INDEPENDENT VERSUS NARROW-MEDIAN ALIGNMENT: COMPARATIVE ECONOMY, SAFETY, AND AESTHETICS

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Independent alignments and other wide-median designs are generally superior to narrow-median designs from the standpoint of safety and aesthetics. For a wide range of design and cost conditions often associated with rural and surburban highway locations, the liberal-median designs are economically competitive with narrow-median designs and deserve increased consideration by the highway design team. Annual costs of selected independent alignment and narrow-median designs are presented for a range of cost and terrain factors. Safety performance requirements are incorporated in a comparison chart that permits rapid, preliminary economic evaluation of typical alternative median designs.

•TOO OFTEN minimum geometric design standards and design guides appear to have been adopted as basic working standards from which departures toward more liberal treatments are assumed to require excessive additional costs. The significance of relations among design features, highway aesthetics, and motoring safety is not always fully appreciated. Common examples are the use of steep side slopes with roadside guardrail instead of unprotected flat slopes (1), short vertical and horizontal curvature instead of longer and more flowing curvature, and narrow medians with or without median barriers instead of wide, variable median width of independent alignment. It is increasingly recognized, however, that the development of more attractive and safer highways requires more than minimum design treatments and that aesthetic and safety factors must be given weightings comparable to economy in the design decision process.

The following sections contain a review of the relative advantages of independent and narrow-median alignment designs and of the criteria necessary for comprehensive evaluation of these alternative designs with regard to economy, safety, aesthetics, and environmental impact. Annual costs of selected independent and narrow-median designs are presented for a range of cost and terrain factors. Economic comparisons are facilitated by charts showing "economic break-even widths" for designs with wide medians—the additional median width that can be added to the minimum design treatment for independent alignment without exceeding the annual cost of an alternative narrow-median design.

COMPARATIVE ADVANTAGES AND DESIGN CRITERIA

The independent alignment consists of roadways for which horizontal and vertical alignments are developed individually to suit location and design requirements; the narrow-median alignment employs the same horizontal alignment and profile for both roadways (although in some cases the latter treatment has been used with rather wide medians in flat terrain locations). On hillside locations the independent alignment places each roadway at a different elevation, and the narrow-median alignment places each roadway at or near the same elevation at a constant distance apart (Fig. 1).

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Economics

The most economical design is the one that has the lowest total annual cost (not necessarily the lowest initial cost); therefore, annual maintenance and road-user costs should be included in the economic analysis. In addition to the major initial costs of earthwork and right-of-way, costs of items such as topsoil, seeding, median and roadside barrier installation, mowing, and maintenance of slopes, culverts, and ditches should also be included in the analysis.

Independent alignment will usually require less earthwork but more right-of-way than the narrow-median design. With its wide, varying median width and narrower grading prisms, independent alignment often permits the designer to avoid areas of difficult topographic, soil, or drainage conditions. The shallower cuts of the independently aligned roadways can mean less likelihood of slope failures and erosion, groundwater problems, and bedrock excavation. The construction of 2 independent roadways widely separated may, however, require more nonproductive equipment movements than would occur in the construction of a narrow-median alignment.

The relative advantages of the 2 types of alignment designs with respect to structure and drainage facility costs will depend on the specific terrain and drainage conditions. Narrowing a wide median where bridge and grade separation costs would otherwise be excessive is not inconsistent with the variable-median-width concept of independent alignment. Independent alignments may increase the number and total length of culverts required, although the wide, varying median may permit taking better advantage of easier stream-crossing sites.

The narrow-median design may require a median barrier to provide adequate safeguard against cross-median collisions, and the independent alignment may similarly require a median guardrail on the upper roadway. The wide median provides an ample reserve for the addition of more traffic lanes should estimates of future traffic be low; the cost of such expansion is negligible compared to the construction of a new, wider highway. When highways with narrow-to-intermediate medians are provided with additional lanes in the median, an additional expenditure must usually be made for a median barrier.

The independent alignment will often yield a number of road-user cost savings not yielded by the narrow-median design. The maintenance and repair of median barriers on highways with narrow medians often require closing median lanes, and the resulting increased user cost is properly assignable to the narrow-median design. According to AASHO, there is another potential benefit to road users from independent alignment (2): "By varying the separation between the two roadways, it is often possible to improve the profile over crests by using a flatter grade on the ascent than on the descent for each direction of travel." Increased traffic capacity is also obtained by this treatment. With independent or wide-median designs, a roadway can be opened to traffic sooner and thus provide earlier service for traffic demands and the attendant user cost savings. If a second roadway is to be provided adjacent to an existing highway to form a divided highway, a wide-median design will result in less interference to traffic during construction and provide both cost and safety benefits. For divided highways with at-grade intersections, the wide median can sometimes obviate the need for traffic signals at low-volume crossroads by enabling 2-step crossing maneuvers. U-turns are also accommodated with less disruption to through traffic.

Accident costs should desirably be included in the economic analysis of alternative designs, although they can be incorporated indirectly in the evaluation procedure as noted below. Aesthetic and environmental costs—less tangible but no less real than the traditional highway economic costs—should also be included in the design decision-making process.

Safety and Driver Comfort

Wide medians improve personal comfort and general motoring safety by reducing the annoyances of headlight glare, buffeting, and noise from traffic on the opposing roadway. But most important, they lessen the chances for cross-median collisions where median barriers are absent.

Figure 1. Basic cross-sectional designs.

