Esthetic Criteria in Freeway Design

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• ALTHOUGH intensive research is being carried out on the functional and structural aspects of the highway, the form of the highway as such has merited much less attention. The independent study of form is unnecessary in the case of those technological tools whose shape is rigorously determined by structural and functional necessities. The highway, by contrast, like a piece of architecture or industrial design, lies in an order of precision where scientifically determined limitations leave the designer considerable freedom to refine form beyond the bare minima of utilitarian standards. Moreover, the eye of the highway user (and non-user as well) perceives the form of the highway not as an engineering problem, but as a visual entity; the highway is seen before it can be traveled on. Being seen is an integral part of its purpose; hence, the importance of the formal or visual approach.

By applying methods of formal esthetic analysis, a distinction between the internal and external harmony of the highway can be made. The former concerns the roadway as an abstract ribbon in space. The latter concerns its relationship with the environment. Some relevant criteria to judge internal harmony are continuity of alignment, three-dimensional coordination, and harmony of enclosed areas. Some relevant criteria to judge external harmony are integration with the macroenvironment and the microenvironment, definition of elements, and frequency and progression of focal points.

Continuity of alignment and the sculptural form of the alignment in general is of the utmost importance, because the pavement of the freeway is by far the most insistent feature in the visual field of the driver (Fig. 1). On a conventional country road at moderate speed, the roadbed occupies some 8 percent of the driver's visual field in perspective, while the roadside may take up 80 percent or more, depending on topography and vegetation. On a six-lane freeway at 25 mph, the share of the roadbed rises

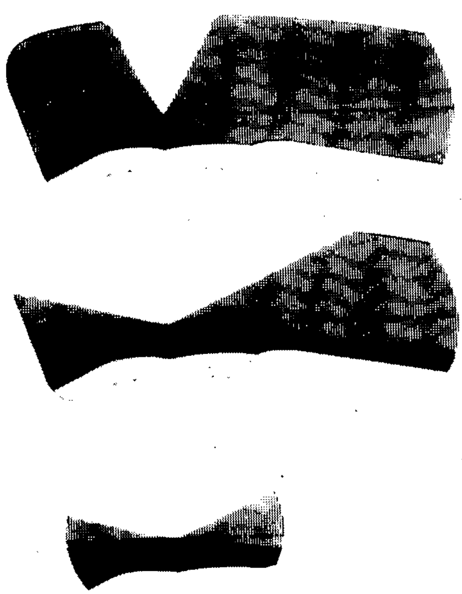

Figure 1. Driver's visual fields.

to 20 percent. Considering the reduction of the cone of vision at 60 mph, the roadbed may occupy close to 30 percent, the sky more than 50 percent, while the share of the roadside shrinks to less than 20 percent of the visual field, and in flat terrain to as little as 5 percent.

In freeway design, the shape of the roadbed itself, as seen in perspective, can become the dominant element of visual, esthetic expression. The alignment of the roadbed consists of curves and tangents, both vertical and horizontal (Fig. 2).

The tangent is esthetically justified in very flat terrain or where the predominant man-made landscape pattern—such as a street grid—is rectilinear. It is easy to design and provides clear orientation, but at the same time, unless aimed at a landmark, it is esthetically uninteresting, because totally predictable; it is monotonous and fatiguing because the view is completely static; it encourages excessive speeds, because the driver tries to "get it over with."

The second most common element of horizontal alignment is the circular arc. It is interesting because it brings more roadside into view, because it shows the driver a changing panorama and arouses a sense of anticipation for what is beyond. A curve encourages attention and a steady hold on the steering wheel. At the same time, the curving roadside provides much better optical guidance, because it is seen ahead, rather than peripherally.

Neither the tangent nor the circu-

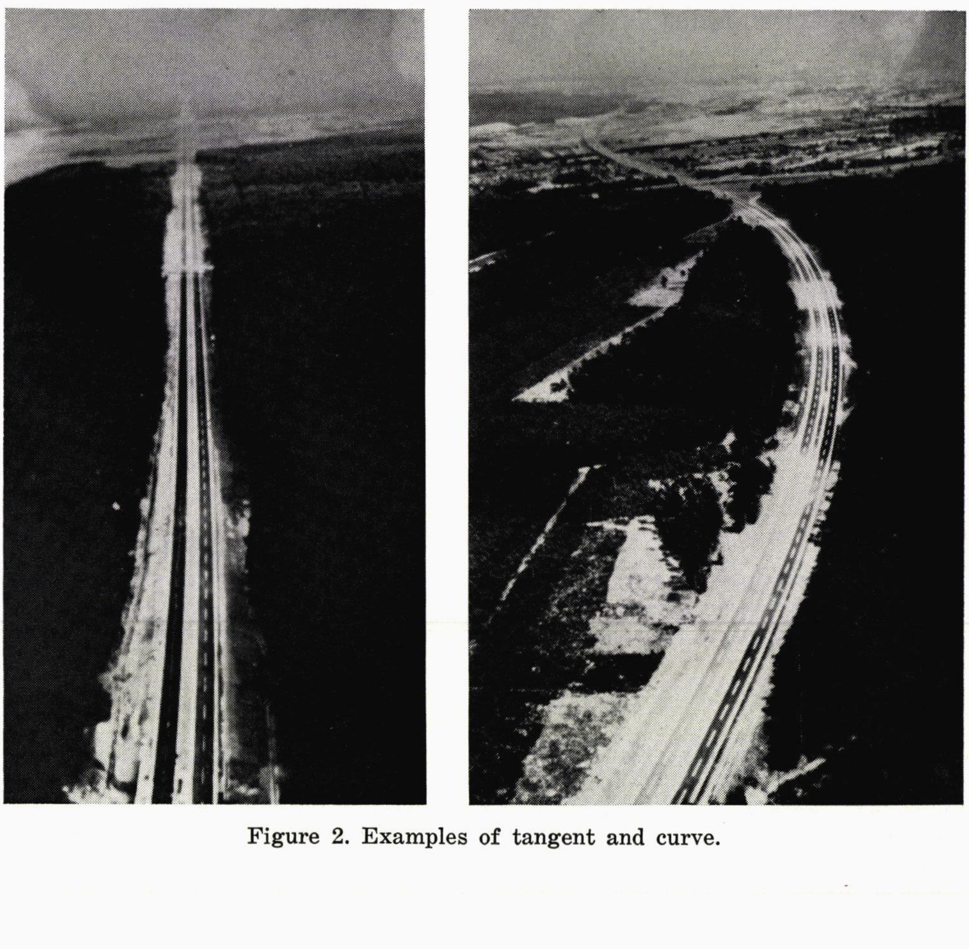

Figure 2. Examples of tangent and curve.

