A Bridge Parapet Designed for Safety

General Motors Proving Ground

Circular Test Track Project

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This paper describes the design and testing of an improved bridge parapet subsequently incorporated in two bridge structures at the General Motors Proving Ground. These parapets are designed to provide maximum safety to the occupants of vehicles which might strike them. Testing involved running full-scale remotely controlled vehicles into test sections constructed especially for this purpose. These vehicles included passenger cars of various sizes and a loaded $2\frac{1}{2}$-ton truck. Performance of the final design is satisfactory in all respects and costs are not excessive.

•THE GENERAL Motors Proving Ground has recently constructed a new circular test track which includes two long-span bridges as part of the access road system. Every effort was put forth to make the entire facility as safe as possible and to incorporate every proven safety feature.

Our full-scale impact test program on highway guardrails (1) showed that most conventionally used bridge rails, or parapets, left much to be desired from a safety standpoint. There are many designs of bridge parapets currently in use but few were actually tested before construction. Some of them, even a bridge rail constructed at the Proving Ground in 1953, appear to be primarily decorative in nature (Fig. 1); some are designed with high strength but produce extensive vehicle damage (Fig. 2); and some are obviously too low to prevent a vehicle going over the top (Fig. 3). Frequent news items show that existing designs often do not retain the vehicle within the roadway (Figs. 4 and 5).

Because of these problems, a group of engineers were assigned to design and test an improved parapet for our new bridges. The following requirements were established for the bridge parapet:

1. It should be virtually impenetrable by any motor vehicle at the 50-mph speed at which the roadway was to be driven and at the relatively low angle of impact attainable within the 28-ft roadway width.
2. It should be designed to minimize longitudinal and lateral decelerations to vehicles impacting it and to their occupants.
3. It should minimize damage to a striking vehicle.
4. It should allow good visibility over the parapet, so passengers in cars of any size could see both above and below the horizon.
5. It should present a pleasing appearance.
6. It should be economical to construct and maintain.
7. The guardrail protecting the approaches should be "blended" and fastened to the ends of the bridge parapet in such a way that a vehicle would not be unreasonably endangered regardless of where it struck the guardrail-parapet system.

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Figure 1. Bridge rail design used on existing Proving Ground overpass constructed in 1953.

Figure 2. High-strength bridge rail which inflicted severe damage while redirecting impacting vehicle.

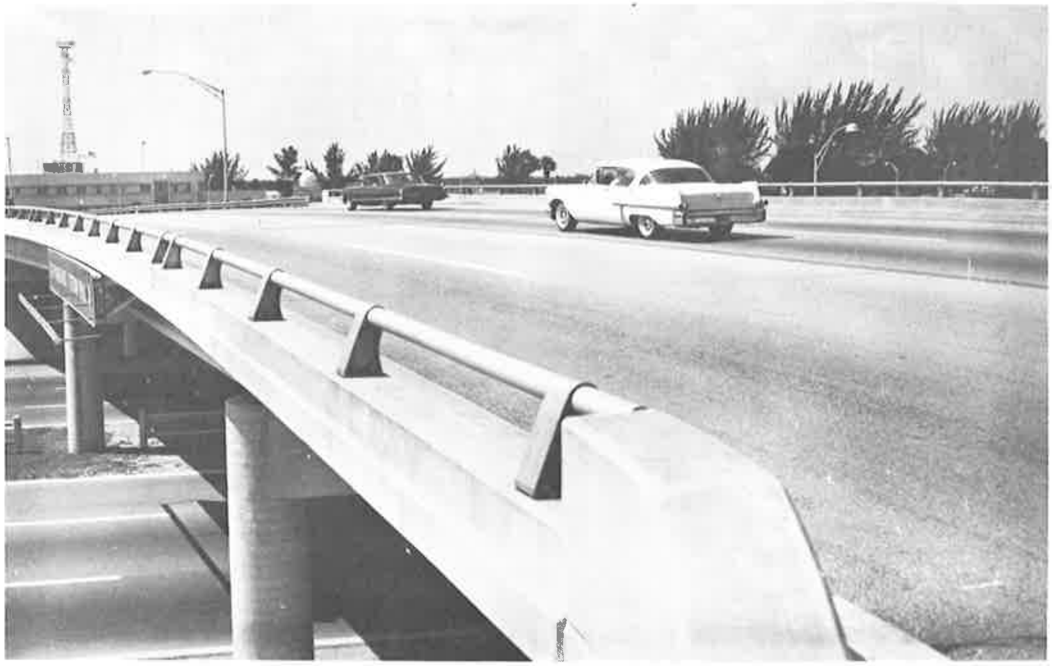

Figure 3. Bridge rail design low enough to permit some impacting vehicles to continue over top.

Figure 4. Bridge rail design lacking sufficient structural strength to retain impacting vehicle on roadway.

Figure 5. Low concrete bridge rail design with top rail lacking sufficient strength to retain impacting vehicle.

Since these bridges were not intended to handle pedestrian traffic, there was no need to consider a sidewalk. In many cases, the sidewalk is placed between the parapet and the road; the resulting curbing provides an unnecessary hazard for the out-of-control vehicle. If a crossing for pedestrians had been desired, the sidewalk would have been placed outboard of the parapet.

Many designs of existing bridge rails, curbs, and highway medians were considered, and several test sections were built and crash tested. The test sections consisted of a 5-in. diameter pipe curb and two sloped face concrete curbs. Figure 6 shows cross-sections of the designs tested. The 65° sloped face redirected the low-angle impacting vehicle more violently than did the 55° design. The pipe curb did not demonstrate any advantage. Some wheel and/or sheet metal damage was experienced with the 65° design. The design with the 55° angled surface was most effective in gently turning the vehicle under low-angle impacts with no sheet metal damage. However, at higher impact angles, the vehicle tended to climb the wall.

During the investigation of existing guardrails and highway median barriers, the designs used extensively in New Jersey had been brought to our attention. One of these is a concave cross-section concrete wall about 23 in. high. Another of a later design had a double sloped cross-section 32 in. high (Fig. 7). Reports from New Jersey indicated that this design performed well. It very successfully prevented cross-median accidents, and at the same time inflicted only minor damage to impacting vehicles (2). This general type of barrier appeared to have considerable merit in satisfying our ground rules; hence, the Proving Ground embarked on a program to develop this barrier into a bridge parapet. Twenty-one tests were run on various configurations before arriving at the final design.

Because of the requirement for good visibility, the height of the concrete portion had to be less than the eye height of a person driving a low vehicle. Drivers' eye heights on twenty-seven 1962 cars ranged from 44 to 48.8 in. above the road surface. All but three of the eye heights were between 45 and 48.8, with eight of them between 47 and 47.5 in. Based on these data, it appeared that a height of 32 in. for the concrete portion would provide adequate visibility (Figs. 8 and 9). Tests conducted during the development program indicated that this height was sufficient to prevent cars from climbing over the wall.