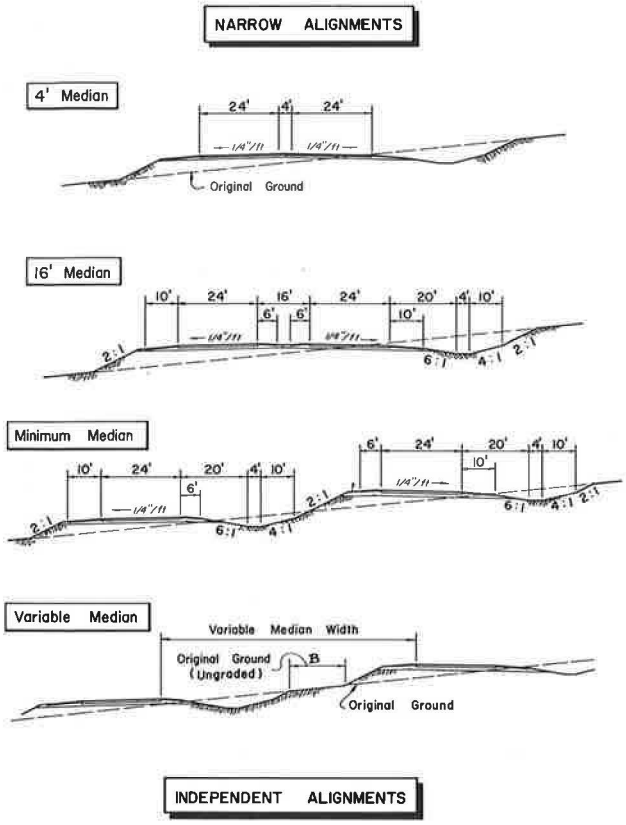


Figure 2. Median barrier requirements.

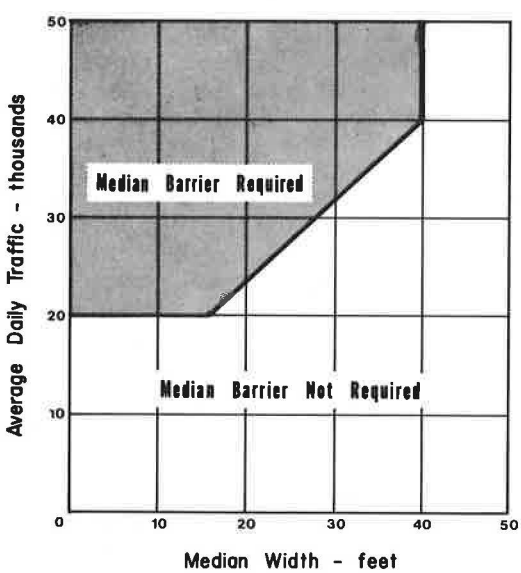
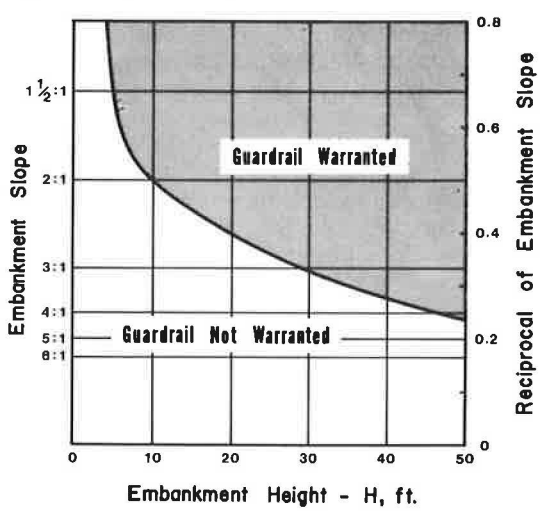


Figure 3. Equal severity curve.



As median width is increased the probability of an out-of-control vehicle crossing the entire median is reduced; and as the traffic volume carried by the highway decreases, the probability of the cross-median vehicle being in conflict with an oncoming vehicle declines. Collision with a median barrier presents a hazard, the severity of which depends on the type of barrier and the trajectory and speed of the vehicle. The installation of a median barrier also cuts the recovery zone in half. General Motors Proving Ground data revealed that with flat embankment slopes (10:1 or flatter) 83 percent of the vehicles that ran off the road were able to recover within 30 ft of the edge of pavement; 87 percent, within 40 ft; and 93 percent, within 50 ft (3). These concepts and findings are incorporated in the median barrier requirements (Fig. 2) developed by the California Division of Highways (4).

Where median cross slopes are steeper than 10:1, the probability of an out-of-control vehicle reaching the opposing roadway increases, and a guardrail may be needed on the median of the upper independent roadway to prevent cross-median accidents. Unfortunately there are no published data that relate vehicle recovery distance to vehicle speed, exit angle, and median cross slope.

Even where the median width of the independent alignment is great enough to minimize cross-median accident potential, it may still be necessary to place guardrail on the median of the upper roadway. Figure 3 shows the "equal severity index" curve developed by the California Division of Highways (5). The curve relates the severity of collision with guardrail to the severity of damage that would probably occur if the vehicles were allowed access to the embankment or median slope of a given height and steepness. The concept assumes that roadside guardrail is not otherwise required because of hazards, such as a dense stand of trees, drainage structures, or a body of water, on or at the foot of the median slope.

Aesthetics and Environment

The independent alignment permits the highway design team to locate and design the highway in a manner that produces a minimum of visual and environmental disruption. It offers ample opportunities for exploiting scenic-view potentials and providing other positive motoring experiences within the route corridor (6, 7, 8). Independent alignment provides greater opportunities for attractive landscaping and retaining native vegetation and imparts a parkway appearance even to the heavily trafficked, general purpose highway. In some cases its use can reduce or even eliminate disruption to historic, archaeologic, and other important sites and facilities.

One of the major factors contributing to the scenic character of widely separated roadways is that the man-made portion of the motorist's visual field—the roadway and side slopes—is reduced, permitting the motorist to see more of the roadside and providing a greater feeling of closeness to the adjacent landscape (6). This is one of the factors that explains the great delight of "shun-piking" along the quiet byway.

