10. EVALUATION OF SIGHT DISTANCE CRITERIA

The ability to see ahead is of the utmost importance in the safe and efficient operation of a vehicle upon a highway. As defined by the American Association of State Highway and Transportation Officials (AASHTO) (Ref. 13), "sight distance is the length of roadway ahead visible to the driver. The minimum sight distance available on a roadway should be sufficiently long to enable a vehicle traveling at or near the design speed to stop before reaching a stationary object in its path. Although greater length is desirable, sight distance at every point along the highway should be at least that required for a below-average operator or vehicle to stop in this distance." Stopping sight distance is therefore a critical criteria in the design or evaluation of any highway.

Evaluation of Sight Distance

There are two sections of the Golden Gate Bridge in which available stopping sight distance would be significantly impacted by the introduction of any median barrier system. On the San Francisco approach to the bridge, there is a horizontal curve with a radius of approximately 1000 feet. The roadway surface is superelevated at a rate of 4.0% and has a 3% longitudinal grade. Based on current AASHTO highway design criteria, this curve has a design speed of approximately 50 mph. On the Marin approach, there is a horizontal curve with a radius of approximately 1075 feet. The roadway surface is superelevated at a rate of 3.7% and has a 2% longitudinal grade, Based on current AASHTO design criteria, this curve has a design speed of approximately 50 mph. The current posted speed limit is 45 mph for both curves.

Of these two curves, the potential safety implications of a sight distance restriction that might be posed by a median barrier system are likely to be more significant on the San Francisco curve for two reasons:

1. this curve has a slightly smaller radius than the Marin curve, and
2. the San Francisco curve is located on the southbound approach to the toll plaza, making the presence of stopped traffic near the curve a relatively more common occurrence.

The extent to which sight distance would be restricted by the presence of a median barrier system was evaluated using criteria established by AASHTO, as follows:

1. driver eye position located in the center of the lane and at an elevation of 3.50 feet above the roadway surface, and
2. target located in the center of the lane ahead of the driver.

In addition, it was assumed that any median barrier would be 32 inches high, lane widths are uniformly 10 feet, and the inside top corner of the barrier would be offset by 1 foot from the edge of the inner lane, resulting in a distance of 6 feet from the center of the lane to the top corner of the barrier. Further, the affect of superelevation on the height of the barrier relative to the height of the driver's eye was considered in this calculation.

This analysis of extent of sight distance restriction is generic in the sense that it does not depend on the specific type or configuration of the median barrier system other than the previously indicated height and lateral offset of the top of the barrier.

For a design speed of 50 mph, current AASHTO design criteria require an absolute minimum available stopping sight distance of 430 feet on a 3% downgrade. Desirable minimum stopping sight distance is 505 feet. In applying these criteria, it is assumed that any object which is 6 inches or more in height in the lane ahead would require the driver to be able to stop.

For drivers in the lane adjacent to a median barrier, the barrier system would limit available stopping sight distance to 219 feet. Objects at distances greater than 219 feet ahead would be partially or fully obscured by the barrier system. An available stopping sight distance of 219 feet is equivalent to a design speed of 30 mph (desirable criteria) to 35 mph (minimum criteria).

Although the AASHTO stopping sight distance criteria are normally based on the ability to see a 6-inch high target in the lane ahead, it should be noted that the barrier system would prevent drivers from seeing objects of significantly greater height that 6 inches. Figure 5 indicates the height of objects that would be hidden from view of a driver by such a barrier system. For example, at a distance of 300 feet ahead, an object of up to 27 inches in height would not be visible to the driver.

Drivers in the second lane out from a barrier system would also have their sight distance limited by the barrier, although not to the extent of drivers in the lane immediately adjacent to the barrier system. Objects in the second lane out that are more than 360 feet ahead of a driver would be partially or fully obscured by the barrier system. Figure 6 indicates the height of objects that would be hidden from view of a driver by such a barrier system.

Significance of Results

The implementation of a median barrier system on the San Francisco curve (and to a slightly lesser extent, on the Marin curve) would result in a substantial limitation on the sight distance available to drivers in the first and second lanes outward from the barrier (on the outside of the curves). Available sight distance would not meet the normally accepted minimum criteria for stopping sight distance at these locations for the design speed of the curves.

It might be argued that without a median barrier system in place, oncoming vehicles in the adjacent lane create a similar sight distance obstruction. However, such oncoming vehicles form moving sight obstructions, and the gaps between such oncoming vehicles provide drivers with an opportunity to view any obstacle in the lane ahead. Additionally, oncoming vehicles create sight obstructions only occasionally, while a median barrier would obstruct the sight of drivers at all times and in all lane configurations.

The degree of hazard posed by a limitation on the drivers' sight distance also requires discussion. The AASHTO stopping sight distance criteria require that a driver be able to see an object at least 6 inches high in the lane ahead in time to be able to stop before striking the object. In fact, a 32-inch high median barrier system (regardless of the specific configuration of the barrier) would actually obstruct the drivers' vision of objects as high as 28 inches. Objects such as cargo dropped from other vehicles, vehicle parts (such as tires or mufflers), animals, or miscellaneous debris could be hidden from view. Perhaps most critical, the brake lights on many automobiles are also below this height. Although passenger cars are now required to be manufactured with a high-mounted center brake light, many older cars which will be in use for many years do not have such lights.

The foregoing discussion is predicated on an assumed driver eye height of 3.5 feet above the pavement, which is the current design criteria utilized by AASHTO. It should be noted that there is currently ongoing discussion within the traffic engineering profession concerning the need to lower this assumed drivers' eye height. A study of driver eye heights (Ref. 16) indicated that approximately 25 percent of driver-vehicle combinations on the road have eye heights lower than 3.5 feet. If a lower eye height is adopted by the profession in future years, the sight distance deficiencies created by a median barrier system will become more critical.

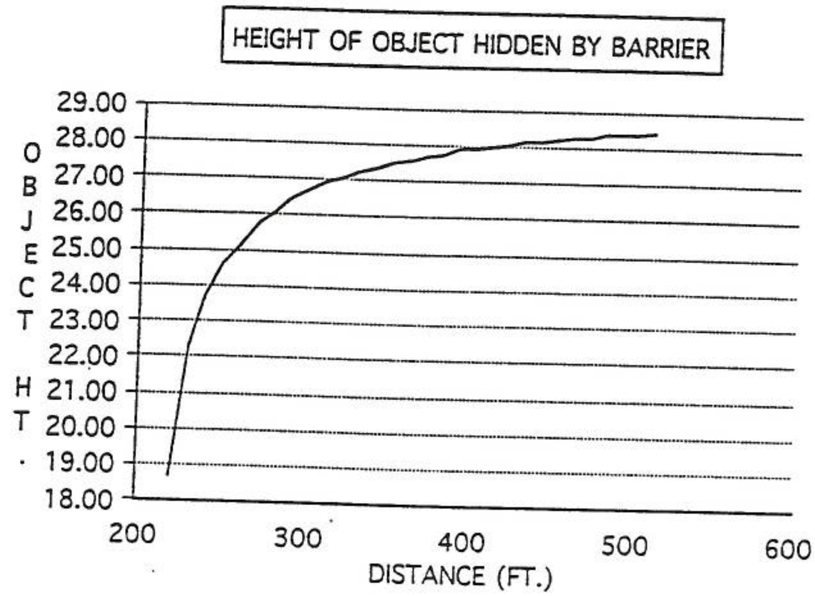

FIGURE 5. Height of Objects in Lane Adjacent to Barrier, Hidden by Barrier System

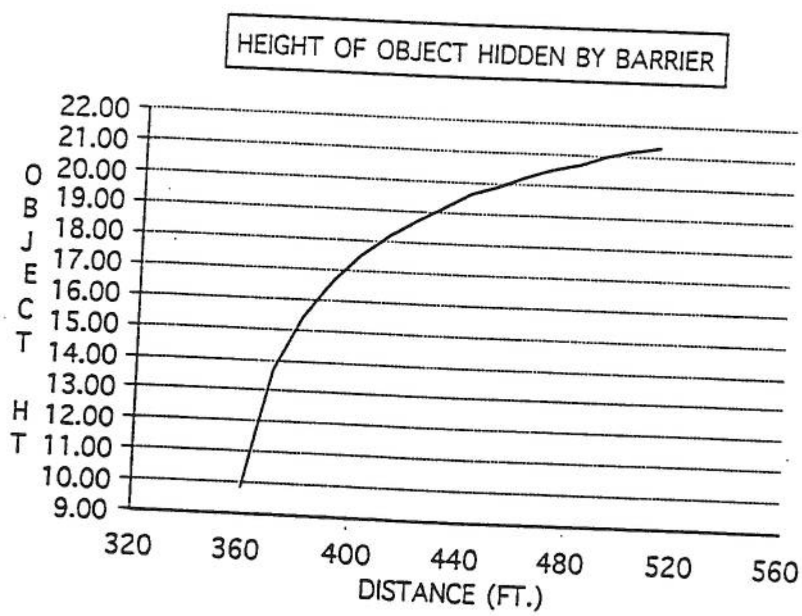

FIGURE 6. Height of Objects in Second Lane Out From Barrier, Hidden by Barrier System

The relationship between sight distance restrictions and highway safety is not abstract or theoretical. The U.S. Department of Transportation report Safety Effectiveness of Highway Design Features (Ref. 14) concluded that "past research has identified a number of traffic, roadway, and geometric features which are related to the safety of horizontal curves. These factors include...Stopping sight distance on curve (or curve approach)."