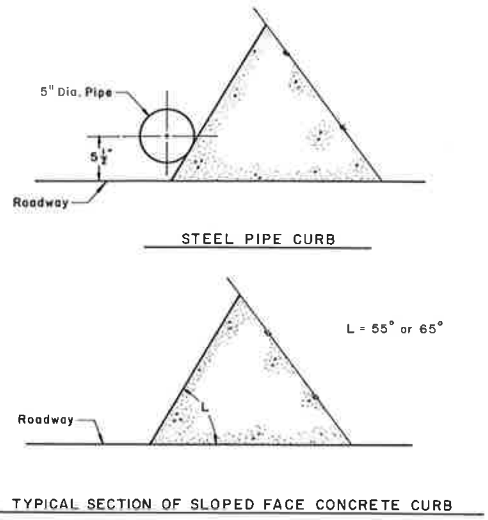

Figure 6. Cross-sectional views of curb designs tested for redirection of low speed and low angle impacts without sheet metal damage.

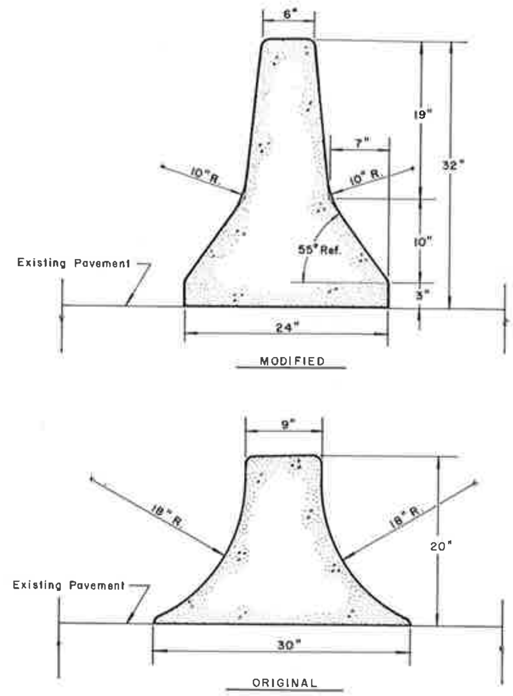

Figure 7. Typical section of New Jersey concrete barrier curb.

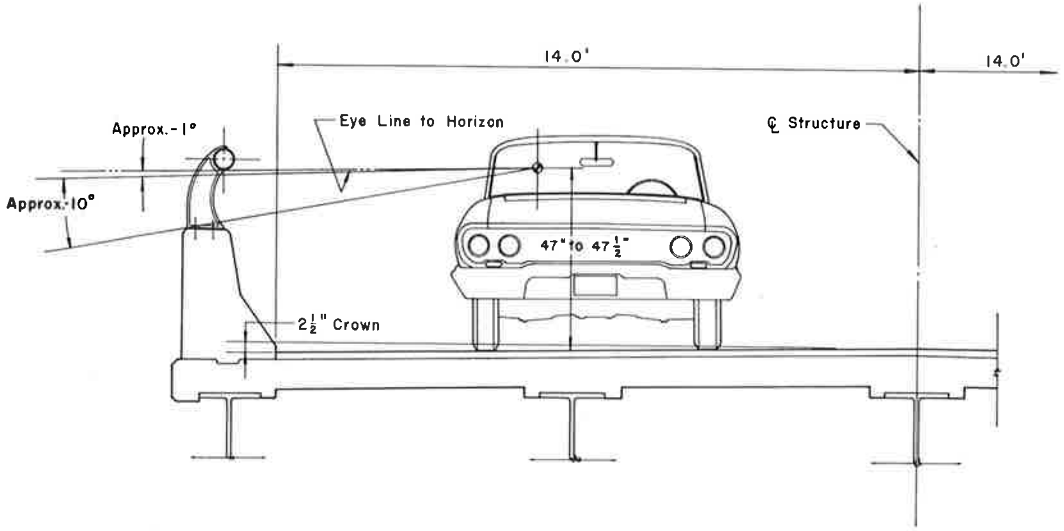

Figure 8. Typical cross-section of Proving Ground overpass.

Figure 9. Driver's eye view.

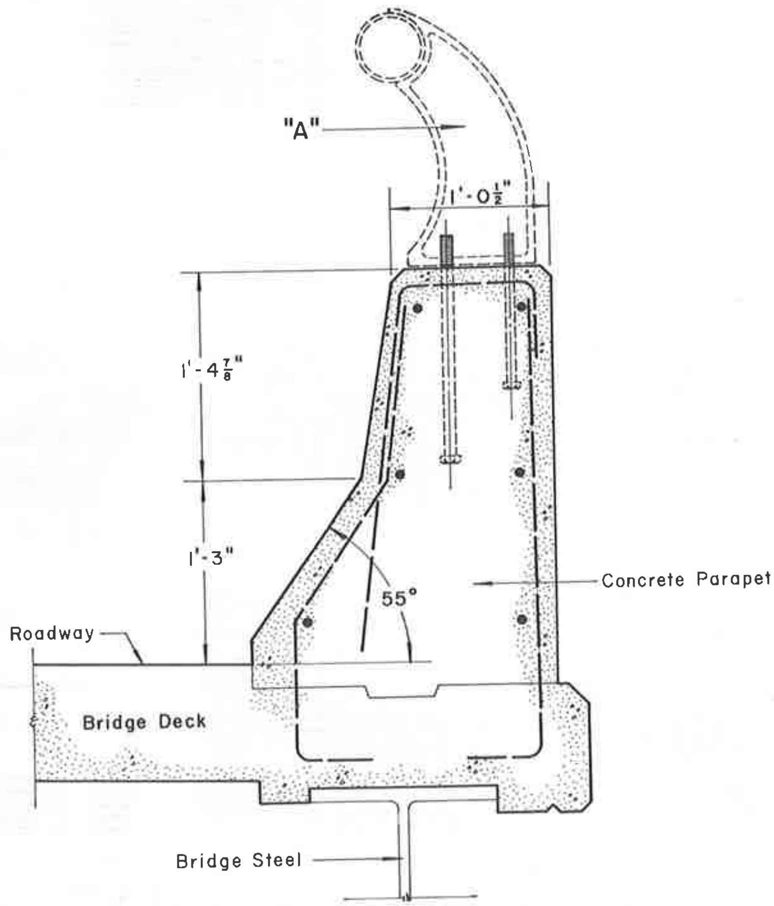

Figure 10. Typical section of Proving Ground concrete parapet.

Previous experience with guardrail testing had made us aware of the advantages to both car and passengers in minimizing lateral decelerations during impacts. Guardrails can be made to do this by utilizing the natural flexibility of the rail and posts, and adding additional flexibility by spring-mounting the rail to the posts. It did not seem practical to utilize this same principle on the bridge parapet because the requirement for impenetrability by all sizes of vehicles called for a lateral strength that could not be obtained with conventional guardrail materials.