In heavily wooded locations the wide, varying median coupled with variations in the distance to the tree line and selected clearings between roadways provides scenic qualities for the motorist. On hillside locations, the independent alignment can provide motorists on the inside roadway a better view because of the elevation above the outside roadway. (If the area is heavily wooded, the independent alignment with stretches of cleared median may be the only suitable way of providing any distant views at all.)

In flat, sparsely wooded terrain, "natural" variations in median width may provide the dominant visual interest for the motorist. The nearly constant width of narrow-to-intermediate medians found too often on Interstate highways in such terrain, however, provides a dull and monotonous motoring experience, the impact of which is heightened when a median barrier is present for long distances. This has implications for traffic safety as well as for aesthetics (a relation present in many of the elements of highway design aesthetics) because driving monotony can contribute to traffic accidents.

On hillside locations the smaller cuts and fills produced by independent alignment and the attendant increased feasibility of flatter side slopes both contribute to the reduction of the visual impact of the terrain "scar." Unsightly erosion, with its adverse effects on surface water quality, is also reduced.

The man-made character of median barriers often used with narrow and intermediate medians is an aesthetic disruption. When they are kinked, damaged, or rusted, their unattractiveness is intensified. Vegetation is often ragged beneath rail barriers, accentuating the unattractiveness of the installation. (These characteristics apply equally to roadside guardrail.) More important, the median barrier creates a discontinuity in the smooth flow of the highway cross section, chopping up the roadway space and interfering with the attainment of a smooth merge of highway and surrounding landscape. It gives the motorist a feeling of confinement or lateral friction, especially when guardrail is present along the outside shoulder.

The wide median, particularly if wooded, probably reduces the frequency of vehicle-struck wildlife (especially deer) by providing an ample "recovery area" for crossing animals. Where development is likely to occur along a new rural or suburban highway, the use of a wide median will reduce the intensity of noise adjacent to the roadways because traffic density is reduced. The wide median also permits the planting of trees and shrubs that tend to reduce perceived noise levels.

CROSS-SECTIONAL MODELS

Several 4-lane cross sections were selected as reflecting a typical range of alternative designs. Figure 1 shows examples of typical narrow-median and independent-alignment designs studied. Cut-and-fill slopes are shown as 2:1, but designs with 4:1 slopes were also treated. Median width is the distance between inside pavement edges. The narrow-median design is shown for the 4-ft and 16-ft width cases. For the general case of independent alignment, the roadway earthwork prisms are separated by natural ground of varying width B. For the minimum median width of independent alignment, the 2 earthwork prisms abut (B = 0). Shoulders are 10 ft on the outside and 6 ft on the inside (median side), except that median shoulders are omitted in the case of the 4-ft narrow-median design. Where roadside guardrail is required, the width of the shoulder is increased by 4 ft to provide barrier post support and an effective shoulder width equivalent, after rounding, to that provided by side slopes 4:1 or flatter without barriers (2, 9).

On hillside locations the roadways of the independent alignment were placed so that earthwork was in balance for each individual roadway. For the narrow-median case, the earthwork balance was based on the entire roadway cross section (traveled ways plus shoulders plus median). Cut volumes, less 10 percent allowance for shrinkage, were balanced against fill volumes, and overhaul charges were neglected. This method appears to be quite reasonable when cut-and-fill slopes are equal and when the unit cost of excavation is approximately equal to the unit cost of borrow.

In this study it was assumed that the unit cost of excavation included the cost of placing excavated material as fill. Where substantial amounts of rock are present, it might be cheaper to minimize excavation and to import large volumes of borrow, placing most of the roadway on embankment.

Figure 4 shows the minimum median widths attained by independent alignments on hillside locations for the given cross sections and their placement on hillsides according to the method of earthwork balancing described above. Minimum median widths are quite substantial even for the case of 2:1 roadside slopes, exceeding 50 ft for original ground cross slopes of about 5 percent or greater.

EARTHWORK AND RIGHT-OF-WAY QUANTITIES

Differences in earthwork and right-of-way quantities largely determine the relative economy of independent-alignment and narrow-median designs without median barrier. Figure 5 shows a plot of excavation volumes for a 1-ft slice of a 16-ft narrow-median design and the independent-alignment design as a function of original ground cross slope (hereafter referred to as "ground slope"). Selected minimum median widths produced by the independent alignments (Fig. 4) have been indicated on their curves. The difference in excavation volumes between the narrow and independent alignments increases with increasing ground slope and is greater for designs with the flatter 4:1 side slopes. For both 2:1 and 4:1 slopes, the narrow-median excavation exceeds that of the indepen-

dent alignment by 25 to 30 percent for ground slopes of 10 percent or greater. An analysis of the effect of median width on excavation differences showed that 4-ft and 40-ft narrow-median designs required respectively about 3 percent and 90 percent more excavation than independent alignment for a ground slope of 10 percent. Figure 5 also shows that at flatter ground slopes (less than 10 percent) there is very little difference in excavation quantities between a design with a 2:1 side slope and one with the more aesthetic and maintenance-free 4:1 side slope.

Figure 6 shows right-of-way requirements for the 16-ft narrow-median and independent-alignment designs for 2:1 and 4:1 side slopes. The border component of the right-of-way (adjacent to the outer cut-and-fill slopes) has been omitted but would be the same for both narrow-median and independent-alignment designs. The right-of-way of the independent alignment exceeds that of the narrow median for all conditions, with the percentage difference in right-of-way increasing to about 25 percent at steeper ground slopes.

ECONOMIC ANALYSES: DESIGNS WITHOUT BARRIER RAILS

Annual Costs

Comparisons were made of the total annual cost of alternative narrow-median and independent-alignment designs based on typical construction costs and maintenance costs, the latter generally representative of conditions and practices in northern, humid areas (1). A 20-year economic life for initial cost items and a 6 percent interest rate were used in all analyses.

