Section 9—DESIGN FORM

9.1 GENERAL

The traditional method of designing roads is to design in three views: plan, longitudinal section and cross section. The road designer often undertakes the design of each view independently of the other two, except that a sight distance diagram may be added to the finished drawing to show the distances at which a driver may see an approaching vehicle or other object on the road ahead. The road user (driver) and the road designer have different appreciations of the appearance of the road for they see it from different angles. The designer is often unaware how his finished design will appear to the person using the road by day and by night.

These limitations can be overcome by considering the road at all stages of design as a three-dimensional structure which should be safe, functional, economical, and aesthetically pleasing. The design criteria discussed in Section 6 (Horizontal Alignment) and Section 7 (Vertical Curves) do not automatically provide a three-dimensional curve which satisfies all the above requirements.

Certain combinations of horizontal and vertical curves can result in people in a vehicle on the road seeing an apparent distortion in the alignment or grade or both even though the horizontal and vertical curves comply with design rules of Section 6 and 7. Other combinations can hide a change in horizontal alignment from the driver. Improving the appearance that a road presents can be expensive if it requires the wholesale moving of a crest to coincide with a horizontal curve or the enlargement of a horizontal curve to encompass a vertical curve. Nevertheless, designing to avoid hidden hazards is essential.

Fig. 9.1, Concepts of Design Form, shows twenty-six combinations of plan and profile of a road that may occur in road design. They are divided into two groups, Good and Poor Design Forms. The former show ways of making a road appear attractive to its users and the latter show combinations of horizontal and vertical curves which appear unattractive and which probably would have higher accident rates.

9.2 THE APPEARANCE A ROAD PRESENTS TO A DRIVER

The driver's view of the road is not static, but is continually changing. Some road features will be in view from all points on a considerable length of

road. Other road features will be in view for only a fleeting moment. A slight kink in alignment could have objectionable appearance on a long sag vertical curve but may not be noticed on a summit vertical curve. Conversely, an intersection which is clearly apparent on a sag vertical curve may be hazardous if it is inconspicuously located on a summit vertical curve.

The smooth curve of a cutting can indicate a corresponding curve in the road alignment, but at a fill there can be a sense of loss of position if the view ahead is open to the sky, i.e. if there is no visual background of fixed objects or land. Bushes along a median strip result in fewer *run-off* accidents than sterile medians whose surface is flush with the road.(14)

Particular care is needed to prevent roadside conditions which are misleading. For example, drivers will not expect a curve if the line of service poles continues straight on or if there is a deceptive gap in the line of trees on the outside of the curve.

Divided roads designed with easy grades and carefully matched curves make driving easier, and will have lower accident rates if they are aesthetically satisfying—a condition which seems to depend mainly on having interesting variations in the shape and vegetation within the cone of the vision.

9.3 FITTING THE ROAD TO THE TERRAIN

A road will generally look attractive to a user if its horizontal alignment and grading are matched, and it will be economical in earthworks if it fits the topography of the countryside.

Horizontal alignment should be as direct as possible consistent with topography. A flowing line conforming to the natural contours is usually more pleasing than one with long tangents which slash through the terrain, or one with curves for no apparent reason. An appropriately curving alignment is in general less expensive to build as interference to natural slopes is kept to a minimum and earthworks are reduced.

Curves of minimum radius or minimum length should be avoided except where they closely follow the contours in very difficult terrain.

9.4 COMBINED HORIZONTAL AND VERTICAL CURVES

9.4.1 General. Where horizontal and vertical curvature are combined the horizontal curve should preferably overlap the vertical slightly. This results in better appearance where the curve is a sag, and results in greater safety where the vertical curve is a crest as the driver is shown which way the road is curving before the surface disappears over the crest.

9.4.2 Horizontal and Vertical Curves at Sags. One way of ensuring that a road in undulating country presents a pleasant appearance is to provide long sag vertical curves which coincide approximately with horizontal