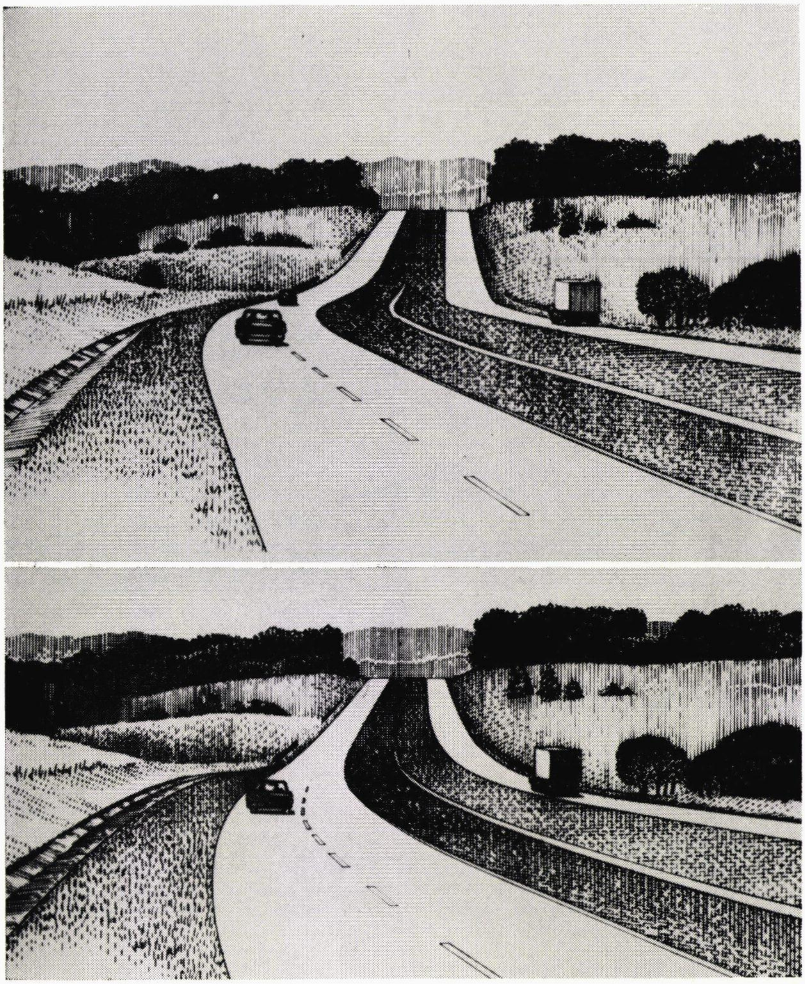

Figure 3. Curve without and with spiral transition.

lar arc, taken in themselves, pose any problems of continuity. The problem arises, when the two are joined, because the straight line, with zero curvature, touches the circle, which appears as an ellipse with a continuously changing curvature, at a point where this curvature appears the sharpest. Perspective foreshortening from a viewpoint only some 4 ft above ground accentuates this discontinuity and makes it, in spite of the huge scale of the curves, visually disturbing.

Clearly, there is visual need for a connecting element whose curvature would gradually change from zero at the tangent to the constant curvature of the circular arc, and join the straight line with the apparent ellipse of the circle in a continuous fashion.

Apart from its visual value, a spiral transition curve of course expresses, in a refined way, the functional performance of a vehicle entering or leaving a curve (Fig. 3). But because spirals in highway design are recognized to be unessential on

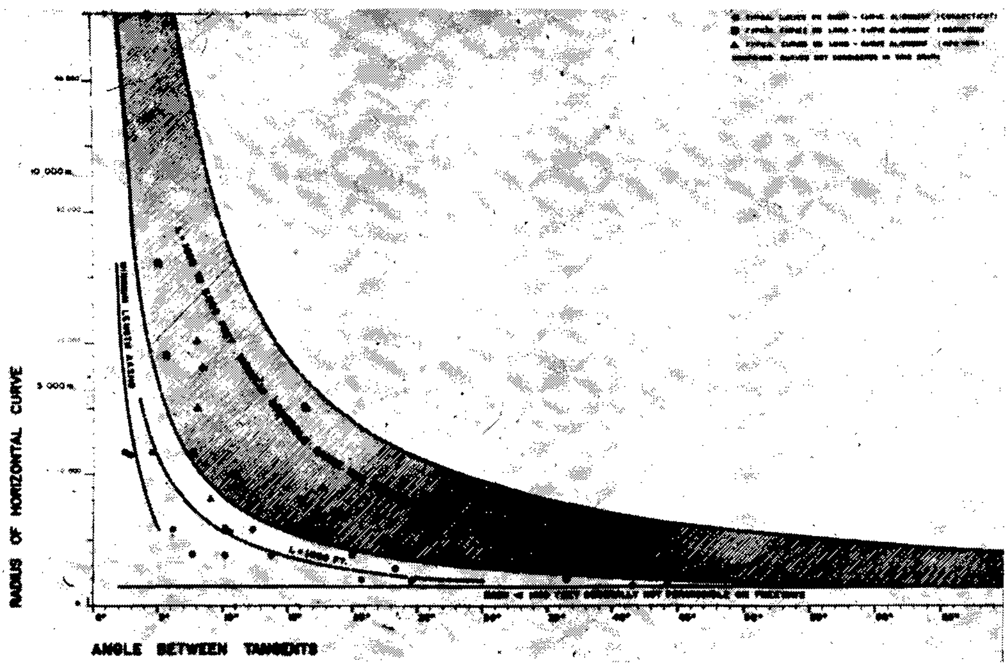

Figure 4. Angle between tangents *vs* radius of horizontal curve.

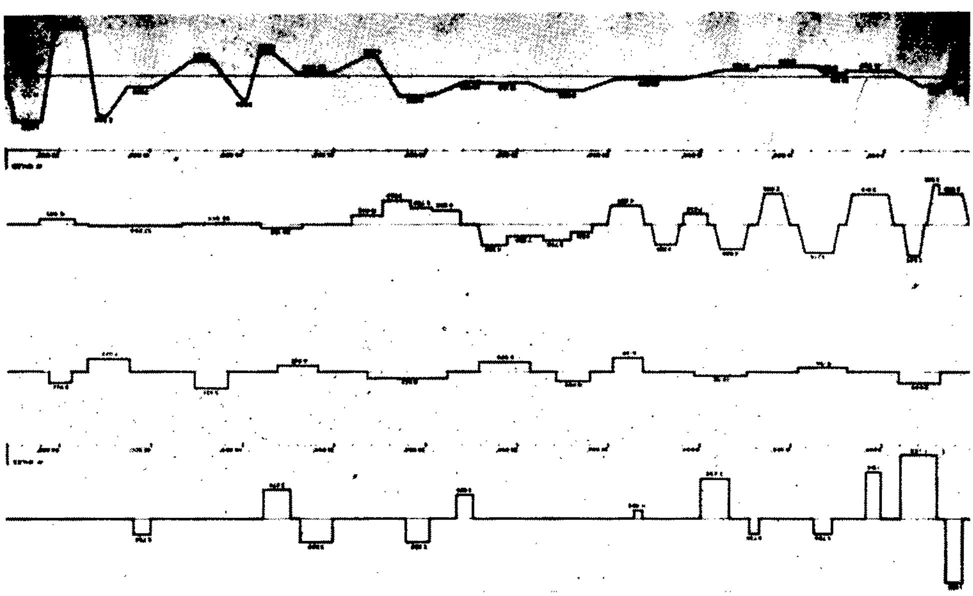

Figure 5. Curvature diagrams for 10-mi stretches of four characteristic kinds of horizontal alignment: Connecticut Turnpike, New York Thruway, Baltimore-Washington Parkway, and Ashaffenburg-Nürnberg Autobahn.

functional grounds, a frankly esthetic standard to determine their use and their minimum length seems justified. It would appear no more arbitrary than the factor C for comfort used in radial acceleration formulas for length of spiral, or the requirement that superelevation runoff be traversed in no less than 2 sec used in calculations tying length of spiral to length of superelevation runoff. For whichever of these two accepted semifunctional calculations governs, the spirals it produces are too short to be visually significant.

The discussion of spirals (that is, the continuity of horizontal form) proceeds to the subject of continuity in horizontal scale. A straight line, in itself, has no scale. But when a straight line has to change direction and is thus interrupted by a curve, the question immediately arises—how long should that curve be to preserve visual continuity? A curve may be nicely transitioned, but if it is too short, it will still appear as an unnatural kink in the road.

Inasmuch as at high speeds the driver focuses some 1,000 to 2,000 ft ahead, it seems that a curve ought to be at least that long to be visually significant while the driver is on it. Systematic observation by several visually trained individuals on a Connecticut freeway indicated that curves shorter than 1,000 ft were generally experienced as "too short." German 1942 geometric standards established 300 m (984 ft) as an absolute minimum for length of curve on the Autobahnen.