Figure 7 shows total annual costs of several alternative median designs as a function of ground slope. An excavation cost of $1/yd^3 and a right-of-way cost of $1,000/acre were used. Other construction and maintenance costs are shown in the figure. Median barriers and roadside guardrails were not included with these designs. For these unit costs, independent alignment is economically competitive with the 16-ft narrow-median design and is quite superior from an economic standpoint to the 40-ft narrow-median design. For example, at a ground slope of about 12 percent, the annual costs of the 16-ft narrow-median and independent-alignment designs are equal (4:1 side slope case), yet the latter provides a median 100 ft wide. At the same ground slope, independent alignment costs about 30 percent less than the 40-ft median but provides a median 2½ times greater than the latter.

Table 1 gives the effect of excavation cost on the relative economy of independent alignment and 16-ft narrow-median design for the 4:1 side slope case. Other costs are the same as those given in Figure 7. As expected, both increased unit cost of excavation and steeper ground slopes tend to favor independent alignment.

Break-Even Analysis

For the examples shown in Figure 7, independent alignment is more expensive than several alternative narrow-median designs at flat ground slopes but is cheaper at steep ground slopes. The ground slope at which the annual costs of alternative independent and narrow-median designs are equal can be referred to as the "break-even" ground slope. At ground slopes steeper than the break-even ground slope, the savings afforded by the use of independent alignment could be used to acquire additional right-of-way for the purpose of widening the median of the independent-alignment design. If the full amount of the savings is so used (bringing the annual cost of the independent alignment up to that of the narrow-median alternative), the total additional median width provided can be called the economic break-even median width. Total median width thus provided by the independent-alignment alternative would consist of the graded (minimum) median width (Fig. 4) plus the ungraded break-even median width. Break-even median widths will, of course, depend on unit costs and the geometry of the alternative designs of the cross section.

If various unit costs of right-of-way are applied to annual cost differences as developed previously, a break-even chart such as Figure 8 can be developed in which break-even median width is related to ground slope and unit right-of-way cost. (A family of such charts could be prepared for other cost variables, such as excavation cost.) As

Figure 4. Minimum median widths for balanced-earthwork independent alignments.

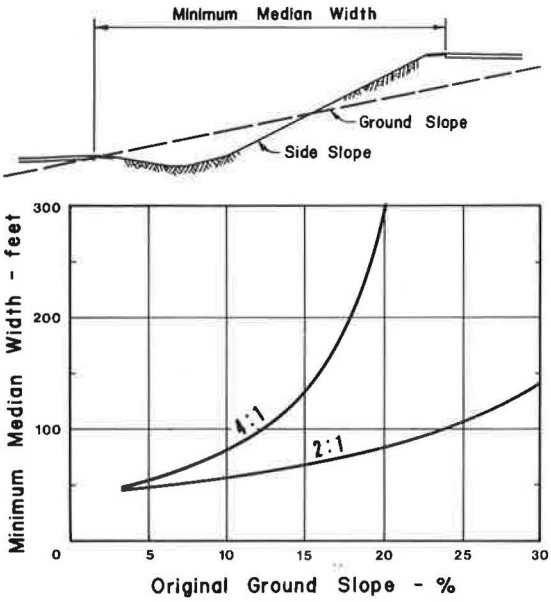


Figure 5. Excavation volumes for selected median designs.

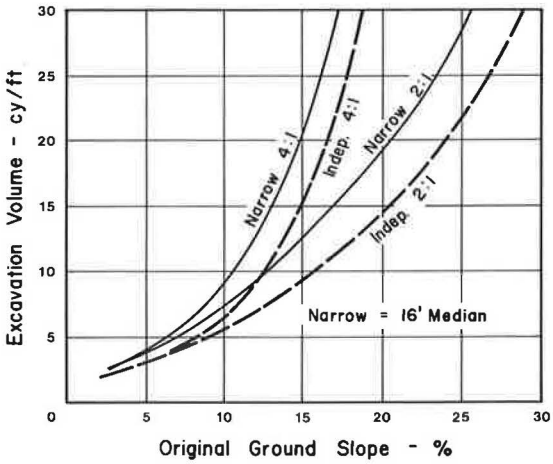


Figure 6. Minimum right-of-way required for selected median designs.

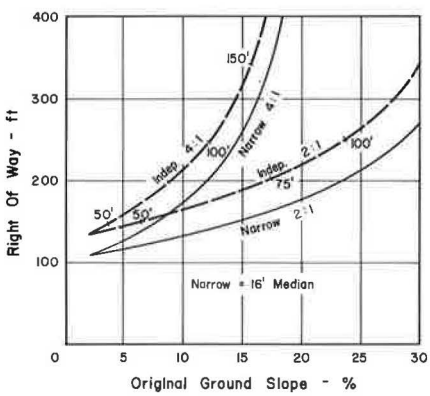


Figure 7. Annual costs of selected median designs.

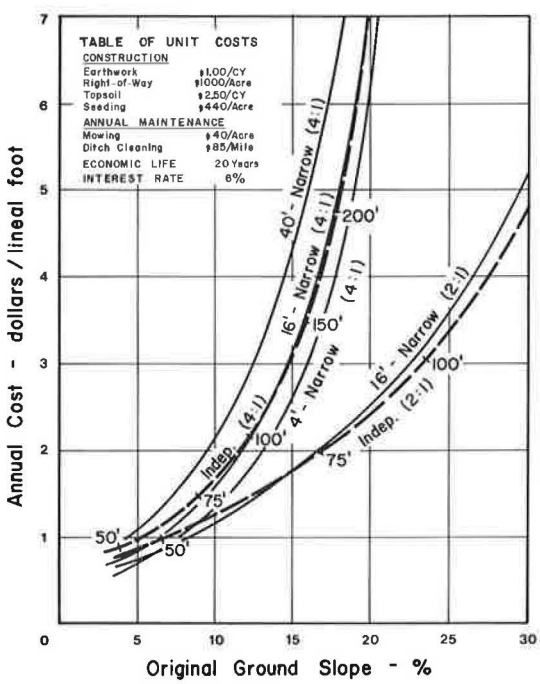


Table 1. Annual costs of independent alignment and 16-ft narrow-median designs at various unit excavation costs (4:1 side slopes).