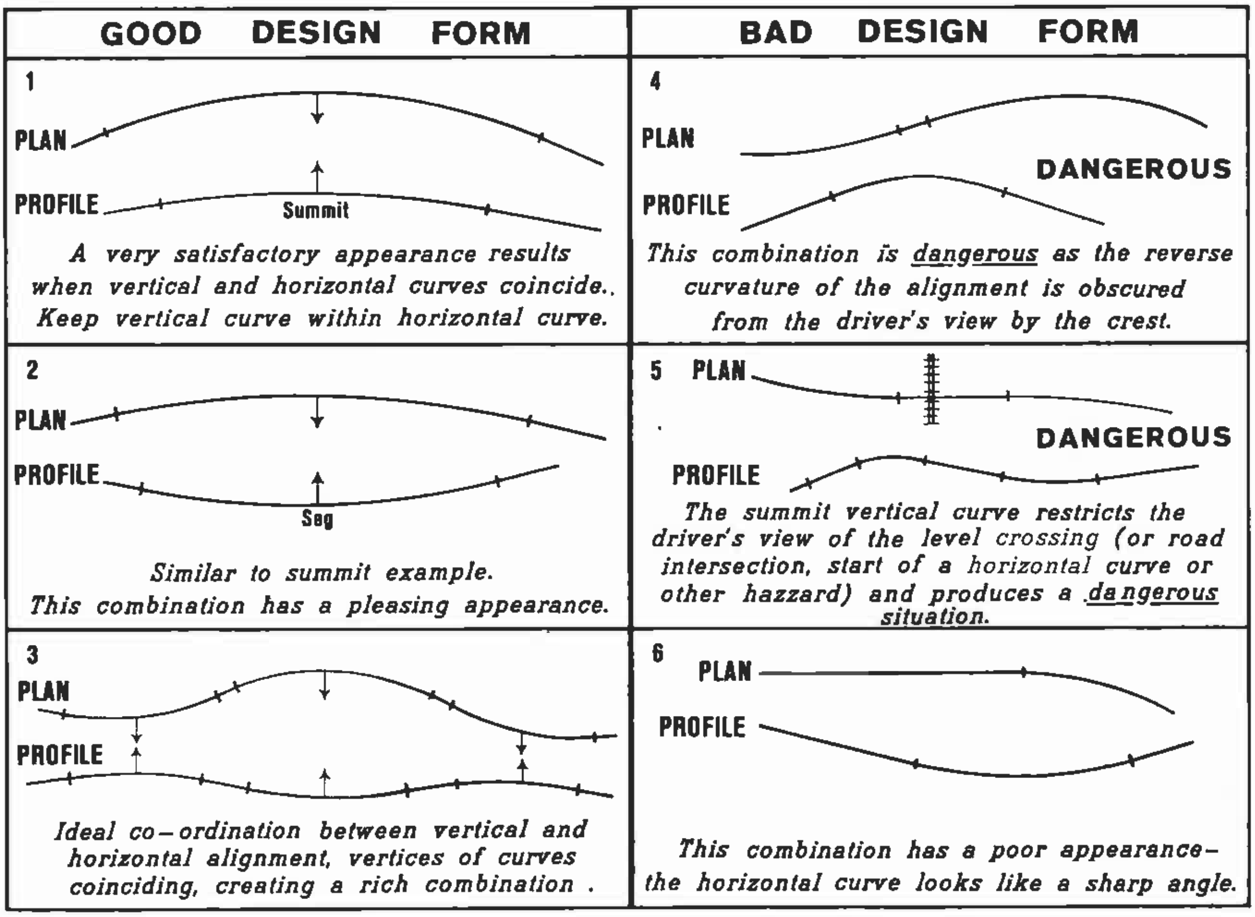

Figure 9.1 (a)

