or indirectly, in payment for any premium or royalty on any patented or proprietary material, specification, or process specifically set forth in the plans and specifications for a project, unless:

(1) Such patented or proprietary item is purchased or obtained through

competitive bidding with equally suitable unpatented items; or

(2) The State highway agency certifies either that such patented or proprietary item is essential for synchronization with existing highway facilities, or that no equally suitable alternate exists; or

(3) Such patented or proprietary item is used for research or for a distinctive type of construction on relatively short sections of road for experimental purposes.

(b) When there is available for purchase more than one nonpatented, nonproprietary material, semifinished or finished article or product that will fulfill the requirements for an item of work of a project and these available materials or products are judged to be of satisfactory quality and equally acceptable on the basis of engineering analysis and the anticipated prices for the related item(s) of work are estimated to be approximately the same, the PS&E for the project shall either contain or include by reference the specifications for each such material or product that is considered acceptable for incorporation in the work. If the State highway agency wishes to substitute some other acceptable material or product for the material or product designated by the successful bidder or bid as the lowest alternate, and such substitution results in an increase in costs, there will not be Federal-aid participation in any increase in costs.

(c) A State highway agency may require a specific material or product when there are other acceptable materials and products, when such specific choice is approved by the Division Administrator as being in the public interest. When the Division Administrator's approval is not obtained, the item will be nonparticipating unless bidding procedures are used that establish the unit price of each acceptable alternative. In this case Federal-aid participation will be based on the lowest price so established.

(d) Appendix A sets forth the FHWA requirements regarding (1) the specification of alternative types of culvert pipes, and (2) the number and types of such alternatives which must

be set forth in the specifications for various types of drainage installations.

(e) Reference in specifications and on plans to single trade name materials will not be approved on Federal-aid contracts.

§ 635.413 Guaranty and warranty clauses.

(a) Except as provided in paragraph (b) of this section, clauses that require the contractor to guarantee or warrant materials and workmanship or to otherwise maintain the work for a specified period after its satisfactory completion by the contractor and its final acceptance by the State, will not be approved for use in Federal-aid contracts. Work performed and materials replaced under such guaranty or warranty clauses after final acceptance of work are not eligible for Federal participation.

(b) Contracts which involve furnishing and/or installing electrical or mechanical equipment should generally include contract clauses that require:

(1) Manufacturer's warranties or guarantees on all electrical and mechanical equipment consistent with those provided as customary trade practice; or

(2) Contractors' warranties or guarantees providing for satisfactory in-service operation of the mechanical and electrical equipment and related components for a period not to exceed 6 months following project acceptance.

§ 635.417 Convict produced materials.

(a) Materials produced by convict labor may only be incorporated in a Federal-aid highway construction project if such materials have been:

(1) Produced by convicts who are on parole, supervised release, or probation from a prison or

(2) Produced in a qualified prison facility and the cumulative annual production amount of such materials for use in Federal-aid highway construction does not exceed the amount of such materials produced in such facility for use in Federal-aid highway construction during the 12-month period ending July 1, 1987.

(b) *Qualified prison facility* means any prison facility in which convicts,

August 27, 1998

Refer to: HNG-14

Mr. Kaddo Kothmann
President
Road Systems, Inc.
P.O. Box 2163
Big Spring, Texas 79721

Dear Mr. Kothmann:

In your July 23 letter to Mr. Henry H. Rentz, you requested the Federal Highway Administration's (FHWA) acceptance of your Flared Energy Absorbing Terminal (FLEAT) with the end offset reduced to 762 mm. My original acceptance letter, dated April 2, 1998, was based on a layout with a 1219 mm offset at the end of the terminal. To support your request, you sent us a copy of a July 15, 1998, test report prepared by the Midwest Roadside Safety Facility entitled "Full-Scale Crash Evaluation of a Flared Energy Absorbing Terminal (FLEAT-350) NCHRP TEST 3-31," a video tape of the test, and detailed drawings of the modified terminal layout.

Only one test was run to confirm the acceptability of the reduced offset and that was test 3-31, a 2000-kg pickup truck impacting the end head-on at 100 km/h. Test results are summarized in Enclosure 1. You stated that test 3-30, an 820-kg car impacting end-on, would be less severe with the reduced offset than the same test which was run successfully with the original 1219-mm offset because of the reduced eccentricity. You also stated that the side redirection tests (3-34 and 3-35) need not be repeated because the effective impact angles would be less with the reduced offset design than they were with the 1219-mm offset which, again, was successfully tested. Based on previous reverse-direction hits on similar terminal designs, test 3-39 was waived earlier for the FLEAT with the 1219-mm offset and was not believed to be needed for the reduced offset option either. The FHWA concurs with your analysis in each case.

Members of my staff have reviewed the information you presented and agree that the FLEAT is acceptable for use on the National Highway System as an NCHRP Report 350 terminal at test level 3 (TL-3) with the reduced offset of 762 mm. We note that the flare on the terminal remains a straight taper over its entire 11.4 m length and that standard line posts start at the beginning of this flare at post number 8. The layout is shown in Enclosure 2. Since the FLEAT is now considered acceptable with either a 762 mm or 1219 mm offset, it is reasonable to conclude that

any offset that falls between the two tested layouts would likewise be acceptable. For this reason, offsets for the intermediate posts are not shown. However, it is critical to the proper performance of the FLEAT that it be installed with a straight taper (not parabolic) that extends back to post number eight and that, as with all gating end treatments, a reasonably traversable runout area is available immediately behind and beyond the terminal.

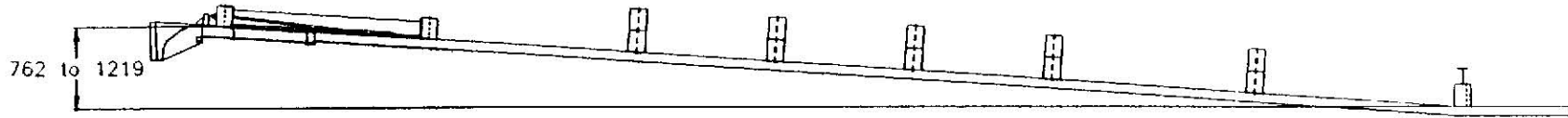
Any questions you may have should be addressed to Mr. Richard Powers at (202) 366-1320.

Sincerely yours,

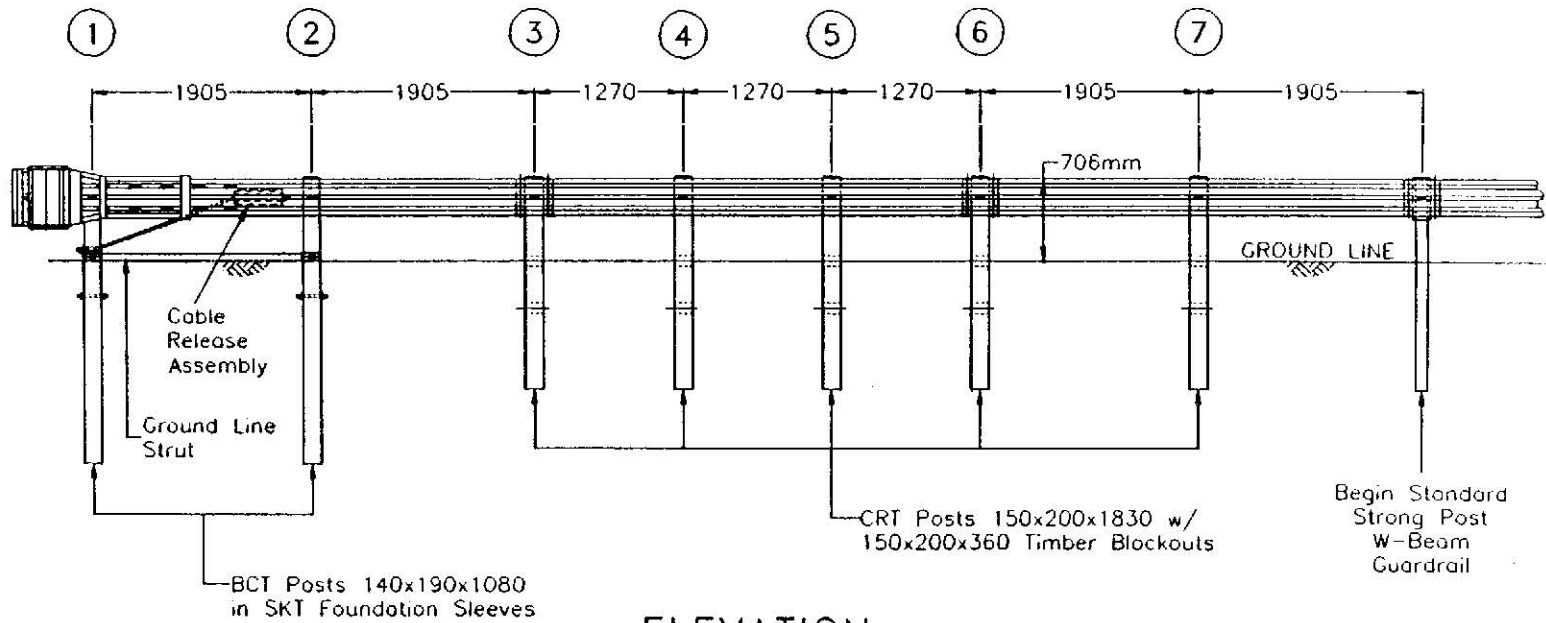
(original signed by Dwight A. Horne)

Dwight A. Horne
Chief, Federal-Aid and Design Division

2 Enclosures
Acceptance Letter CC-46A



PLAN

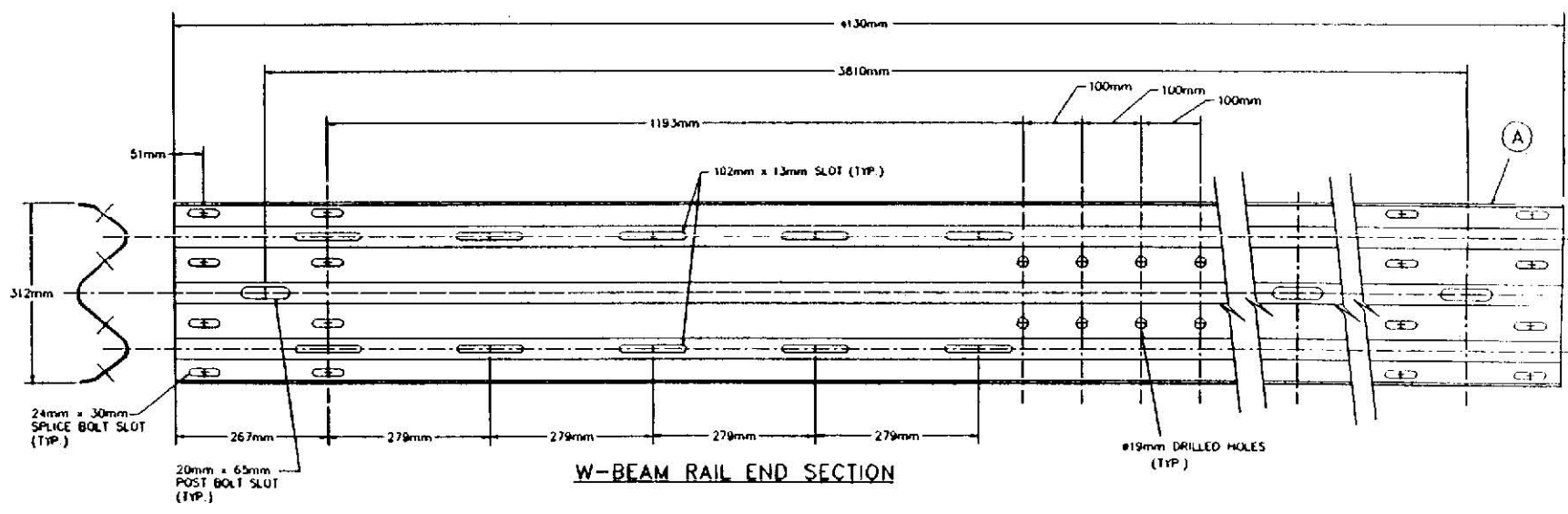


ELEVATION

FLARED ENERGY ABSORBING TERM
(FLEAT-350)

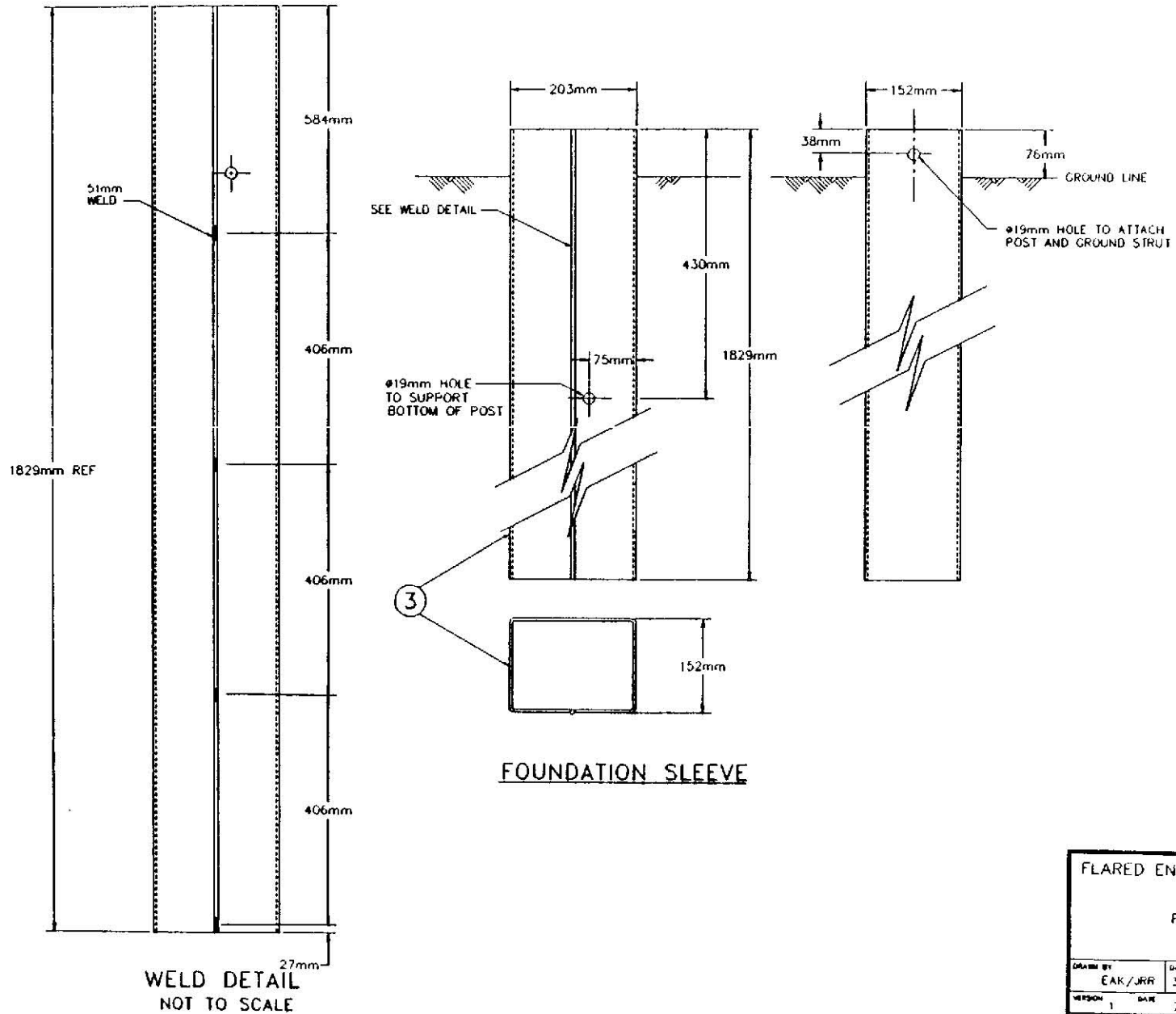
DRAWN BY EAK	DATE 3/20/98	CHK. BY SYSTEM	PL.
REVISION DATE 7/16/98		JRR	