Further, the Transportation Research Board report Relationship between Safety and Key Highway Features, a Synthesis of Prior Research (Ref. 15) indicates that "for safety of highway operations, the designer must provide sight distances of sufficient length along the highway that most drivers can control their vehicles to avoid collision with other vehicles and objects that conflict with their path....Adequate sight distances have been defined as a function of operating speeds and are achieved by designing nonrestrictive horizontal and vertical alignment and by avoiding sight obstructions...on the inside of horizontal curves."

This same report points out that stopping sight distance related accidents "are event oriented. The mere presence of a segment of highway with inadequate stopping sight distance does not guarantee that accidents will occur. Stopping sight distance related accidents occur only after an event or events create a critical situation. These events can take the form...of conflicting vehicles, the presence of objects on the road, poor visibility, or poor road surface conditions, or all of these events." The likely presence of vehicles stopped in and upstream of the San Francisco toll plaza, in combination with frequent fog and wet pavement conditions, are the events that combine to make the sight distance restriction posed by a median barrier system of critical concern.

Finally, it should also be recognized that the stopping sight distance criteria utilized by AASHTO form a minimum highway design criteria. As AASHTO points out (Ref. 13), "these distances are often inadequate where drivers must make complex or instantaneous decisions, when information is difficult to perceive, or when unexpected or unusual maneuvers are required. Limiting sight distances to those provided for stopping may also preclude drivers from performing evasive maneuvers, which are often less hazardous and otherwise preferable to stopping....In these circumstances, decision sight distance (emphasis added) provides the greater length that drivers need. Decision sight distance is the distance required for a driver to detect an unexpected or otherwise difficult-to-perceive information source or hazard in a roadway environment that may be visually cluttered, recognize the hazard or its potential threat, select an appropriate speed and path, and initiate and complete the required safety maneuver....Its values are substantially greater than stopping sight distance." One of the examples that AASHTO provides of typical locations where decision sight distance should be provided is approaching toll plazas.

11. LANE WIDTH AND BARRIER POSITIONING

At the present time, the pavement width on the Golden Gate Bridge is a total of 62 feet, divided among six moving traffic lanes. The two outside lanes are each 11 feet wide, with all interior lanes being 10 feet wide.

For over 50 years, the standard design lane width for lanes on freeways and arterial highways has been 12 feet. However, many highways exist and continue to function with satisfactory safety and efficiency with lane widths less than this desired standard. In fact, a widely applied congestion mitigation strategy for urban freeways has been the reduction in lane widths in order to provide more moving traffic lanes without major pavement widening. In some cases, lane widths of 10.5 feet have been used with reportedly satisfactory results (Ref. 19). Further, the American Association of State Highway and Transportation Officials has recognized that lane widths as narrow as 10 feet are acceptable on existing high-speed roadways (running speeds greater than 40 mph) where truck and bus traffic represents less than 15% of daily volume (Ref. 20). However, it is clearly recognized that narrower lane widths are associated with reduced efficiency of traffic flow and increased frequency of lane-change and side-swipe accidents. To the extent that they can be achieved, wider lanes are desirable.

Under typical highway conditions, where curbs or barriers are adjacent to moving traffic lanes, effective lane width is lost due to drivers shying away from the roadside obstruction. It is considered desirable to offset the curb or barrier a minimum of 1 foot away from the edge of the lane to provide for a "shy distance". However, informal observations of vehicle positioning within the outside lanes on the Golden Gate Bridge has indicated that drivers do not show any significant tendency to shy away from the existing curb barriers. In addition, observations of driver lane positioning adjacent to the Quickchange Barrier system in operation on the Auckland Harbour Bridge suggest that drivers also do not shy away from this barrier system. Nevertheless, it appears to be desirable to maximize lane widths on the Golden Gate Bridge for lanes that are adjacent to the outside curb barrier and adjacent to any potential median barrier system.

Use by Large Vehicles

Traffic counts on the Golden Gate Bridge indicate that less than 5% of vehicles using the bridge are trucks, buses, or other large vehicles. Transit buses make up the majority of these larger vehicles. Because of their greater size, such vehicles are of special concern when considering narrow lane widths.

Buses currently used by the Golden Gate Bridge, Highway, and Transportation District are 8.5 feet wide. However, these buses actually occupy a wider "swept path" as they travel around the curves at the north and south ends of the bridge, due to off-tracking of the rear wheels. The actual swept path of such a bus was calculated as 9.0 feet.

In addition, these buses are equipped with outside mirrors on both the right and left front corners of the buses. These mirrors extend out approximately 10 inches on each side of the bus. Even if steered precisely down the center of a lane, these buses do not fit within a 10-foot lane without encroachment over the lane lines by the mirrors. Wider lane widths for the outside lanes on the Bridge would be highly desirable to allow for large vehicle off-tracking in the curves, minor variations in lane positioning, and possible lateral movement due to wind gusts.

Lane Widths and Lateral Positioning of a Movable Median Barrier System

A number of possible alternatives exist for the lateral placement of a movable median barrier system on the Bridge. As previously discussed, lane width is of critical concern when considering the potential application of a median barrier system on the Golden Gate Bridge. Systems that minimize the loss of lane width due to the physical width of the barrier would be preferred.

Several assumptions have been made in evaluating alternative barrier system placements:

1. The existing lane widths on the Bridge (11-foot outside lanes, 10-foot interior lanes) can be changed if

desired.

2. The existing practice of marking lane lines with raised pavement markings will be continued.

3. A movable median barrier system can be positioned with sufficiently reliable accuracy to straddle the line of raised pavement markers if it is desired to center the barrier system over a lane line.

4. Desirably, all lanes should be at least 10 feet wide; and in no case should any lane be less than 9 feet wide. Desirably, the outside lanes should remain 11 feet wide. Desirably, the lanes adjacent to a movable median barrier system should be as wide as possible. Desirably, when the roadway is in the 4/2 configuration, the two-lane section should be more than 20 feet wide.

5. A movable median barrier system with a barrier width of 1 foot or less and a base width of 2 feet or less is feasible.

Several potential lane configurations are illustrated in Figures 7 through 14. These represent different combinations of marked lane widths, and the resulting effective lane widths with a one-foot barrier system positioned in the 3/3 and 4/2 lane configurations. In this analysis, it has been assumed that such a barrier system would have a base which is two feet wide which could either straddle or be located adjacent to the lane line raised pavement markers. Lane widths indicated in these diagrams should be considered nominal lane widths; that is, actual lane widths may be as much as about 3 inches wider or narrower than indicated as a result of having to position the base of the movable median barrier system adjacent to the raised pavement markers. In some cases, slight improvements in barrier positioning may be possible if the raised pavement markers on some lane lines were removed and replaced with pavement markings that are flush with the roadway surface or recessed into the roadway surface.

None of these alternatives completely satisfies all of the desired lane width criteria. Table 27 indicates the relative rating of each alternative with regard to four desired lane arrangement issues.

TABLE 27. Summary of Alternative Lane Arrangements

ALTERNATIVE	LANE WIDTH ADJ. TO CURB	LANE WIDTH ADJ. TO MEDIAN	TOTAL WIDTH 2-LANE SECTION	LANE WIDTH LESS THAN 10 FEET
A	++	--	+	-
B	-	-/++	+	--
C	-	++/-	--	-
D	-	++/-	+	-
E	++	+/-	++	--
F	+	--/+	+	--
G	+	+/-	-	-
H	-	+	-	+

Ratings:
++ much better than other alternatives
\+ somewhat better than other alternatives
\- somewhat worse than other alternatives
-- much worse than other alternatives

The preceding rating of alternative lane configurations does not indicate any one alternative which is obviously superior to the others. The selection of an appropriate lane configuration depends on the relative importance of achieving the various objectives.

It appears that one of the most important of these objectives is to provide the maximum lane width in the outside curb lanes to accommodate buses and other large vehicles. If an alternative lane configuration can accomplish this without seriously compromising other objectives, then that would be the preferred alternative.

The two alternatives which are most highly rated with regard to width of outside lanes are Alternatives A and E. Both of these alternatives provide 11.0-foot outside lanes. Alternative A provides only 9.5-foot lanes for all lanes adjacent to the median barrier system in both the 3/3 and 4/2 configurations. It also provides a total width of 20.5 feet for the two-lane roadway in the 4/2 configuration.

Alternative E provides 10.0-foot lanes for both of the lanes adjacent to the median barrier system in the 3/3 configuration and one 10.0-foot lane and one 9.0-foot lane adjacent to the median barrier system in the 4/2 configuration. The 9.0-foot lane is on the four-lane roadway side of the 4/2 configuration where the effect of the narrow lane would be expected to be of least significance. However, when accounting for the width of the raised pavement markers, the actual width of this lane from face of barrier to lane line would be closer to 8 feet 9 inches, an undesirably narrow lane width. This alternative also provides a total width of 21.0 feet for the two-lane roadway in the 4/2 configuration. However, some of the lanes which are not adjacent to the median barrier system are 9.5 feet wide.