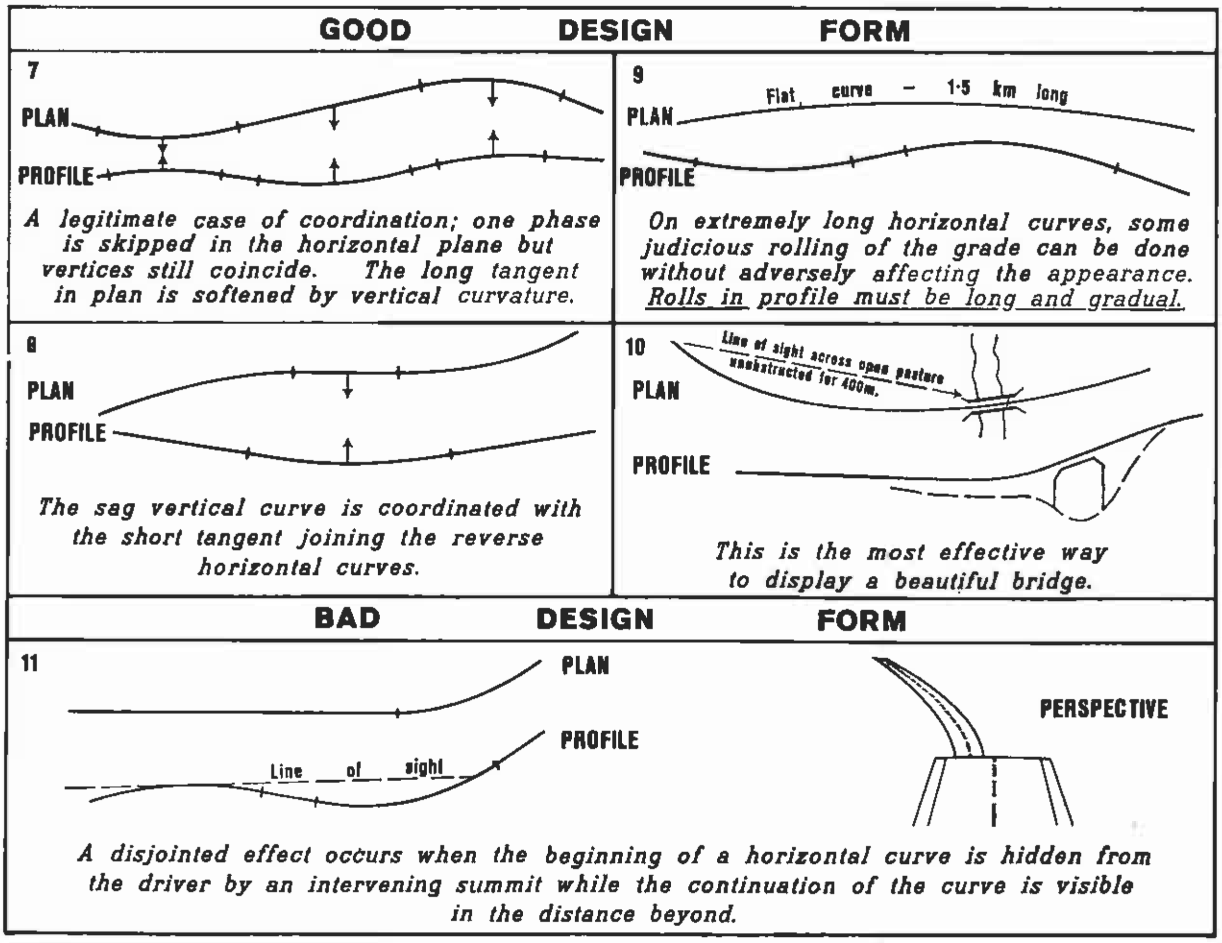

Figure 9.1 (a) (cont.)