Ground Slope (percent)	Annual Cost ($) at $1/Yd³			Annual Cost ($) at $2/Yd³		
	Independent	Narrow Median	Difference	Independent	Narrow Median	Difference
5	0.96	0.83	0.13	1.21	1.15	0.06
10	1.67	1.59	0.08	2.28	2.40	-0.12
15	3.10	3.14	-0.04	4.43	4.91	-0.48
20	7.39	7.77	-0.38	10.90	12.45	-1.55

an example, for a rural land value of $500/acre and a 15 percent ground slope, the independent alignment with 4:1 side slopes could include a break-even median width of 100 ft when the alternative is a 16-ft narrow-median design (point A, Fig. 8). The total median width provided by the independent-alignment design would then be 236 ft—the graded or minimum median width of 136 ft (Fig. 4) plus the 100-ft break-even median width.

Where the annual cost of the independent alignment exceeds the annual cost of a narrow-median alternative, the savings provided by the latter could be spent in widening its median. This situation is shown in Figure 8 by the shaded lower portion. Because widening a narrow-median alignment entails additional excavation as well as right-of-way ("narrow" sketch, Fig. 8), a much smaller break-even median width results for a given annual cost difference, as shown by the scale change below the 0 ordinate in Figure 8. For a ground slope of 15 percent and a right-of-way cost of $2,000/acre, a break-even median width of 7 ft (point B) could be added to the narrow-median design for a total median width of 23 ft (7 ft plus 16-ft basic median width).

The costs of topsoil, seeding, and mowing shown in Figure 7 were used in determining break-even median widths for the narrow-median designs but were neglected for the independent alignments. Because the independent-alignment break-even median width can usually be left undisturbed by construction requirements and operations, no topsoil or seeding would be required; existing vegetation would probably be preserved, and mowing operations would be confined to the immediate roadside. On the other hand, the entire width of the narrow-median design is disturbed by construction, making topsoil and seeding operations imperative. Relatively narrow medians usually require mowing for appearance and for control of saplings that might become hazardous.

The foregoing analysis does not fully meet the requirements of a valid economic comparison because narrow-median designs lacking a median barrier normally provide less traffic safety than independent alignment; the disparity increases as traffic volume increases. Furthermore, should increased traffic and cross-median accident experience necessitate the installation of a median barrier on the narrow-median design, whatever economic advantage it might have had initially could be entirely lost. The following section investigates the effect on comparative economy when median and roadside barriers are required to place the alternative median design treatments on a more equivalent safety basis and to better reflect the traffic service requirements of major highways.

DESIGNS WITH BARRIER RAILS

Safety Requirements

The median-barrier requirements guide shown in Figure 2 recommends that no median barrier be installed on relatively flat medians exceeding 40 ft in width, regardless of traffic volume carried, except after adverse accident experience. A 40-ft median that includes a moderate-to-steep cross slope would probably not provide enough space for recovery of a run-off-the-roadway vehicle from the upper roadway because of the acceleration provided by the falling median slope. However, vehicles from the lower roadway would have to overcome a significant grade in order to reach the upper roadway. For those conditions, a single guardrail along the inside shoulder of the upper roadway would suffice to prevent cross-the-median collisions.

The problem remains that there is no firm empirical basis available for accurate determination of those combinations of traversable median width and steeper median slope that provide adequate recovery space for vehicles leaving the upper roadway at high speeds. The General Motors Proving Ground data cited earlier and the California median-barrier requirements chart provide only a partial basis for approaching this problem. Nevertheless, for purposes of simplicity it has been assumed for median slopes in the range of 2:1 to 4:1 that 100 ft of relative obstacle-free median width will provide ample recovery space in nearly all cases. (The GM data showed that 93 percent of the run-off-the-roadway vehicles recovered on flat side slopes within 50 ft of the edge of pavement, or half this distance.) Some degree of safety factor is present in this assumption because the 14 ft of rising foreslope of the lower roadway plus its ad-

Figure 8. Break-even median width as a function of right-of-way cost for independent alignment versus 16-ft narrow-median design (4:1 side slopes).