In Figure 4, angles between tangents are plotted against radii, and the resulting hyperbolas are lines of equal length of circular curve. The 1,000-ft length is shown as a suggested minimum, and the area between 1,500 and 5,500 ft is shaded as the desirable range for the length of simple circular curves on freeways. Dots indicate radii used on a typical section of a shortcurve freeway alignment in Connecticut; triangles and squares, clustering toward the upper end of the graph, are typical radii on long-curve alignments in New York and Maryland.

Striving for longer and hence flatter curves could lead to making the radius so large that the curve will be hardly distinguishable from a straight line. What is then the longest reasonable radius? Hans Lorenz points out that curves generally cease to be visually significant if the visible part of the curve accomplishes a turn of 2 to 3 degrees or less. This rule seems to be borne out by the visual experience on freeways with very flat curves, such as the Baltimore-Washington Parkway. However, it makes curves with radii up to 80,000 ft quite realistic (Fig. 5).

Another way to approach the scale of horizontal curves is by comparing their length with that of the tangents. Most widely used in America is the long-tangent short-curve alignment. Typically, this consists of straight sections 1 to 3 mi or more long, connected by curves about 1,500 ft long with 2,000- to 12,000-ft radii. From the definition of continuity this is the epitome of discontinuous alignment, for every curve and every tangent is clearly seen as a separate thing. Curves usually make up less than one-fifth of such an alignment.

On divided highways, passing sight distance is of no consequence, and the only reason for the use of long tangents here is probably the tradition of railroad engineering. The fact is somehow often overlooked that if the angle between two tangents is given, a flat curve will result in a shorter and more directional alignment than a sharper one. More familiar functional arguments against the short-curve long-tangent alignment are that curves at the end of long tangents are accident-prone and that long straight sections produce monotony. It appears logical to increase the length of curves to such a degree

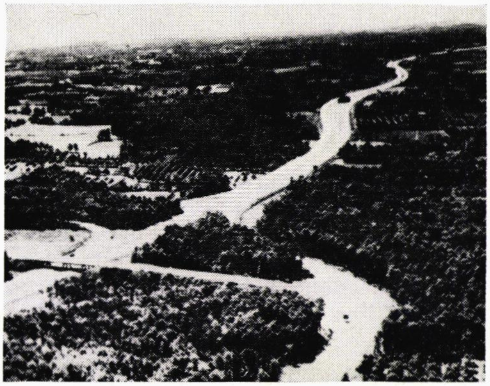

Figure 6. Long-curve short-tangent section of New York Thruway and tangentless section of Ashaffenburg-Nürnberg Autobahn; design speed 160 km per hr.

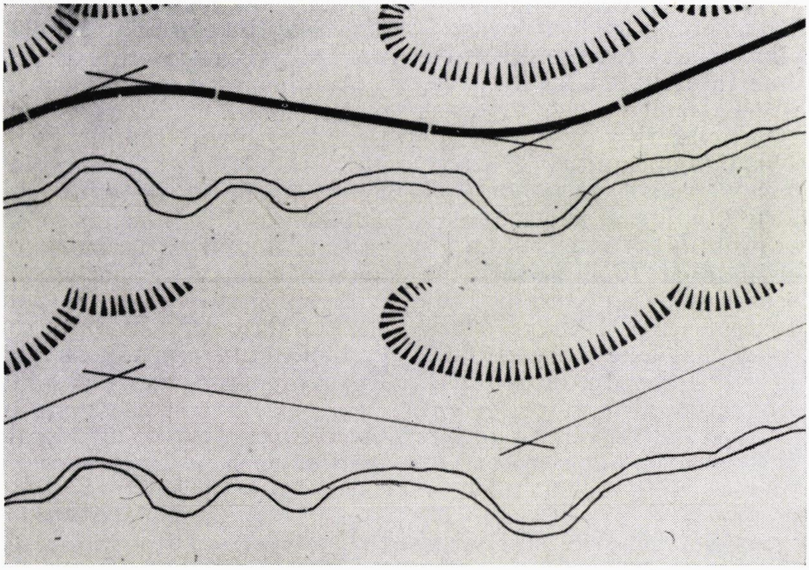

Figure 7. Discontinuous tangent-and-curve alignment.

that they surpass by far the length of tangents, arriving at the long-curve short-tangent alignment.

For this design, not a straight line but rather a flat curve is taken as the basic unit of alignment (Fig. 6). For example, the basis for the geometric design of the Garden State Parkway was a curve with a 15,000-ft radius. Only about one-third to one-fifth of such an alignment consists of straight sections. The latter are not meant to read as tangents visually, in perspective, but rather to appear as a part of a continuous compound curve.

The only esthetic difficulty with this alignment is that unless the radii are extremely long—which is often not permitted by topography and other restrictions—the connection be-

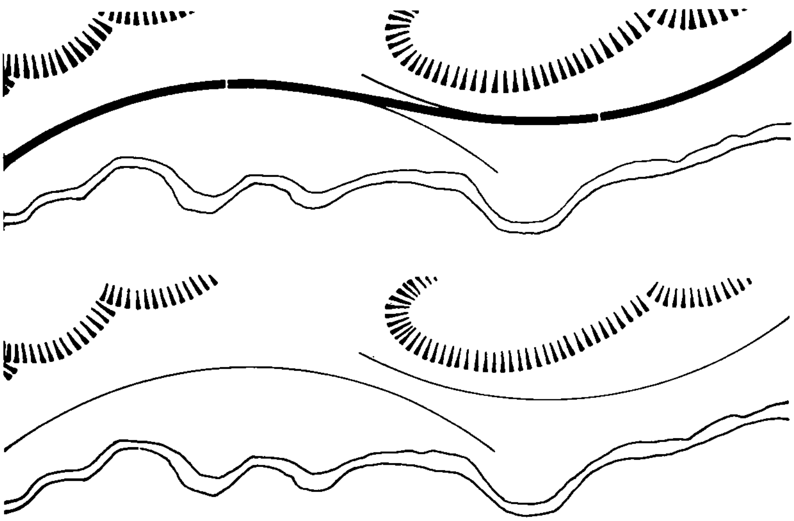

Figure 8. Continuous curvilinear alignment.

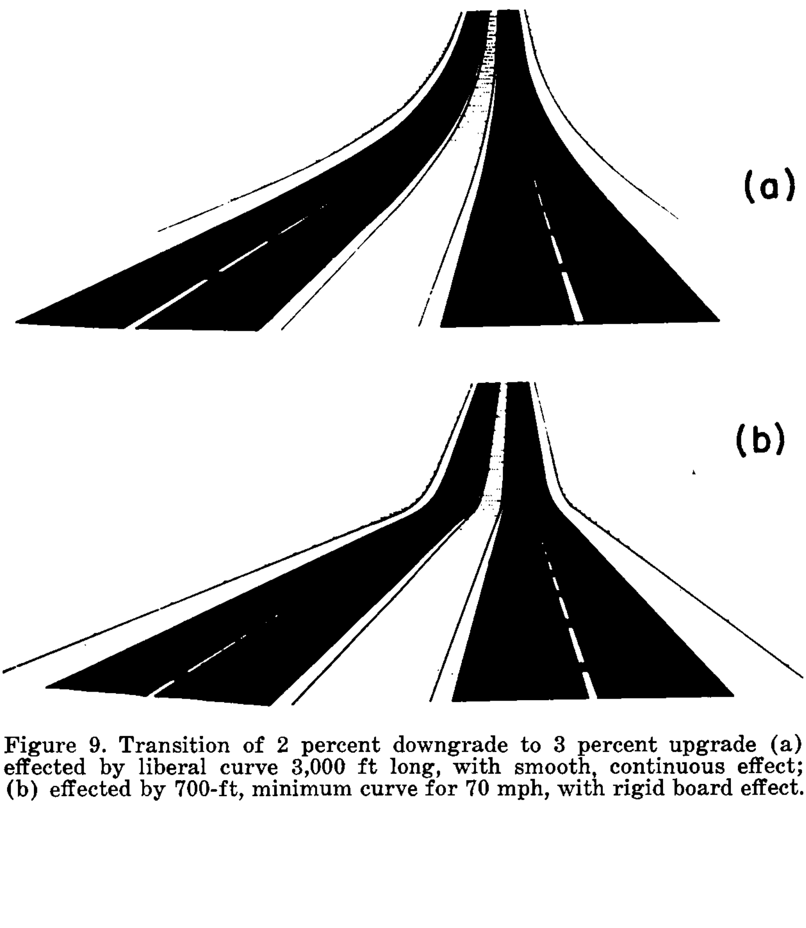

Figure 9. Transition of 2 percent downgrade to 3 percent upgrade (a) effected by liberal curve 3,000 ft long, with smooth, continuous effect; (b) effected by 700-ft, minimum curve for 70 mph, with rigid board effect.