Figure 11. Placement of junction of upper and lower angled faces chosen to permit low-speed, low-angle impacts without sheet metal damage.

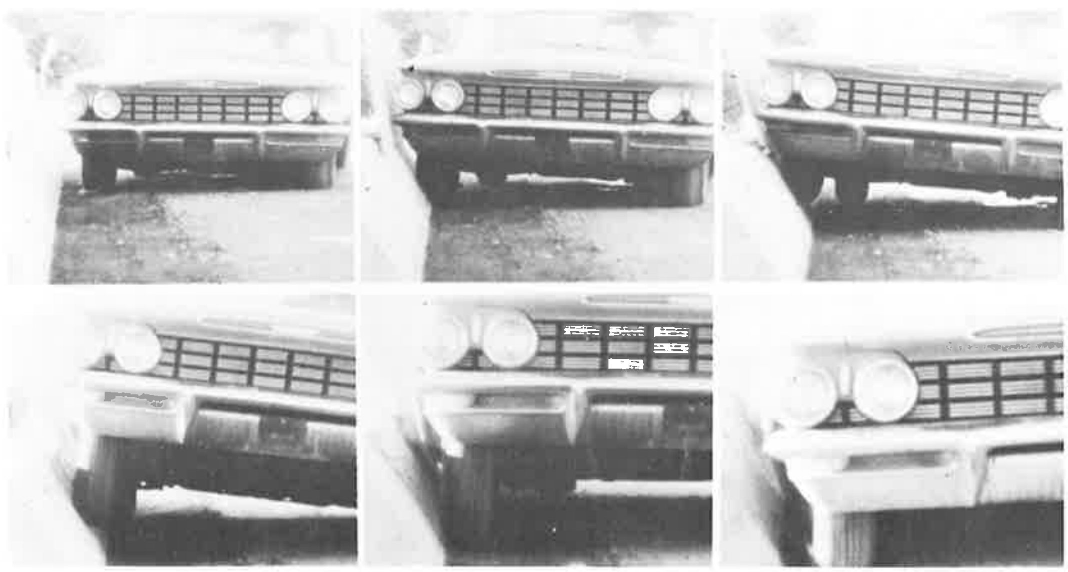

Figure 12. Hand driven evaluations of 55° sloped face. Vehicle "rides up" as it is redirected. Plywood mock-up above concrete was used during dynamic tests to evaluate other design dimensions.

As indicated earlier, the 55° angled face permitted low-angle impacts without sheet metal damage but involved a climbing tendency when impacted at higher speeds and angles. Careful measurements were made on vehicles to determine the proper elevation of the junction of the two angled faces of the parapet in order to eliminate sheet metal contact with the upper portion when the wheel contacted the base. After a series of plywood mock-ups were constructed and tested, an elevation of 15 in. was chosen.

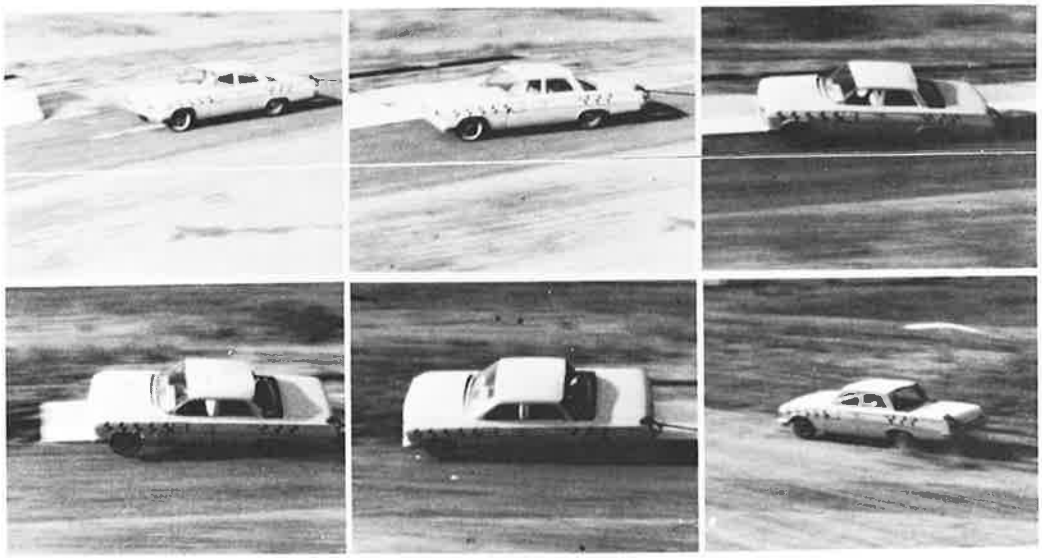

Figure 13. Dynamic test photo sequence where vehicle was remotely driven into finished design test section of bridge rail at 50 mph and 12°.

Figure 14. View of test section of bridge rail showing scrub marks from repeated testing; rail at top not design used in final system.

Figure 15. Remotely driven car redirected by rail; impact conditions, 50 mph at 12° angle.

Figure 16. Position of test car after impacting bridge rail test section at 50 mph and angle of 12°.

A short section of a proposed design was constructed using a near-vertical upper face similar to the New Jersey median (Fig. 10). The relationship between the final parapet design and a car is shown in Figure 11.

The Proving Ground staff tested this design with extreme thoroughness. Since this parapet was to be installed on a bridge located on access roads with a 50-mph speed limit, tests were confined to a maximum speed of 50 mph. The initial tests evaluated its performance under glancing low-angle and low-speed impacts up to 10° and 30 mph. Under most such conditions, the tire would ride up the lower portion of the barrier rather readily, but when the steeper section was encountered, the car was banked and the front wheel forced into a turn to deflect the vehicle back toward the roadway (Fig. 12). Several remotely controlled high-speed impacts were made at speeds up to 50 mph and angles to 12°, and in no case did the car climb to the top of the barrier or show any tendency to climb over it (Fig. 13). In most runs, the damage to the car consisted only of front bumper and fender rubbing and sometimes an upsetting of front wheel alignment. Figure 14 shows a test section (not the final design) with various scrub marks. These were not the final brackets. The test section has been repeatedly struck at 50 mph at an 8° angle by manually driven cars with no vehicle damage and no driver concern.

Figure 15 shows a remotely driven car being turned by the barrier after striking it at 50 mph at a 12° angle. This angle was chosen as representative of the maximum angle attainable within this 28-ft roadway width by a vehicle traveling at this speed. Figure 16 shows that the car was turned nearly parallel to the rail at the conclusion of this test. The car was guided by electrical remote control and stopped by remote application of its own brakes. Figure 17 shows the car after the test. This car had been used in previous tests and the headlight was missing before the impact. The right front fender was damaged when it hit the temporary rail support bracket, but the car was driven away from the test site under its own power. Lateral decelerations to the simulated human occupant during this run did not exceed 3 g. The fact that the car climbs the wall and tends to bank reduces lateral decelerations on the occupants much as going around any banked turn does.