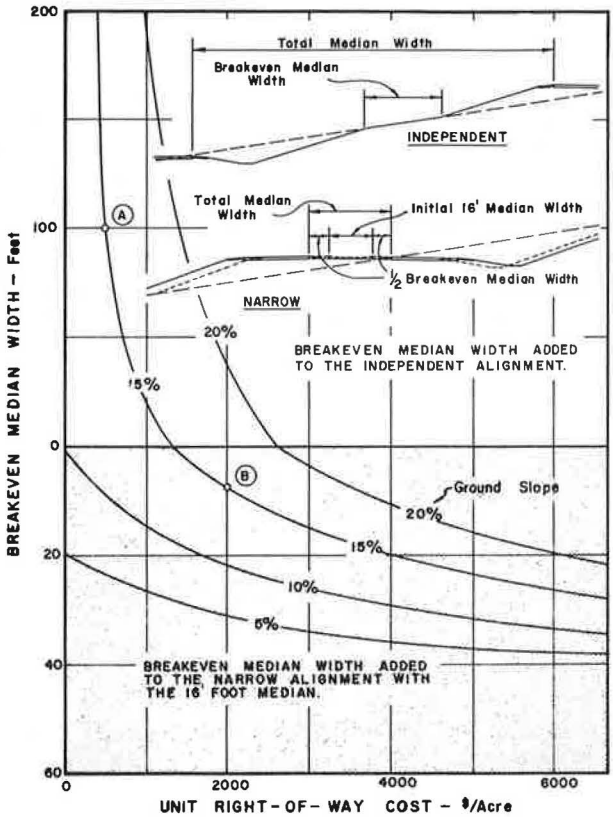
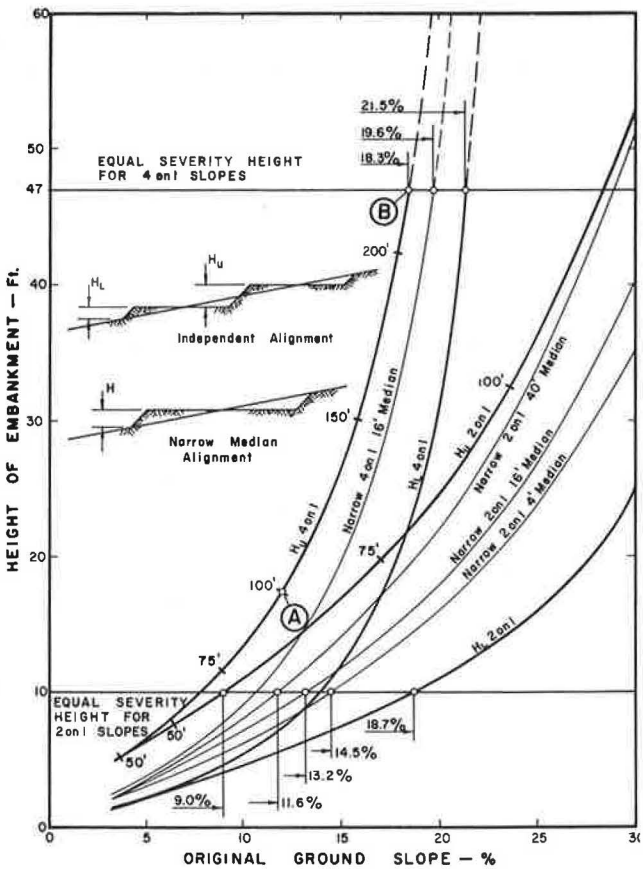


Figure 9. Roadway embankment heights.



jacent ditch bottom (Fig. 1) would tend to decelerate the vehicle somewhat. It is fully recognized, however, that a more realistic approach would show this "minimum safety median width" to be a function of ground slope across the median.

Beyond the 100-ft width, it is assumed that the space between the upper and lower roadways no longer functions as a median and can be treated as "roadside" from the safety performance standpoint and handled according to roadside hazard warrants and the equal severity concept discussed earlier (Fig. 3). Roadside guardrail may be similarly required along the outer shoulder of the outer (downhill) roadway on both the narrow-median design and independent alignment.

The requirements for median barriers or roadside guardrails are essentially presented on a sufficiency basis only; i.e., although both a median barrier and a wide barrier-free median may perform equally well in preventing most errant vehicles from reaching the opposite roadway, their relative safety performance for the errant vehicle may be quite dissimilar. This implication is also present in direct use of the equal severity concept for unprotected roadsides. For example, how much safer is vehicle recovery on a 4:1 slope 40 ft high compared to an impact with guardrail (Fig. 3)?

Figure 9 shows embankment heights as a function of ground slope for several of the 4-lane cross-sectional designs used in this study. The equal severity heights for 2:1 and 4:1 side slopes have also been indicated. Figure 9 shows the embankment heights—and thus ground slopes—at which it becomes advisable to install roadside guardrail on both independent-alignment and narrow-median designs. Because 4:1 slopes would probably not be used where guardrail is required (embankment height of more than 47 ft), the curves for the 4:1 case have been broken in this region. Two embankment heights must be defined for the independent-alignment case: (a) the embankment height for the upper roadway, H_U, the difference in elevation between the upper and lower roadways, and (b) the embankment height for the lower roadway, H_L, the difference in elevation between the shoulder break and the embankment toe. For a given side slope and ground slope, narrow-median designs have a higher embankment height on the outer roadway than independent alignments.

Selected minimum median widths produced by independent alignment are marked on the curves for upper roadway embankment height. For the 4:1 side slope case, the assumed 100-ft safety median width occurs on independent alignment at a ground slope of about 12 percent (point A). At flatter ground slopes, the median width falls below 100 ft and guardrail may be necessary on the upper roadway because of the hazard potential of the lower roadway. However, it may prove more economical to simply provide additional median width—in the manner of economic break-even median width—so that the total median width is at least equal to the assumed 100-ft safety median width. This method is used throughout the remainder of this analysis.

Independent alignments with medians exceeding the 100-ft safety width do not require guardrail protection unless the embankment height exceeds the equal severity height for that slope steepness or unless side slope hazards are present. In the 4:1 side slope case, the 47-ft equal severity height is reached at a ground slope of 18 percent (point B). At steeper ground slopes, the upper fill slope would probably be steepened because guardrail would be present, and the 4:1 slope would be approaching the existing ground slope.

In all safety analyses, the potential for run-off-the road accidents and the likely severity of such accidents should also be taken into account when decisions are made among alternative median system designs.

Annual Cost Comparisons

If guardrail and median barrier requirements are determined on the basis of the guides and assumptions previously discussed, the total annual costs of the various median designs will be substantially increased over those shown in Figure 7 for designs without barriers, particularly for the narrow-median designs. Figure 10 shows annual costs of independent alignment and the 4-ft and 16-ft narrow-median designs with median barrier for the 4:1 side slope case. Cost curves are also plotted for the narrow-median designs without median barrier for comparison. Right-of-way cost is taken at

Figure 10. Annual costs of selected median designs, with and without median barrier (4:1 side slopes).