Alternatives F and G both provide 10.5-foot outside curb lanes. However, Alternative F provides 9.5-foot lanes adjacent to the median barrier system in both the 3/3 and 4/2 configuration, while Alternative G provides only a 20.0-foot two-lane roadway width in the 4/2 configuration.

Of the available alternatives, it appears that Alternative E offers some important advantages over the other alternatives. Although this alternative makes use of lane widths that are less than desirable for some lanes, it also maximizes the width of the most critical lanes: those adjacent to the curb barriers and within the two-lane roadway section of the 4/2 lane configurations. It should be further studied for potential implementation if a movable median barrier system is to be considered for installation on the Golden Gate Bridge. Replacement of the raised pavement markers along some lane lines with flush or recessed markings would slightly reduce the narrow lane width problems for this alternative. However, it is emphasized that neither this alternative nor any of the others considered completely satisfies all of the desired lane width criteria for the Golden Gate Bridge.

The selection of this (or any of these alternatives) presumes that sufficient accuracy can be attained in the placement of the movable median barrier system to permit the base of the barrier system to straddle or be positioned immediately adjacent to the raised pavement markers along the lane lines. Experience with several existing installations of the Quickchange Barrier System suggest that this precision in barrier placement is feasible with this particular type of system, using automatic guidance control of the transfer vehicle. Other types of movable barrier systems that may be considered for installation on the Golden Gate Bridge should be capable of attaining similar reliability in placement accuracy. If placement accuracy is questionable for a candidate movable barrier system, full-scale crash testing of the proposed system should include an evaluation of the barrier performance if the barrier were inadvertently placed with one side of its base resting atop the raised pavement markers. Previous studies have found that such tipping of the vertical axis of a barrier may have significant effects on its performance in crashes (Ref. 21).

Finally, it is noted that if a movable median barrier system were installed on the Golden Gate Bridge, there would no longer be any need for the current system of using plastic tubes to separate the opposing lanes of traffic. However, the installation of a movable median barrier system would not preclude the continued use of tubes to close buffer lanes during the off-peak periods, if so desired. As previously discussed, the presence of buffer lanes offers a safety benefit by providing a refuge area for disabled vehicles. Because buffer lanes are currently utilized only during periods when traffic volumes are relatively low (and hence the probability of disabled vehicles is also low), it is difficult to estimate the likely effect of eliminating such buffer lanes on accidents on the Bridge. A prudent strategy, in the event that a movable median barrier system were installed on the Golden Gate Bridge, would be to monitor vehicle disablements and accidents during late night hours, and if such accidents increased in frequency consider implementing buffer lanes using the plastic tubes to close one lane in each direction during periods when traffic volumes are low.

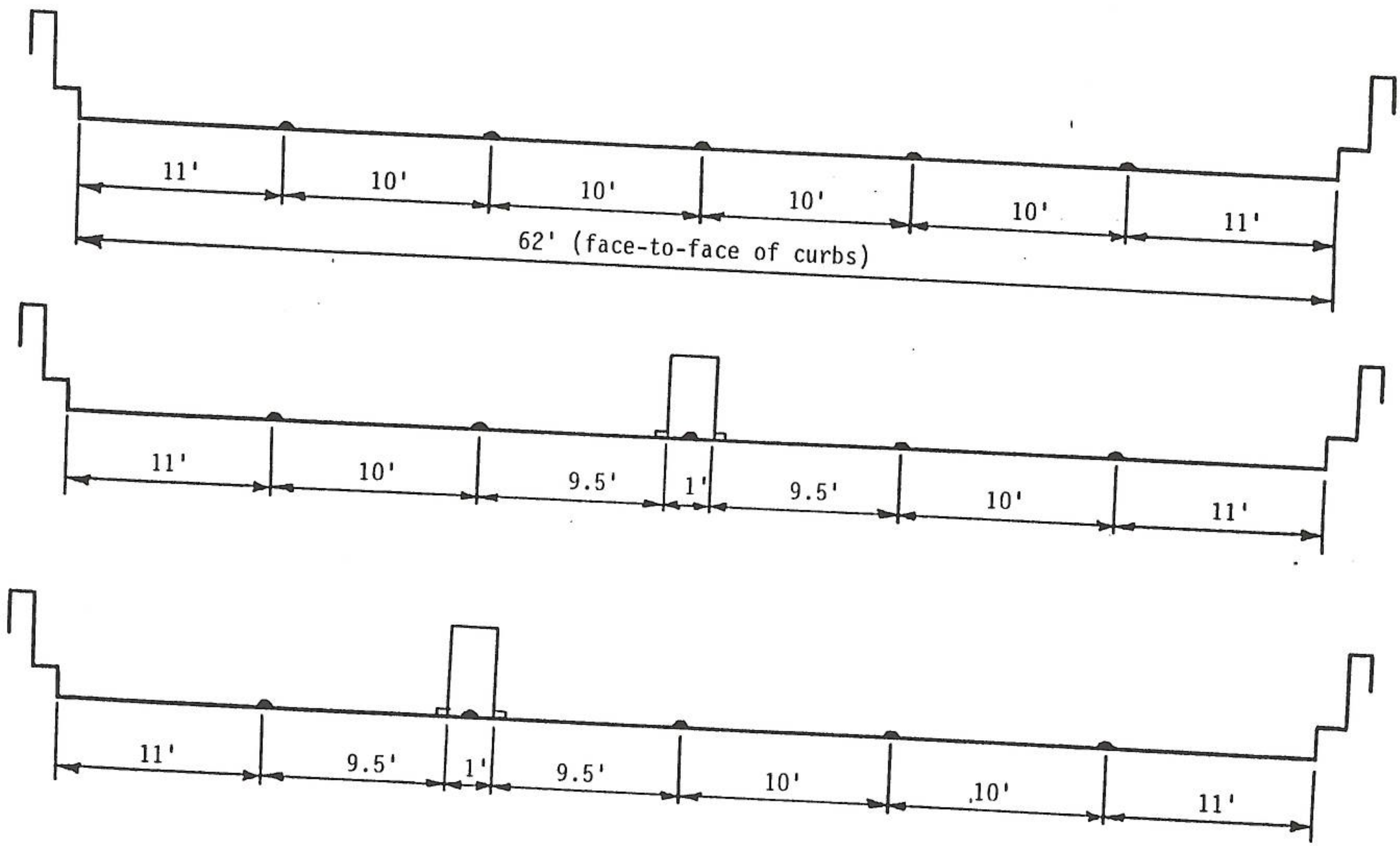

FIGURE 7. Alternative A, Lane Widths and Lateral Placement of Movable Median Barrier System

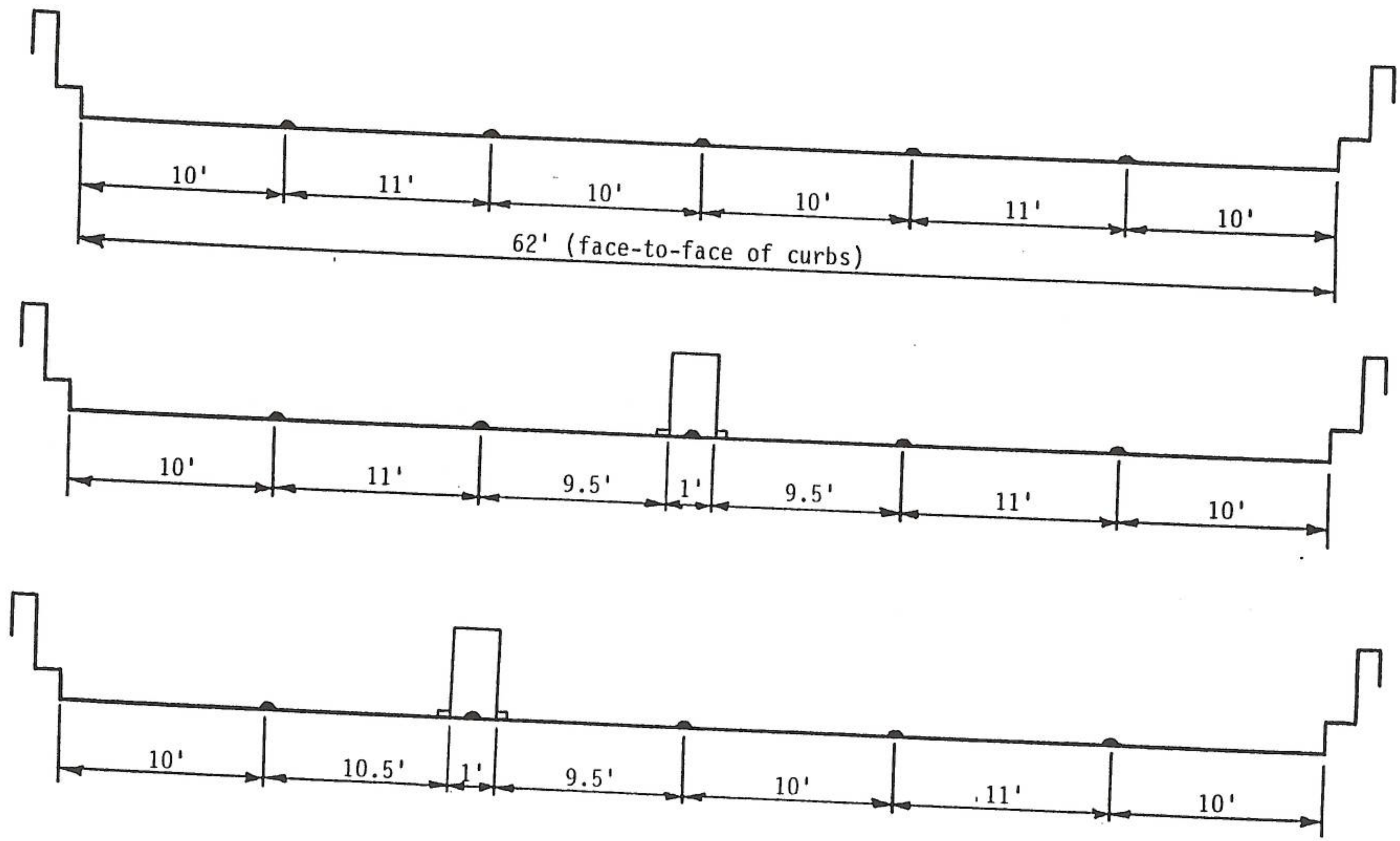

FIGURE 8. Alternative B, Lane Widths and Lateral Placement of Movable Median Barrier System