ITEM NO.	QTY	DESCRIPTION	MATERIAL
A	1	RAIL END SECTION	12 GA. W-BEAM



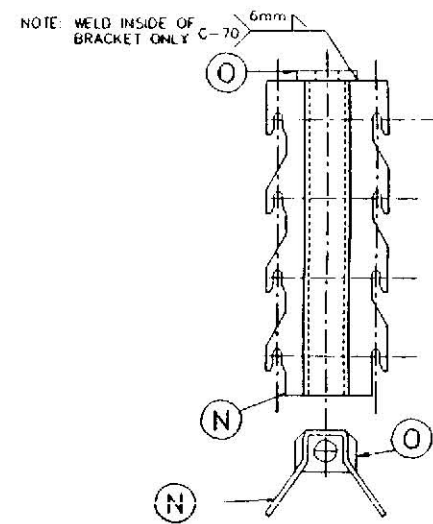
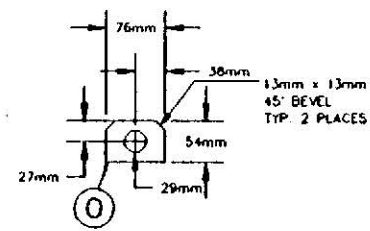
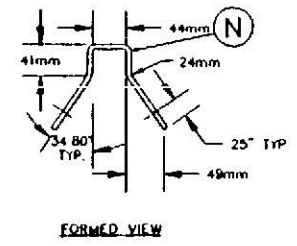
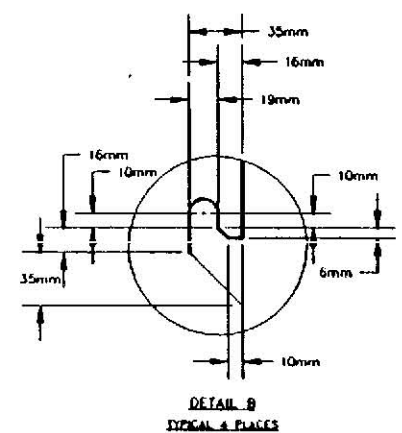
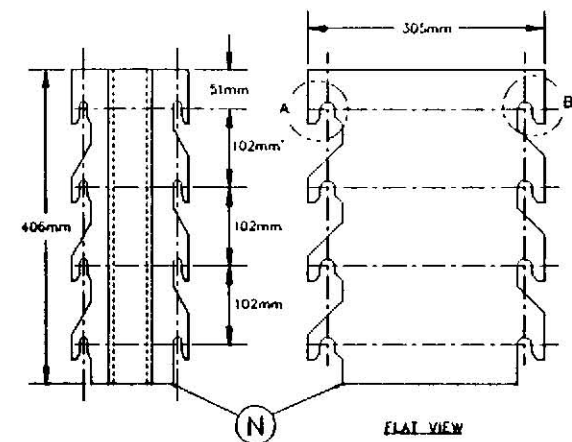
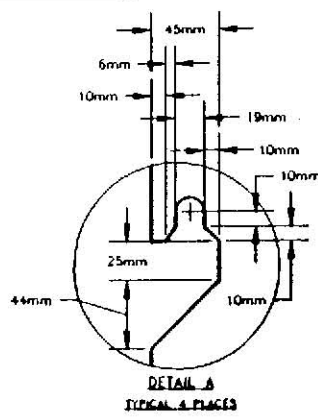
FLARED ENERGY ABSORBING TERM (FLEAT-350)			
W-BEAM RAIL END SECTION			
DRAWN BY	DATE	CHK. BY	NO.
JRR	3/20/98	SYSTEM	
VERSION	DATE		
1	7/10/98		

ITEM NO	QTY	DESCRIPTION	MATERIAL
3	2	FOUNDATION SLEEVE	50 ksi 3mm P



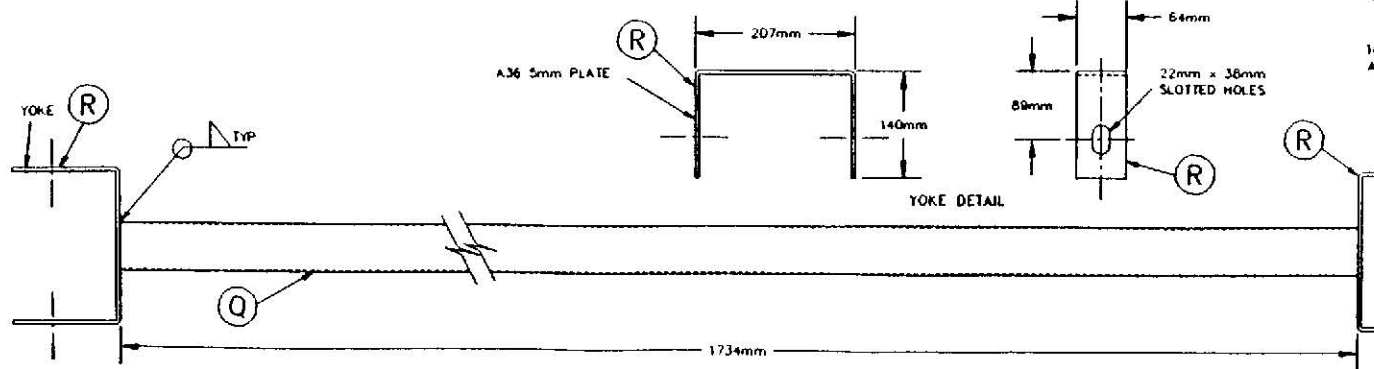
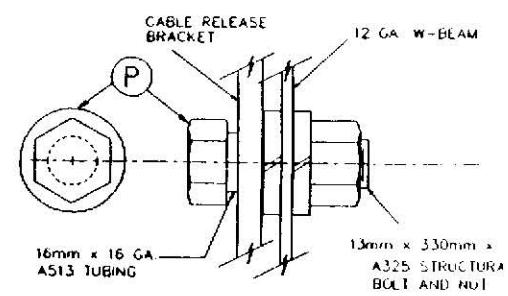
FLARED ENERGY ABSORBING TERM (FLEAT-350)			
FOUNDATION SLEEVE			
DRAWN BY EAK/JRR	DATE 3/20/98	DRAWN BY SYSTEM	PG 3
VERSION 1	DATE 7/10/98		

ITEM NO	QTY	DESCRIPTION	MATERIAL
N	1	CABLE RELEASE BRACKET	A36 3mm PLATE
O	1	CABLE RELEASE PLATE	A36 13mm PLATE
P	8	QUICK RELEASE BOLTS	A325
Q	1	GROUND STRUT	54mm x 54mm x 14 GA T
R	2	YOKES	A36 5mm PLATE

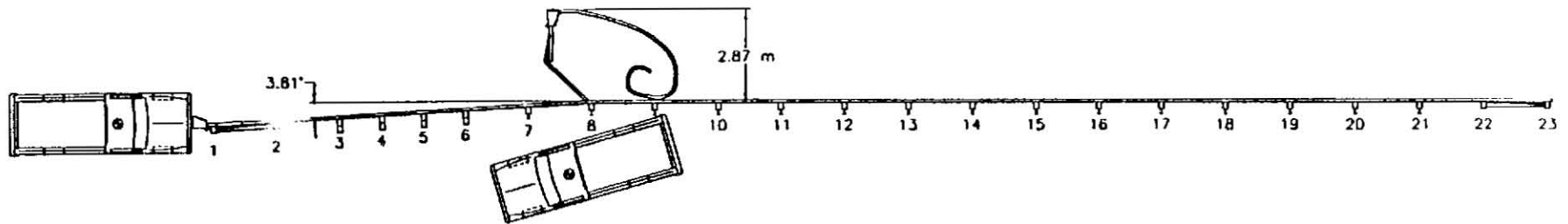
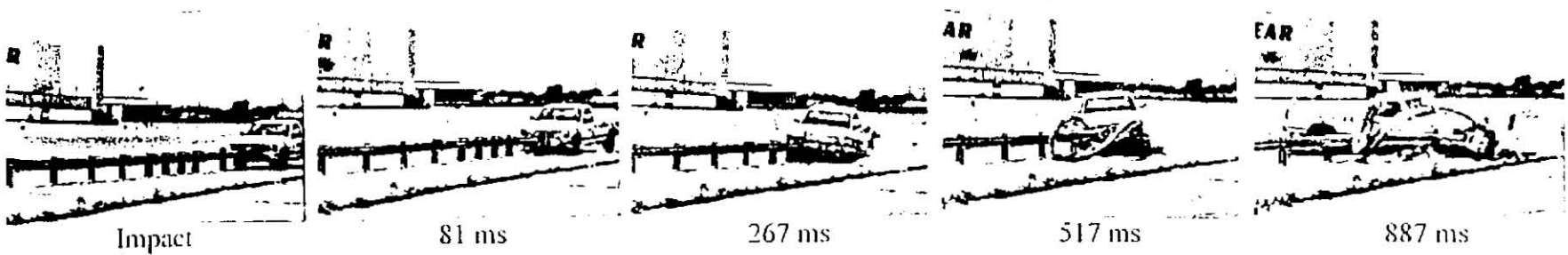


CABLE RELEASE BRACKET

CABLE RELEASE PLATE



FLARED ENERGY ABSORBING TIER (FEAT-350)			
CABLE RELEASE BRACKET			
CABLE RELEASE PLATE			
SLEEVED BOLT			
GROUND STRUT			
YOKES			
DRAWN BY	DATE	CHK. SLT	PC
EAK/JRR	3/20/98	SYSTEM	
WORKSH	DATE		
1	7/10/98		



30

Test Number	FLEAT-3
NCHRP 350 Test Designation	3-31
Date	6/26/98
Installation	FLared Energy Absorbing Terminal
System length	40.0 m
Head Dimensions (LxWxH)	1557 mm x 356 mm x 490 mm
Face Angle	6.0 degrees
Flare Details	
Length	11.43 m
Offset	0.61 m
Angle	3.81 degrees
Guardrail	12-gauge W-beam
End Terminal Posts	
Numbers 1-2	BCT timber posts 140x190x1080 long in foundation tubes with groundline strut
Numbers 3-6	CRT timber posts 150x200x1830 long
Numbers 7-8	W150x13.5 steel posts, 1830 long
Vehicle Model	1992 Chevy 2500 ¾-Ton Pickup
Vehicle Weight	
Curb	1885 kg
Test Inertia	1996 kg
Gross Static	1996 kg

Speed	
Impact	100.43 km/h
Exit	N.A.
Angle	
Impact	0 deg
Exit	N.A.
Occupant Impact Velocity	
Longitudinal	6.16 m/s
Lateral	0.157 m/s
Occupant Ridedown Deceleration	
Longitudinal	7.0 g's
Lateral	6.7 g's
Vehicle Damage	
TAD	12-FC-2, 3-RP-1
VDI	12FCLN2, 03RPEN1
Vehicle Rebound Distance	N.A.

Conversion Factors: 1 in. = 2.54 cm; 1 lb = 0.454 kg

Figure 10. Summary of Test FLEAT-3.

May 21, 1999

Refer to: HMHS-

CC46B

Mr. Kaddo Kothmann
President, Road Systems, Inc.
1507 E. 4th
P.O. Box 2163
Big Spring, Texas 79721

Dear Mr. Kothmann:

In your April 8 letter to Mr. Henry Rentz, which was forwarded to me for action, you requested the Federal Highway Administration to accept a modified version of your FLEAT guardrail terminal as meeting the test level 2 (TL-2) evaluation criteria contained in the National Cooperative Highway Research Program (NCHRP) Report 350. To support your request, you included a copy of a January 30, 1999 report prepared by the Midwest Roadside Safety Facility, entitled "FULL-SCALE CRASH EVALUATION OF A TL-2 FLARED ENERGY ABSORBING TERMINAL (FLEAT-TL2)" and a video tape of the additional test that was run to verify acceptable performance of the modified design.

As noted in your letter and in the test report, the FHWA has previously accepted the 11.4-m long TL-3 FLEAT with permissible end offsets from 762 mm to 1219 mm. The modified or TL-2 FLEAT is only 7.62-m long, but with the same flare rates as the TL-3 design. Thus, the end offsets for the TL-2 FLEAT will range from 508 mm to 813 mm. The TL-2 FLEAT uses two fewer CRT posts (three vs. five) than the TL-3 design. Line posts may be either steel posts with timber or recycled blocks, or wood posts and blocks, since the system was tested with the more critical steel line posts. Design details for the TL-2 FLEAT are shown in Enclosure 1. After analyzing the results of tests conducted at 100 k/hr on the TL-3 designs with either the full 1219 mm offset or with the reduced 762 mm offset, you concluded that NCHRP Report 350 tests 2-30, 2-31, 2-34, and 2-39 need not be conducted at the reduced impact speed of 70 k/hr. We concur. Test 2-35 was run and is described in the above-referenced report. Appropriate evaluation criteria were met. A summary of that test is shown in Enclosure 2.

Based on our review of the information you provided, we find the TL-2 FLEAT acceptable for use on the National Highway System (NHS) when such use is requested by a transportation agency. This acceptance assumes that the modified FLEAT will be installed as tested and at locations where anticipated impact speeds will not exceed 70 k/hr. Because it remains a proprietary device, its use on Federal-aid projects, except exempt, non-NHS projects, is subject to the conditions listed in Title 23, Code of Federal Regulations, Section 635.411.