Experiments were run to determine whether a reduction in coefficient of friction of the sloped surface would affect the performance in any way. The surface was first ground smooth, then greased, but performance was not changed. It was learned that

Figure 17. Damage to test car as result of 50 mph impact with bridge rail at angle of 12° (headlights removed before test).

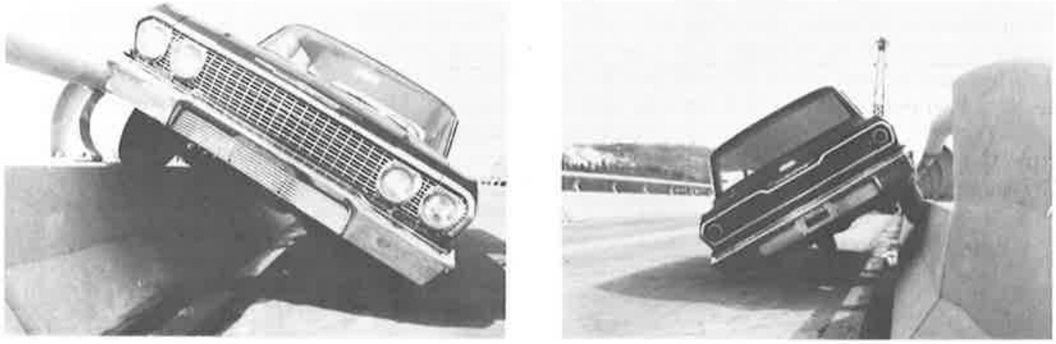

Figure 18. Placement of right front wheel of test vehicle on concrete parapet to show proximity of sheet metal to rail and wheel to post.

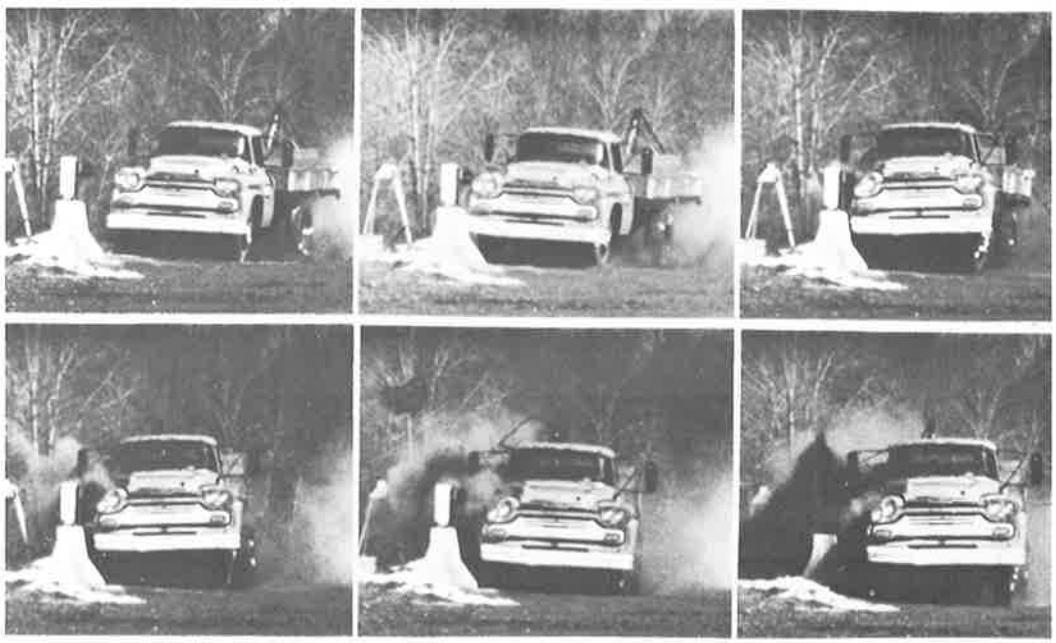

Figure 19. Photo sequence of $2\frac{1}{2}$ ton 16,000-lb GVW truck impacting bridge rail at 37 mph and 13°; top rail in this sequence in experimental position.

the height to which a car climbs the parapet is determined primarily by the lateral inertia force of the vehicle and the lateral friction force developed by the outside wheels. Tests indicated that the friction force of the wheel in contact with the parapet did not influence the action of the impacting vehicle as it was redirected by the rail.

It was fully realized that the 32-in. height of the concrete wall was not sufficient to guarantee that larger trucks would be safe. Accordingly, a pipe rail was installed on top to provide a higher barrier and to increase the height of the fulcrum over which a high-center-of-gravity vehicle would have to roll. For a rough approximation, the height of the rail should approach the height of the center of gravity of any vehicle using the bridge. Top rails are used on many bridges; however, most of these are made of relatively light-walled steel or aluminum tubing mounted on cast aluminum brackets.