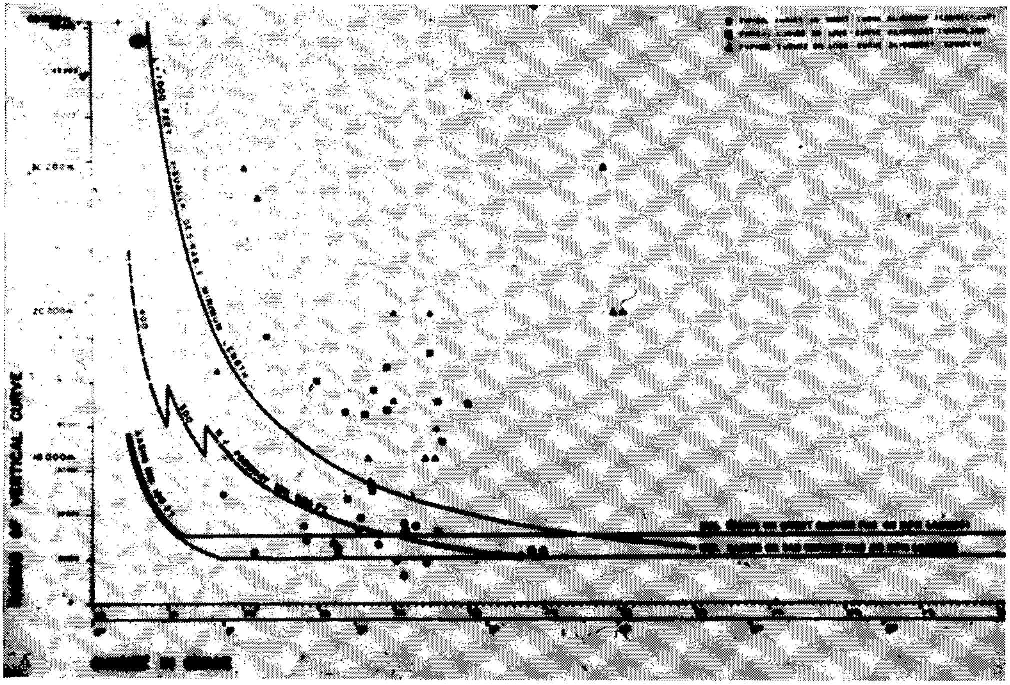

Figure 10. Radius *vs* angle between tangents for vertical curves on three typical kinds of alignment. Vertical radius approximately equal to 100 *K* for small angles if parabolic curve treated as circular for purposes of comparison.

tween circular curves and tangents appears discontinuous. Hence, spiral transitions have to be introduced. Now, if the tangents are as short as "spline" alignment requires them to be and spiral transitions are made as long as recommended, then very little room is often left for the tangent. The next logical step, then, is the continuous curvilinear alignment.

This consists of long, flat circular curves, simple and compound, connected by fairly long spiral transitions, with about two-thirds of the alignment on circular arcs and one-third on spirals, and approaches the ideal of continuity in form and in scale.

Discarding the traditional, discontinuous tangent-and-curve alignment in favor of the new continuous curvilinear alignment naturally requires a radical break with accepted procedures of design.

The old procedure was to use given topographic controls to establish the basic tangents, and then connect them with circular arcs (Fig. 7).

The new procedure would be to use given topographic controls to establish the basic circular arcs, as flat and as long as practicable, and then join them with suitable transition curves (Fig. 8). The tangent is thus eliminated as a dominant element of design, except under urban or other special conditions.

The continuity of alignment can be expressed and studied graphically and mathematically by means of the curvature diagram, or $1/r$ graph. The method is simple and easy to visualize. One merely plots the centerline of the highway along the horizontal axis

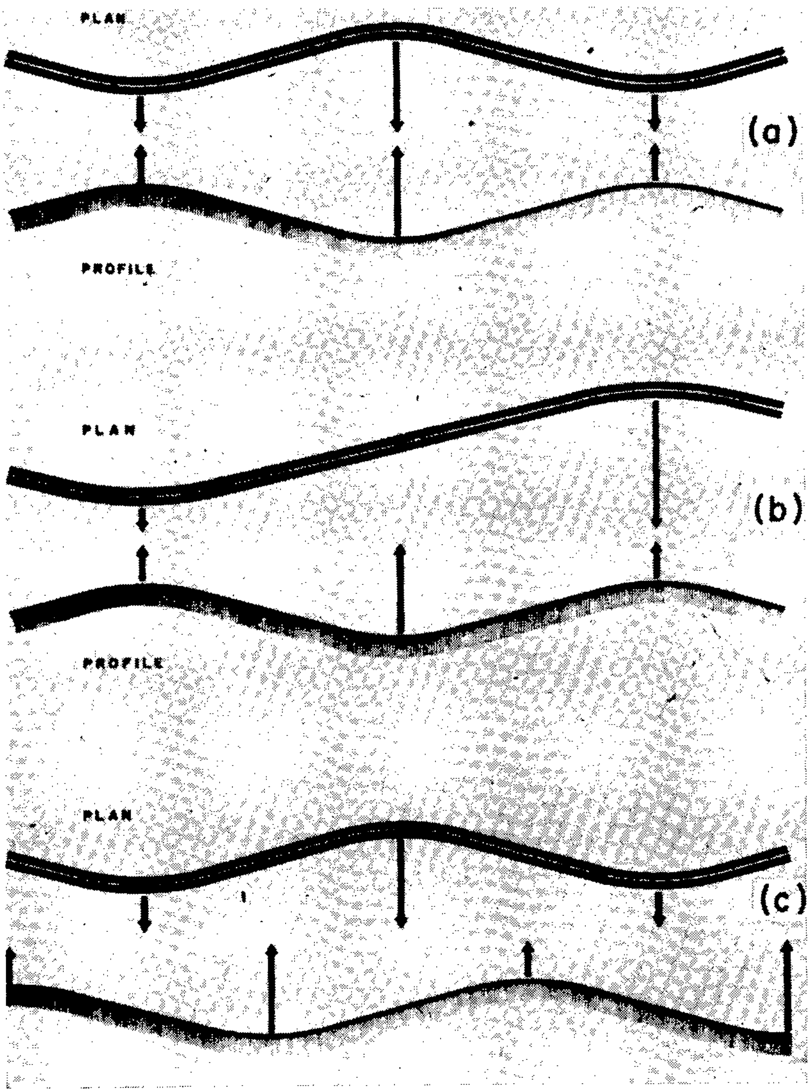

Figure 11. Coordination between vertical and horizontal alignment.

of the graph, and the value 1 divided by radius, along the perpendicular axis. In such a diagram, the tangent appears as a straight line on the horizontal axis. A circular curve appears as a straight line parallel to the axis, but at a distance $1/r$ from it, up or down, depending on whether it is a right or left turn. The spiral appears as a sloping straight line, connecting the two. In essence, the $1/r$ diagram shows the second derivative of the highway curvature, which represents, among other things, the movement of the steering wheel. Areas enclosed between the $1/r$ line and the horizontal axis show L/r; *i.e.*, they are proportional to the angle between tangents.