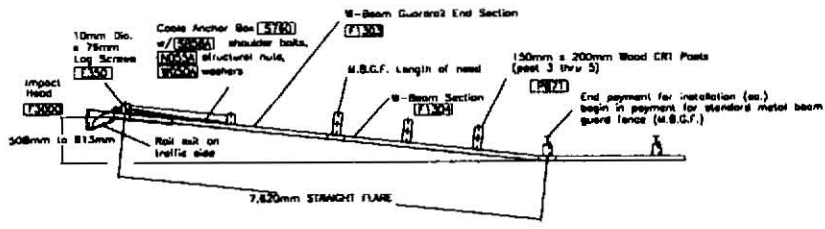
Sincerely yours,

(original signed by Dwight A. Horne)

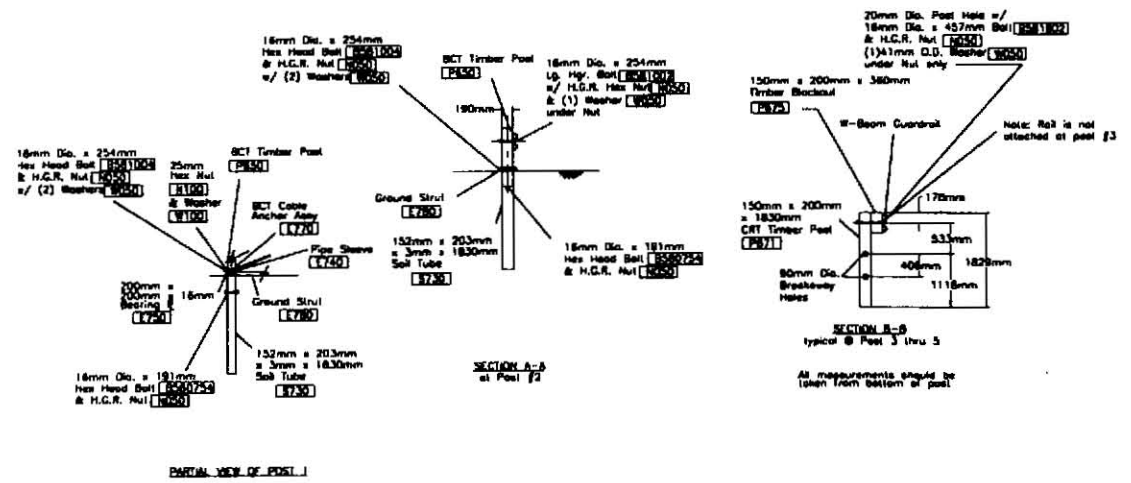
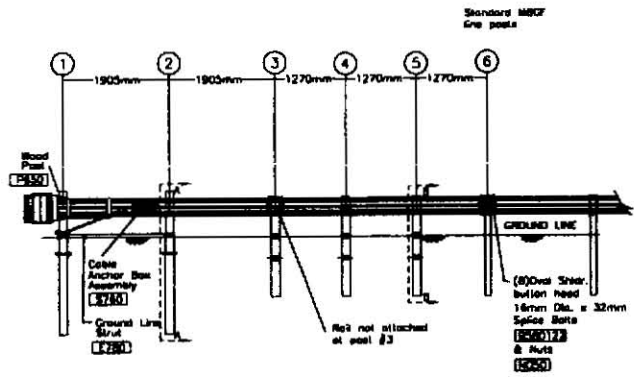
Dwight A. Horne

Director, Office of Highway Safety Infrastructure

2 Enclosures



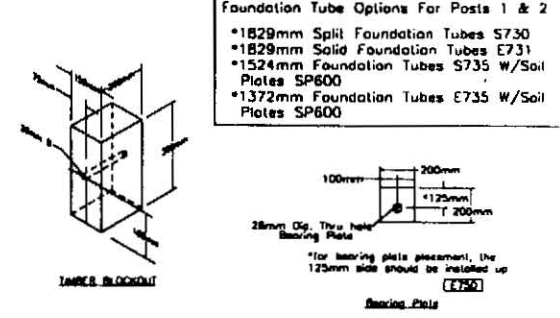
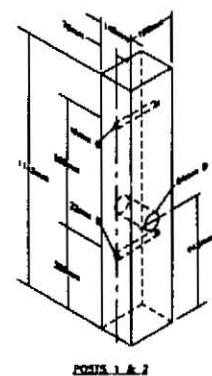
TRAFFIC



GENERAL NOTES

1. Wood posts are required with the FLEAT.
2. All bolts, nuts, cable assemblies, cable anchors and bearing plates shall be galvanized.
3. The soil tubes shall not protrude more than 100mm above ground (measured along a 1500mm cord). Site grading may be necessary to meet this requirement.
4. The soil tubes may be driven with an approved driving head. Soil tubes should not be driven with the wood post in the tube. If the tubes are placed in drilled holes, the backfill material must be satisfactorily compacted to prevent settlement.
5. When rock is encountered during excavation, a 300mm Dia. post hole, 500mm deep may be used if approved by the engineer. Granular material will be placed in the bottom of the hole approx. 85mm deep to provide drainage. The soil tubes will be field cut to length, placed in the hole and backfilled with adequately compacted material excavated from the hole.
6. The breakaway cable assembly must be taut. A locking device, (vice grips or channel lock pliers) should be used to prevent the cable from twisting when tightening nuts.
7. The wood blockouts should be "low nailed" to the rectangular wood posts to prevent them from turning when the wood shrinks.

ITEM #	QTY	BILL OF MATERIALS
F3000	1	IMPACT HEAD
F1303	1	W-BEAM GUARDRAIL END SECTION, 12 GA.
F1304	1	W-BEAM GUARDRAIL CENTER SECTION, 12 GA.
S730	2	*FOUNDATION SOIL TUBE, 152mm x 203mm x 1830mm
E740	1	PIPE SLEEVE
E750	1	BEARING PLATE, 200mm x 200mm x 18mm
S760	1	CABLE ANCHOR BOX
E770	1	BCT CABLE ANCHOR ASSEMBLY
E780	1	GROUND STRUT
P650	2	140mm x 190mm x WOOD POSTS
P671	3	150mm x 200mm x WOOD CRT POST
P675	3	150mm x 200mm x 390mm TIMBER BLOCKOUT
HARDWARE		
B580122	16	16mm Dia. x 32mm SPLICE BOLT
B580754	2	16mm Dia. x 191mm HEX BOLT
B581004	2	16mm Dia. x 254mm HEX BOLT
B581002	1	18mm Dia. x 254mm H.G.R. BOLT (POST 2 ONLY)
B581802	3	18mm Dia. x 457mm H.G.R. BOLT (POST 3 THRU 7)
N050	24	16mm Dia. H.G.R. NUT (SPLICE 24 SOIL TUBES 2, STRUT 2, POST 2, 1; POST 3 THRU 7, 5.)
W050	8	H.G.R. WASHER
N100	2	25mm ANCHOR CABLE HEX NUT
W100	2	25mm ANCHOR CABLE WASHER
E350	2	10mm x 76mm LAG SCREW
S760A	8	CABLE ANCHOR BOX SHOULDER BOLTS
N055A	8	13mm A325 STRUCTURAL NUT
W050A	16	27mm OD X 14mm ID A325 STR. WASHER



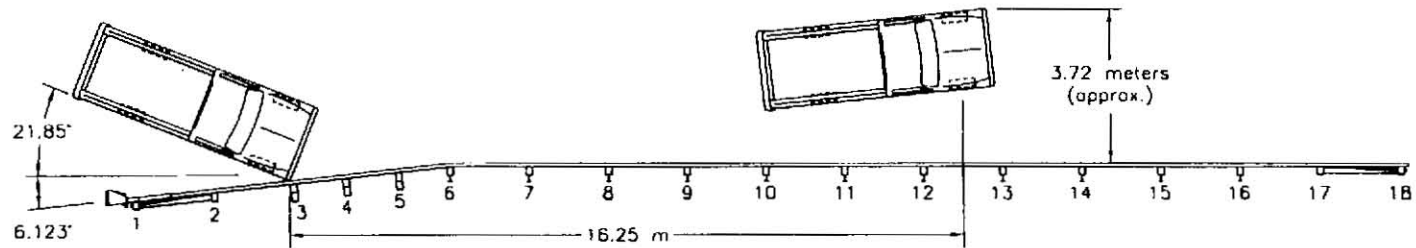
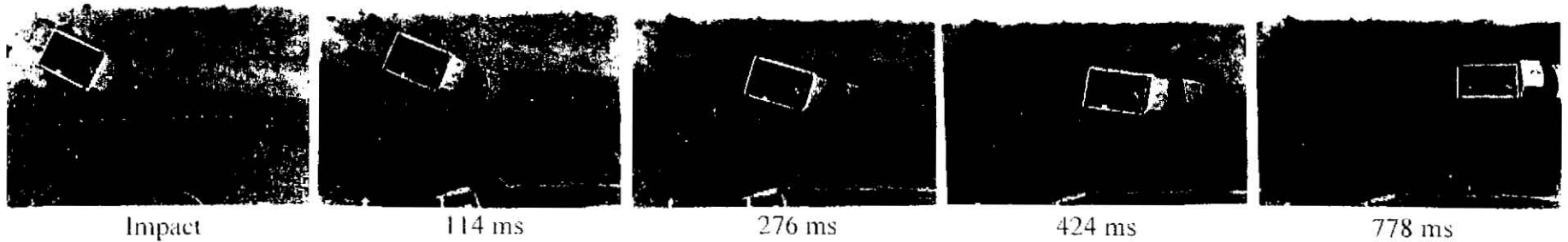
Foundation Tube Options For Posts 1 & 2

- *1829mm Split Foundation Tubes E730
- *1829mm Solid Foundation Tubes E731
- *1524mm Foundation Tubes E735 W/Soil Plates SP600
- *1372mm Foundation Tubes E735 W/Soil Plates SP600

FLored Energy Absorbing Terminal
FLEAT TL-2
508 to 813mm Offset

DRAWN/REVISED BY	DATE REVISED	DRG NO.	PG	OF
JRR/JRR	05/03/99	FLT-M	1	1

ROAD SYSTEMS INC.
BIG SPRING, TX
(915)-263-2435 or (815)-464-5917



Test Number	FL EAT-4
NCHRP 350 Test Designation	2-35
Date	12/15/98
Installation	FLared Energy Absorbing Terminal
System length	30.5 m
Head Dimensions (LxWxH)	1557 mm x 356 mm x 490 mm
Face Angle	6.0 degrees
Flare Details	
Length	7.62 m
Offset	0.81 m
Angle	6.123 degrees
Guardrail	12-gauge W-beam
End Terminal Posts	
Numbers 1-2	BCT timber posts 140x190x1080 long in foundation tubes with groundline strut
Numbers 3-5	CRT timber posts 150x200x1830 long
Number 6	W150x13.5 steel posts, 1830 long
Vehicle Model	1992 Chevy 2500 ¼-Ton Pickup
Vehicle Weight	
Curb	2061 kg
Test Inertia	2034 kg
Gross Static	2034 kg

Speed	
Impact	71.7 km/h
Exit	N.A.
Angle	
Impact	21.9 deg (to tangent)
Exit	N.A.
Occupant Impact Velocity	
Longitudinal	3.93 m/s
Lateral	3.10 m/s
Occupant Ridedown Deceleration	
Longitudinal	6.9 g's
Lateral	5.3 g's
Vehicle Damage	
TAD	1-FR-1
VDI	01FR1E1
Vehicle Rebound Distance	3.72 meters (approx.)

Conversion Factors: 1 m = 2.54 cm; 1 lb = 0.454 kg

Figure 10. Summary of Test FL EAT-4.

ENCLOSURE (2)



US Department
of Transportation
**Federal Highway
Administration**

400 Seventh St., S.W.
Washington, D.C. 20590

August 27, 1999

Refer to: HMHS-CC61

Mr. Kaddo Kothmann
President
ROAD SYSTEMS, INC.
P.O. Box 2163
Big Spring, Texas 79721

Dear Mr. Kothmann:

In your July 30 letter, you requested the Federal Highway Administration's (FHWA) acceptance of a steel breakaway post as an alternative to the weakened timber posts that are currently used in your SKT-350 and FLEAT-350 w-beam guardrail terminals. These breakaway posts are comprised of a lower stub post connected to an upper post by splice plates welded to the flanges of the stub post along the bottom and sides of the plates and connected to the upper post with two 31-mm diameter plug welds. This design causes the plug welds to yield at relatively low loads when the posts are struck head on and the welds are loaded in torsion, but the connection can sustain loads as high as 89 KN when loaded laterally in shear. Enclosure 1 shows the breakaway end posts, the breakaway line posts, and the splice weld details. All other features of the SKT-350 and the FLEAT-350 remain unchanged from the original designs.

To show that the steel breakaway posts functioned as desired, you ran three tests on the alternative design, and provided me with copies of the test reports for staff review. Summaries of each of the tests are shown in Enclosure 2.

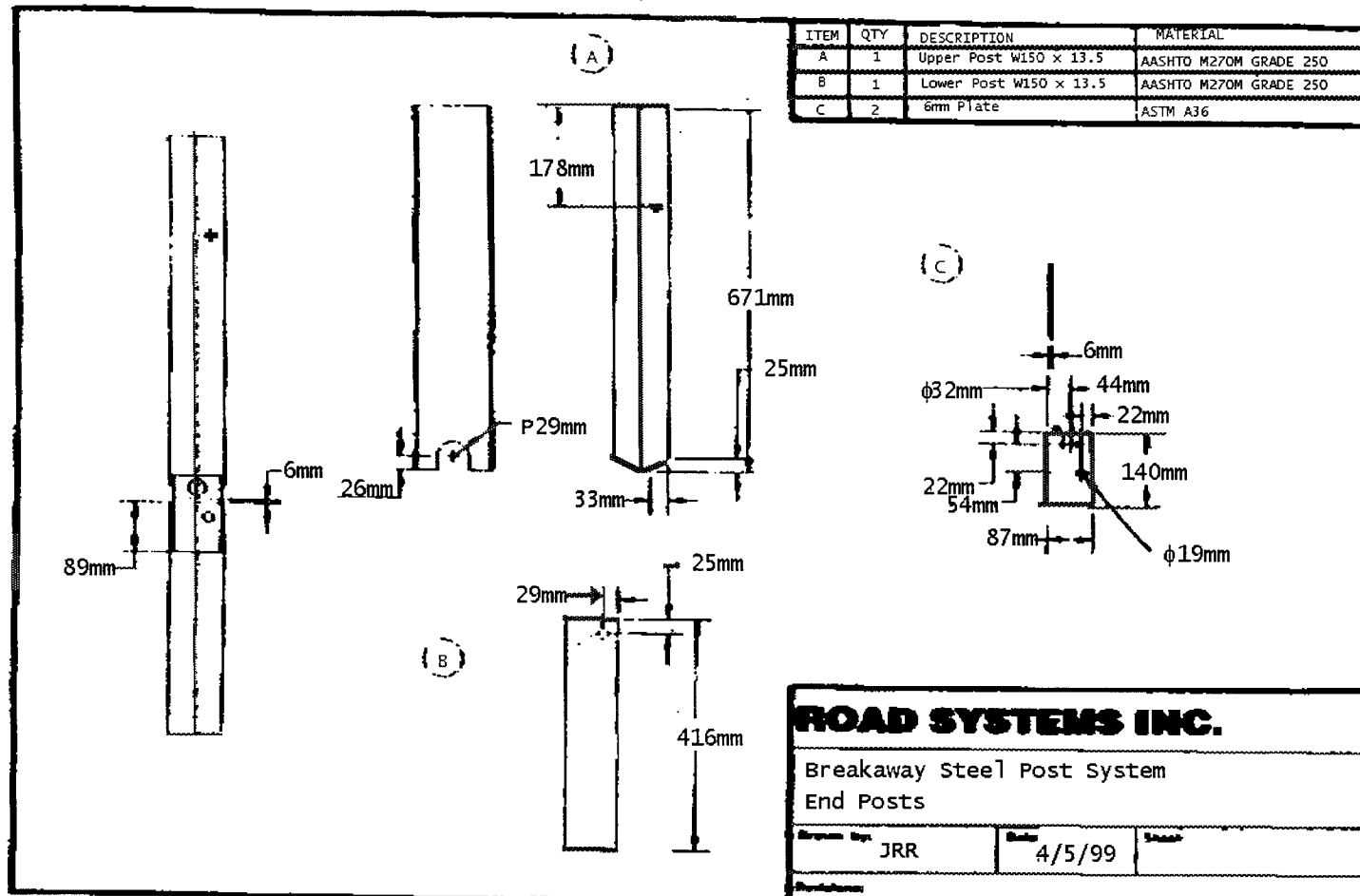
We believe that the tests you ran satisfactorily demonstrate that the steel breakaway posts are an acceptable alternative to the original wood post designs for the SKT-350 and the FLEAT-350 and may be used as such on the National Highway System when requested by a transportation agency.