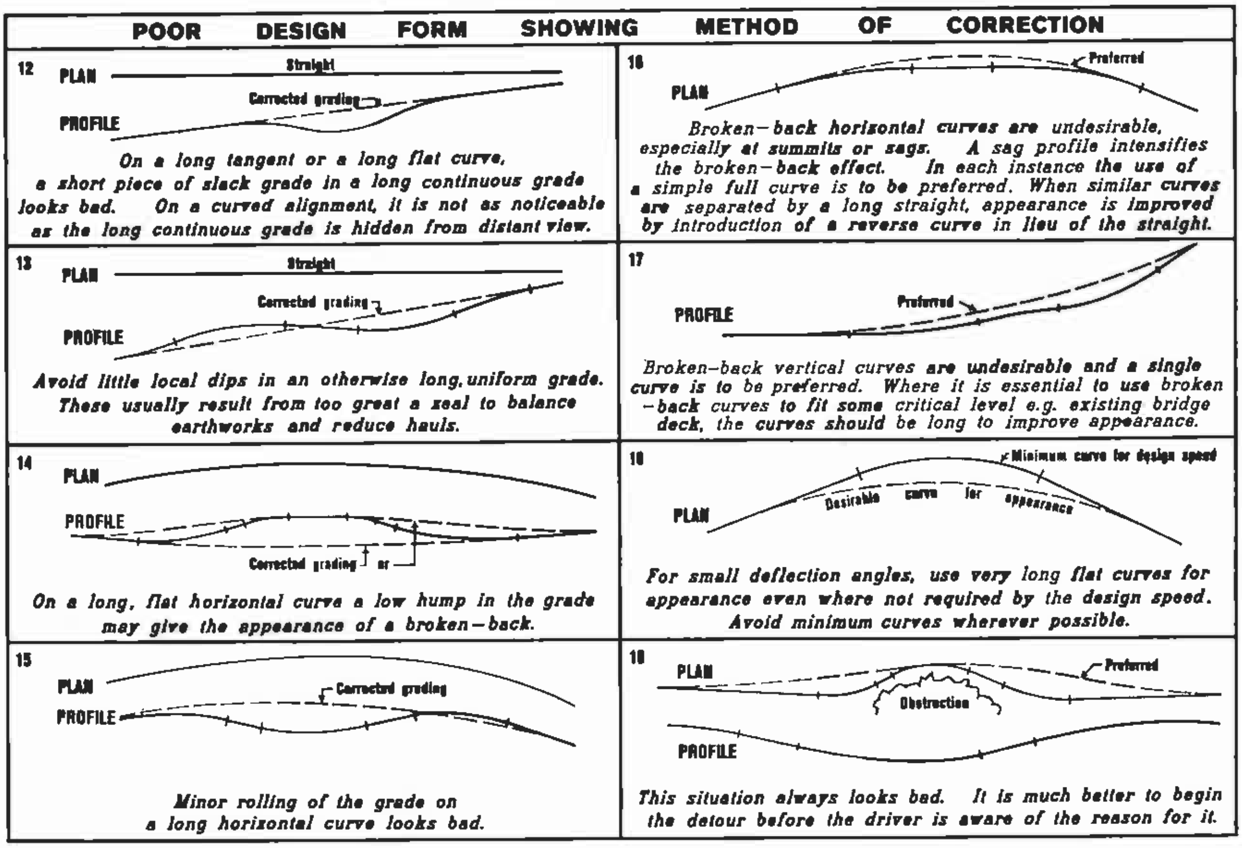

Figure 9.1 (b)

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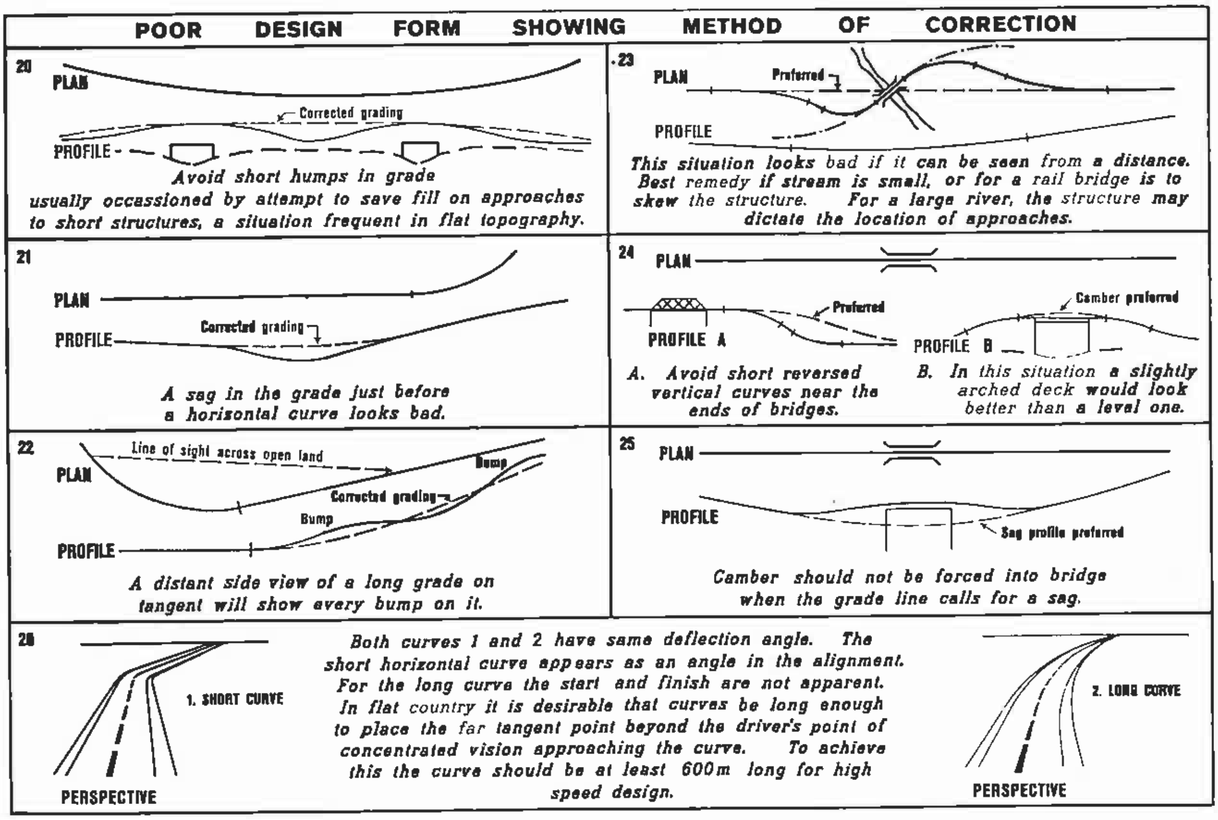

Figure 9.1 (b) (cont.)