No less important than horizontal

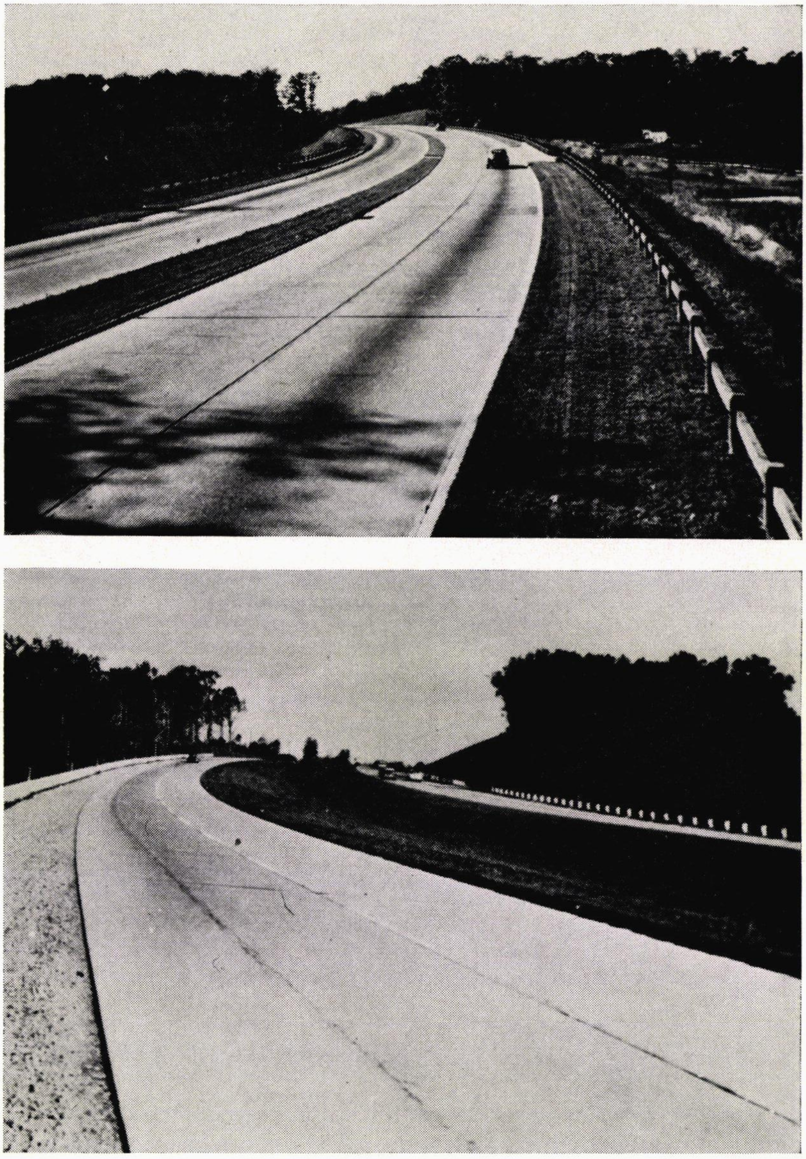

Figure 12. Vertical curvature superimposed on horizontal curvature.

continuity is continuity of alignment in the vertical plane (Fig. 9). Again, the accepted minimum functional requirements for length of vertical curve result in changes of direction that appear visually abrupt and discontinuous. Minimum length of sag curves for differences in grade between 1 and 6 percent ranges from 200 to 900 ft, and such short vertical curves are out of scale both with the adjoining tangents and with the sweeping flow of horizontal curves.

The standard practice on freeways

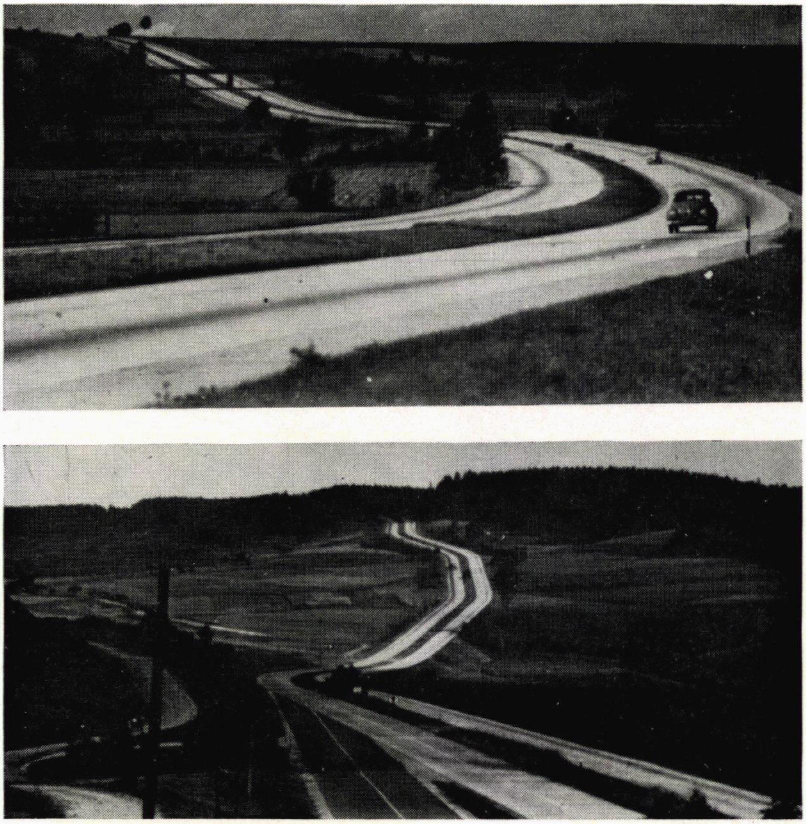

Figure 13. Examples of continuous and discontinuous alignment in Germany.

with a conventional long-tangent short-curve plan is to employ long tangents and short curves in profile as well, making the vertical curves as short as the functional standards will permit, with a deleterious effect on esthetic continuity. Only parkways and freeways with a curvilinear-type horizontal alignment have made use of very long vertical curves so far. The Baltimore-Washington Parkway or the Ashaffenburg-Nürnberg Autobahn, for example, successfully use sag curves 1,500 to 3,000 ft long, which is often 2 to 3 times more than would be required by minimum utilitarian standards (Fig. 10).

The tendency to minimize tangents in profile leads to the continuous curvilinear alignment in the vertical plane. Though curves may make, in moderately hilly terrain, some 25 percent of the conventional vertical alignment, they can make up, under comparable circumstances, as much as 50 percent of the curvilinear vertical alignment. This means, essentially, reducing the number of vertical curves and increasing the length of the remaining ones more than twice. This is particularly important in the case of sag curves and small changes of grade, where perspective foreshortening is acute.

Figure 14. Variable median spoiled by discontinuous alignment and lack of continuity in slope grading.

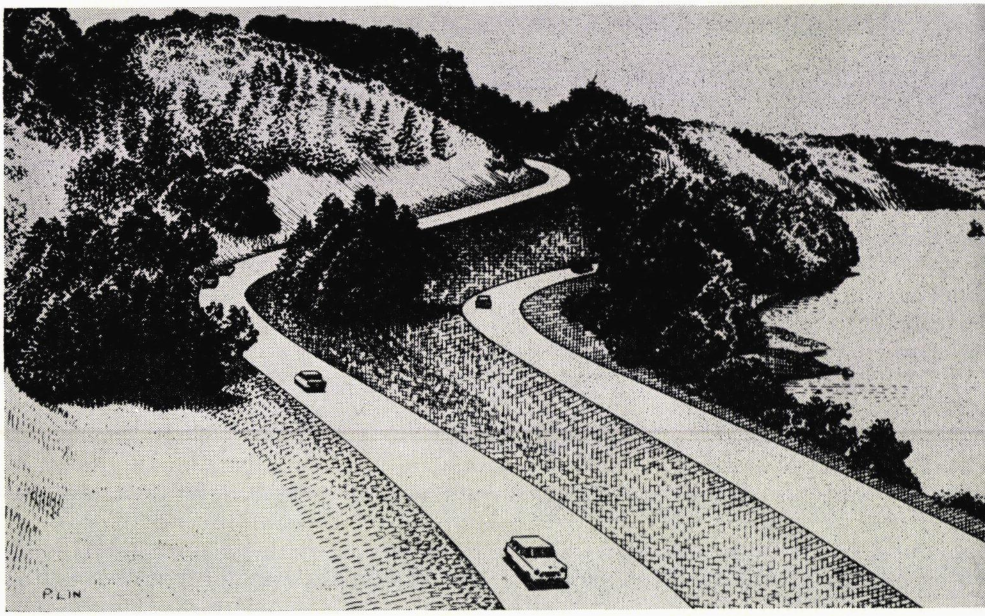

Figure 15. Superior median design, George Washington Parkway.

