January 24, 1997 6

John Neil
General Motors Proving Ground
Milford, MI 48380-3726

Re: Design of Traffic Barrier for Milford Test Track

Dear John:

MwRSF's effort to design a barrier for the Milford Test Track have been successfully completed. The recommended design is shown on Attachment 1 and contained in Autocad files on an enclosed disk. The basic design includes two 10-ga W-beam guardrail elements mounted on W6X12 steel posts. The rails are mounted 15 and 30 inches above the track surface on 110 in long posts. The upper rail element is blocked-out 12 in while the lower element has only a 6 in. block-out. Note that the rails and blockouts are attached to the posts with button head bolts without washers. This design allows the rails to become detached to prevent the rail from being pulled down by the posts during large lateral deflections. The design process implemented to develop this design is briefly summarized below.

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The first phase of the barrier design project involved estimating possible impact conditions for various classes of vehicles. HVOSM, a lumped parameter vehicle handling code, was used to estimate the highest impact angle that each class of vehicle could attain during a loss of control event. You provided the following vehicles and speeds to be used in that analysis.

Vehicle	Operating Speed
C/K 1500 (extended cab, V8)	100 mph
Pontiac Trans Am	140 mph
GMC Suburban	100 mph
Buick Park Avenue	125 mph

Although I originally requested that GM provide vehicle data, such as center of gravity height and roll, pitch, and yaw moments of inertia with which to estimate impact speeds, I later concluded that reasonable estimates can be used to find appropriate impact conditions within an acceptable level of accuracy. Unfortunately, the HVOSM program was not written with the intention of modeling vehicles traveling around banked tracks at speeds up to 140 mph and

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therefore the program's terrain input arrays were a little to small. The program was revised to eliminate this problem and the design impact conditions for each vehicle were estimated by simulating two different steering scenarios. Both scenarios began with the vehicle traveling in the neutral position where no steering would be required. The first scenario involved the driver making a quick steering maneuver to propel the vehicle up the track and into the barrier. This scenario estimated the maximum angle that a vehicle could attain without losing any of its initial speed. The second scenario involved the driver making an avoidance maneuver by first steering down the track and then making a hard correction toward the barrier. The distance that the vehicle was steered down the track was varied over a wide range for each vehicle considered. When vehicles were steered too far down the track, the vehicle would spin-out during the over-correction stage of the simulation and the resulting impact angle would be reduced. Since the loss of control conditions are dependent on both the vehicle speed and its kinematic characteristics, the optimum distance for the steer down maneuver was different for each vehicle. Impact conditions resulting for each of the two scenarios are shown below.

Vehicle	Scenario 1		Scenario 2	
	Speed mph	Angle deg	Speed mph	Angle deg
C/K 1500 (extended cab, V8)	97	13	84	20
Pontiac Trans Am	137	8	120	14
GMC Suburban	97	12	84	19
Buick Park Avenue	122	11	108	18

Our research has indicated that Impact Severity (IS) as defined below is a good indicatot r of the magnitude of an impact with a longitudinal barrier.

$$IS = \frac{1}{2} m (V \sin\theta)^2$$

where:

IS = Impact Severity, (ft-lb or N-m)
m = mass (lb-sec^2/ft or kg)
V = velocity (ft/sec or m/sec)
θ = impact angle (deg)

When ~~the~~ compared in terms of IS value, the second scenario was found to yield more severe impact conditions than the first for all four vehicles. Therefore, impact conditions from the second scenario were used in the design of the barrier system.

Although a number of barrier concepts were investigated, the design shown on Attachment 1 was found to offer a high capacity at a relatively low cost. Steel posts were selected to eliminate problems associated with the decay of wood posts embedded in soil. Routed wood blocks are used to avoid the possibility of collapse of a steel shaped block. Steel W-beam rails were chosen because these widely used barrier elements are very effective and relatively inexpensive.

A critical part of the proposed barrier system is the bending strength of the posts used in the design. The posts can fail as a result of bending of the steel or post rotation in the soil. Note that when the soil fails the post's point of rotation is much lower than that associated with bending of the post. Lowering the point of rotation generally improves the barrier's performance by reducing the potential for wheel snag on the posts and maintaining the rail height as the barrier deflects laterally. Thus, it is desirable to design a barrier system in which the post rotates in the soil rather than bending near the ground line. Further, much of the energy dissipation associated with a flexible barrier is concentrated in the rotation of the posts. Therefore, it is desirable to generate high soil forces without allowing the post to fail in bending. Bogie vehicle tests were conducted to examine the limiting performance of the posts in either situation. A total of 6 bogie tests were conducted in this phase. Four of these tests examined post forces when failure is in the soil and 2 tests were designed to identify the dynamic failure loads associated with bending in the post. The soil rotation tests showed that sustained bending soil resistance forces are generally proportional to the square of the embedment depth. Further, a standard W6x9 steel post embedded in a well compacted cohesionless soil was found to begin to fail in bending at embedment depths of approximately 40 inches. The post strength tests verified that a standard W6x9 steel post can sustain dynamic bending moments equal to approximately 1.5 times the plastic moment for the steel.