Sincerely yours,

Dwight A. Horne
Director, Office of Highway Safety Infrastructure

2 Enclosures

Figure 9. Steel Breakaway End Post



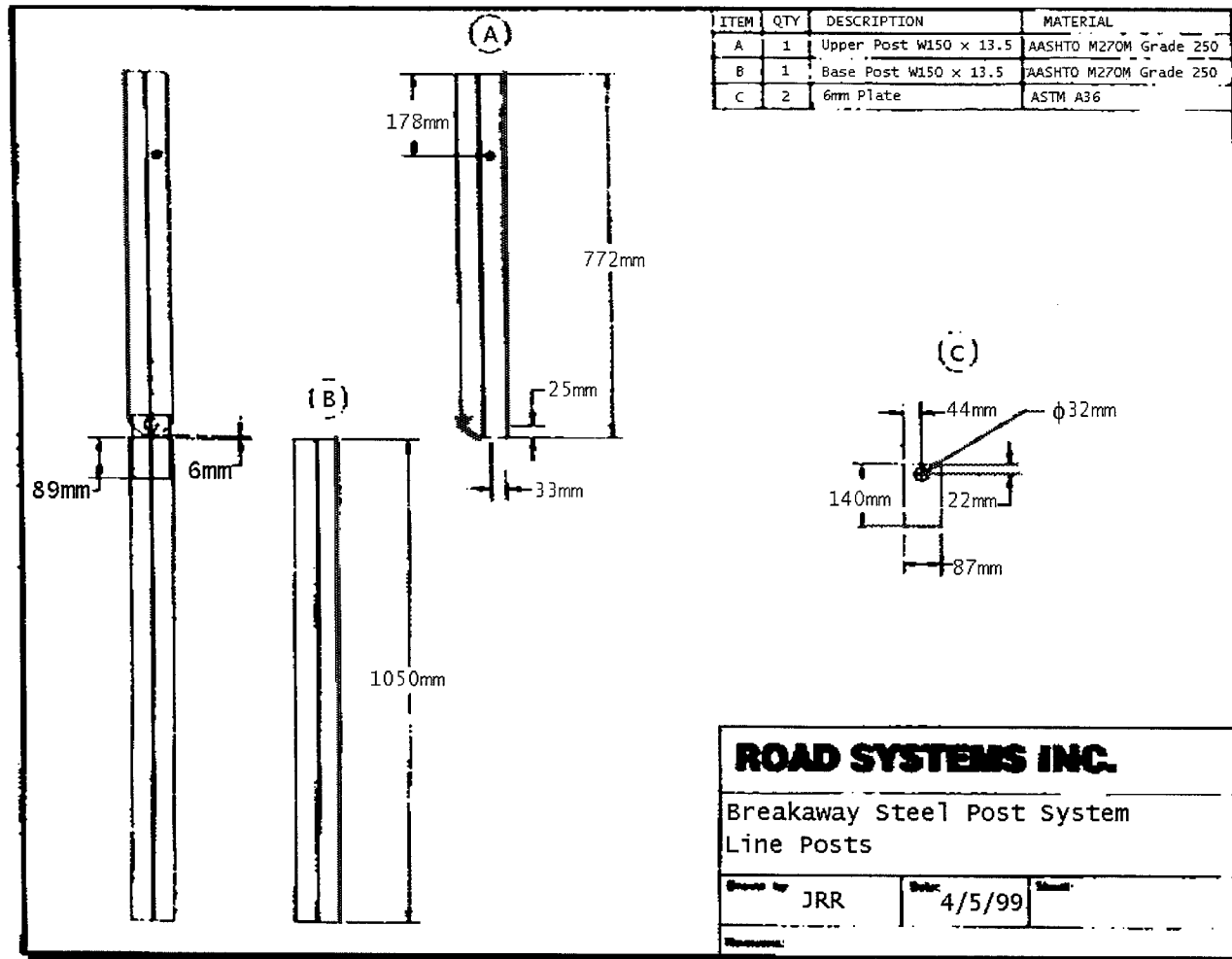
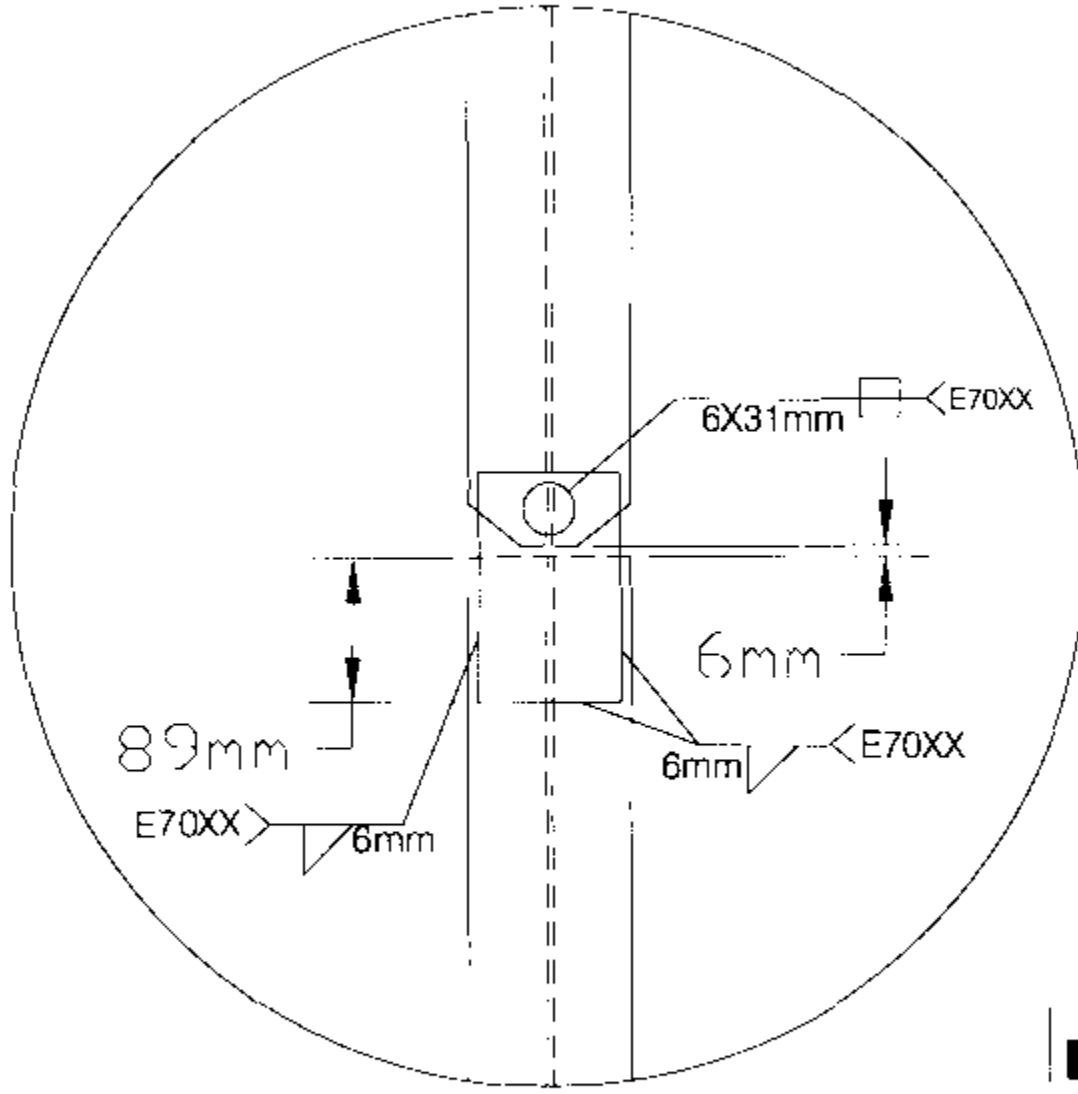


Figure 11. Steel Breakaway Line Post

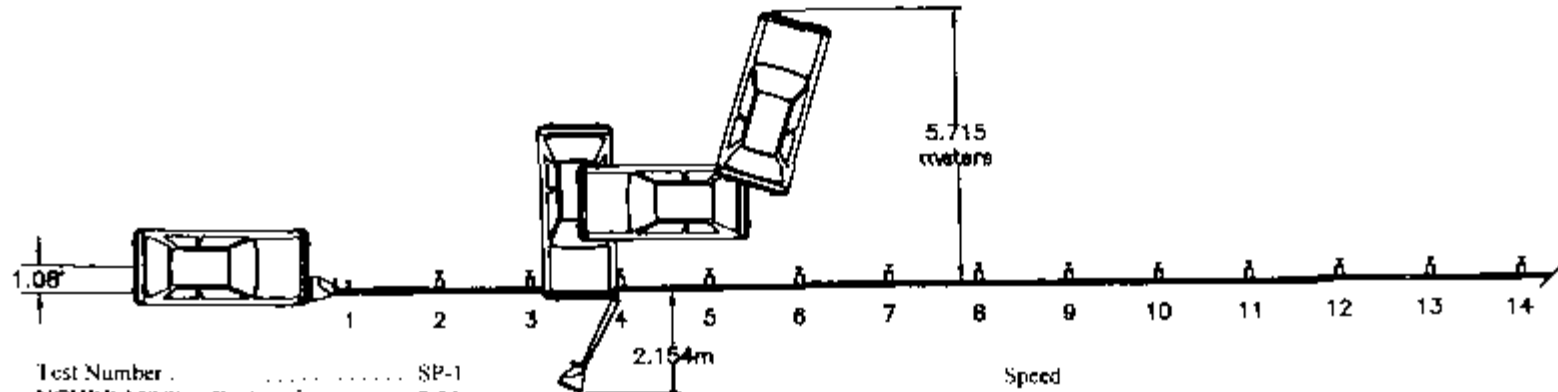
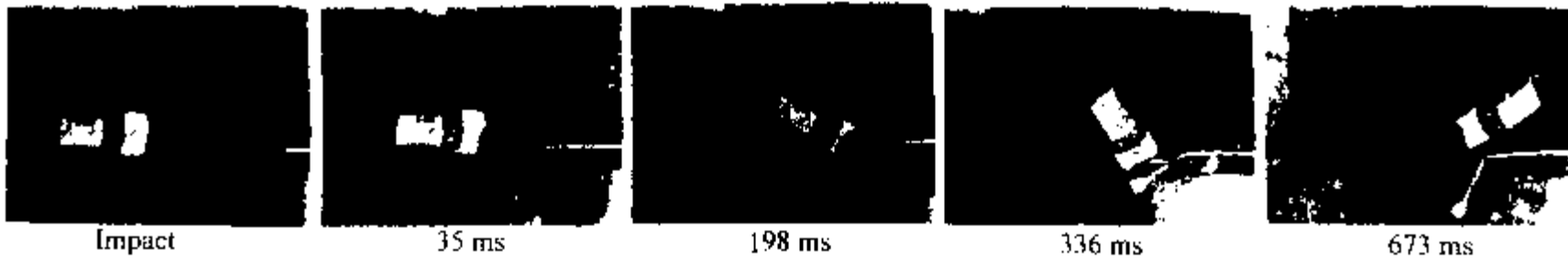


Note:
Weld typical on both flanges
of post.

ROAD SYSTEMS INC.

**Steel Line Posts
Weld Details**

Drawn by	Date	Sheet
JHA	6/29/99	
Revisions		

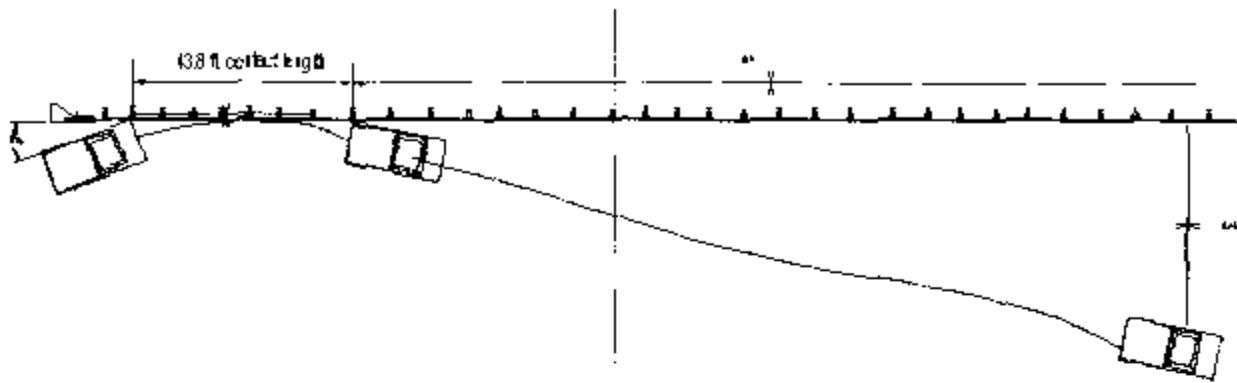


Test Number	SP-1
NCHRP 350 Test Designation	3-31
Date	2/2/98
Installation	Sequential Kinking Terminal
System length	41.91 m
Head Dimensions (LxWxH)	2104 mm x 508 mm x 508 mm
Face Angle	0.0 degrees
Guardrail	12-gauge W-beam
End Terminal Posts	
Number 1	W150x13.5 BCT steel post, 1080 mm long in SKT foundation tube w/ modified groundline strut to post 2
Number 2	W150x13.5 BCT steel post, 1830 mm long in SKT foundation tube w/ modified groundline strut and 200x150x360 mm routed timber block
Numbers 3-8	W150x13.5 CRT steel posts, 1830 mm long w/ 200x150x360 mm routed timber block
Vehicle Model	1993 Ford Festiva Compact Car
Vehicle Weight	
Curb	795 kg
Test Inertia	819 kg
Gross Static	894 kg

Speed	
Impact	98.64 km/h
Exit	N.A.
Angle	
Impact	1.08 deg (on head)
Exit	N.A.
Occupant Impact Velocity	
Longitudinal	8.40 m/s
Lateral	3.51 m/s
Occupant Ridedown Deceleration	
Longitudinal	12.12 g/s
Lateral	10.81 g/s
Vehicle Damage	
TAD	12-FR-3
VDI	12FREN2
Vehicle Rebound Distance	5.7 meters (approx)