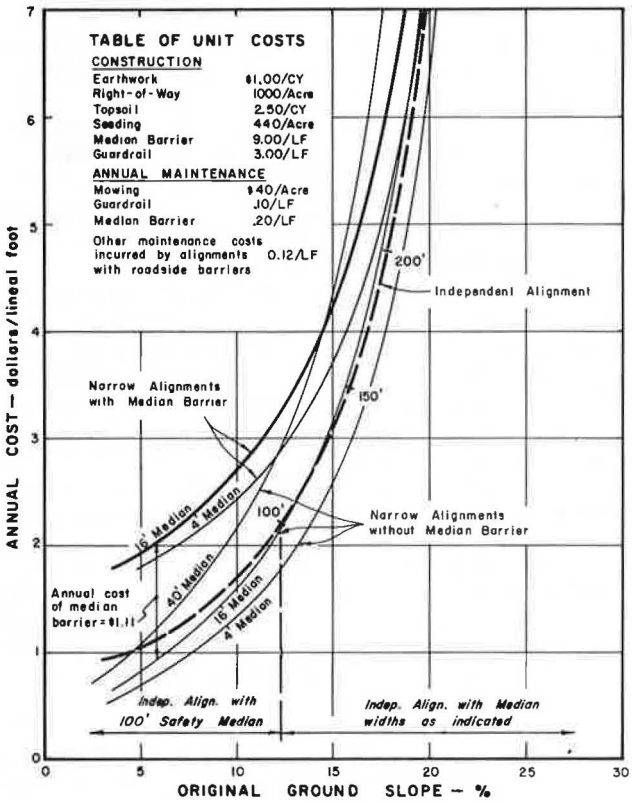


Figure 11. Annual costs of independent-alignment design and narrow-median designs with median barriers (guardrail included where warranted by equal severity curve, 2:1 side slopes).

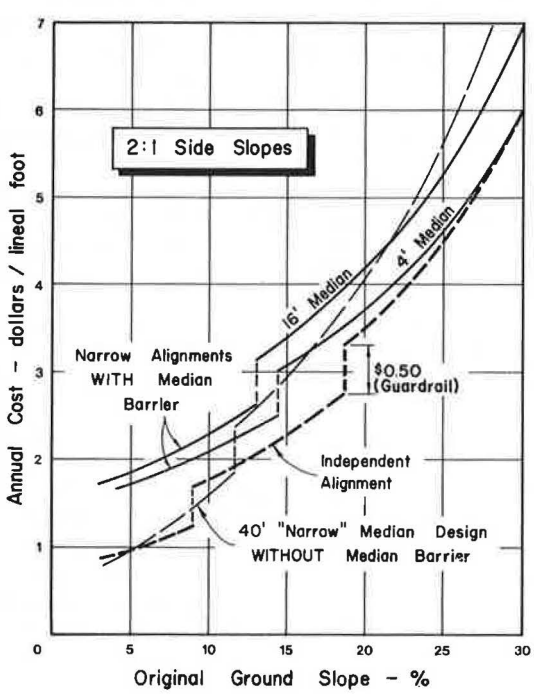
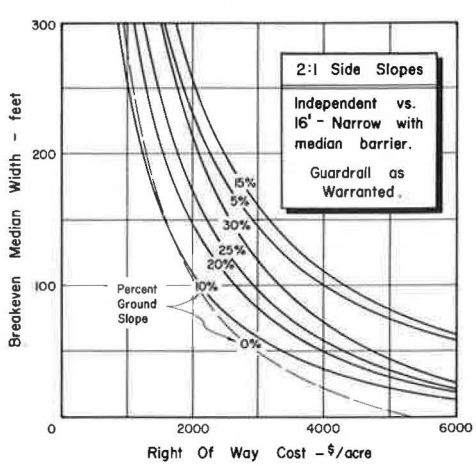


Figure 12. Break-even median width as a function of right-of-way cost for independent alignment versus 16-ft narrow-median design with median barrier (guardrail included where warranted by equal severity curve, 2:1 side slopes).



$1,000/acre, the in-place cost of median barrier at $9.00/lin ft, and the annual maintenance cost of the median barrier at $0.20/lin ft. Other costs are shown in Figure 7.

The cost of independent alignment includes the cost of a median width of 100 ft or greater in accordance with the safety median width criterion postulated above. For example, at a 5 percent ground slope, the cross section geometry of the independent alignment would produce a median width of about 56 ft. To increase this to 100 ft would require an additional expenditure of 9 cents, on an annual cost basis, and the alternative of installing and maintaining a guardrail on the upper roadway would cost about 46 cents on an annual basis. For ground slopes steeper than 12 percent, the independent alignment naturally produces a median width greater than 100 ft.

There is little difference in the cost of independent alignment and the 16-ft narrow-median design without barriers—the latter is slightly cheaper at flat ground slopes, and the former is slightly cheaper at steeper ground slopes. The requirement for a median barrier on the 16-ft design results in substantial economic superiority for the independent-alignment design over the entire range of ground slopes. Even the narrow 4-ft median with median barrier is more expensive than the independent-alignment alternative. Alternatively, a narrow-median design with a flat 40-ft median could be used to avoid the installation of guardrail, but Figure 10 shows that independent alignment would be consistently cheaper for ground slopes steeper than 12 percent.

The installation and maintenance of a median barrier cost $1.10/lin ft on an annual basis assuming that its useful life is 20 years. If damage to the barrier from accidents or poor maintenance practices or changes in design standards force premature replacement of large sections of barrier, its annual cost would be higher (e.g., $1.54 if replaced at the same cost after 10 years), further reducing any economic advantage it might have had originally.

Several of the alternative designs shown in Figure 10 would produce embankment heights greater than the 47-ft equal severity height at ground slopes of about 20 percent. However, the cost of the necessary roadside guardrail is not shown in those instances because the extremely rapid rise in total annual cost at ground slopes greater than about 15 percent would no doubt require use of side slopes steeper than 4:1. The effect of roadside guardrail requirements on annual cost is more clearly shown in the case of 2:1 side slopes (Fig. 11).