Concepts of Design Form
Based on extracts from a publication by W. Brewster Snow and Man Made America by Tunnard and Pushkarev

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curves. If the drainage structure in the sag is a culvert, combining the horizontal and vertical curve presents little difficulty; if it is a bridge, then the structure may have to be built on a combined vertical and horizontal curve. The alternative is to construct the bridge on a straight with similar curves at each end of the structure, an arrangement which would give a disjointed look unless the structure is long enough to be the dominant feature of the road.

9.4.3 Horizontal and Vertical Curves at Crests. A horizontal curve on a crest has less influence on the appearance of a road than at a sag. Minimum radius horizontal curves are undesirable at crests for two reasons: the crest may mask the sharpneses of the horizontal curve; to achieve a given sight distance benching below road levels may be necessary (see Section 5, Sight Distance). One advantage of a combined horizontal and vertical curve is a saving in earthworks when the road passes over a spur or saddle.

9.5 HORIZONTAL ALIGNMENT

9.5.1 Road Speed and Horizontal Curves. There is evidence that most drivers approaching a horizontal curve adjust their speed to match the radius of the curve provided they can see it.(14) A driver in motion gauges the curvature of the road ahead by the apparent movement of reference marks on the curve.(15) His speed of approach does not seem to be influenced by the superelevation as much as by the curvature. A driver endeavours to enter a curve at a speed he thinks is appropriate and then adjusts speed to accord with the feel of the side thrust engendered by the radius and the superelevation. As his speed matches the elements of the curve it is important that the radius of the curve be not changed (e.g. by inserting a compound curve) for it is difficult to assess change in the radius from a moving vehicle already on the curve. The occasions on which compound curves may be used are discussed later in this Section.

The designer sees the layout in plan and is aware of all changes in alignment. A driver sees less. In daylight he may see the road ahead and its slight variations in alignment but at night time, or dusk, or when it is raining, the driver may have a poor view of the road ahead especially if he is relying on headlights as they shine tangentially, not around the curve.

In road design a crest should not obscure a horizontal curve if the radius of the horizontal curve is such that an approaching driver must reduce speed. Even slight crests can hide a change in alignment. The presence of the trap, i.e. a concealed horizontal curve, is not revealed by a conventional sight distance diagram, but must be sought by careful scrutiny of the design.

On the approach to a sharp curve, the pavement—not an object 200 mm high—must be visible for a sufficient distance to allow speed reduction, unless there are other permanent features, e.g. cuttings, which give clear indications of the curvature. At crests where the horizontal curve is sharp,

it is preferable that the vertical curve be contained within the horizontal curve since by this means the horizontal curve becomes visible ahead of the crest.

9.5.2 Design of Horizontal Curves in Easy Country. The radius chosen where the terrain is not a factor should be one in which the centripetal force is slight. A good design approach is that the $e + f$ value (equal to $V^2/127R$) should not exceed 0·07 which establishes the desirable minimum radius of curves for various design speeds given in Table 9.1.

TABLE 9.1
Desirable Minimum Radius for Horizontal Curves

Speed—km/h	Radius—metres
100	1100
110	1400
120	1600
130	1900

Arc lengths for curves used in these conditions should exceed about one-third the radius specified above to avoid the appearance of an alignment composed of short curves. Curving alignment composed even of large radius curves may restrict sight distance and hence inhibit overtaking. The view available across a chord of a large radius horizontal curve may be inadequate for safe overtaking. Where the curve is a left hand one the view is curtailed by the vehicle being overtaken.

Although generous arc lengths are recommended, horizontal curves on two-lane roads exceeding 1200 m in length should be carefully examined to assess the effect on overtaking manoeuvres.

On two-lane roads, long tangents are the best way of ensuring that overtaking sight distance is available. In level country, long straights on roads usually have to be accepted. The deliberate introduction of curves in plain country to break the monotony of long straights results in bends which look out of place. At night time unless the change in alignment is considerable oncoming headlights still remain a nuisance to drivers.