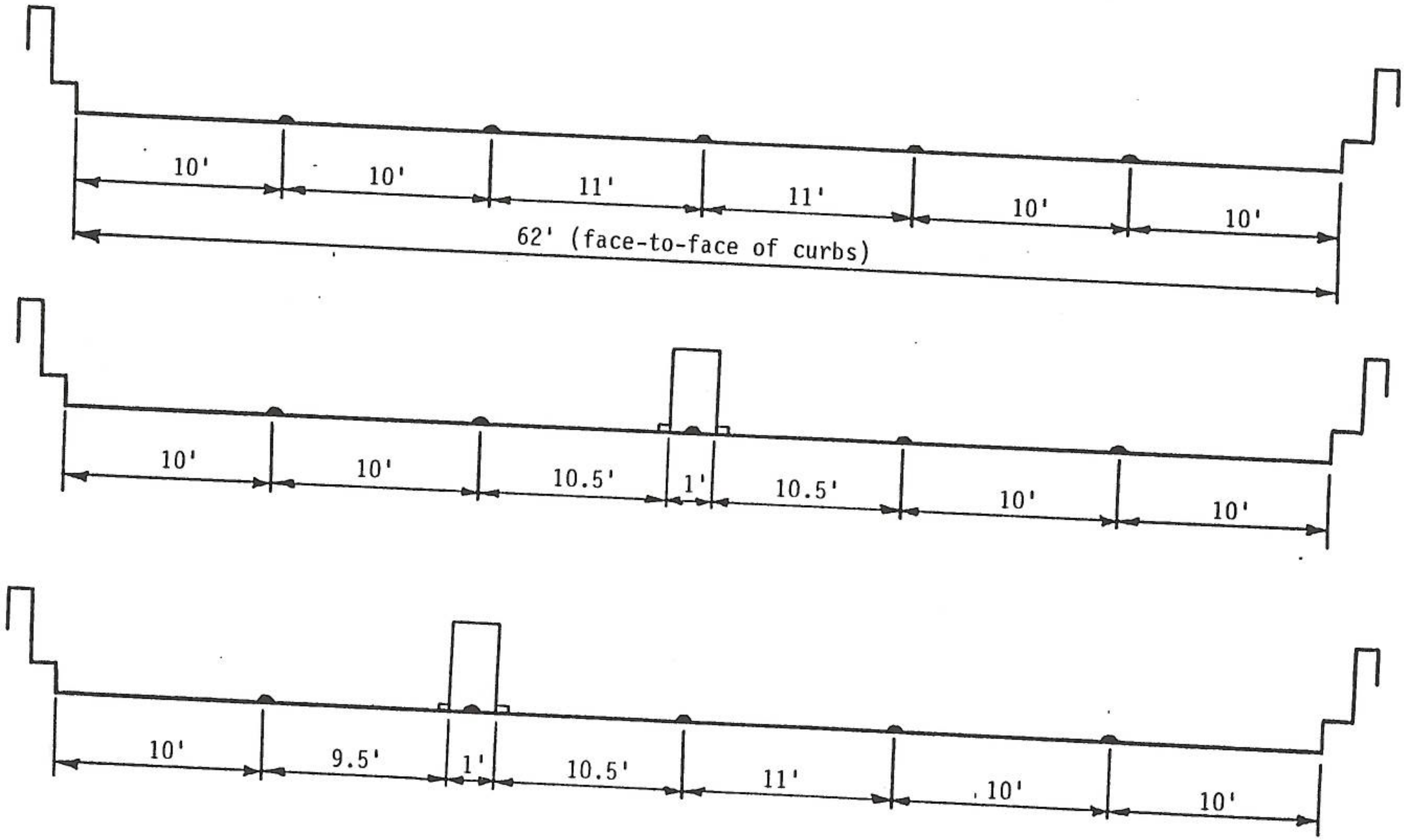

FIGURE 9. Alternative C, Lane Widths and Lateral Placement of Movable Median Barrier System

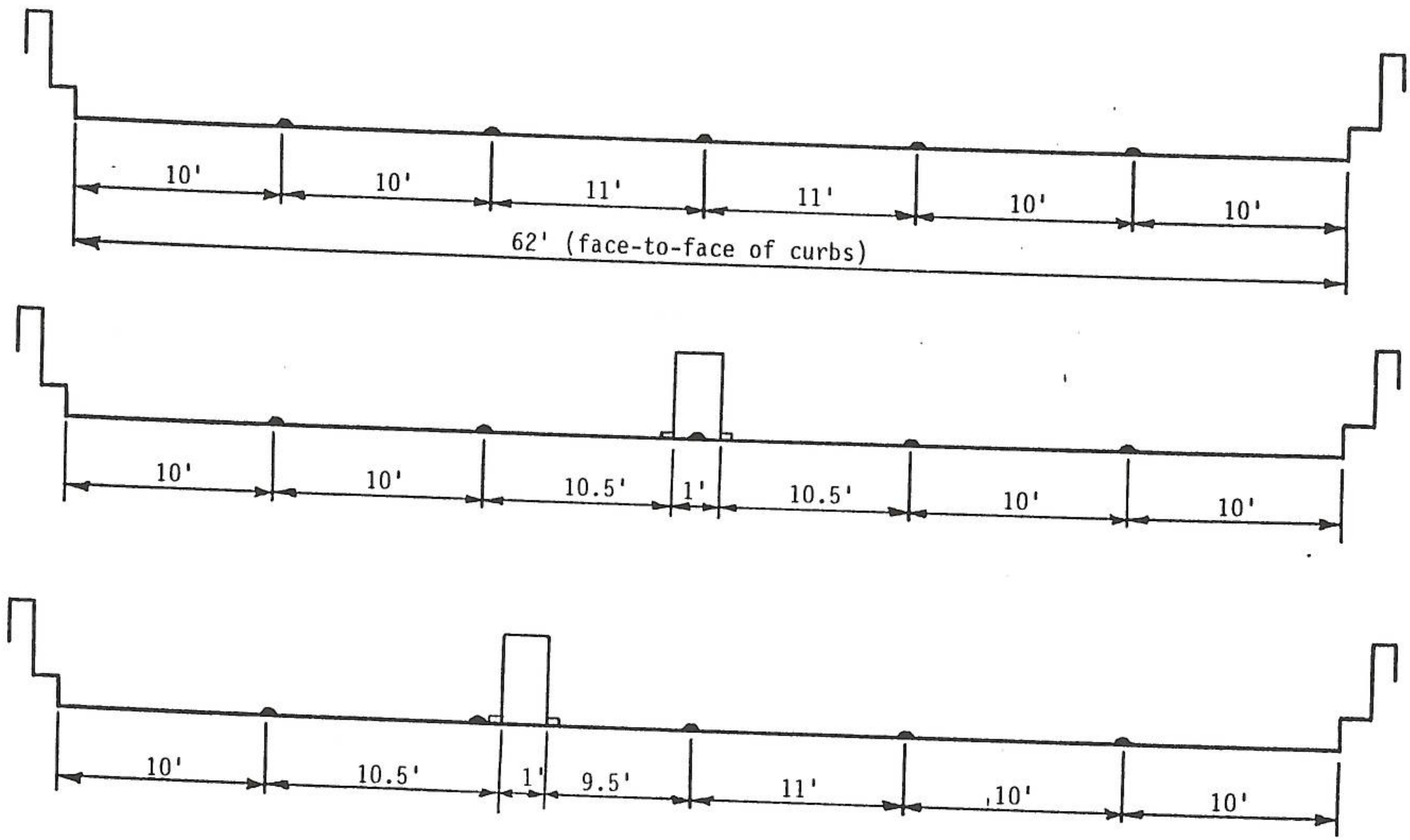

FIGURE 10. Alternative D, Lane Widths and Lateral Placement of Movable Median Barrier System