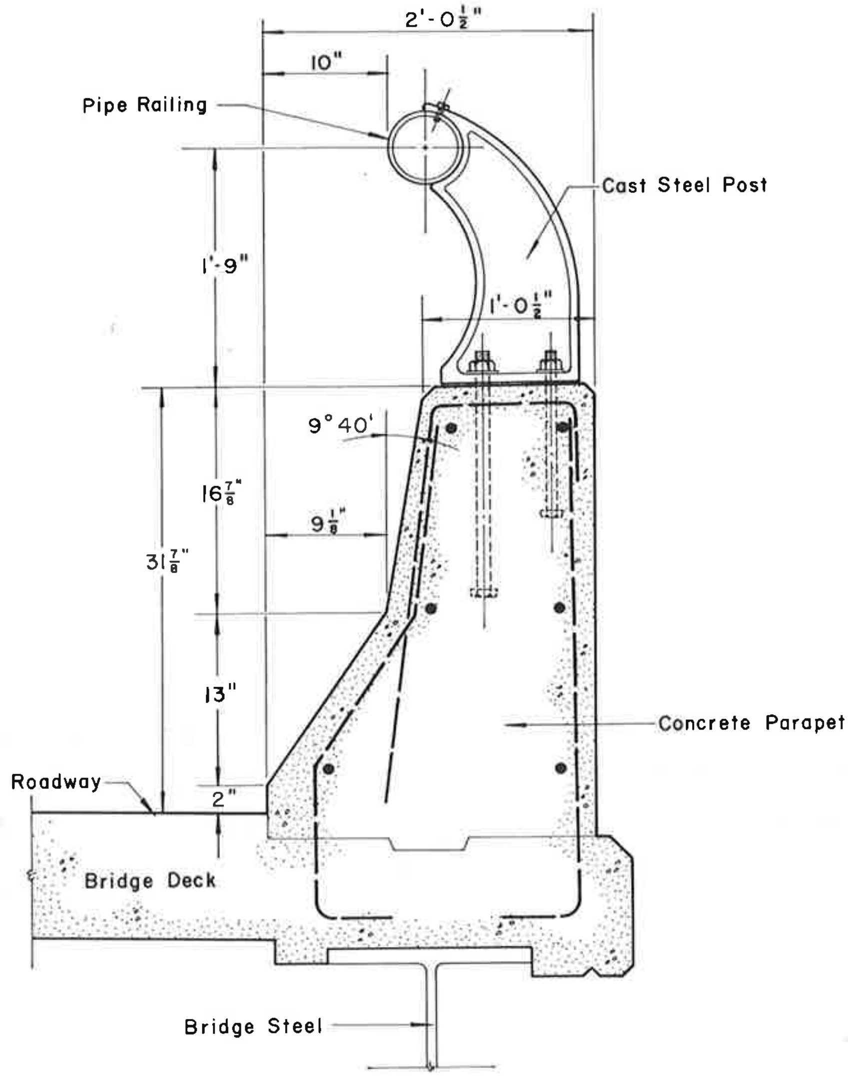

Figure 20. Typical section of Proving Ground bridge parapet.

The U. S. Bureau of Public Roads has issued a proposed recommendation for strength requirements for bridge rails (3). These indicate that the rail should be able to resist a lateral force of 15,000 pounds at any point along its length. Commercially available rails and brackets were tested, and none even came near meeting this requirement, so we designed a bracket that would give the required strength and still present a good appearance.

The same specifications require the rail on a parapet of this general configuration to withstand a transverse load of 15,000 lb (P/2, where P = 30,000 lb). It is further specified that the brackets be designed for a transverse load of 0.8 P/2 and a simultaneous longitudinal load of 0.4 P/2. This means that our brackets must withstand a transverse load of 12,000 lb and a simultaneous longitudinal load of 6,000 lb. The brackets as actually fabricated were tested at a transverse load of 22,000 lb without failure, indicating a substantial margin of safety over the BPR recommendations. Bracket spacing is determined primarily by the requirement that the pipe rail withstand

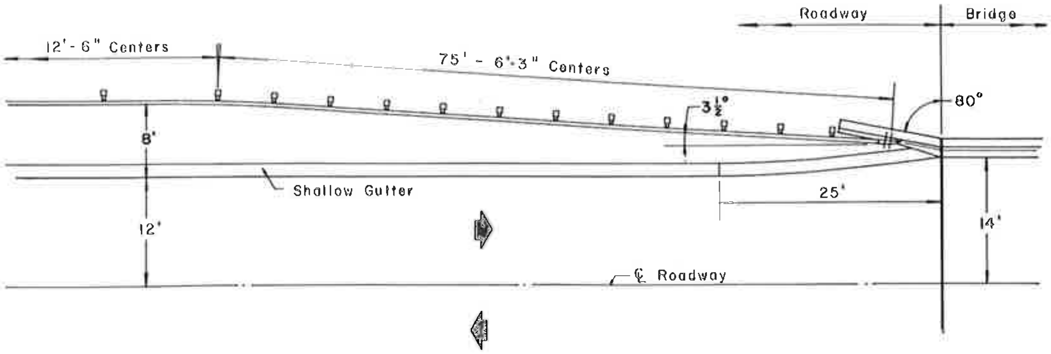

Figure 21. Typical plan of bridge approach.

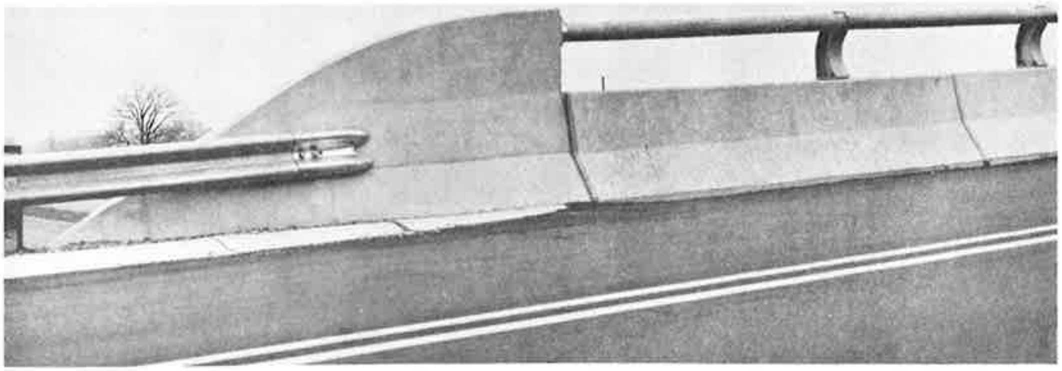

Figure 22. View of bridge rail end wall and blending of adjacent guardrail.

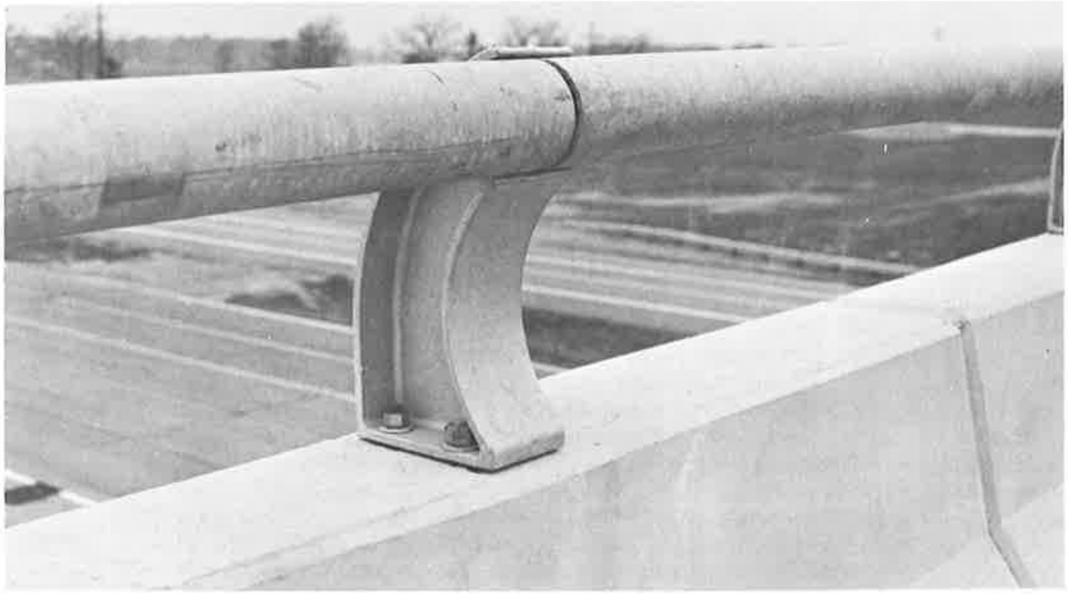

Figure 23. Detail of top rail construction on finished bridge.