Where a horizontal curve with a radius smaller than those found elsewhere on the road is used, or the radius of the curve approaches the minimum for the design speed, it is essential that the curve be visible from both approaches. Unless curves are of large radius they should not occur on high fills with only the sky as a background.

9.5.3 Compound Curves. Compound circular curves may be used where:

(i) the topography or the position of an existing control (e.g. bridge or level crossing) makes it extraordinarily difficult to use a single curve.

(ii) The compound curves are of large radius and form part of a continuously changing alignment. Transition curves are used between two curves forming a compound curve except where the flatter curve has a radius less than one and a half times the radius of the other.

In the first case, where the flatter curve has a radius less than three times the radius of the sharper, the application of superelevation is modified. The fall is reduced on the flatter curve and increased on the sharper to reduce the amount of change in side friction as a vehicle goes from one curve to another.

In the second case, the transition used is similar in form to the transition between tangent and curve.

9.5.4 Reverse Curves. Reverse circular curves with common tangent points should be avoided because of the difficulty in changing superelevation direction. A short tangent of say $0{\cdot}4V$ metres will assist this warping. Reverse curves with common TS (tangent spiral) points or with short tangents between the TS points are acceptable. Superelevation transitions between reverse curves with short straights between them, are formed by warping the pavement from superelevation one way to superelevation the other. The road shape should not return to a crowned section unless this section can be maintained for several hundred feet.

9.5.5 Similar Curves. Similar curves linked by short tangents are undesirable on the grounds of both appearance and safety. There is a maximum length of short tangent which does not have much visual or practical effect, and a minimum length of long tangent which is required to give visual and practical separation of the two curves.

The maximum short straight which should be used with minimum radius curves is of the order of $0{\cdot}6V$ metres (V is speed in km/h), i.e. 2 seconds travel time. Thus, in most cases a single curve of slightly greater radius can be substituted for the separate curves and tangent, and this should be done where possible. With a short straight it will not be possible to revert to two-way crossfall, although a better visual effect might be obtained by reducing the one-way crossfall slightly on the straight—this will reduce the amount of steering correction required.

The minimum long straight to be used can be determined by allowing for normal two-way crossfall to be achieved, and maintained for perhaps 4 seconds. This leads to a total length of straight of between $3V$ and $4V$ metres (based on the superelevation transition lengths of Table 8.5). Such a tangent length is visually satisfactory. Where a minimum straight is not

available, the use of smaller radius curves may suffice to give additional tangent distance. Being sharper, these curves will serve to accentuate the difference between tangent and curve.

From the above, it can be seen that tangent lengths in the range say $0{\cdot}6V$ to $3V$ metres are visually and functionally unsatisfactory, and should be avoided wherever possible.

9.6 VERTICAL ALIGNMENT

Longitudinal sections composed of long tangents and generous vertical curves should be sought in preference to a grade line with numerous changes and short tangents. Compound and broken-back sag curves should be avoided. In designing the grade line, hidden dips can be avoided by adopting a sight distance based on a zero height of object, i.e. the pavement ahead, and making sure the pavement surface does not temporarily go out of view. Where the horizontal alignment contains tangents long enough to allow overtaking, the profile should not contain minor bumps or hollows which would obstruct sight distance.

Broken-back grade lines, i.e. two vertical curves in the same direction separated by a short tangent, should be avoided. The combination is unattractive in appearance, especially in sags, and should be replaced by a single long vertical curve. Usually the difference in levels between points on a compound curve and points on a single curve is not great.

It is common practice in road design for two reverse vertical curves to meet at a common tangent point. Here vertical acceleration caused by the change of path of the vehicle in a vertical plane is greater than if each curve ended on a tangent grade.

The algebraic sum of the changes of vertical acceleration should not exceed the maximum value, usually $0{\cdot}1g$. If there is difficulty in meeting this requirement a length of straight grade should be inserted between the reverse curves so that the vehicle for a time is wholly on a straight grade.

9.7 INTERSECTIONS

At intersections on roads with moderate to steep grades, the grade through the intersection should not normally exceed 3 per cent. In really difficult terrain 6 per cent may have to be accepted. It should be noted, however, that the grading of both roads through the intersection should be very carefully checked for comfort particularly where various movements can take place at speeds over 30 km/h. This is very important at channelized intersections where opposing directions of travel on one or both roads are well separated.

Consideration should also be given to providing better than stopping sight distance as the reaction time to realize that a slowly moving vehicle will not clear the intersection in time is greater than that involved in merely seeing the vehicle or any other obstruction.