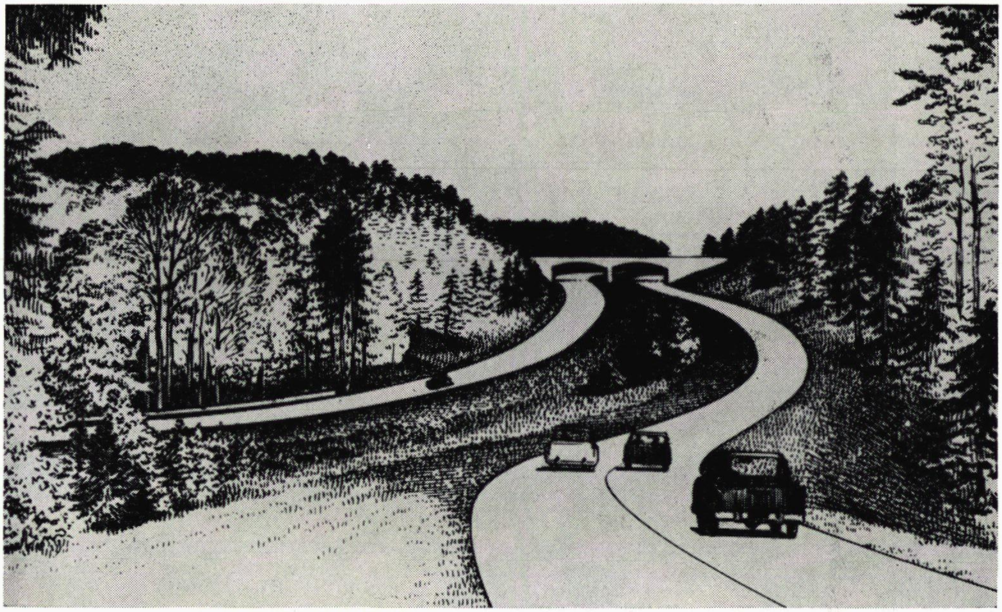

Figure 16. Superior median design, Baltimore-Washington Parkway.

Continuity in plan and continuity in profile will lead to continuity in three dimensions only if the vertical and horizontal elements are carefully coordinated.

1. A generous alignment in one plane does not associate itself with small and frequent adjustments in the other. The length of vertical curves (and grades, for that matter) should be influenced by the length of the horizontal elements on which they are superimposed.

2. Although the scale of vertical and horizontal elements should be related, they should not commence and terminate simultaneously. Fritz Heller points out that the eye may find it disturbing when the vertical and horizontal alignment change at the same time, because any irregularities at this point will be emphasized in perspective and be cumulative in effect. Desirably, horizontal curvature should always "lead" vertical curvature somewhat, and should remain somewhat (but not too much) longer than the latter. This overlapping will also promote safety through optical guidance.

3. Elements of the plan should generally coincide with those of the profile not only with respect to length but also with respect to location. The rule suggested by Hans Lorenz is that the vertex or turning point of a vertical curve should roughly coincide with the vertex of the horizontal curve.

The vertices may be, at times, shifted as much as one-quarter of a phase, but a shift of one-half a phase results in an unsightly situation where the vertical curve lies at the beginning of the horizontal curve, creating the impression of a sharp angle.

Figure 11a shows the classic case of coordination between vertical and horizontal alignment. The vertices of horizontal and vertical curves coincide, creating a rich effect of three-dimensional S-curves, composed of

Figure 17. Example of integration between freeway and river valley.

convex and concave helixes. Figure 11b shows a legitimate case of coordination. One phase is skipped in the horizontal plane, but vertices still coincide. The long tangent in plan is softened by vertical curvature. Figure 11c shows weak coordination. Vertical alignment is shifted one-half of a phase with respect to horizontal alignment, vertices coincide with points of inflection. Superelevation in this case occurs on grade, and crests and sags have normal crowned section; in the first case, superelevation occurs on crests and sags, and grades have normal crowned section. Figure 12 shows two examples of vertical curvature superimposed on horizontal curvature, creating a rich three-dimensional curve, the helix.

Desirably one should think of the alignment (and study it through visual aids) as a continuous sculptured three-dimensional curve and not as a result of random superposition of plan and profile. Every movement of the vehicle along the paved ribbon should be subject to description in one unequivocal three-dimensional term; it should not consist of a series of small movements within a larger one (Fig. 13). Such an approach will eliminate common faults such as the "broken back," "hidden dip," or "roller coaster" alignment. If the hills should not be leveled, the remedy for the "roller coaster" is to introduce some horizontal curvature that will prevent the crest-after-the-next-one from being seen. In effect, this

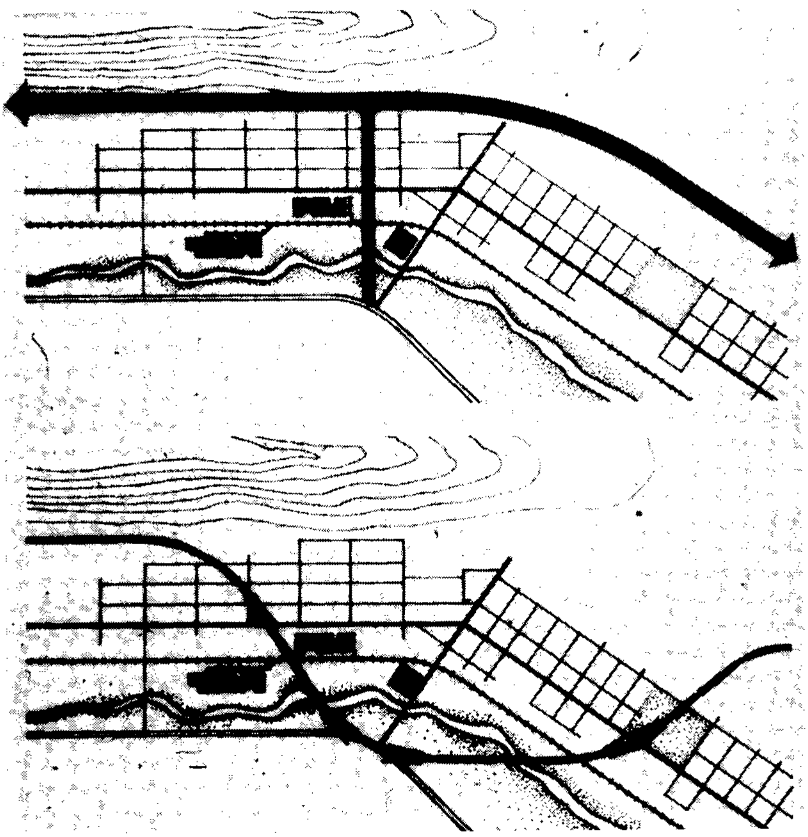

Figure 18. Street grid (top) integrated with freeway; (bottom) violated by freeway.

means setting a limit on sight distance, so that the driver can concentrate visually on the movement he is about to perform now. This increases attention and anticipation, which are indispensible to esthetic enjoyment.