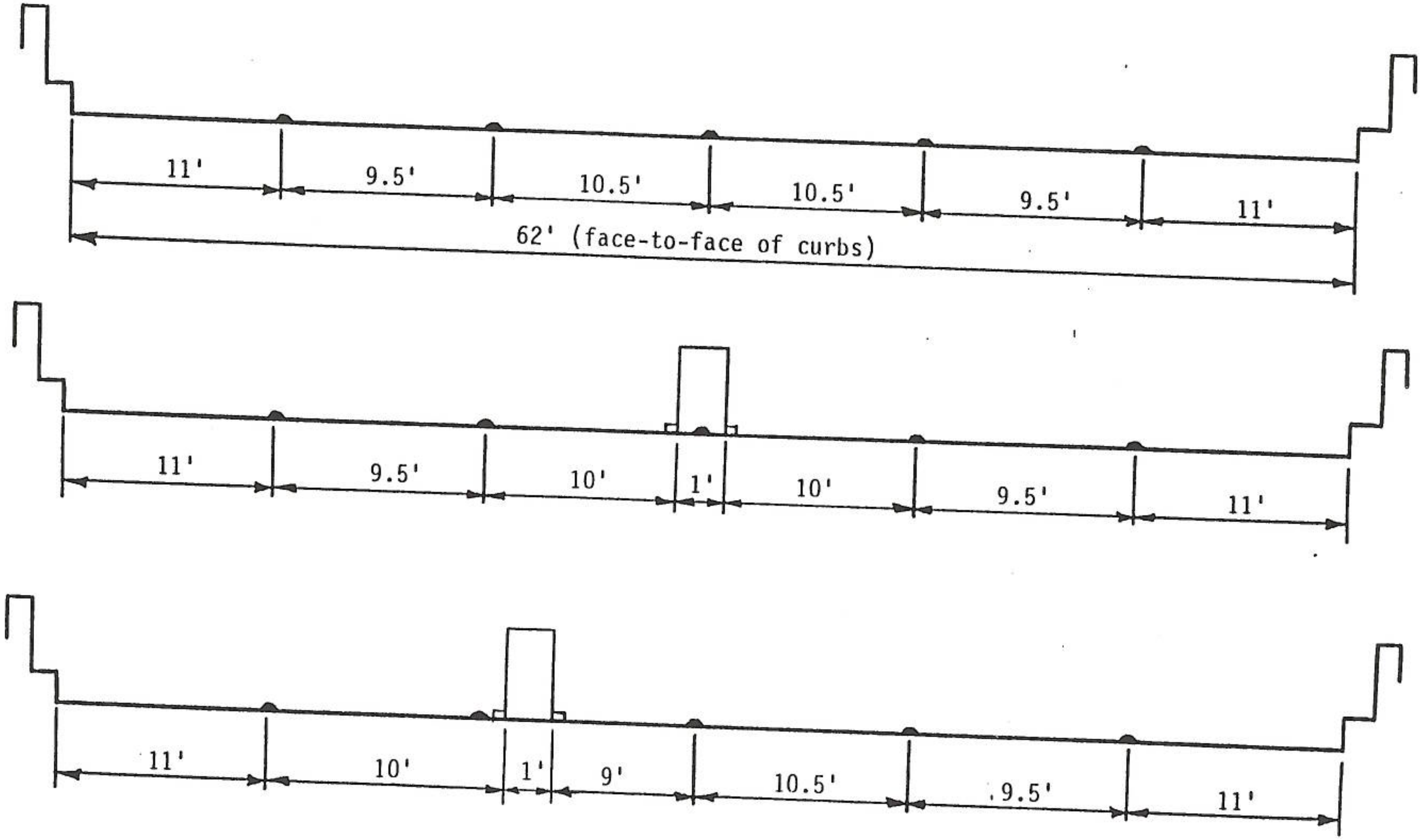

FIGURE 11. Alternative E, Lane Widths and Lateral Placement of Movable Median Barrier System

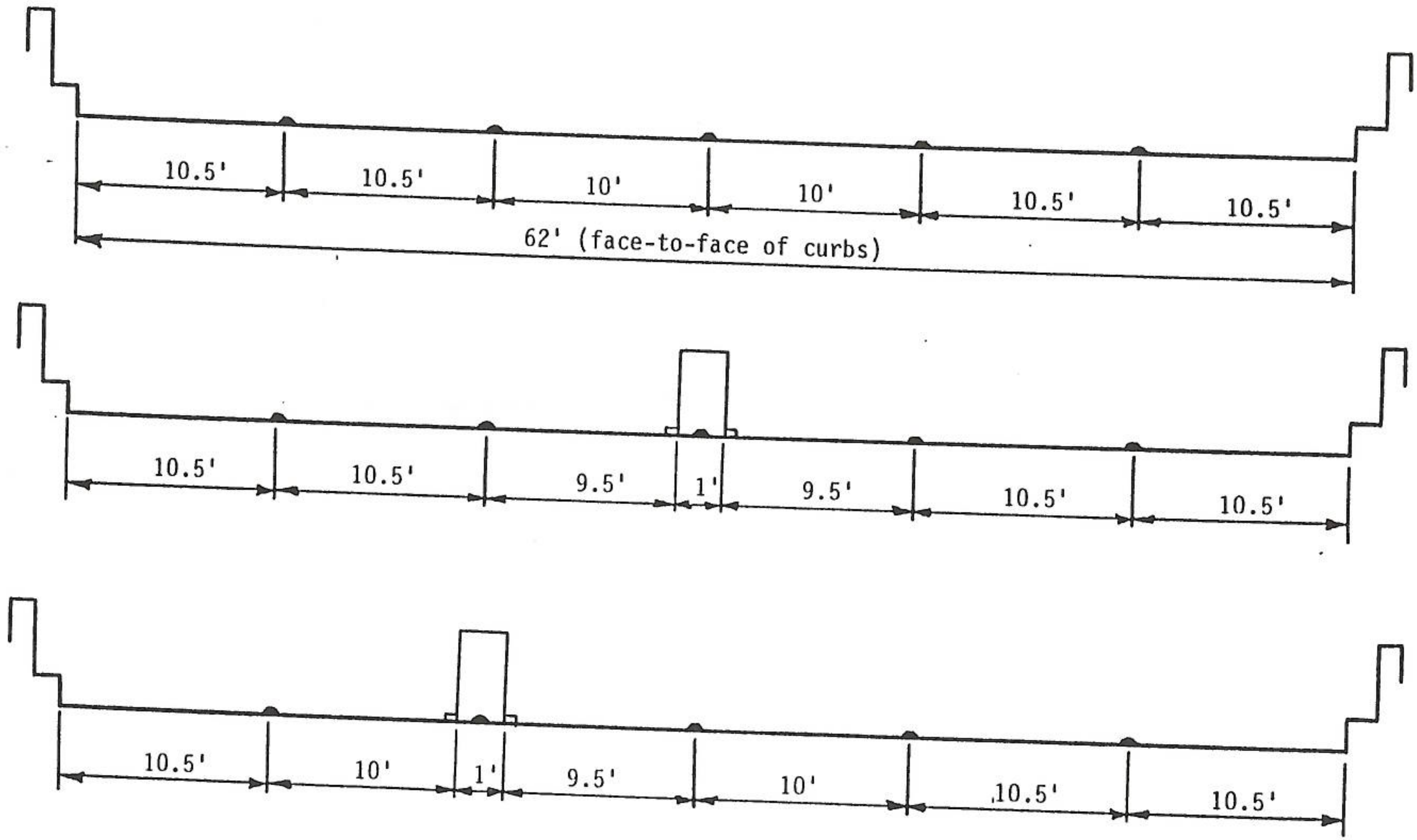

FIGURE 12. Alternative F, Lane Widths and Lateral Placement of Movable Median Barrier System