Figure 11 shows annual costs of the alignment designs with the steeper 2:1 side slopes, again with the same unit costs. The vertical steps that occur in each curve represent the increases in annual cost resulting from the installation and maintenance of guardrail at the 2:1 slope's equal severity embankment height of 10 ft. The in-place cost of guardrail is taken at $3.00/lin ft and its maintenance at $0.10/lin ft/year.

Figure 4 shows that independent alignment with 2:1 side slopes does not produce a 100-ft median width at ground slopes less than 24 percent. However, because the embankment height of the upper roadway exceeds the equal severity height at ground slopes greater than 9 percent, a roadside guardrail is required and the minimum safety median width requirement is superseded. Therefore, its cost is not included in the annual cost curve at ground slopes steeper than 9 percent. At a ground slope of 18 percent, the equal severity concept warrants the installation of guardrail on the lower roadway as well. The several narrow-median designs require a single guardrail at ground slopes ranging from 11 to 15 percent.

Figure 11 shows that independent alignment is significantly cheaper than narrow-median designs with median barrier for ground slopes up to about 30 percent, and only then does its cost start to exceed the substandard 4-ft narrow-median case. The independent design and the 40-ft narrow-median design (which does not require a median barrier) are nearly equal in cost at flat ground slopes, but the independent design gains a sizable cost advantage at steeper ground slopes.

Figure 12 shows the effect of right-of-way value on the relative economy of narrow-median designs with barrier and independent alignment. The 16-ft narrow-median design is used because it could be considered a typical minimum treatment for heavily trafficked, high-speed highways (6-ft inside shoulders plus 4 ft for a barrier and offset allowances). Side slopes are 2:1, and the break-even median widths are based on the cost curves shown in Figure 11. The unusual arrangement of break-even curves for the

several ground slopes results from the nonuniform variation in annual cost differences caused by the introduction of guardrail at specific ground slopes as shown in Figure 11. At a right-of-way cost of $2,000/acre, breakdown median widths of 100 to 250 ft can be added to minimum median widths of 50 to 150 ft (Fig. 4) depending on the specific ground slope. Even at $4,000/acre, independent alignment can provide total median widths ranging from about 100 to 200 ft at a total annual cost no greater than that of the narrow-median design with barrier.

The additional median width provided on independent alignments by both the economic break-even median width and the 100-ft safety median width requirement will have a slope flatter than the adjacent roadside slopes if the ground slope is uniform. The resulting shelf-like configuration would probably help to check the downward momentum of out-of-control vehicles from the upper roadway, the extent of speed reduction being dependent on its width and steepness. (Obviously a very narrow, unrounded "shelf" might present a severe overturning hazard to an out-of-control vehicle, and such designs should be avoided.) If that relief slope is ignored, the safety performance of the independent alignment design is underestimated somewhat, and safety comparisons with the narrow-median alternatives might thus be considered somewhat conservative.

In extremely flat terrain where roadways are built with minimal excavation or entirely on low fills the concept of the independent alignment no longer fully applies. However, the use of wide medians is still often substantially more economical than designs with narrow medians, without barriers as shown by the 0 percent curve in Figure 12. Roadways were assumed to be entirely on embankment with a fill height of 3 ft at the outside edge of the subgrade. Median fill slopes were taken as 6:1 to be consistent with current practice and the geometry shown in Figure 1. In this case the earthwork cost is somewhat greater for the wide-median design, and this extra cost plus the increased right-of-way cost is balanced against the cost of installing and maintaining a median barrier. The California Division of Highways standard of median width 40 ft or greater for barrier-free design is met for right-of-way cost up to $4,000/acre (24-ft break-even median width plus the 16-ft comparison width).

APPLICATION CONSIDERATIONS

Certainly the uniform terrain conditions assumed in this study will seldom be found in practice, and actual annual costs will differ somewhat from those presented here. However, it is believed that "theoretical" break-even charts of the type presented here can still adequately reflect the relative economy of alternative median designs, particularly when applied to individual route analysis segments by using weighted average ground slopes. (Frequent changes in median design, however, as between independent-alignment and narrow-median designs with barrier, should be avoided regardless of the outcome of the economic analyses.)

Break-even charts based on 4-lane cross sections can be used for quick preliminary evaluation of designs having 6 or 8 lanes, if it is recognized that the increased number of lanes tends to favor independent alignment. On the other hand, designs with foreslopes or ditches narrower than those used in the development of the charts will tend to favor narrow-median designs. Superelevation will tend to increase the cost of narrow-median designs more than that of independent-alignment designs.

Break-even charts can be readily developed for a wide range of cost and design conditions and used as a guide or starting point, followed where necessary by detailed analyses. The general procedure lends itself readily to computer treatment and can be incorporated in basic earthwork and route-alignment programs.

SUMMARY AND CONCLUSIONS

Highway planners and designers should give increased attention to the benefits and feasibility of independent alignment and other wide-median alternatives for median design. These designs are generally superior to narrow-median designs from the standpoint of aesthetics and traffic safety. For a wide range of typical cost and terrain conditions associated with many rural and suburban locations, the annual cost of independent-alignment designs will be little more, and in many instances considerably less, than the cost of alternative narrow-median designs, especially where a median

barrier is required with the latter. Independent alignments and other wide-median designs with median widths of up to 100 to 200 ft can often be built and maintained at no greater cost than some narrow-median designs, even where right-of-way cost is as high as $4,000 to $5,000/acre.

Economic comparison charts incorporating median and roadside safety requirements can be easily developed for quick preliminary evaluation of alternative median designs for representative design and cost conditions. The analysis procedure can be readily incorporated in routine earthwork computer programs.

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