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Further investigations of the dynamic effects of installing the posts on an angle were conducted to provide more detailed force deflection information. Attachment 2 shows a force deflection curve from a post installed at an angle of 26 degree and a total embedment length of 57 inches. Results of 6 bogie tests of posts installed at an angle were used to establish the force deflection characteristics of the posts used in the proposed design.

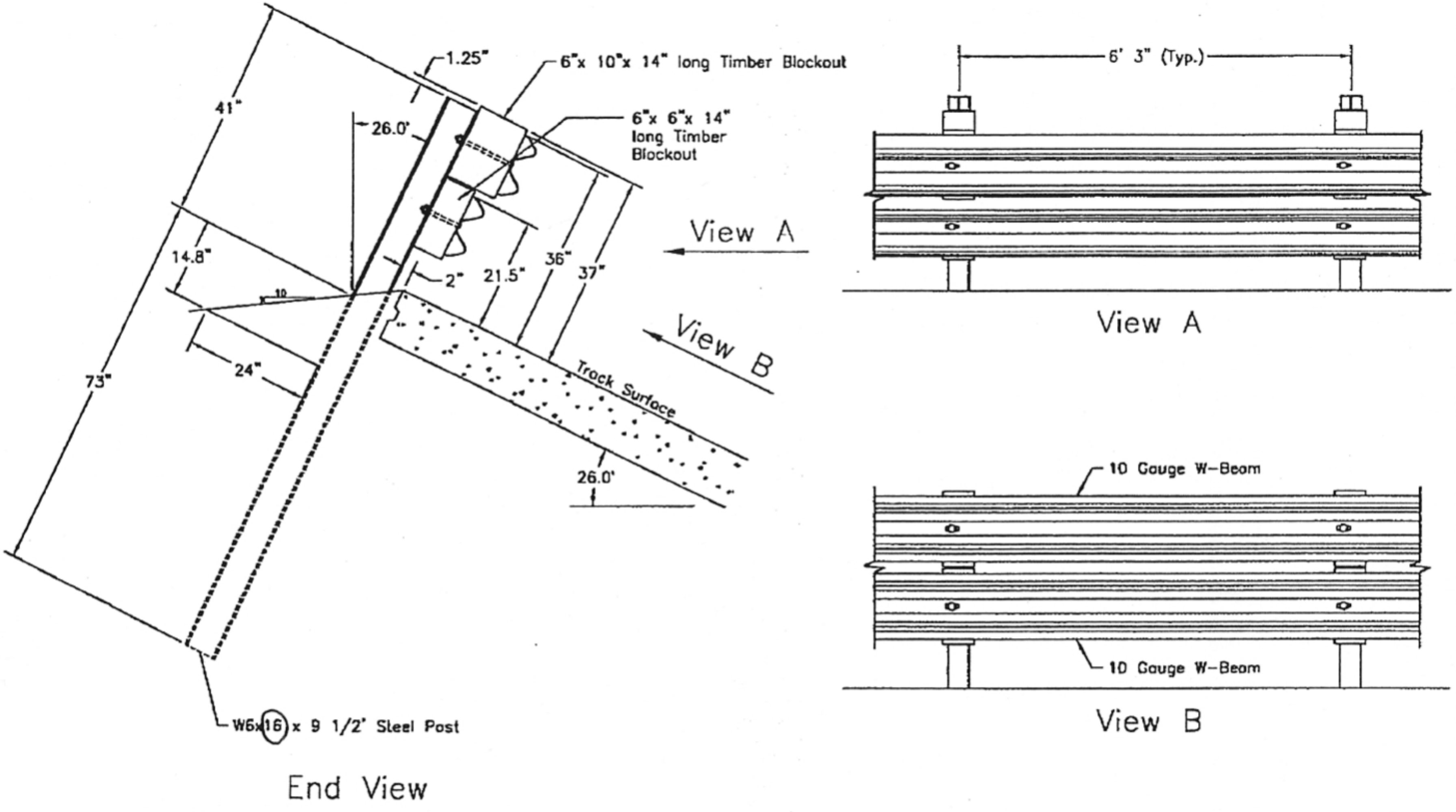
Barrier VII, a finite element analysis program, was used to analyze the capacity of the proposed barrier design for all of the design impact conditions described above. This analysis established the final barrier design details, such as post spacing and embedment. Under the most severe impact conditions, the barrier was predicted to deflect approximately 33 in. This level of deformation is considered to be well within the acceptable range for a barrier of this type. Additional simulation runs were made to investigate the barrier's performance under frozen soil conditions. This analysis explored the potential for severe snagging or pocketing on the stiff steel posts used in the design. Although the barriers deflections were predicted to be much lower under these adverse conditions, there was no indication that wheel snag or pocketing could occur.