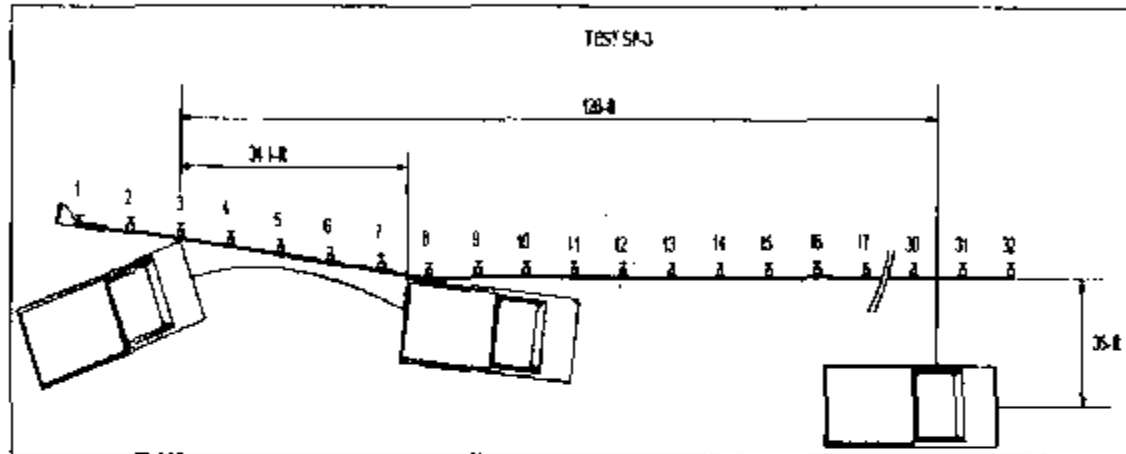
Conversion Factors: 1 in. = 2.54 cm, 1 lb = 0.454 kg

Figure 17. Summary of Test SP-1



General Information		Test Vehicle (continued)		Ridedown Accelerations (g's)	
Test Agency	Southwest Research Institute	Mass (kg) Dummy(s)	75.0	Y-direction	12.6
Test Number	SP-2	Mass (kg) Gross Strain	2030.0	Test Article Deflection (mm)	
Test Date	Feb. 18, 1999	Impact Conditions		Dynamic	1189
Test Article	Guardrail End Terminal	Speed (km/h)	100.1	Permanent	935
Type	Sequential Kinking Terminal	Angle (deg)	20.0	Vehicle Damage	
Installation Length (m)	61	Exit Conditions		Exterior	
Barrier	W-beam	Speed (km/h)	64.9	VDS	11FQ
Soil Type and Condition	S1 Dry	Angle (deg)	15.8	DCDC	11FNEN
Test Vehicle		Occupant Risk Values		Interior	
Type	Standard Pickup	Impact Velocity (m/s)		OCCI	LF000000
Designation	2000P	X-direction	3.8	Post-Impact Vehicular Behavior	
Model	1993 Chevrolet C-20	Y direction	3.5	Maximum Roll Angle (deg)	7.3
Mass (kg) Curb	1925	Ridedown Accelerations (g's)		Maximum Pitch Angle (deg)	4.5
Mass (kg) Test Inertial	1925	X-direction	10.6	Maximum Yaw Angle (deg)	Not Available

Figure 13. Impact Description and Summary of Results, Test SP-2



General Information		Test Vehicle (continued)		Ridedown Accelerations (g's)	
Test Agency	Southwest Research Institute	Mass (kg) Dummy(s)	75.0	Y-direction	7.8
Test Number	SP-3	Mass (kg) Gross Static	2020.0	Test Article Deflection (mm)	
Test Date	13-Apr-99	Impact Conditions		Dynamic	1217
Test Article	4-ft Offset Guardrail End Terminal	Speed (km/h)	104.5	Permanent	1080
Type	Sequential Kinking Terminal	Angle (deg)	20.4	Vehicle Damage	
Installation Length (m)	61	Exit Conditions		Exterior	
Barrier	W-beam	Speed (km/h)	55.1	VDS	11FQ-2
Soil Type and Condition	S1-Dry	Angle (deg)	16.0	DCDC	11FNEN
Test Vehicle		Occupant Risk Values		Interior	
Type	Standard Pickup	Impact Velocity (m/s)		OCDI	LF000000
Designation	2000P	X-direction	5.5	Post-Impact Vehicular Behavior	
Model	1993 Chevrolet C-20	Y-direction	3.6	Maximum Roll Angle (deg)	5
Mass (kg) Curb	1945	Ridedown Accelerations (g's)		Maximum Pitch Angle (deg)	9.4
Mass (kg) Test Inertial	1945	X-direction	7.5	Maximum Yaw Angle (deg)	Not Available

Figure 14. Impact Description and Summary of Results, Test SP-3

June 1, 2001

HSA-CC46C

Mr. Kaddo Kothmann
President
Road Systems, Inc.
1507 E. 4th Street
Big Spring, TX 79720

Dear Mr. Kothmann:

Your May 2 request for acceptance of a modified post layout for the FLEAT w-beam guardrail terminal is approved, based on staff review of a previous test you conducted on the FLEAT with breakaway steel posts and on a more recent test of a similar design with weakened wood posts on 1.9 m (6ft-3in) centers for posts 3 through 6.

Whereas the original FLEAT consisted of two breakaway anchor posts followed by four breakaway posts on 1.27 m (4ft-2in) centers and a seventh breakaway post at the standard 1.9 m (6ft-3in) spacing, the modified design will consist of the same number of breakaway posts, but spaced equally on 1.9 m (6ft-3in) centers. The last breakaway post will be located at the beginning of the terminal taper 11.4 m (37.5 feet) from the first terminal post. The first unmodified line post (wood or steel) will be 13.3 m (43.8 feet) from the terminal nose. The beginning of the length of need on the FLEAT remains unchanged at the third post, 3.8 m (12.5 feet) from the terminal end.

The breakaway anchor posts may be either the weakened timber posts originally tested or the steel breakaway posts accepted in my August 27, 1999 letter to you. Likewise, the remaining five posts may be either weakened wood posts or the tested breakaway steel post design. The modified post spacing is applicable to the FLEAT terminal throughout the currently accepted range of end-offsets.

Sincerely yours,

(original signed by Frederick G. Wright, Jr.)

Frederick G. Wright, Jr.
Program Manager, Safety

August 24, 2001

Refer to: HSA-10/CC46D

Mr. Kaddo Kothmann
President, Road Systems, Inc.
1507 E 4th St.
Big Spring, TX 79720

Dear Mr. Kothmann:

In your May 18 letter, you described a FLEAT guardrail terminal modified for use with a strong post, w-beam guardrail median barrier and provided preliminary summary information on the tests that were run at Southwest Research Institute to verify its compliance with current evaluation criteria. You also included a videotape of the tests that were conducted. Mr. Richard Powers of my staff received single copies of the final reports, entitled "FULL-SCALE CRASH EVALUATION of a FLEAT MEDIAN TERMINAL SYSTEM", TESTS FMT-1, FMT-2, and FMT-3M on August 22.

As seen in Enclosure 1, the FLEAT-MT is nearly identical to the previously accepted FLEAT roadside terminal. Since its intended use is to terminate a double-faced, strong post w-beam median barrier, two impact heads are required. One of these is at the fourth post in from the end of the barrier and fits over the backside w-beam rail element. The other impact head fits over the end of the traffic-side rail element 5717 mm ahead of the first and is offset 610 mm from the face of the median barrier proper in a straight flare. Minor modifications were made to the design to obtain satisfactory results in the reverse direction impact described below.

Based on the similarity of the FLEAT-MT to the roadside FLEAT design and layout, you reviewed the tests upon which acceptance of the FLEAT was based and concluded that only three additional tests would be required to certify the median terminal under NCHRP Report 350. My staff concurred with your analysis. The first test conducted was NCHRP Report 350 test 3-35, the 2000-kg pickup truck redirection test. The truck impacted the terminal at post 3, the beginning of the length of need, at 100.4 km/h and 20.8 degrees. Although all evaluation criteria were satisfied, the test vehicle snagged on post 7, which was a standard steel line post. This result was discussed with your consultant, Dr. Dean Sicking, and it was decided to make post 7 a breakaway design to improve test performance. This change is not reflected in the test reports, but is shown in Enclosure 1.

The second test was NCHRP Report 350 test 3-31 where the pickup truck impacted the FLEAT-MT head-on at 99.8 km/h. The truck was brought to a controlled stop in approximately 10 m, with 6.8 m of the front rail and 1.9 m of the back rail being extruded. Occupant impact velocity was 5.6 m/sec and the subsequent ridedown acceleration was 12.9 g's.

The final test was NCHRP Report 350 test 3-39, the reverse-direction impact that is required for devices such as median barrier terminals that are likely to be struck from either direction. When this test was first run, the pickup truck snagged on the downstream cable anchor and subsequently overturned. When a deflector bracket was added to the downstream end of the cable anchor, the vehicle was successfully redirected and all evaluation criteria were satisfied.

Based on the information you presented, I agree that the FLEAT-MT, as shown in Enclosure 1, meets the NCHRP Report 350 evaluation criteria for a test level 3 (TL-3) terminal and may be used on the National Highway System (NHS) to terminate a w-beam median barrier when such use is accepted or specified by the appropriate contracting agency. As a proprietary product, the conditions listed in Title 23, Code of Federal Regulations, Section 435.411 apply to its use on Federal-aid projects located on the NHS.

Sincerely yours,
(original signed by Rudolph M. Umbs)
Frederick G. Wright, Jr.
Program Manager, Safety

Enclosure

APPENDIX G – WYBET APPROVAL LETTERS

The FHWA approval letters can be found on their web site at:

http://safety.fhwa.dot.gov/fourthlevel/hardware/term_cush.htm



U.S. Department
of Transportation

**Federal Highway
Administration**

400 Seventh St. SW
Washington, D.C. 20590

August 19, 1999

Refer to: HMHS-CC60

Mr. King K. Mak
Research Engineer
Safety & Structural Systems Division
Texas Transportation Institute
College Station, TX 77843-3135

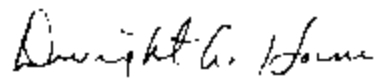
Dear Mr. Mak:

In your July 29 letter to me, you requested the Federal Highway Administration's (FHWA) acceptance of Wyoming's box-beam guardrail and median barrier end terminals, called the WYBET-350 and the WYBET-350 (MB), respectively, as National Cooperative Highway Research Program (NCHRP) Report 350 test level 3 (TL-3) designs. The original designs had both been accepted previously under NCHRP Report 230 evaluation criteria. To support your request, you also sent two copies of the Texas Transportation Institute report, entitled "NCHRP REPORT 350 EVALUATION OF THE WYOMING BOX-BEAM END TERMINAL (WYBET-350)", dated June 1999, and videotape copies of the crash tests that were run. Summaries of these tests are shown as Enclosure 1. Test 3-35 was run on both the guardrail and median barrier terminal designs.

The original WYBET designs consisted of an impact head, outer and inner steel tubes containing energy absorbing fiberglass/epoxy composite tubes, and an end anchorage assembly. Both Report 350 designs are similar in design to the Report 230 versions, but have some important differences. Enclosure 2 lists all of the design changes, the most significant one being Item 12, the increased length of the Stage 1 composite tube and the corresponding decrease in the length of the Stage 2 tube. This change was needed to meet the passenger ridedown acceleration in test 3-30. Because the crush force characteristics of the composite tubes are critical to proper impact performance of the WYBET-350 terminal, your test Report recommends that a "rigorous quality control and acceptance/rejection procedure be instituted by (the manufacturer) and the state Departments of Transportation to ensure that the composite tubes used in field installations are within the specifications". I strongly endorse this recommendation. Enclosure 3 shows the general design and layout of the WYBET-350 and the WYBET-350 (MB). Complete drawings are available from Mr. William B. Wilson, Wyoming DOT Standards Engineer, at (307) 777-4216 or via e-mail at bwilson@missg.state.wy.us

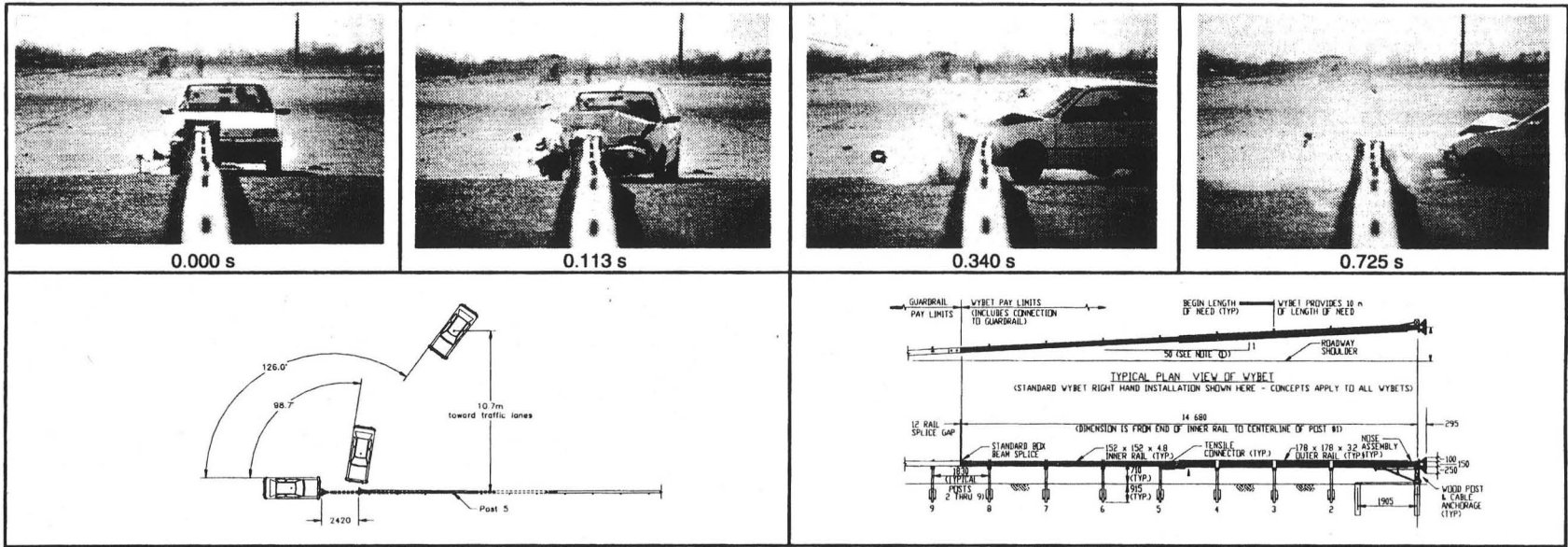
Members of my staff have reviewed the material you have submitted and agree that the WYBET-350 and the WYBET-350 (MB), as tested, satisfy the evaluation criteria recommended in Report 350 for a TL-3 terminal. Either design may be used on the National Highway System when such use is requested by the appropriate transportation agency. I understand that these designs are considered proprietary (except in Wyoming) so their use on Federal-aid projects, except exempt, non-NHS projects, is subject to the conditions listed in Title 23, Code of Federal Regulations, Section 635.411. Please call Mr. Richard Powers at (202) 366-1320 should you have any questions.