A final note with regard to the internal harmony of a freeway concerns the design of shapes, enclosed by the twin ribbons of pavement, as they appear in perspective. Merely to introduce a varying median, without carefully studying its appearance, is not enough (Fig. 14). For example, differences in width and in elevation should be introduced on curves, never on tangents (Figs. 15 and 16).

Turning now from the subject of internal harmony to that of external harmony, to the integration of the road with its environment, recounting a few of the governing principles is sufficient.

A freeway should have the look of permanence and belonging in the landscape or cityscape (Fig. 17). For this purpose, it should follow, rather than crisscross, the dominant geometric order of its surroundings (Fig. 18). Hills should not be straddled perpendicularly to the contours, but rather at an oblique angle. Location of cuts should be related to natural depressions in a ridge, and if a valley is to be crossed, the in-

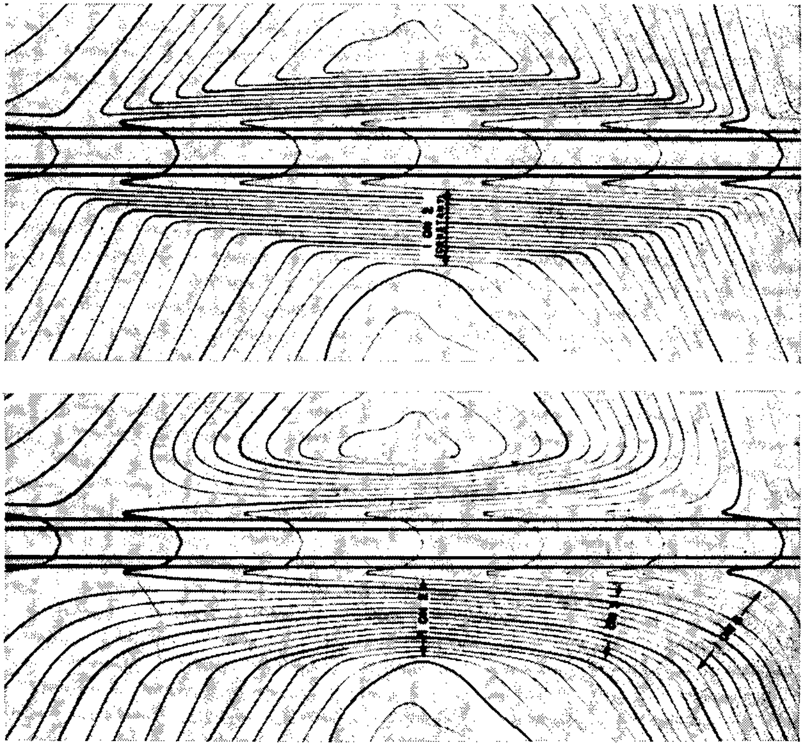

Figure 19. Slope of bank kept constant (top); length of incline kept constant (bottom).

tegrity of its space should be preserved either by an open viaduct design or by a very flat embankment.

The cross-section should be continuous, and the side slopes as gentle as possible. A recent German grading standard suggests that in cuts, instead of keeping the slope of the bank constant, the length of the incline should be kept constant, thus resulting in a varying slope that gently blends into the natural topography (Fig. 19).

Guide rails and similar barriers violate the continuity of the cross-section and should be replaced, as far as possible, by flat slopes.

Separation of the freeway from surrounding development is imperative (Fig. 20). The scale of a freeway is such that it demands a broad strip of land so as to live a life of its own and not conflict visually with residential, industrial, or commercial development. The standard 300-ft right-of-way, leaving a buffer strip of some 80 ft on each side, is barely sufficient to satisfy the requirement for visual articulation. A 400-ft right-of-way could be a desirable minimum for suburban conditions, and still wider green strips, perhaps doubling as recreational or watershed protection lands, are desirable. Rest turnouts on freeways in particular should have ample room.

In dense urban areas, where wide rights-of-way are not feasible, the paramount need is for strong design controls to establish proper massing and setbacks for buildings and to

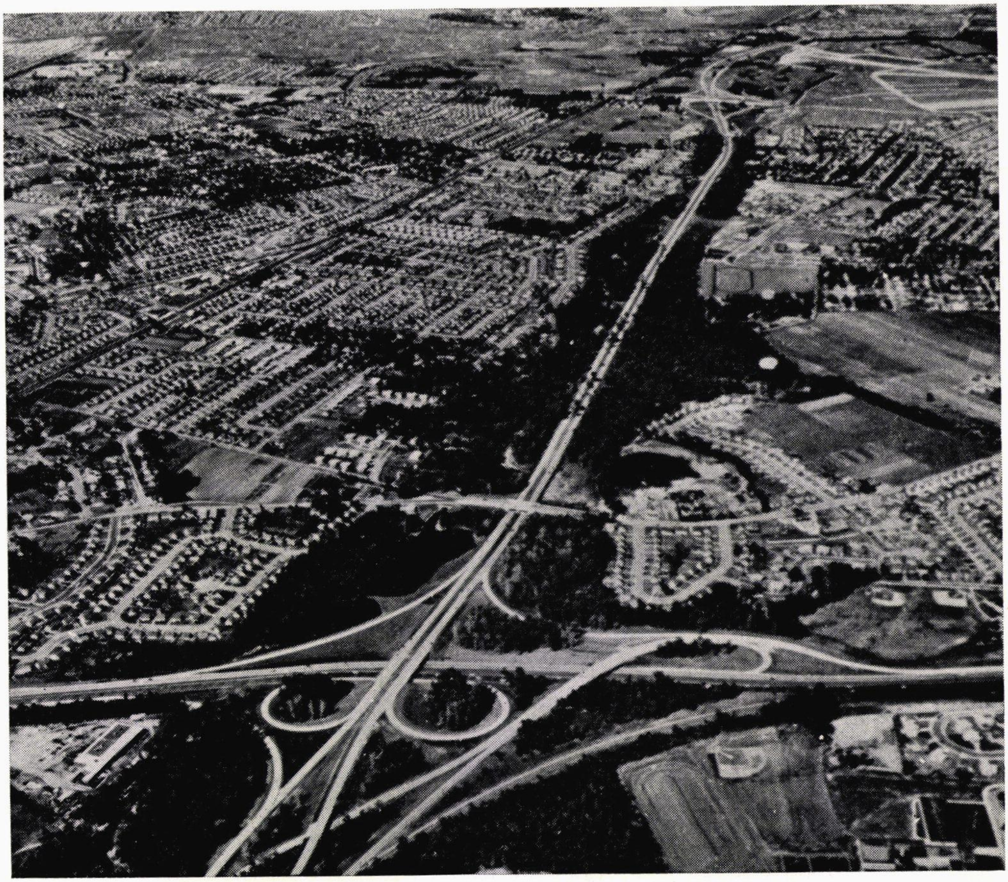

Figure 20. Clean separation between freeway and residential development, Meadowbrook Parkway, Long Island.

eliminate billboards and overhead wiring (Fig. 21). The integrity of the visual space of the freeway should not be violated by extraneous objects.

When all the requirements for continuity of alignment and cross-section for integration with the landscape and proper visual articulation, are taken care of, the freeway will be pleasant, fitting, and clean. However, it may turn out to be somewhat dull, unless vistas and landmarks are provided along the way. In order not to distract the driver by sideways views, the vertical and horizontal alignments should be oriented in such a way as to bring these focal elements into the driver's forward cone of vision. Views of the ocean, of lakes and valleys, of urban panoramas, bridges, industrial and utility structures are all suitable as focal points (Fig. 22), but perhaps giant, abstract pieces of sculpture could provide a fitting link between the fine arts and the art of highway building (Fig. 23).