Figure 24. Overall view of completed bridge structure.

Figure 25. Overall side view of completed bridge span.

15,000 lb applied at the midpoint between two brackets. Utilizing the design method in Section II, Article 1.2.11 (E) in the BPR specifications, we used an 8-ft nominal spacing between brackets and 5-in. extra heavy galvanized steel pipe. This design exceeds the BPR requirements. The brackets are designed of dip-galvanized cast steel, with an open clamp toward the road to provide a smooth "rub rail" for a vehicle striking the pipe. Provisions are made for rail expansion. Brackets are mounted to the parapet with two 1- by 18-in. and two $\frac{3}{4}$- by 12-in. high-tensile bolts.

The rail installed on the mock-up in Figure 14 is held in place with conventional aluminum brackets because the special brackets were not available during this phase of the testing period.

To establish the optimum lateral location of the rail, vehicles of all types were driven so that their wheels rubbed the parapet. The lateral extremities of the vehicles were measured and the rail positioned so that no vehicle would rub it until the body had rolled appreciably toward the rail. Tests determined that the rail did not contact sheet metal of cars. The inside of the cast-steel post (see A in Figure 10) was made concave to minimize the chance of contact with any portion of a wheel that might climb the concrete section. Under the most severe condition, a wheel might be rolling along the top of the concrete with the side of the wheel rubbing on the rail (Fig. 18); even in this extreme condition, the wheel would climb over the base of the steel posts without undue damage to either the post or the wheel.

Following the installation of the pipe rail at the established point, a full-scale test was run during which a $2\frac{1}{2}$-ton loaded stake truck was remotely driven into the test section at a speed of 37 mph and an angle of 13°. The performance of the section was entirely satisfactory in all respects (Fig. 19).

Figure 20 shows the complete cross-section of the bridge parapet finally used. The height of the parapet was dictated primarily by performance considerations. The height of the rail was dictated by performance considerations and visibility (Fig. 8). The lateral positioning of the rail was established by the need to have the sheet metal of a vehicle contact the rail at the same time the front wheel reached the top of the concrete parapet.

With the parapet itself designed and tested, we next devised an end wall that would protect the end of the parapet and rail from an end-on hit by an out-of-control vehicle approaching the bridge. This design is best shown in Figures 21 and 22. The wall slopes backward and downward and is overlapped by the approach guardrail, so that even if a car's wheels have climbed the guardrail and the vehicle is sliding along it, the wheels will encounter a sloping surface when they strike the parapet end section. The approach guardrail uses 6-ft 3-in. post spacing for the last 75 ft of rail before the parapet, and the rail is securely bolted to the parapet to develop maximum strength. This doubling of the number of posts supporting the approach guardrail greatly improved the performance of the conventional guardrail at this critical point. If the parapet was to be exposed to traffic speeds of 65 mph or higher, closer post spacing would be recommended, both adjacent to the parapet and in the main guardrail on the approaches. Figures 23, 24 and 25 show details of the completed bridges. Working drawings for the parapets are included in the Appendix.

SUMMARY

This bridge parapet satisfied our requirements in all respects. It costs approximately 20 percent more than conventional parapets but is considerably safer. Much of the increased cost is primarily due to the greater strength built into the pipe railing and supporting brackets. The concrete parapet itself should be no more expensive to construct than many conventional designs, and its superior performance has been proven by an adequate number of full-scale tests.

ACKNOWLEDGMENTS

We wish to thank the many individuals who participated in this project and contributed their work and ideas. This includes members of the Proving Ground Experimental Engineering, Plant Engineering, and Photographic Groups as well as several people from various state highway departments whose suggestions and encouragement were of great benefit.

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3. Proposed Specifications for Bridge Railings. U. S. Bureau of Public Roads, Washington, D. C., April 1962.

Appendix

WORKING DRAWINGS FOR PARAPETS

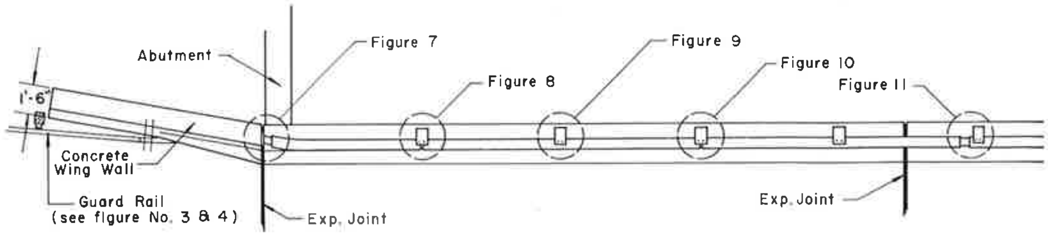

Figure 1A. Typical plan.

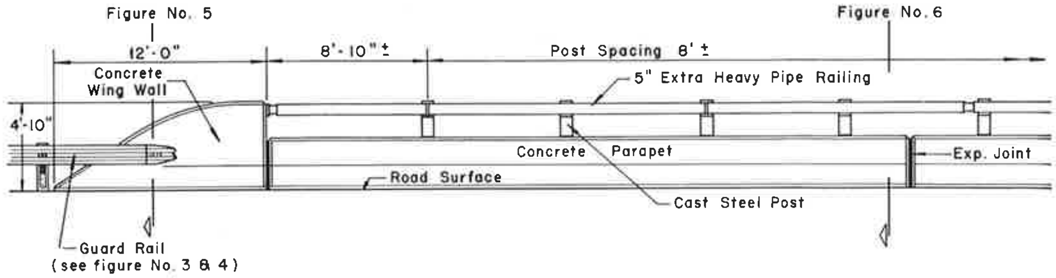

Figure 2A. Typical elevation.

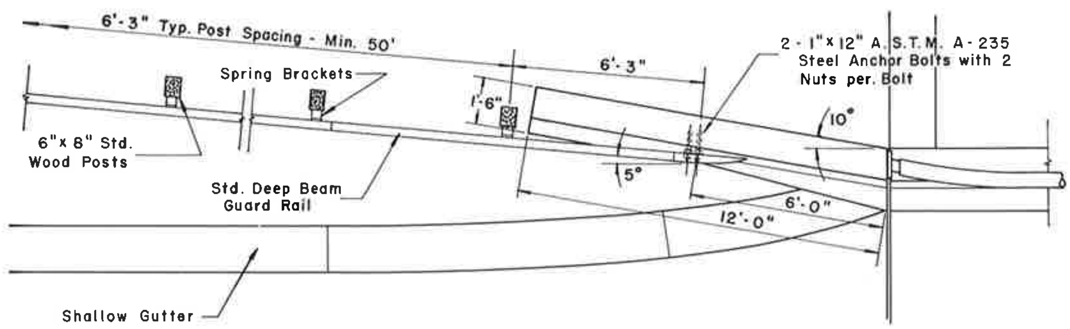

Figure 3A. Plan.