Sincerely yours,



Dwight A. Horne
Director, Office of Highway Safety Infrastructure

3 Enclosures



99

General Information

Test Agency Texas Transportation Institute
 Test No. 473160-10
 Date 02/15/99

Test Article

Type Terminal
 Name or Manufacturer WyBET-350
 Installation Length (m) 55.1
 Material or Key Elements ... Tubular Steel Rail Elements on Steel posts

Soil Type and Condition

Standard soil, dry

Test Vehicle

Type Production
 Designation 820C
 Model 1994 Geo Metro
 Mass (kg)
 Curb 763
 Test Inertial 820
 Dummy 76
 Gross Static 896

Impact Conditions

Speed (km/h) 98.7
 Angle (deg) 0

Exit Conditions

Speed (km/h) 14.9
 Angle (deg) 98.7

Occupant Risk Values

Impact Velocity (m/s)
 x-direction 10.9
 y-direction No Contact
 THIV (km/h) 38.9
 Ridedown Accelerations (g's)
 x-direction -12.0
 y-direction No Contact
 PHD (g's) 12.1
 ASI 1.17
 Max. 0.050-s Average (g's)
 x-direction -14.0
 y-direction 3.3
 z-direction 4.3

Test Article Deflections (m)

Dynamic 2.88
 Permanent 2.63

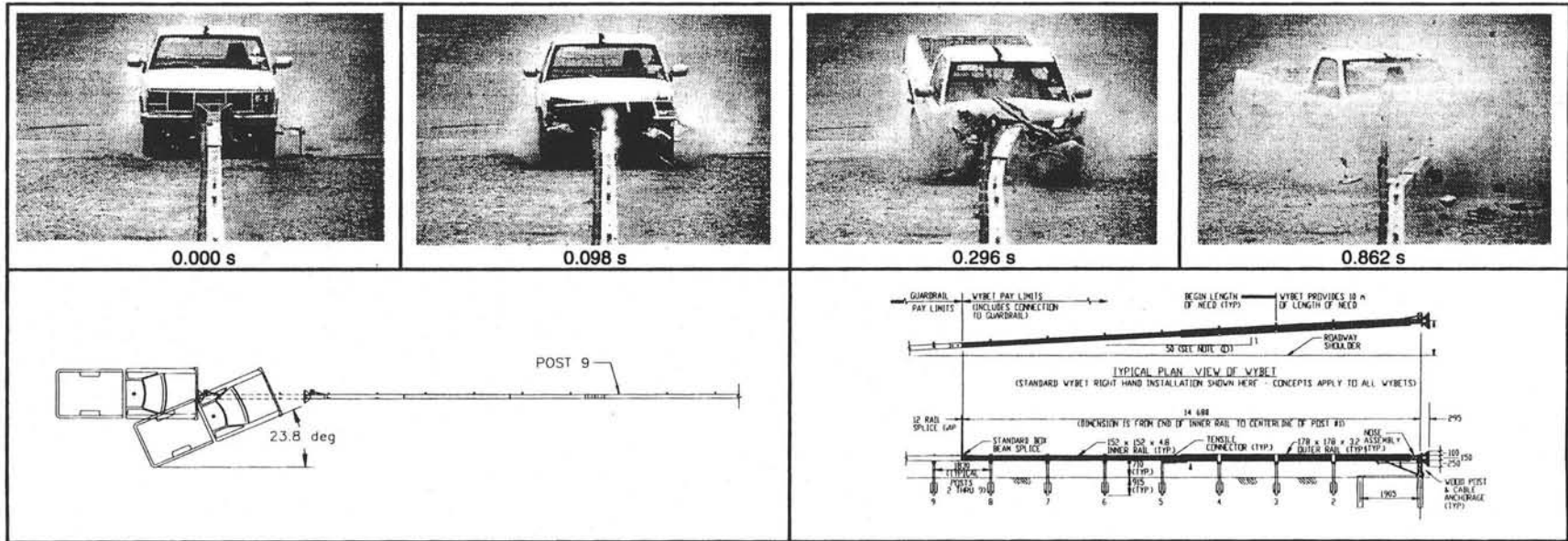
Vehicle Damage

Exterior
 VDS 12FD4
 CDC 12FDEW4
 Maximum Exterior
 Vehicle Crush (mm) -410
 Interior
 OCDI FS0020000
 Max. Occ. Compart.
 Deformation (mm) 107

Post-Impact Behavior

(during 1.0 s after impact)
 Max. Yaw Angle (deg) 122
 Max. Pitch Angle (deg) 8
 Max. Roll Angle (deg) -8

Figure 59. Summary of results for test 473160-10, NCHRP Report 350 test 3-30.



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General Information

Test Agency Texas Transportation Institute
 Test No. 473160-3
 Date 03/12/98

Test Article

Type End Treatment
 Name WYBET-350
 Installation Length (m) 55.1
 Material or Key Elements Tubular Steel Rail Elements on Steel posts

Soil Type and Condition

Standard Soil, Dry

Test Vehicle

Type Production
 Designation 2000P
 Model 1993 GMC 2500 pickup truck
 Mass (kg) Curb 1864
 Test Inertial 2000
 Dummy No dummy
 Gross Static 2000

Impact Conditions

Speed (km/h) 102.5
 Angle (deg) 0

Exit Conditions

Speed (km/h) 6.9
 Angle (deg) 24.0

Occupant Risk Values

Impact Velocity (m/s)
 x-direction 9.5
 y-direction 2.3
 THIV (km/h) 39.6
 Ridedown Accelerations (g's)
 x-direction -15.9
 y-direction -2.9
 PHD (g's) 15.9
 ASI 1.20
 Max. 0.050-s Average (g's)
 x-direction -14.7
 y-direction -1.9
 z-direction 4.4

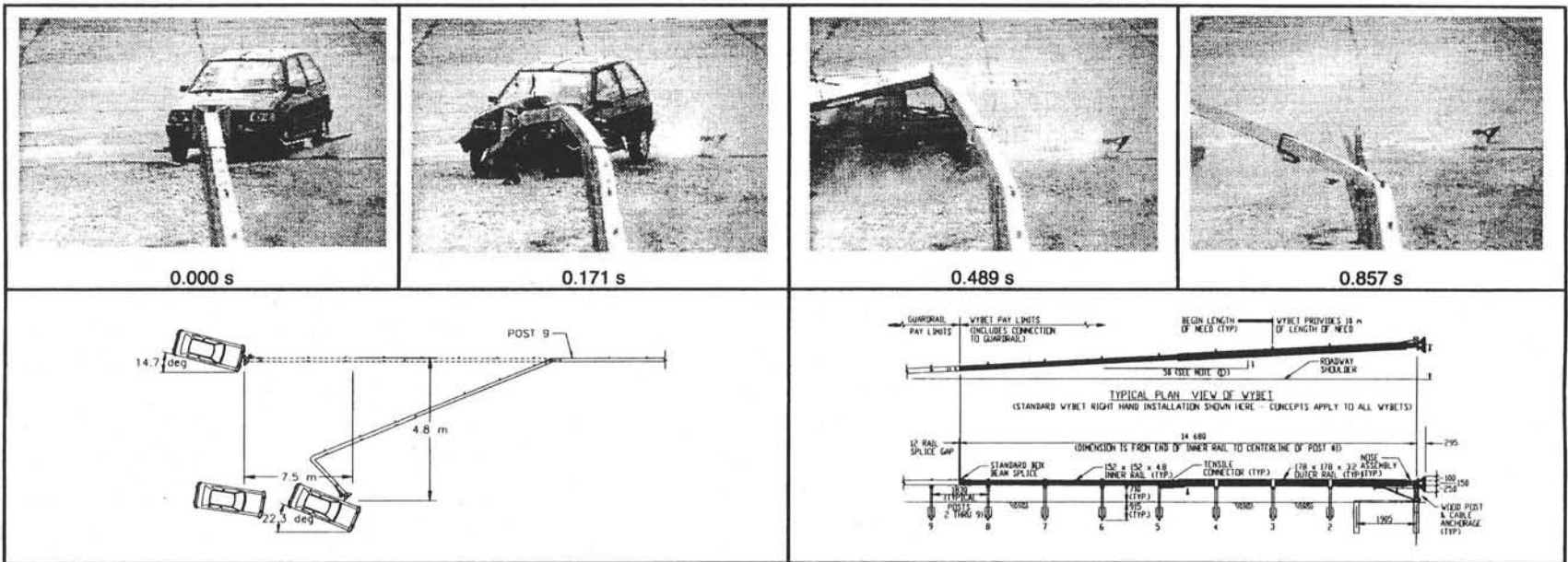
Test Article Deflections (m)

Dynamic 4.11
 Permanent 4.11

Vehicle Damage

Exterior
 VDS 12FC3
 CDC 12FCEN3
 Maximum Exterior
 Vehicle Crush (mm) 530
 Interior
 OCDI FS1000000
 Max. Occ. Compart.
 Deformation (mm) 35
Post-Impact Behavior
 (during 1.0 s after impact)
 Max. Yaw Angle (deg) -23
 Max. Pitch Angle (deg) -14
 Max. Roll Angle (deg) 13

Figure 34. Summary of results for test 473160-3, NCHRP Report 350 test 3-31.



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General Information

Test Agency Texas Transportation Institute
 Test No. 473160-1
 Date 03/04/98

Test Article

Type End Treatment
 Name or Manufacturer WYBET-350
 Installation Length (m) 55.1
 Material or Key Elements ... Tubular Steel Rail Elements on Steel Posts

Soil Type and Condition

Standard soil, Dry

Test Vehicle

Type Production
 Designation 820C
 Model 1993 Ford Festiva
 Mass (kg)
 Curb 846
 Test Inertial 820
 Dummy 75
 Gross Static 895

Impact Conditions

Speed (km/h) 99.5
 Angle (deg) 14.7

Exit Conditions

Speed (km/h) 8.7
 Angle (deg) 22.3

Occupant Risk Values

Impact Velocity (m/s)
 x-direction 10.3
 THIV (km/h) 37.0
 Ridedown Accelerations (g's)
 x-direction -9.7
 y-direction 4.5
 PHD (g's) 9.9
 ASI 1.3
 Max. 0.050-s Average (g's)
 x-direction -15.2
 y-direction 2.5
 z-direction 2.4

Test Article Deflections (m)

Dynamic 9.16
 Permanent 7.48

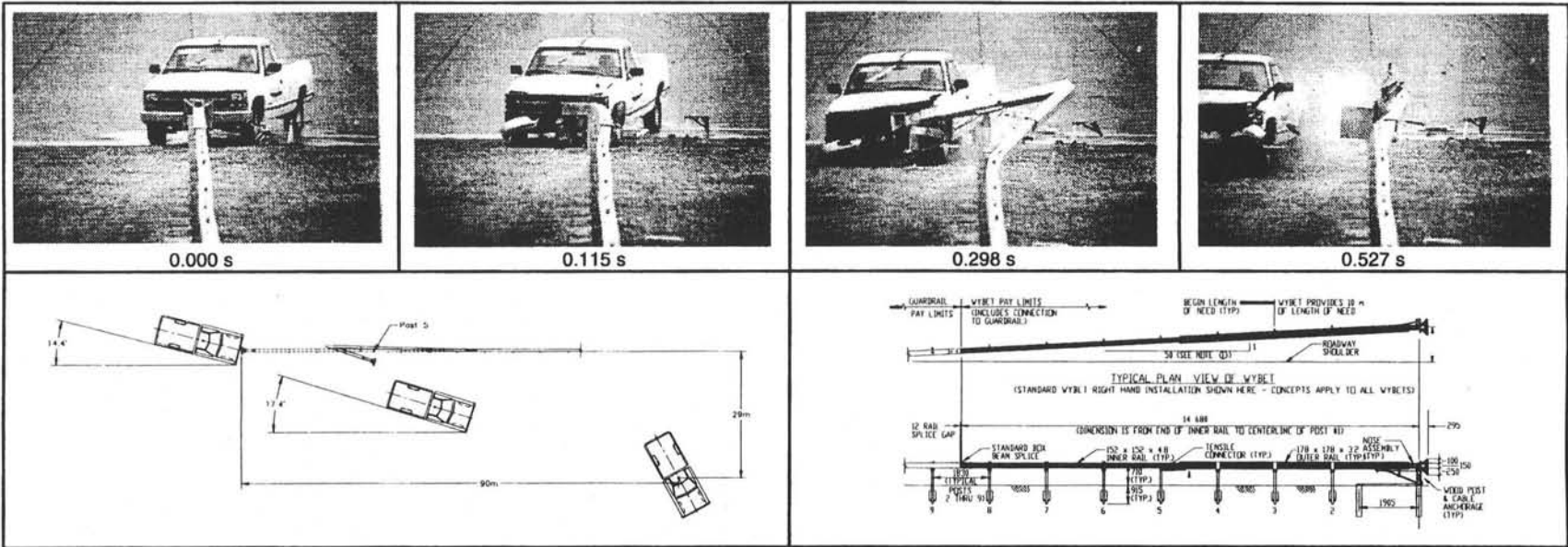
Vehicle Damage

Exterior
 VDS 12FD5
 CDC 12FDEK3
 Maximum Exterior
 Vehicle Crush (mm) 300
 Interior
 OCDI FS0010000
 Max. Occ. Compart.
 Deformation (mm) 45

Post-Impact Behavior

(during 1.0 s after impact)
 Max. Yaw Angle (deg) 31
 Max. Pitch Angle (deg) 3
 Max. Roll Angle (deg) 7

Figure 16. Summary of results for test 473160-1, NCHRP Report 350 test 3-32.