Currently, the cost for materials for this design is estimated at approximately $19.00/ft. A local guardrail erector has estimated that this barrier could be installed for approximately the same cost as the materials. Thus, GM's total cost should be approximately $38.00/ft.

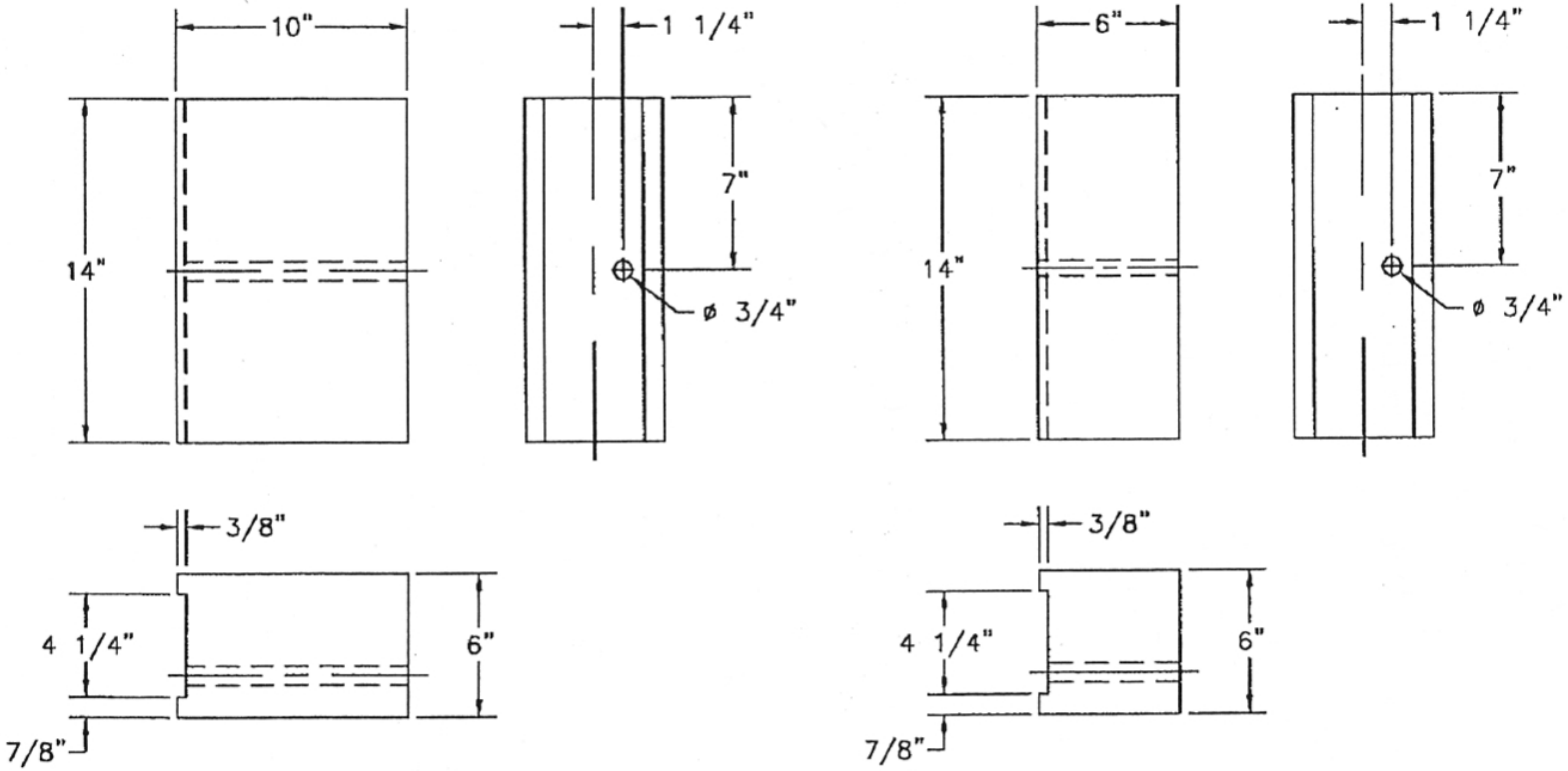
Please call or e-mail me if you have any questions or need additional information.