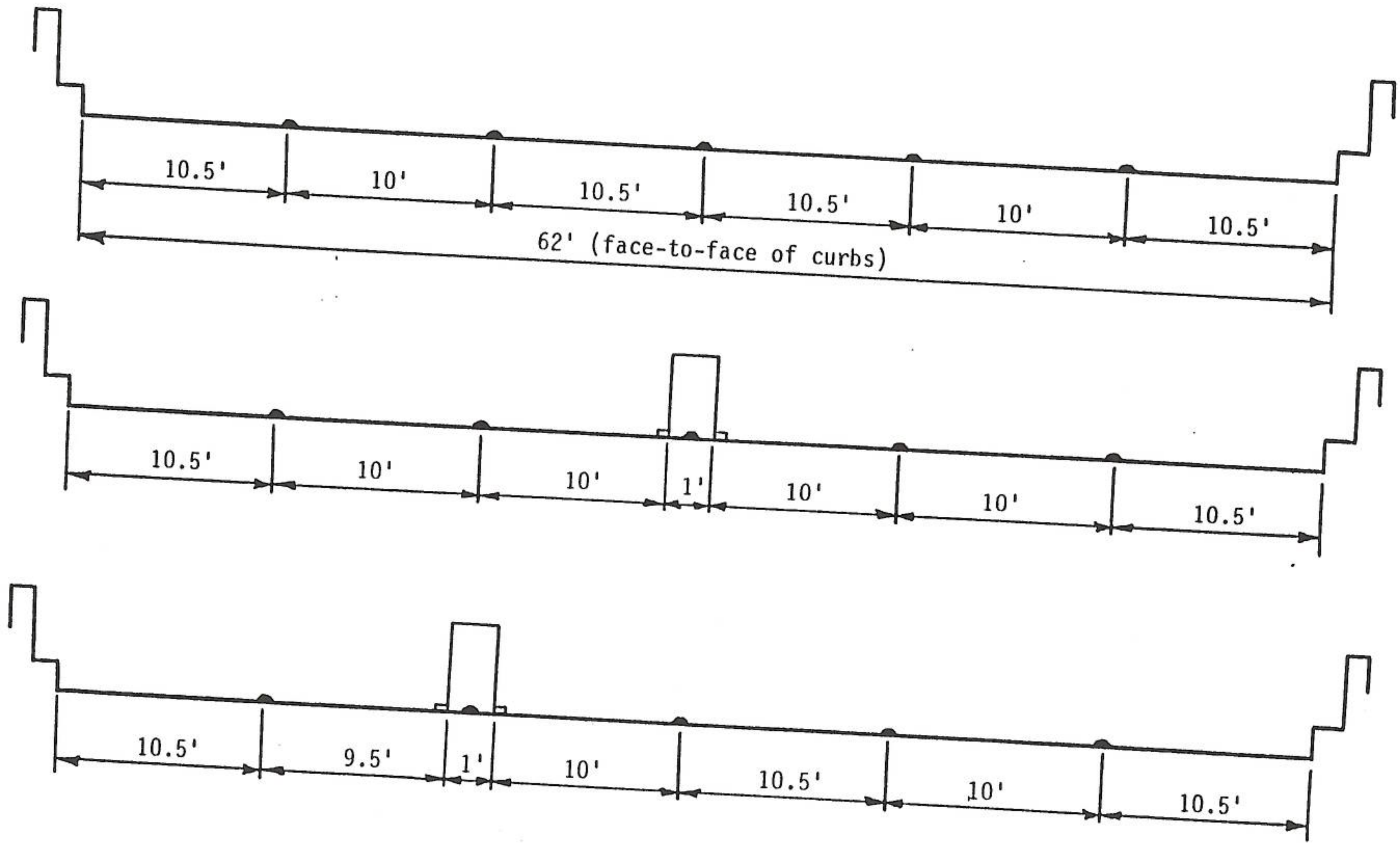

FIGURE 13. Alternative G, Lane Widths and Lateral Placement of Movable Median Barrier System

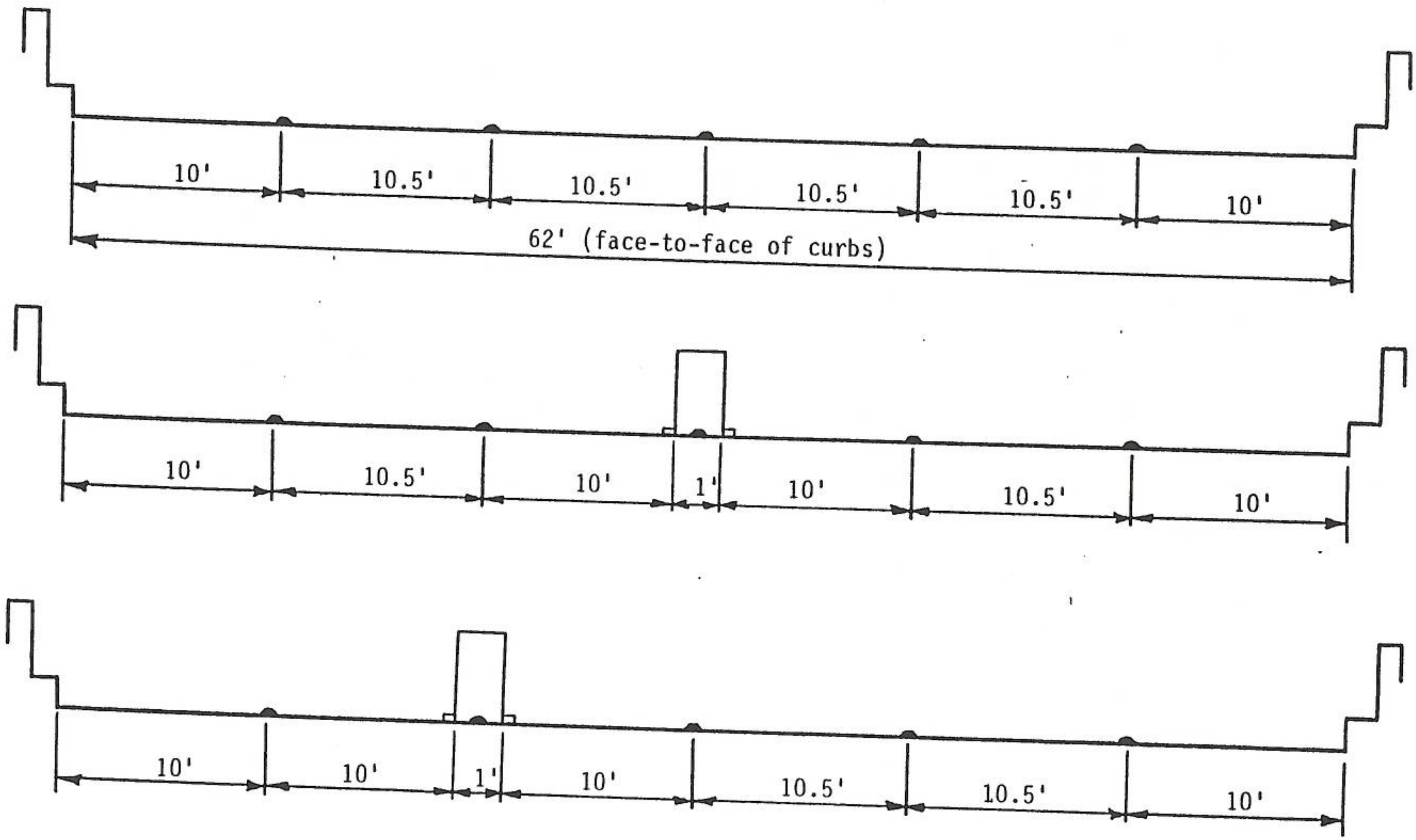

FIGURE14. Alternative H, Lane Widths and Lateral Placement of Movable Median Barrier System

12. EMERGENCY VEHICLE ACCESS

The ability of emergency response vehicles and personnel to get to the site of an accident quickly may have important implications for the survivability of victims of serious accidents. The ability to quickly respond and remove stalled or collision-damaged vehicles also has important implications for traffic congestion and motorist delay due to blocked roadway lanes and resultant accidents associated with slowed or stopped traffic.

Of the 230 accidents in a five-year period used as the basis for analysis of existing accident characteristics on the Golden Gate Bridge, one or more ambulances were called to the scene of 68 accidents (30%). Fire department vehicles responded to 40 accidents (17%). Tow trucks were called to the scene of 164 accidents (72%). In addition, Bridge personnel respond to numerous stalled vehicles each year.

If a movable median barrier system were installed on the Bridge and its approaches, some negative affect on the speed and efficiency of emergency vehicle response would be expected. Although relatively low (typically 32 inches), the barrier system would hamper movement of emergency personnel and their equipment if it were necessary to access an accident *.Uscene from the opposite side of the barrier. More importantly, the ability to get emergency vehicles, such as tow trucks, to the accident scene would be restricted, especially under congested conditions when all lanes in one direction may be blocked by stopped or slowed traffic due to the accident. It would be possible to gain access to such an accident by backing or driving the emergency vehicles the "wrong way" on the blocked roadway. In fact, this has been done when conditions warranted in the past.

Even using "wrong way" access, the presence of a movable median barrier system would potentially impact the efficiency with which emergency vehicles could be dispatched to an accident scene. If an essentially continuous barrier were in place extending from the existing median barrier in the connecting freeway on the Marin approach to the toll plaza on the San Francisco approach, no U-turns would be possible within this 1.73 mile distance. This would make it inconvenient and time-consuming to get from one side of the barrier to the other, especially at the Marin end where the interchange at Alexander Avenue would provide the only means of accessing the other side of the roadway. For example, if a median barrier system were present and an accident occurred which blocked the northbound lanes, emergency vehicles approaching from the toll plaza would be required to travel northbound the full length of the Bridge in the southbound lanes, turn off the roadway at the Alexander Avenue interchange, re-enter the northbound lanes at the interchange, and travel southbound in the northbound lanes to reach the accident scene. As mentioned earlier, it is possible to stop traffic movement on the Bridge to permit the wrong way travel by emergency vehicles. However, longer response time would be expected as a result of the installation of a movable median barrier system.

It does not appear to be feasible to provide "gates" or openings in a movable barrier system to provide emergency access across the barrier. Any such longitudinal barrier system depends on the continuity of the barrier system to provide adequate impact performance. Gates or openings in the barrier system would likely have a severe adverse affect on its ability to minimize lateral deflections and control the rebound of impacting vehicles.

It should also be recognized that a movable median barrier system would potentially reduce flexibility in operations at an accident scene. The maneuverability of emergency equipment within the confined roadway width (especially in a two-lane configuration) would be negatively impacted. Flexibility in directing traffic around an accident scene would be similarly impacted; oncoming traffic lanes could not be temporarily used to allow traffic to bypass the accident scene.