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General Information

Test Agency Texas Transportation Institute
 Test No. 473160-11
 Date 03/05/99

Test Article

Type End Treatment
 Name or Manufacturer WyBET-350
 Installation Length (m) 55.1
 Material or Key Elements ... Tubular Steel Rail Elements on Steel posts

Soil Type and Condition

Standard soil, dry

Test Vehicle

Type Production
 Designation 2000P
 Model 1994 Chevrolet 2500 pickup truck
 Mass (kg)
 Curb 1845
 Test Inertial 2000
 Dummy No Dummy
 Gross Static 2000

Impact Conditions

Speed (km/h) 99.0
 Angle (deg) 14.4

Exit Conditions

Speed (km/h) 62.2
 Angle (deg) 17.4

Occupant Risk Values

Impact Velocity (m/s)
 x-direction 7.0
 y-direction No contact
 THIV (km/h) 25.1
 Ridedown Accelerations (g's)
 x-direction -5.8
 y-direction No contact
 PHD (g's) 6.5
 ASI 0.57
 Max. 0.050-s Average (g's)
 x-direction -6.8
 y-direction 2.2
 z-direction -1.6

Test Article Deflections (m)

Dynamic 2.85
 Permanent 1.65

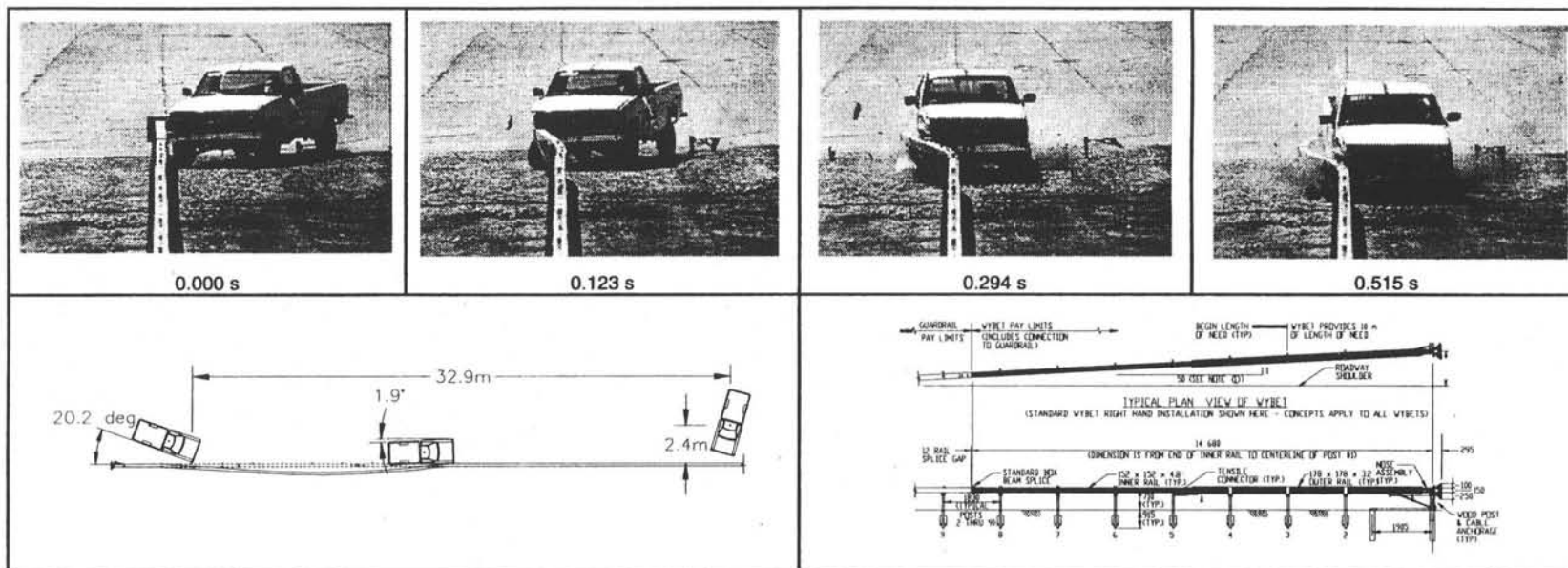
Vehicle Damage

Exterior
 VDS 12FC2
 CDC 12FDEW2
 Maximum Exterior
 Vehicle Crush (mm) 480
 Interior
 OCDI FS0000000
 Max. Occ. Compart.
 Deformation (mm) nil

Post-Impact Behavior

(during 1.0 s after impact)
 Max. Yaw Angle (deg) -8
 Max. Pitch Angle (deg) -4
 Max. Roll Angle (deg) 10

Figure 67. Summary of results for test 473160-11, NCHRP Report 350 test 3-33.



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General Information

Test Agency Texas Transportation Institute
 Test No. 473160-2
 Date 03/10/98

Test Article

Type End Treatment
 Name or Manufacturer WYBET-350
 Installation Length (m) 55.1
 Material or Key Elements Tubular Steel Rail Elements on Steel posts

Soil Type and Condition

Standard soil, Dry

Test Vehicle

Type Production
 Designation 2000P
 Model 1992 Chevrolet 2500 pickup
 Mass (kg)
 Curb 2078
 Test Inertial 2000
 Dummy No dummy
 Gross Static 2000

Impact Conditions

Speed (km/h) 99.5
 Angle (deg) 20.2

Exit Conditions

Speed (km/h) 69.4
 Angle (deg) 1.9

Occupant Risk Values

Impact Velocity (m/s)
 x-direction 4.1
 y-direction 4.1
 THIV (km/h) 16.7
 Ridedown Accelerations (g's)
 x-direction -12.7
 y-direction -7.0
 PHD (g's) 21.4
 ASI 0.5
 Max. 0.050-s Average (g's)
 x-direction -3.3
 y-direction -4.4
 z-direction 2.2

Test Article Deflections (m)

Dynamic 0.96
 Permanent 0.75

Vehicle Damage

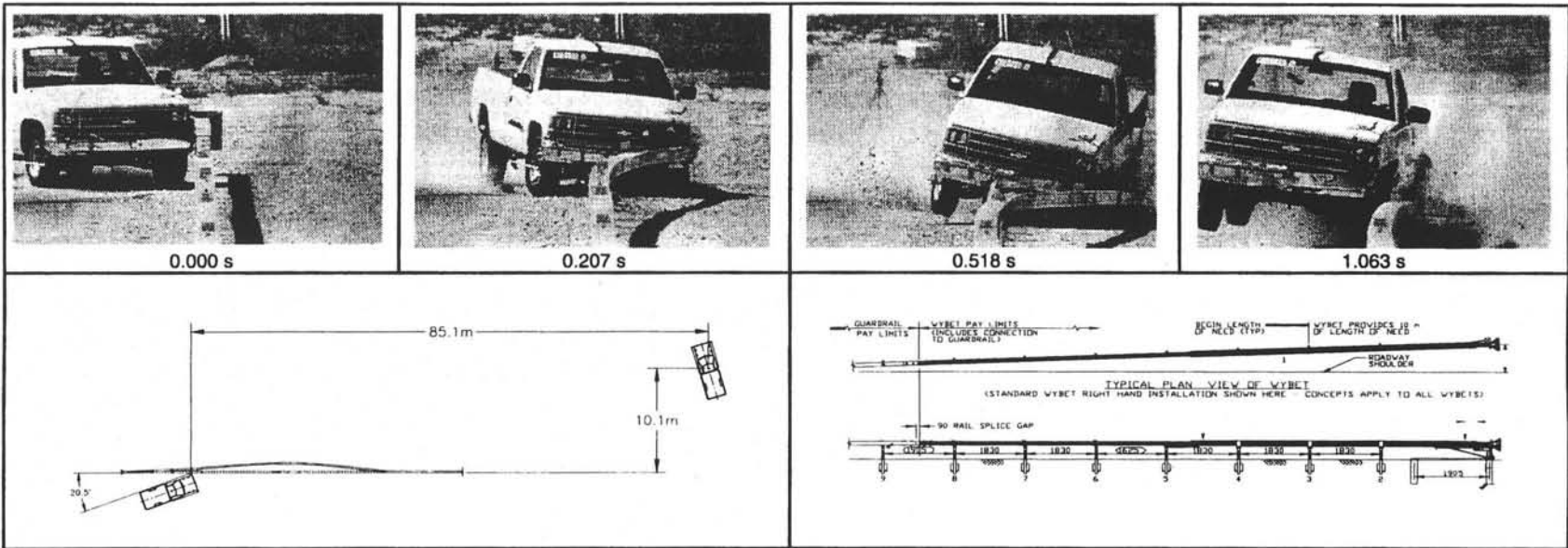
Exterior
 VDS 01RFQ3
 CDC 01RFEW2
 Maximum Exterior
 Vehicle Crush (mm) 475
 Interior
 OCDI FS0000000

Max. Occ. Compart. Deformation (mm) 0

Post-Impact Behavior

(during 1.0 s after impact)
 Max. Yaw Angle (deg) -27
 Max. Pitch Angle (deg) -3
 Max. Roll Angle (deg) -6

Figure 24. Summary of results for test 473160-2, NCHRP Report 350 test 3-35.



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General Information

Test Agency Texas Transportation Institute
 Test No. 473160-5
 Date 04/30/98

Test Article

Type End Treatment
 Name WYBET-350-Median Barrier
 Installation Length (m) 55.1
 Material or Key Elements Tubular Steel Rail Elements on Steel posts

Soil Type and Condition

Standard Soil, Dry

Test Vehicle

Type Production
 Designation 2000P
 Model 1992 Chevrolet 2500 pickup truck
 Mass (kg) Curb 2060
 Test Inertial 2000
 Dummy No dummy
 Gross Static 2000

Impact Conditions

Speed (km/h) 100.1
 Angle (deg) 20.5

Exit Conditions

Speed (km/h) N/A
 Angle (deg) N/A

Occupant Risk Values

Impact Velocity (m/s)
 x-direction 3.8
 y-direction 3.1
 THIV (km/h) 13.5
 Ridedown Accelerations (g's)
 x-direction -4.4
 y-direction 6.7
 PHD (g's) 8.2
 ASI 0.46
 Max. 0.050-s Average (g's)
 x-direction -2.3
 y-direction 4.0
 z-direction 2.0

Test Article Deflections (m)

Dynamic 1.61
 Permanent 1.60

Vehicle Damage

Exterior
 VDS 01LFQ3
 CDC 01LFEW2
 Maximum Exterior
 Vehicle Crush (mm) 220
 Interior
 OCDI FS0000000
 Max. Occ. Compart.
 Deformation (mm) 0

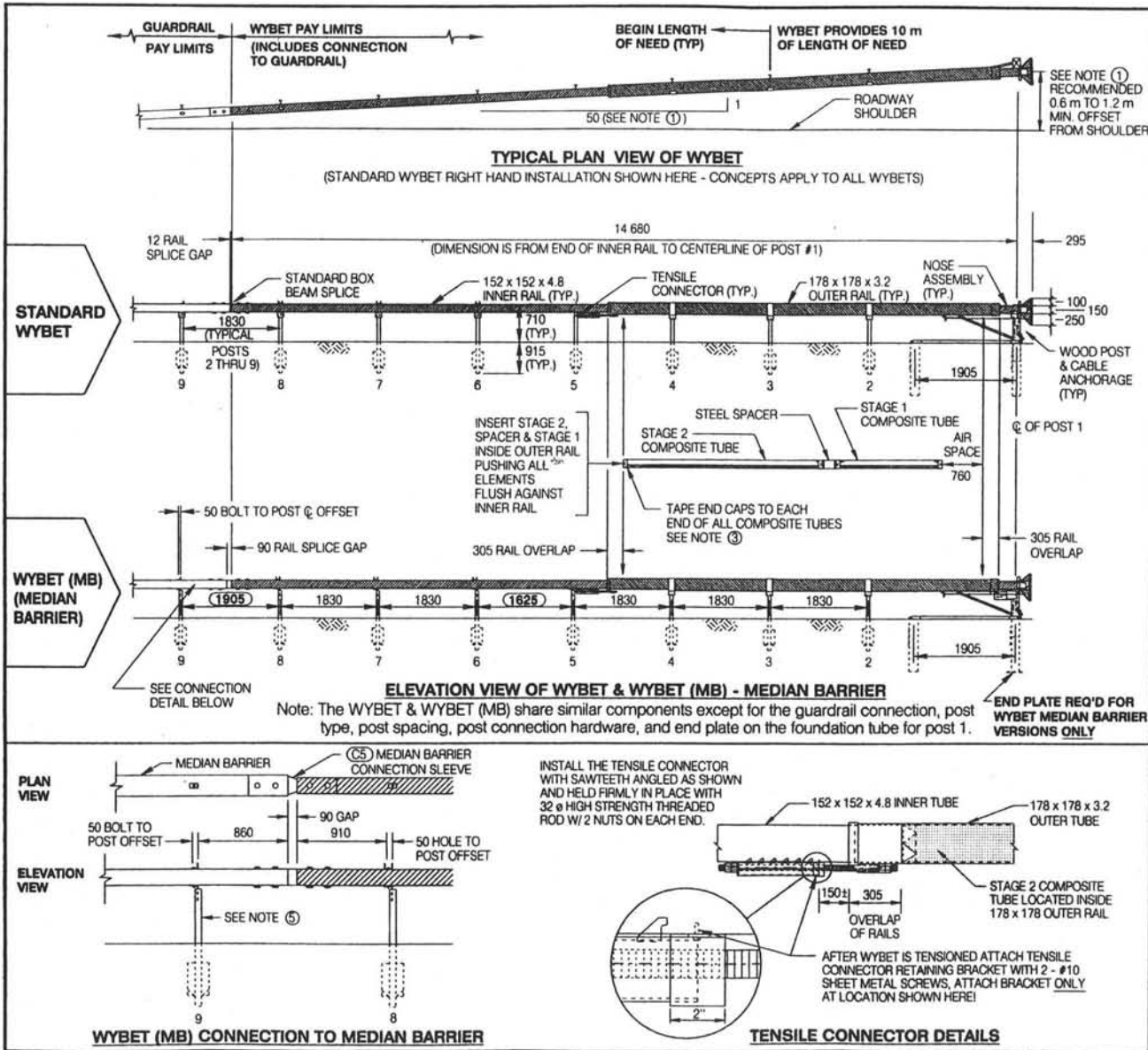
Post-Impact Behavior

(during 1.0 s after impact)
 Max. Yaw Angle (deg) 26
 Max. Pitch Angle (deg) -3
 Max. Roll Angle (deg) -24

Figure 75. Summary of results for test 473160-5, NCHRP Report 350 test 3-35.

Table 1. Summary of design modifications to WYBET.

Item	Description	Design Modification
1	Slotted bearing plate	Eliminate the 25 mm x 6 mm (1 in. x ¼ in.) spacer strap on top of the plate.
2	Pipe sleeve	Change the length from 150 mm to 140 mm (6 in. to 5-1/2 in.).
3	Ground line strut bolt	Change the length from 250 mm (10 in.) to 240 mm (9-1/2 in.).
4	Bearing plate attachment hardware	Change from 5 mm x 50 mm (3/16 in. x 2 in.) lag bolts to 16d nails
5	Washers @ soil plate	Eliminate 2 washers at each bolt on the soil plate.
6	Head to post lag screw	Change the length from 130 mm (5 in.) to 100 mm (4 in.).
7	16-mm (5/8-in.) nut	Replace the small finished nuts with large guardrail nuts.
8	End post (post 1)	Place the impact head on top of the end post for the shoulder barrier, similar in design to that of the median barrier.
9	Wood strut	Add the wood strut to the end post of the shoulder barrier version, similar in design to that of the median barrier version.
10	Tensile connector bracket	Add a bracket at the upstream end of the tensile connector to keep it from dropping out of the slots.
11	Width of composite tube cap	Increase the width of the composite tube caps from 75 mm (3 in.) to 100 mm (4 in.) to minimize the potential for splintering of the composite tubes.
12	Lengths of composite tubes	Increase the length of the stage 1 composite tube from 1830 mm (6 ft) to 2290 mm (7-1/2 ft) and reduce the length of the stage 2 composite tube from 3860 mm (12 ft 8 in) to 3400 mm (11 ft-2 in) to provide more energy absorbing capability for the small car impacts.



WYBET & WYBET (MB) GENERAL NOTES

WYBET Terminals Shown Herein have been successfully tested to NCHRP 350, Test Level 3 with no flare required for proper performance.