Sincerely,

Dean L. Sicking, Ph.D., P.E.
Director, MwRSF



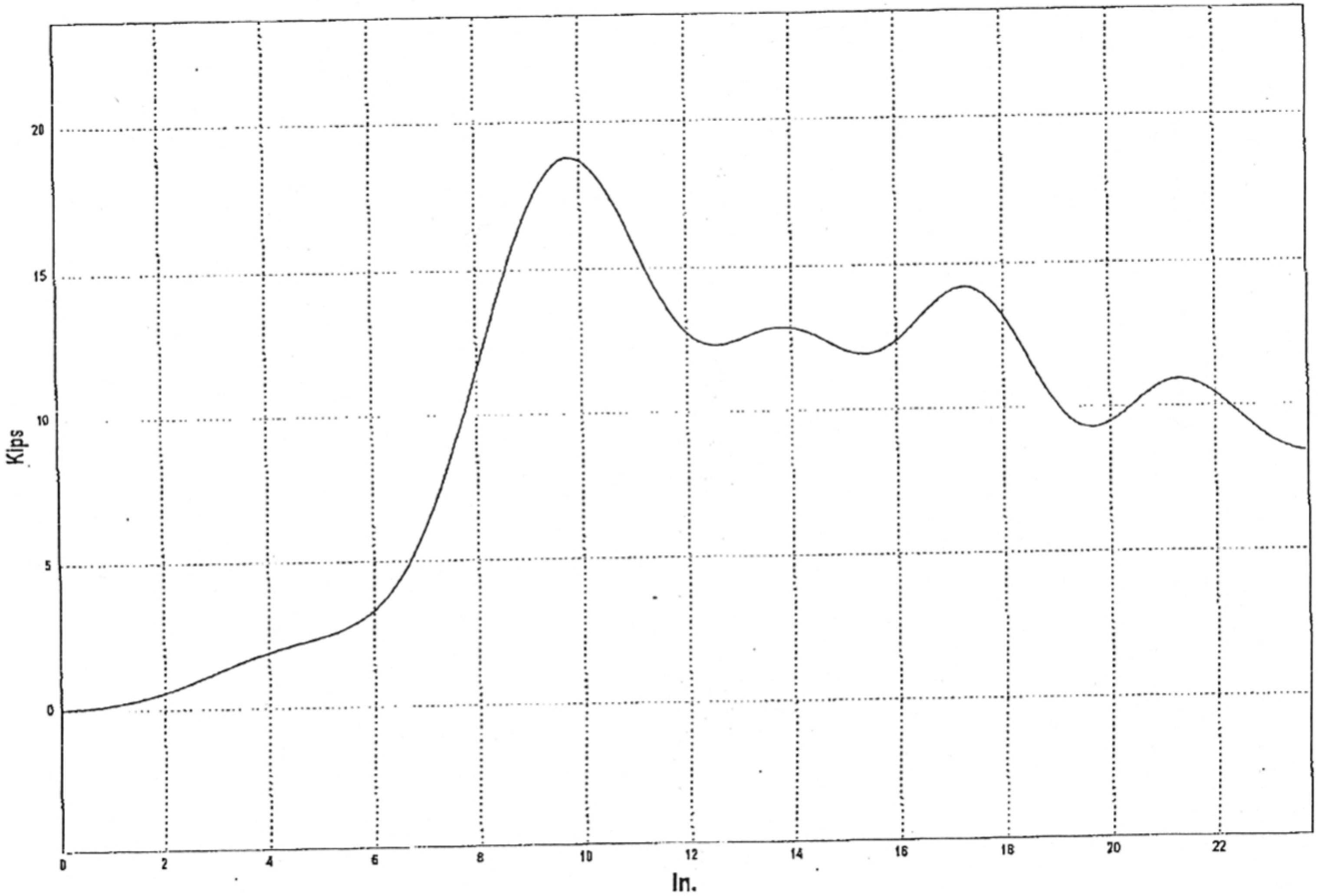
Attachment 1. Barrier Design for General Motors Milford Proving Grounds.



Routed Blockout
Top

Routed Blockout
Bottom

Attachment 1. (Cont.) Blockout Details.



Attachment 2. Force Deflection Curve from Bogie Tests of Angled Post.