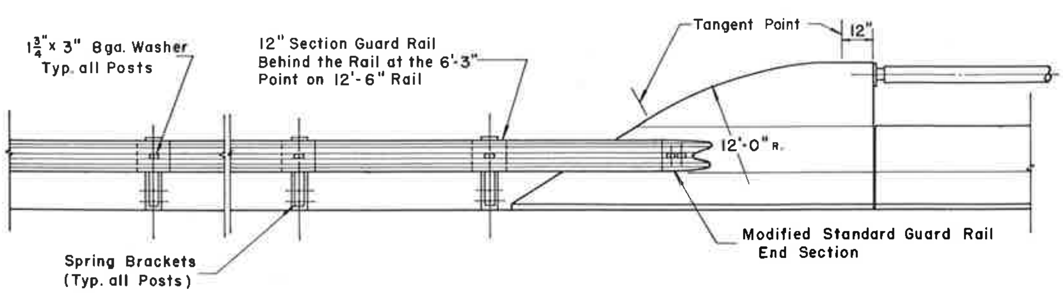

Figure 4A. Elevation.

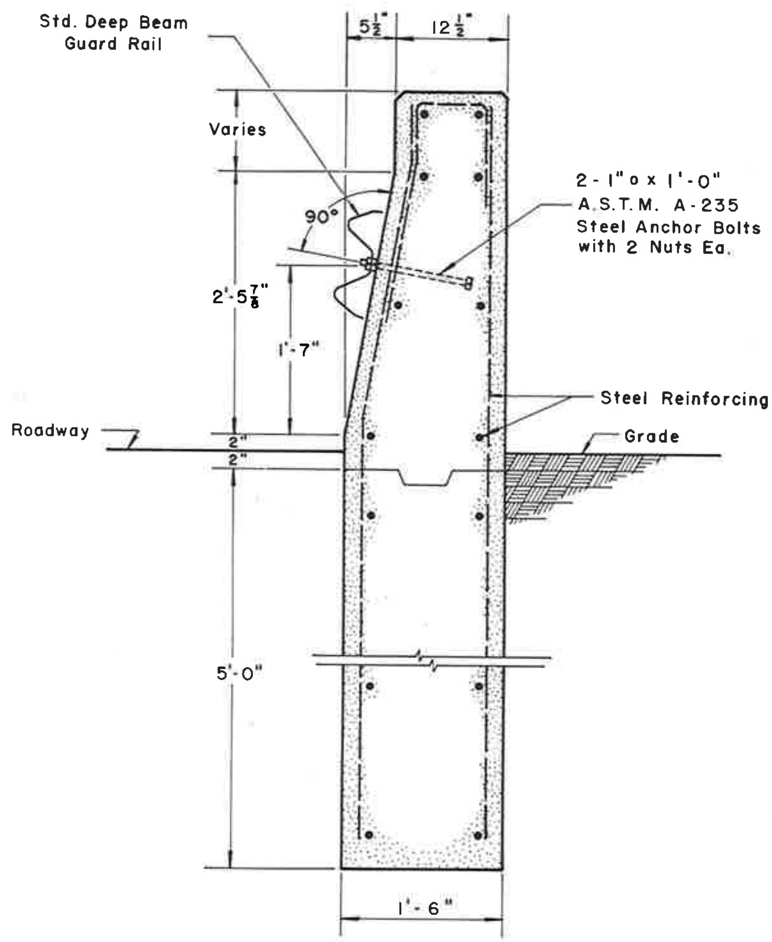

Figure 5A. Section at guardrail connection.

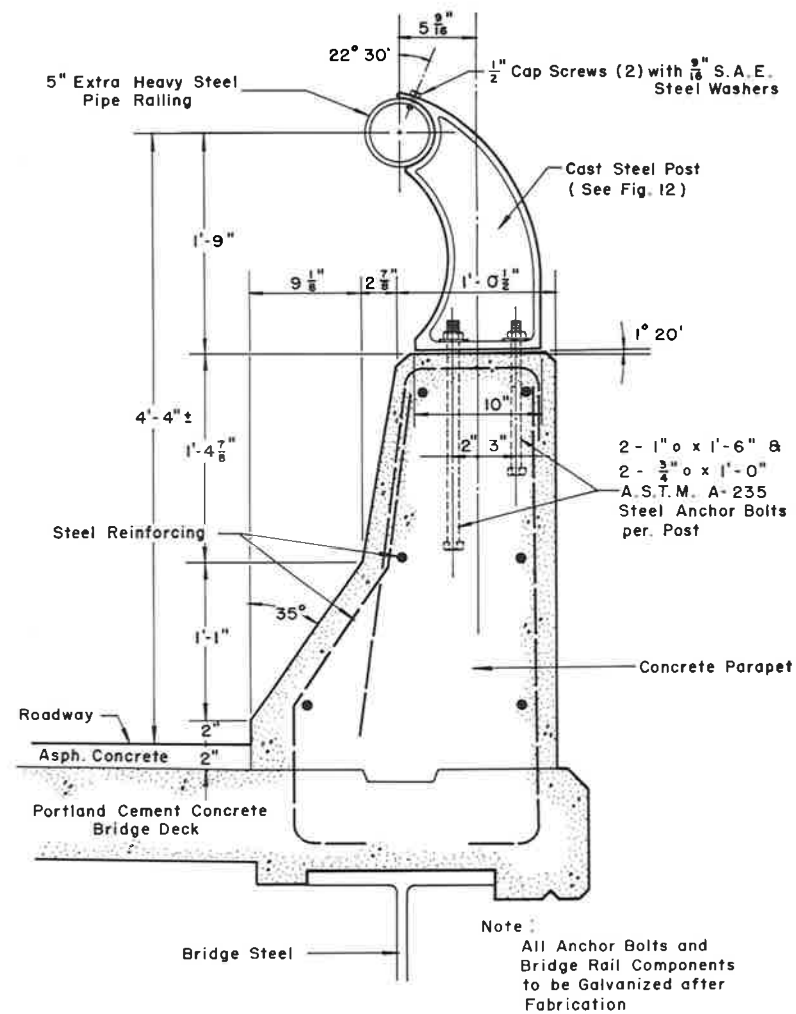

Figure 6A. Typical cross-section.