- ① **GUARDRAIL & WYBET ALIGNMENT:** Where no flare is indicated in the plans (i.e. a tangent layout) and the guardrail is located at the roadway shoulder, it is strongly encouraged to place the last 200 ft. of guardrail including the WYBET on a 1:50 flare to offset the head of the terminal roughly 4 feet from the shoulder to prevent nuisance impacts with snowplows, etc. Where grading won't permit a 4 foot offset, a 2 foot offset is desirable. It is recommended that WYBET terminals not be flared greater than a 1:25 with respect to the roadway (1:15 absolute maximum flare). The entire length of the WYBET shall be straight without kinks and should match the alignment of the adjacent guardrail to the greatest extent possible.
- ② **PRE-INSTALLATION PROCEDURE:** The contractor shall slide the 6" x 6" inner rail inside the 7" x 7" outer rail using only manual labor to insure there is no binding or residual warpage caused by welding or other defects.
- ③ **COMPOSITE TUBES:** Stage 1 & 2 composite tubes provide the energy absorption mechanism for the WYBET and shall be manufactured in strict conformance to the specifications including proper cutting of tulips and taping of end caps at each end of each tube. End caps shall be taped by double wrapping with 4" wide duct tape or a 4X wrap of 2" wide duct tape. Tape shall bear a minimum of 2 1/2" on the end cap and 2 1/2" on the composite tubes.
- ④ **TENSIONING THE WYBET:** The contractor shall tighten the cable anchor and retighten the tensile connector. Once the system is tight, the tensile connector retaining bracket shall be installed in the location shown at the leading edge of the tensile connector.
- ⑤ **WYBET MEDIAN BARRIER INSTALLATIONS:** Connection of WYBET's to older paddle mounted median barrier shall require that a minimum of the next 10 posts beyond the WYBET be modified to a positive connection as a part of the WYBET installation.

WYOMING DEPARTMENT OF TRANSPORTATION
STANDARD PLAN

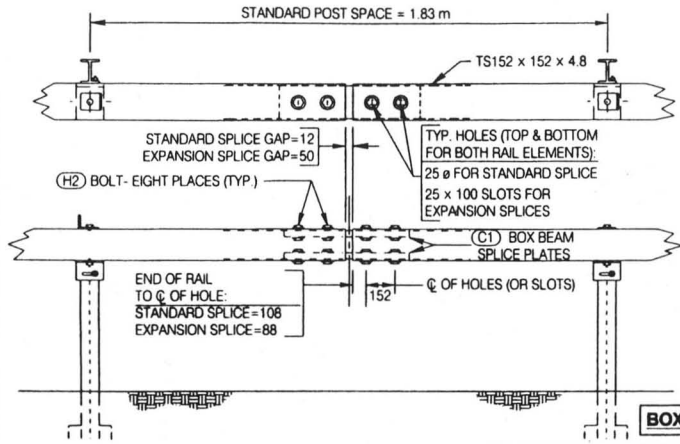
BOX BEAM GUARDRAIL

WYBET INSTALLATION DETAILS

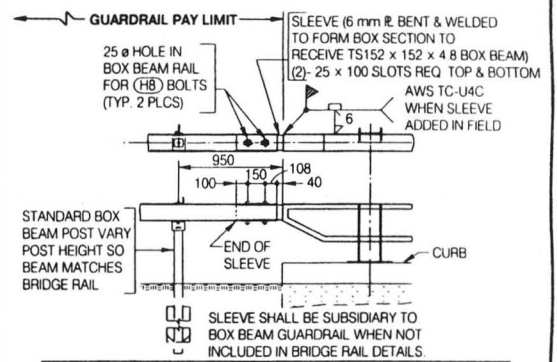
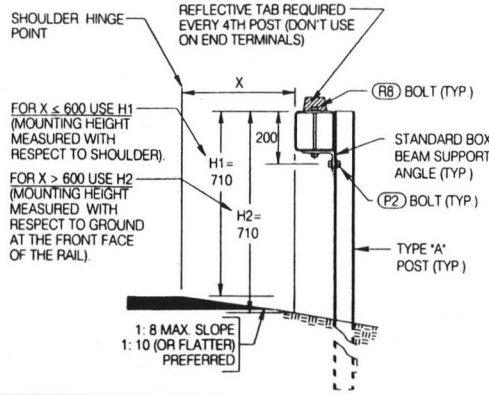
Date Issued	SEPT 1999	STANDARD PLAN NUMBER
Designed by	WBSH	M606-02C SHEET 08 OF XX
Drawn by	CSO	
Checked by	WBW	
Revised by	ENOR SER	

NOTE:
ALL DIMENSIONS GIVEN
ARE IN MILLIMETERS (mm)
UNLESS NOTED OTHERWISE.

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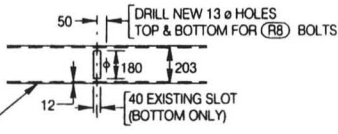
BOX BEAM GUARDRAIL DETAILS



EXIT END CONNECTION TO STEEL BRIDGE RAILING

(Only for exit ends of one-way traffic bridges i.e. divided highways)

MODIFYING EXISTING PADDLE MOUNTED MEDIAN BARRIER TO STANDARD MEDIAN BARRIER CONNECTION.



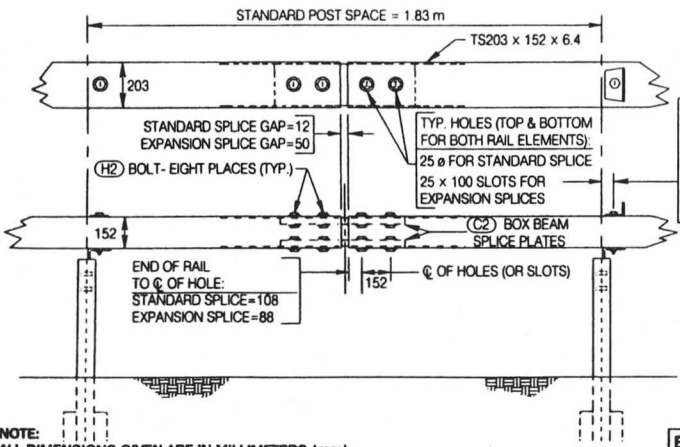
BOTTOM VIEW

GENERAL NOTES FOR BOX BEAM AND BOX BEAM MEDIAN BARRIER

The standard post spacing shall be 1.83 m. The minimum post spacing shall be 1.2 m.

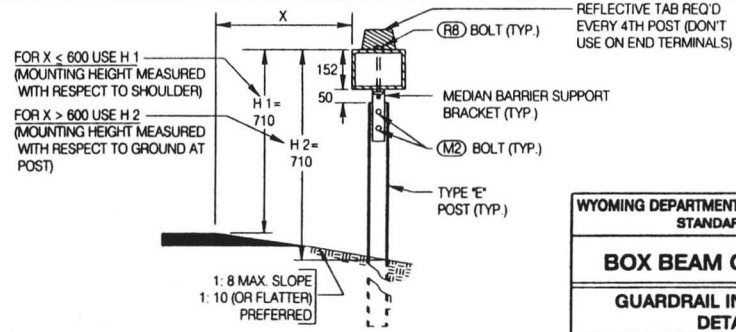
Rail elements shall be furnished in nominal lengths to provide either 3, 4, 5 or 6 post spaces unless physical constraints require odd lengths of rail elements. The nominal rail length shall not be less than 5.49 m.

Expansion splices shall be placed in all box beam installations over 90 m long and at intervals not to exceed 150 m. Expansion splices when required shall be roughly equally spaced in the guardrail run.



BOX BEAM MEDIAN BARRIER DETAILS

IMPORTANT!
RAIL BOLT IS OFFSET 50 FROM POST C. BRACKET SHALL ANGLE AWAY FROM ADJACENT TRAFFIC AND AWAY FROM WYBET TERMINALS



STANDARD MEDIAN BARRIER POST (TYPICAL)
(POSITIVE CONNECTION)

BOLT REQUIREMENTS

HIGH STRENGTH HEAVY HEX RAIL SPLICE BOLTS

- (H2) 19 X 50 (A325) + 1 HARDENED WASHER (F436)
- (H4) 19 X 100 (A325) + 2 HARDENED WASHERS (F436) + 1 NUT (A194-2HM)
- (H8) 19 X 200 (A325) + 2 HARDENED WASHERS (F436) + 1 NUT (A194-2HM)

POSTS BOLTS - HEX HEAD (MILD STEEL)

- (M2) 19 X 40 (A307) + 2 WASHERS (F844) + 1 NUT (A563)
- (P2) 13 X 40 (A307) + 2 WASHERS (F844) + 1 NUT (A563)

RAIL BOLTS - HEX HEAD (MILD STEEL)

- (R4) 10 X 90 (A307) + 2 WASHERS (F844) + 1 NUT (A563)
- (R8) 10 X 190 (A307) + 2 WASHERS (F844) + 1 NUT (A563)

WYOMING DEPARTMENT OF TRANSPORTATION
STANDARD PLAN

BOX BEAM GUARDRAIL

GUARDRAIL INSTALLATION DETAILS

Date Issued	SEPT. 1999	STANDARD PLAN NUMBER
Designed by	WBW	M606-02C SHEET 06 OF XX
Drawn by	CSO	
Checked by	WBW	
Revised by	ENGR. SER	

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ENCLOSURE 3 (2 of 2)

NOTE:
ALL DIMENSIONS GIVEN ARE IN MILLIMETERS (mm)
UNLESS NOTED OTHERWISE.



U.S. Department
of Transportation

**Federal Highway
Administration**

400 Seventh St., S.W.
Washington, D.C. 20590

November 12, 1999

Refer to: HMHS-CC60A

Mr. King K. Mak
Research Engineer
Texas Transportation Institute
College Station, Texas 77843-3135

Dear Mr. Mak:

In your October 12 letter, you requested the Federal Highway Administration's (FHWA) review and approval of the specifications for the energy-absorbing composite tubes used in the Wyoming Box-Beam End Terminal (WYBET-350) that was accepted for use on the National Highway System on August 19, 1999. These specifications were developed by the Texas Transportation Institute for the Wyoming Department of Transportation, but can be used by any Department of Transportation that uses box-beam guardrail and the WYBET-350 terminal.

The specifications, which are enclosed, appear to satisfy the need for quality control of the composite tubes to ensure adequate crash performance of the WYBET-350, and we find them acceptable.

Sincerely yours,

A handwritten signature in cursive script that reads "Dwight A. Horne".

Dwight A. Horne
Director, Office of Highway Safety Infrastructure

Enclosure

SPECIFICATIONS AND TEST PROCEDURE FOR COMPOSITE TUBE

This specification outlines the material properties and required energy dissipation properties for the fiberglass/epoxy composite tubes used in the Wyoming box-beam end terminal (WYBET). Two stages of energy dissipation are employed in the design: the first stage consists of a 152-mm (6-in.) diameter composite tube with a 3.2-mm (0.125-in.) wall thickness, and the second stage a 152-mm (6-in.) diameter composite tube with a 6.4-mm (0.25-in.) wall thickness.

General Specifications

- The fiberglass/epoxy composite tube shall be manufactured using the "pultrusion" process and consists of a glass fiber reinforced resin matrix with a glass resin ratio of approximately 50 percent. The resin shall consist of isophthalic polyester and glass reinforcement shall include the following three varieties:
 - a. A surface mat shall be used on all exterior surfaces for chemical resistance and containment of other reinforcement fibers.
 - b. Continuous glass strand rovings shall be used internally for longitudinal strength.
 - c. Continuous strand mats shall be used internally for transverse strength.
- The composite material shall exhibit the following minimum mechanical properties:
 - a. Ultimate Tensile Strength:

(Longitudinal Coupon)	205 Mpa (30,000 psi)
(Transverse Coupon)	48 Mpa (7,000 psi)
(Full Section in Bending)	138 Mpa (20,000 psi)
 - b. Ultimate Compressive Strength:

(Longitudinal Coupon)	205 Mpa (30,000 psi)
(Transverse Coupon)	102 Mpa (15,000 psi)
(Full Section in Bending)	138 Mpa (20,000 psi)
 - c. Ultimate Shear Strength 31 Mpa (4,500 psi)
 - d. Ultimate Breaking Strength 205 Mpa (30,000 psi)
 - e. Modulus of Elasticity
(Full Beam Section in Bending) 17237 Mpa (2.5 x 10⁶ psi)
 - f. Barcol Hardness 50

Crash Force Characteristics

- The energy dissipation properties of the composite tube shall be evaluated using static compressive testing. The composite tubes shall have the following static energy dissipation properties:

First stage composite tube -- 152-mm (6-in.) diameter with 3.2-mm (0.125-in.) wall thickness

Average Crush Force, F_c	85 ± 13 kN (19 ± 3 kips)
Maximum Compressive Force, P	116 kN (26 kips)

Second stage composite tube -- 152-mm (6-in.) diameter with 6.4-mm (0.25-in.) wall thickness

Average Crush Force, F_c	178 ± 18 kN (40 ± 4 kips)
Maximum Compressive Force, P	245 kN (55 kips)

Definitions of the average crush force, F_c , and maximum compressive force, P, are illustrated in the following figure. The average crush force shall be determined based on crush forces from 152 mm to 355 mm (6.0 in. to 14.0 in.) of crush. The maximum compressive force shall be determined between 90 mm to 152 mm (3.5 in. to 6.0 in.) of crush.

Acceptance/Rejection Criteria

- The acceptance/rejection criteria will be based on the crush force characteristics, i.e., average crush force, F_c , and maximum compressive force, P. The properties outlined in the "General Specifications" are provided for information purposes and are not considered in the acceptance/rejection criteria.
- A minimum of three (3) static compressive tests should be conducted at an independent testing laboratory. The three samples shall be randomly selected, one each from the beginning, middle and end of the production run being evaluated. Each test specimen shall be 610 mm (24 in.) long and a 100 mm (4 in.) long tulip shape shall be cut into one end of the test specimen. End caps shall be used with the specimen on both ends.

The test specimen shall be crushed statically at a rate of 50 mm (2 in.) per minute and the total crush length or displacement shall be no less than 355 mm (14.0 in.).

- The batch is considered acceptable if the following conditions are met:
 - The average crush force characteristics for the three specimens are within the acceptable ranges as specified above and repeated below:

First stage composite tube -- 152-mm (6-in.) diameter with 3.2-mm (0.125-in.) wall thickness

Average Crush Force, F_c	85 ± 13 kN (19 ± 3 kips)
Maximum Compressive Force, P	116 kN (26 kips)

Second stage composite tube -- 152-mm (6-in.) diameter with 6.4-mm (0.25-in.) wall thickness

Average Crush Force, F_c	178 ± 18 kN (40 ± 4 kips)
Maximum Compressive Force, P	245 kN (55 kips)

2. The crush force characteristics for each of the three specimens do not exceed the acceptable ranges by more than 10 percent. In other words, each specimen shall not exceed the following static energy dissipation properties:

First stage composite tube -- 152-mm (6-in.) diameter with 3.2-mm (0.125-in.) wall thickness

Average Crush Force, F_c	85 ± 22 kN (19 ± 5 kips)
Maximum Compressive Force, P	127 kN (28.5 kips)

Second stage composite tube -- 152-mm (6-in.) diameter with 6.4-mm (0.25-in.) wall thickness

Average Crush Force, F_c	178 ± 36 kN (40 ± 8 kips)
Maximum Compressive Force, P	267 kN (60 kips)

Static Crush Test Pultruded Fiber-Glass Tube