13. BENEFIT-COST ANALYSIS

Benefit-cost analysis is a tool to aid in decision making by allowing a comparison between the overall costs of a project (capital, operating, and maintenance) with the overall benefits of the project expressed in dollar values. A project which has a benefit-cost ratio of more than 1.0 is one which will return more that $1 in benefits for each $1 that the project costs. In other words, the results are worth the project costs and the project is worth implementing if sufficient funds are available and there are no alternative projects being considered which have a higher benefit-cost ratio.

The usefulness of a benefit-cost analysis depends on the extent to which relevant costs and benefits of the project can be expressed in dollar values. Some potential costs or benefits are difficult to quantify and still harder to value in dollars. Examples of such difficult-to-value impacts include reductions in air pollutant emissions or aesthetics. It must be remembered in interpreting a benefit-cost analysis that such impacts that cannot be valued are ignored by the analysis.

In order to compare all costs and benefits for the same time periods, it is necessary to amortize the barrier system installation costs over the usable life of the system. For this analysis, it is assumed that all of the installation costs must be amortized over a relatively short 10-year period. This appears to be a reasonable expected useful lifetime for the barrier transfer vehicles, and assures that any potential investment in such a system is recaptured relatively quickly. An interest rate of 6% was utilized, consistent with typical government bond issue interest rates. Further, annual costs and benefits are assumed to increase over the 10-year analysis period at an inflation rate of 2% per year. Average annual costs and benefits at the midyear of the 10-year analysis period have been used for this analysis.

Relevant costs for implementing a movable median barrier system on the Golden Gate Bridge include:

1. Installation Costs. This includes the costs of system design, purchase of the barrier system, transfer vehicles, crash cushion for the San Francisco approach, transfer vehicle storage facility, median modifications on the Marin approach, spare parts, personnel training, etc. This cost has been estimated by Barrier Systems, Inc. as $6,460,000 (Ref. 26). When amortized over the 10-year analysis period, the initial installation cost of $6,460,000 is equated to a series of 10 uniform annual costs of $878,000.

2. Operating and Maintenance Costs. This includes personnel to operate transfer vehicles and relocate the crash cushion; personnel, equipment, and materials to maintain and repair the transfer vehicles, barrier system, and crash cushion; and fuel and lubricants. The costs include only those expenses in excess of costs currently incurred for personnel and equipment used in placing and relocating the plastic tubes. It is assumed that personnel currently employed for tube placement and relocation can be trained to operate the transfer vehicles and relocate the crash cushion. Operating and maintenance costs have been estimated by Barrier Systems, Inc. as $100,000 to $600,000 per year (Ref. 26). It is assumed that these operating and maintenance costs will increase over the 10-year analysis period at an inflation rate of 2% per year. The average operating and maintenance costs are calculated as $110,000 to $662,000 at the midpoint of the 10-year analysis period. It appears that the costs in excess of current expenses for placing and relocating the plastic tubes would likely be in the lower portion of this cost range because much of the personnel costs will simply replace current personnel costs.

3. Excess Delay and Fuel Consumption. This includes the value of time to roadway users who may incur excess delay when an accident occurs due to longer emergency vehicle response times and inability to route traffic around accident sites by using oncoming lanes and the excess fuel consumed because of the resulting congestion. Although it is likely that some excess delay and fuel consumption will occur in some circumstances, it is not possible to reliably estimate the magnitude of these costs with available information. Therefore, although it is recognized that these costs may exist, they will not be included explicitly in this analysis.

Relevant benefits that will result from the implementation of a movable median barrier system on the Golden Gate Bridge include:

1. Reduced Accident Frequency and Severity. This includes costs for property damage to vehicles and cargo, medical care, lost wages, loss of vehicle use, funeral costs, legal costs, pain and suffering, and loss of quality of life. Although difficult to value, such costs must be considered in a benefit-cost analysis. Various organizations have arrived at values for accidents of different severity levels. These are generally thought of as the price that society is willing to pay to avoid the occurrence of an accident. For example, the U.S. Department of Transportation places a value of $2.6 million on each fatal accident avoided (Ref. 27). The American Association of State Highway and Transportation Officials recommends a value of $1 million (Ref. 25). The California Department of Transportation (Ref.) uses a value of $901,000 (Ref. 2) for highways in rural areas (appropriate for application of the Golden Gate Bridge in terms of typical vehicle speeds and absence of crossroads and driveways). For this analysis, the accident costs utilized by the California Department of Transportation will be used. However, the relationship between these accident costs and the resulting benefit-cost ratio will also be further examined in a sensitivity analysis.

   Based on an analysis of accident experience on comparable facilities discussed previously in this report, it is estimated that the installation of a movable median barrier on the Golden Gate Bridge would change annual accident frequency as indicated in Table 28. Further, utilizing accident costs determined by the California Department of Transportation, the annual benefit due to reduced frequency and severity of accidents is also shown in Table 28.

   For this analysis, it is assumed that the volume of traffic using the Golden Gate Bridge will remain constant over the 10-year analysis period, and hence, the current annual accident frequency and severity will remain unchanged if no movable median barrier system is installed. It is further assumed that the value of accidents avoided will increase over the 10-year analysis period at an inflation rate of 2% per year. The total estimated accident reduction benefit is calculated as $699,000 to $831,000 at the midpoint of the 10-year analysis period.

TABLE 28. Annual Accident Reduction Benefits Based on California Department of Transportation Values

Accident Severity	Estimated Change in Accident Frequency	Current Annual Accidents	Annual Accidents Reduced	Accident Value* (Ref. 2)	Annual Accident Cost Benefit
Fatal	-100%	0.6	0.6	$994.700	$597,000
Injury	-20 to 40%	20.4	4.1 to 8.2	$24,800	$102,000 to $203,000
Property Damage	-0 to 30%	25.0	0 to 7.5	$4.100	$0 to $31.000

* Accident values adjusted for 2% annual inflation rate

2. Reduced Delay and Fuel Consumption. This includes the value of time to roadway users who may incur less delay due to fewer accidents and reduced fuel consumption because of the avoidance of resulting congestion. Although it is likely that some delay and fuel consumption reductions will occur in some circumstances, it is not possible to reliably estimate the magnitude of these benefits with available information. Therefore, although it is recognized that these benefits may exist, they will not be included explicitly in this analysis.

Based on the foregoing analyses of costs and benefits associated with the potential installation of a movable median barrier system on the Golden Gate Bridge, a benefit-cost ratio of 0.45 to 0.95 is calculated. A benefit-cost ratio of less than 1.0 generally indicates that a proposed project does not represent an appropriate investment of limited funds. Therefore, based only and the benefits of accident reduction, it appears that an investment in the installation of a movable median barrier system on the Golden Gate Bridge is not economically justified. Another way of looking at these figures is to conclude that an expenditure of $1,647,000 to $2,567,000 is required to avoid 1 fatal accident on the Bridge. Whether such an expenditure is appropriate is a decision that must be made by the Golden Gate Bridge, Highway and Transportation District.

Sensitivity Analysis

As previously discussed, the outcome of the benefit-cost analysis is influenced, to some extent, by the values used for accident costs. The accident costs utilized by the California Department of Transportation are somewhat lower than those suggested by the American Association of State Highway and Transportation Officials and by the U.S. Department of Transportation. Table 29 indicates the accident reduction benefits that result from the use of accident costs utilized by these other organizations. As in the previous analyses, it is assumed that accident costs will continue to increase at an inflation rate of 2% per year, and values representing the midpoint of the 10-year analysis period are used.

TABLE 29. Annual Accident Reduction Benefits Based on American Association of State Highway Officials and U.S. Department of Transportation Values

Accident Severity	Annual Accidents Reduced	AASHTO Accident Value*	AASHTO Annual Accident Benefit	U.S. DOT Accident Value*	Annual Accident Cost Benefit
Fatal	0.6	$1,104,000	$662,000	$2,870,000	$1,722,000
Injury	4.1 to 8.2	$37,900	$155,000 to $311,000	$55,000	$225,000 to $451,000
Property Damage	0 to 7.5	$3,500	$0 to $26,000	$2,200	$0 to $16,000

* Accident values adjusted for 2% annual inflation rate

Based on the value of accidents avoided utilized by the American Association of State Highway Officials, a benefit-cost ratio of 0.53 to 1.01 is calculated. If annual operating and maintenance costs are near the low limit of the range estimated by Barrier Systems, Inc. and the accident reduction is near the high limit of the range estimated based on accident experience on comparable bridges, an investment in the installation of a movable median barrier system on the Golden Gate Bridge is marginally economically justified based only and the benefits of accident reduction.

However, based on the value of accidents avoided utilized by the U.S. Department of Transportation, a benefit cost ratio of 1.26 to 2.22 is calculated. Even if annual operating and maintenance costs are near the upper limit of the range estimated by Barrier Systems, Inc. and the accident reduction is near the low limit of the range estimated based on accident experience on comparable bridges, an investment in the installation of a movable median barrier system on the Golden Gate Bridge is definitely economically justified based only on the benefits of accident reduction.