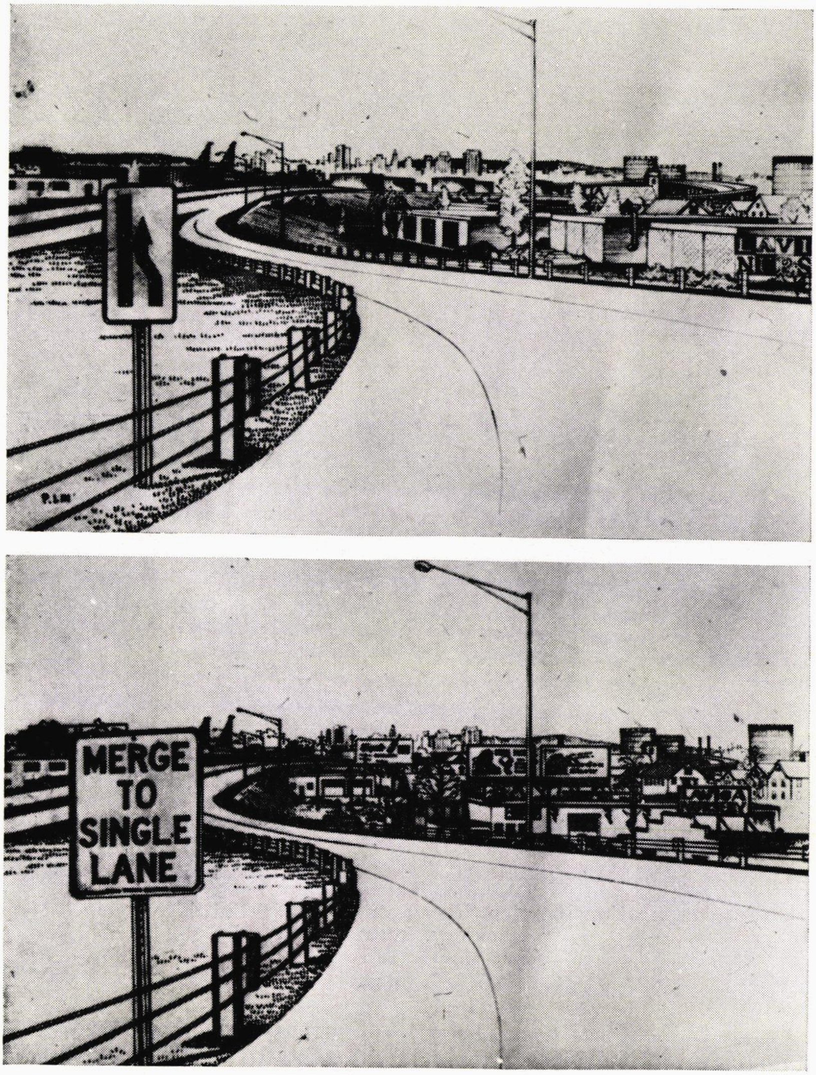

Figure 21. Use of strong design controls (top); integrity of visual space violated by extraneous objects (bottom).

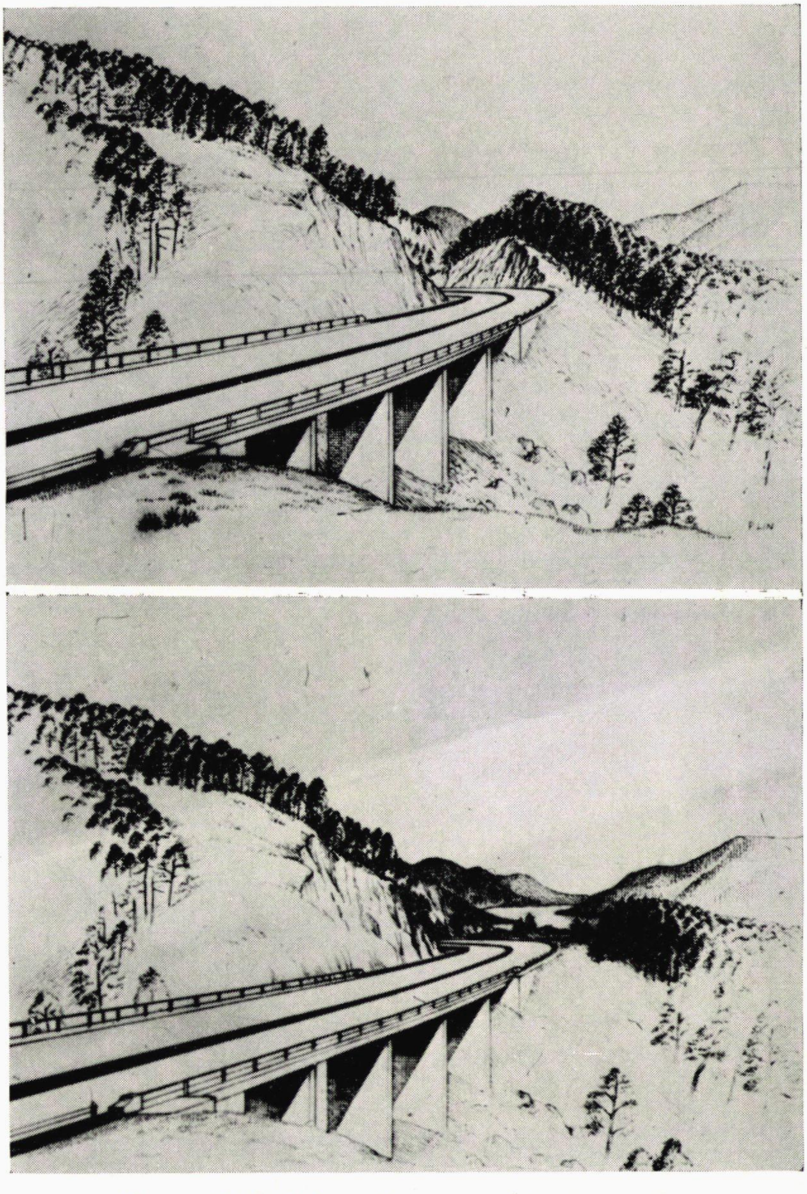

Figure 22. Rock formation removed to open a view.

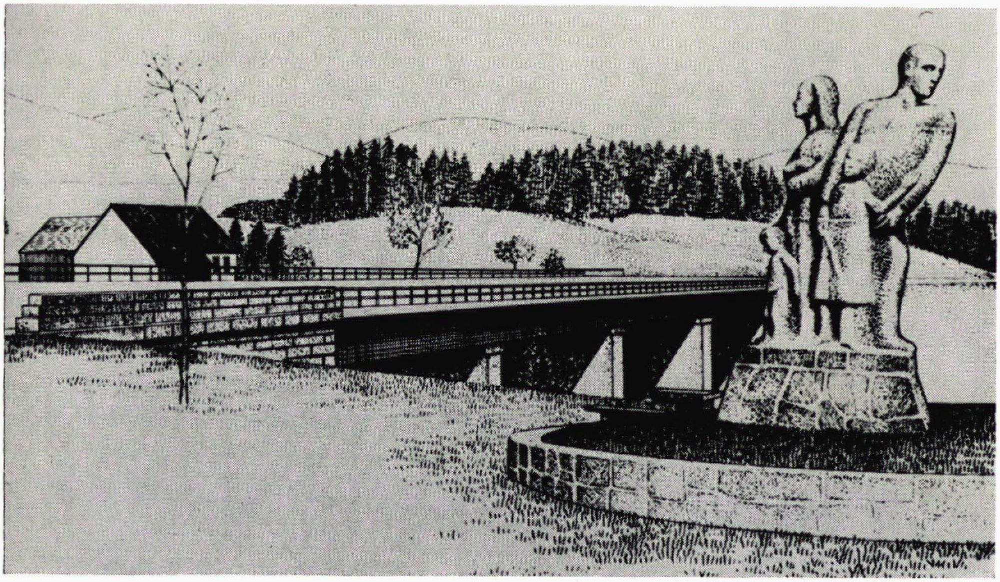

Figure 23. Small sculpture group in rest turnout on Austrian freeway.