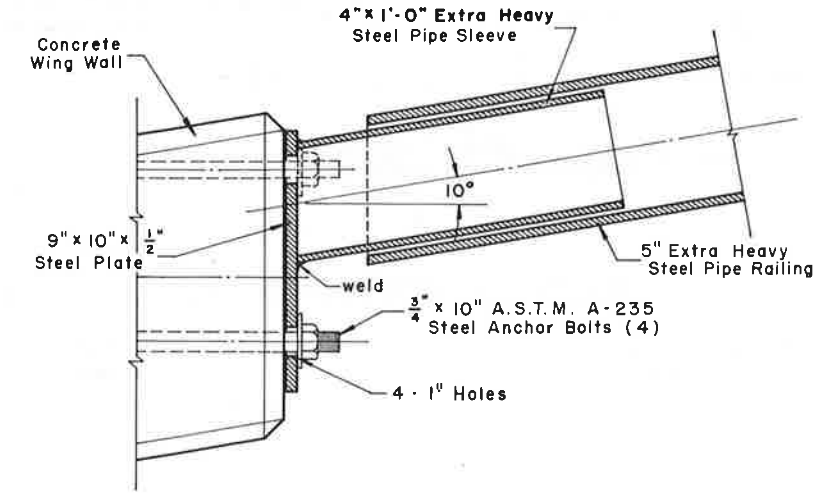

Figure 7A.

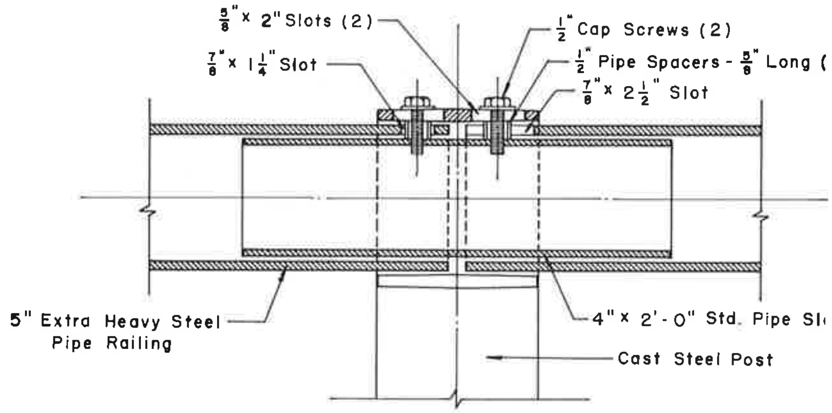

Figure 8A.

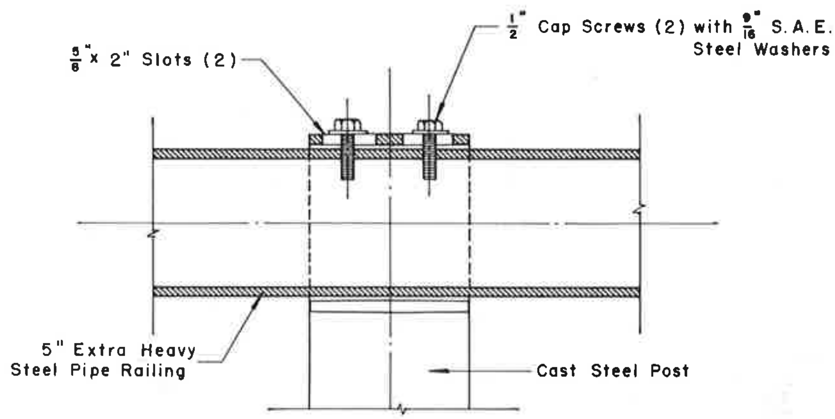

Figure 9A.

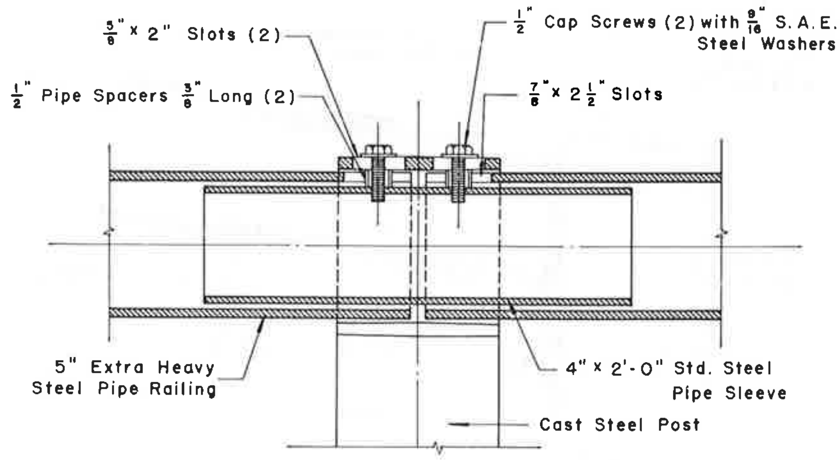

Figure 10A.

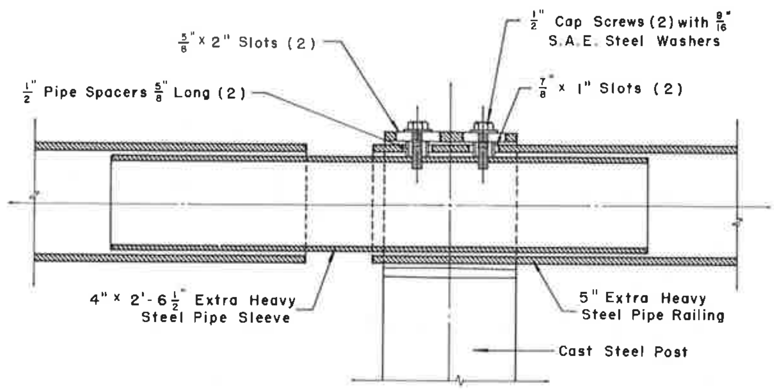

Figure 11A.

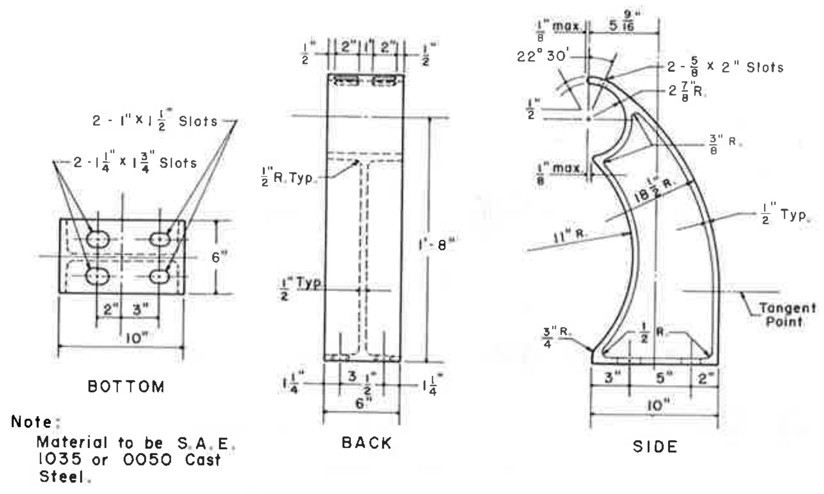

Figure 12A. Cast steel post details.