Clearly, the outcome of a benefit-cost analysis of the potential installation of a movable median barrier system on the Golden Gate Bridge is highly sensitive to the value of accidents avoided and to the annual operating and maintenance costs for the system. As a result, the benefit-cost analysis does not provide a clear-cut answer concerning economics of investments in such a movable median barrier system. Rather, the benefit-cost analysis should be considered one factor, among many, that must be evaluated by the Golden Gate Bridge, Highway and Transportation District in deciding on a course of action.

14. CONCLUSIONS

The following is a summary of conclusions regarding the anticipated impacts of a movable median barrier system on safety and traffic operations on the Golden Gate Bridge and its approaches:

1. The current accident rate on the Golden Gate Bridge is 0.64 accidents per million vehicle-miles of travel which is significantly less than would normally be expected for this type of roadway facility. This current accident rate is also approximately one-half of the accident rate on the Bridge prior to the improvement project which widened the roadway width to 62 feet. Accident rates on weekends are significantly higher than the overall accident rate. The presence of stopped or slow vehicles is a significant contributing factor in accident occurrence. Forty-five percent of the accidents on the Bridge involve injuries or fatalities. In a five-year period, 24 accidents occurred in which one or more vehicles crossed the dividing line into oncoming traffic (10 percent of all accidents). These cross-over accidents had a higher average severity, with 69 percent involving injuries or fatalities.

2. Accident experience on several comparable facilities suggest that there remains a significant concern that overall accidents as well as injury accidents could increase on the Golden Gate Bridge if a movable median barrier system were installed. However, the most directly applicable accident experience (Auckland Harbour Bridge and San Diego-Coronado Bridge) suggest that overall accidents as well as injury and fatal accidents would be reduced if a movable median barrier system were installed. The observed total accident frequency reductions after installation of movable median barrier systems on these bridges actually exceeded the number of crossover accidents that were eliminated by the barrier systems. No increases in non-crossover injury and fatal accident frequency were observed on either bridge. in fact a decrease in non-crossover injury and fatal accidents occurred on the Auckland Harbour Bridge. It is not intuitively obvious why such decreases in non-crossover accidents would occur after installation of a movable median barrier system. Nevertheless, the current data from the Auckland Harbour Bridge and the San Diego-Coronado Bridge indicate the likelihood of secondary safety benefits from the movable median barrier system in reducing non-crossover accidents. It must be recognized that this contradictory data increases the uncertainty in estimating the safety implications of installing a movable median barrier system on the Golden Gate Bridge. Nevertheless, it appears that the most likely outcome of installation of a movable median barrier on the Golden Gate Bridge would be a small reduction in property damage accidents (0 to 30%), an elimination of most fatal accidents, and a 20% to 40% reduction in injury accidents.

3. The Narrow Quickchange Movable Barrier system appears to satisfy all of the desired performance criteria for application on the Golden Gate Bridge except for maximum lateral deflection which is somewhat more than the desired criterion of 30 inches. Because relatively few barrier impacts would be expected to exceed this 30-inch criterion in actual practice, the Narrow Quickchange Movable Barrier system may be considered marginally acceptable in this regard. If a movable median barrier system were to be installed on the Golden Gate Bridge, the Narrow Quickchange Movable Barrier system would be preferred over the standard Quickchange Movable Barrier system. No other movable barrier systems are known to meet desired criteria. However, if any other systems become available which satisfy appropriate performance criteria, they also should be considered for potential application.

4. The south end of a movable median barrier system should be terminated in the toll plaza area, north of the toll booths, anchored. and treated with an acceptable crash cushion. The north end of a movable median barrier system should be extended beyond the end of the existing freeway median barrier and terminated within the northbound freeway roadway.

5. Through the horizontal curves on the San Francisco and Marin approaches, a movable median barrier system would restrict the ability of drivers in the adjacent lanes to see obstacles in their path. This sight restriction would limit the design speed on these curves to 30 to 35 mph based on current highway design criteria. As

a practical matter, it is unlikely that drivers would reduce their speeds to 30 to 35 mph on these curves in response to warning or regulatory speed signs.

6. For lanes adjacent to a movable median barrier system that are maintained as 10 or more feet in width, no significant changes in lateral positions of vehicles within the lanes are likely, and no decreases in traffic-carrying capacity of the roadway are likely. The installation of a movable median barrier system would result in the loss of one or more feet of overall roadway width. If implemented, the barrier can and should be positioned such that the minimum width of any pair of lanes is at least 20 feet. Desirably, it should be positioned such that the existing 11-foot curb lane widths are also retained. None of the barrier positioning alternatives examined in this study were entirely satisfactory; all required the use of one or more lanes which were less than desirable widths.

7. A movable median barrier system would result in reduced speed, efficiency, and flexibility in responding to and removing traffic accidents or stalled vehicles on the Bridge. This would result in longer periods of congestion and increased chances for accidents related to slow or stopped traffic.

8. The outcome of a benefit-cost analysis of the potential installation of a movable median barrier system on the Golden Gate Bridge is highly sensitive to the value of accidents avoided and to the annual operating and maintenance costs for the system. As a result, the benefit-cost analysis does not provide a clear-cut answer concerning economics of investments in such a movable median barrier system. Rather, the benefit-cost analysis should be considered one factor, among many, that must be evaluated by the Golden Gate Bridge, Highway and Transportation District in deciding on a course of action.

A number of important changes have occurred since the Traffic Safety Study for a Proposed Movable Barrier on the Golden Gate Bridge (Ref. 1) was prepared by the Northwestern University Traffic Institute in 1985. These include:

1. More than 10 years of accident experience on the Bridge has been accumulated since the Bridge roadway was widened to 62 feet. Overall accident rates on the Bridge have decreased significantly from those reported in the previous study, but average accident severity has increased.

2. Movable barrier systems have been installed on a number of permanent and temporary applications throughout the world, and useful accident data from some of these installations is available.

3. New technology and refinements in previous designs have eliminated several characteristics of candidate movable barrier systems and end treatments that were considered objectionable in the previous study.

We continue to have reservations about several negative impacts of a movable median barrier system on the Golden Gate Bridge. Among these concerns are the affect of a barrier system on driver sight distance, the potential for secondary impacts due to barrier deflection and vehicle rebound, the loss of potential refuge for disabled vehicles in the buffer lanes and consequent potential for rear-end collisions, and reduced speed and efficiency of emergency vehicle response. The benefit-cost analysis performed does not yield a clear-cut indication of the economic desirability of such a movable median barrier system. Nevertheless, the movable median barrier systems in use in several permanent installations around the world have generally been successful in virtually eliminating head-on collisions and have not generally increased other accidents. Although the Golden Gate Bridge continues to enjoy an enviable traffic safety record, increasing severity of accidents in recent years is a concern. If the Golden Gate Bridge, Highway and Transportation District elects to install such a movable median barrier system, the Narrow Quickchange Barrier system appears to best satisfy desired performance criteria for application on the Golden Gate Bridge.

Issues Requiring Further Study

Several important issues remain to be resolved, if the Golden Gate Bridge, Highway and Transportation District elects to move forward with the installation of a movable median barrier system on the Golden Gate Bridge. These include:

1. Lateral positioning of the barrier system. Several alternative barrier positioning schemes were evaluated in this study. None were fully satisfactory in terms of desired lane widths. These alternatives should be reviewed by the District, based on the relative importance of the various lane width criteria to determine that scheme which best meets the needs of the District. The desirability and feasibility of replacing raised pavement markers along the lane lines with flush or recessed markings should also be considered in the context of alternative barrier positions.

2. Anchorage for the San Francisco end of the barrier system. As discussed in this report, satisfactory functioning of the barrier system and crash cushion at the San Francisco end requires the development of an anchorage system. Although such an anchorage appears to be technically feasible, it must be designed and tested before a movable median barrier system can be installed.

3. Guidance system for the barrier transfer vehicle. Because of the relatively narrow lanes and the possible need to locate a barrier system with its base adjacent to or straddling the raised pavement markers on the Bridge, precise placement of the barrier system is important. A guidance system which assures consistent, accurate placement of the barrier system as it is moved from one position to another must be designed and tested.

4. Procedures for emergency vehicle response. In conjunction with emergency vehicle operating agencies, strategies must be developed for responding quickly and effectively to accidents on the Bridge, depending on lane configurations. Of particular concern is the development strategies for accessing the accident site, removing stalled or damage vehicles, and relocating the barrier system if it has been displaced by the accident. Specialized equipment such as double-ended tow trucks may need to be acquired.

Potential Implementation Strategy

The ultimate decision of whether or not to move forward with the installation of a movable median barrier system must be made by the Golden Gate Bridge, Highway and Transportation District. If the District determines that the installation of a movable median barrier system is desirable, it should consider the feasibility and desirability of initially leasing such a system for a period of two to three years. As previously discussed, there are a number of technical issues relative to such a movable median barrier system that have not been satisfactorily resolved. A trial installation would permit an evaluation of such a system on the Golden Gate Bridge, and may lead to a better understanding of such issues before a final commitment to purchasing the system is made. During the trial installation period, accident frequency and severity should be closely monitored. Frequency and magnitude of barrier impacts and displacements should also be carefully recorded. Finally, alternative emergency vehicle response strategies can be tested and evaluated.

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