COMPENSATING GRADES FOR CURVATURE.

The subject of compensating grades on curves in order to offset the increased train resistance due to curvature crops up periodically, and it is evident that practice in this direction is not only very diverse but is based upon a very uncertain foundation. The following article was compiled and published by the Engineering News, and presents the whole matter so fully that we reproduce it in full. It is mentioned in the early and noted "Shunk" and "Searles" field-books, the former giving a formula which is quoted below (by Mr. Beahan). In "Field Engineering" (1887), by W. H. Searles, the curve resistance (lb. per ton) on a curve of given degree is stated as $0.56 \times D$, while the grade (per cent.) on tangent having the same resistance as the given curve is stated as $0.025 \times D$. Thus the resistance and compensation were assumed to vary directly with the degree of curve, which is now almost universally recognized to give incorrect results. On the subject of compensation, Mr. Searles stated as follows:

"In locating a road, the maximum grade should be reduced on a curve by the amount of the equivalent grade of the curve [see formula above.—Editor.] so that the resistance may be no greater on the curve than elsewhere. But grades less than the maximum need not be reduced for the curves upon them, unless the sum of the grade and the grade equivalent exceeds the maximum."

The most extensive analysis (and we might say the only thorough analysis) of the subject is that given in Wellington's "Economic Theory of the Location of Railways" (1887), and we recommend a careful study of the exposition there given, with the reservation that the reader should remember that the conclusions may not apply directly under modern conditions of rolling stock and traffic. As a compilation of opinions on the subject would be incomplete without some outline of those of Mr. Wellington, we give below a few extracts together with his summary of conclusions:

Under three different conditions curvature may come (in advance of gradients) as a limiting agent to fix the weight of trains:

1. When curves are introduced on a maximum grade without reducing the rate of the latter by compensation for curvature, so as to keep the aggregate resistance constant on both curves and tangents. 2. When a line is nearly or quite level, and yet runs through a region requiring curvature which (as is very apt to happen on such lines) cannot be "compensated" because there are no grades, or no sufficiently high grades to reduce, in order to eliminate their additional resistence. 3. When on lines of the latter (or any other) class curvature of such short radius is used as to limit the length of trains more than would the same amount of curvature with longer radii. These causes are more or less interrelated.

The proper rate of compensation is not a fixed quantity, but may, under varying circumstances, vary within somewhat wide limits. The more usual rates are from 0.03 to 0.05% per degree of curvature, corresponding to 0.06 to 1.0 lb. per ton per degree. If the precise amount of curve resistance were known, and if it were always the same, of course but one rate of compensation would be proper, but as its precise rate is not known, and as there is strong reason to believe that in starting a train it may possibly amount to as much as 2 lb. per ton, a compensation sufficient to equalize curve resistance in ordinary circumstances cannot be assumed to be certainly sufficient at points where speed may be expected to be very slow, as toward the top of long grades and occasionally at other points.

Under these circumstances, prudence would indicate that wherever there is no physical limit to the possible reduction of grade on curves, it should be made ample, so that the curves should certainly offer no greater resistance than the adjacent tangents. At stations this rule would require a grade reduction of 0.1% per degree.

On the other hand, when we are merely trying to equalize the tangent and curve resistance on a long ascent, and whatever is taken off the curves must be added on to the tangents, no such practice is proper. If we come as near to an exact equality as we can, in compensating for curvature, it is of no importance whether our compensation is a little too great or a little too small. In the one case trains will stall on the tangents and in the other on the curves; that is all. Our object is simply to guard against a certainty of stalling on either. Nothing more than this is important.

Hence it may well be that on a long and crooked ascent, where the curvature greatly exceeds the tangents, yet where there are one or two considerable tangents, prudence will require the assumption of a very low rate of compensation; for otherwise a very slight loss of elevation on each curve, multiplied by many curves, will prevent our attaining the desired summit without a considerable increase of the normal tangent grade. If we have guessed right as to the real curve resistance, this may do no harm; but, on the other hand, if we have guessed wrongly, and exaggerated the probable curve resistance, we shall have unnecessarily increased our tangent grade. Hence, by assuring a low rate of curve resistance in such a case, we can hardly in any case lose anything appreciable, and may save a needless loss of grade. A compensation rate of 0.03% per degree of curvature may then be proper, below which the rate of comsation should never fall.

For the same reasons, it may well happen that at different points on the same line different rates of compensation may be proper. Where the loss of elevation by a high rate of compensation is a very serious matter, because of a great amount of curvature, it may be taken at a minimum. At other points, where there is less curvature to be compensated and a higher compensation can be had at little or no cost, it should there be used. The effect will be to make most of the maximum grade scattered over the division a little easier to handle trains on than the longest or worst grade. This may well result in handling a car or two more than would be deemed possible were the resistance as great at two or three points as it is at one.

It is always worth while to keep a little below the maximum where possible, at moderate cost. This is only another application of the same principle, but, owing to the uncertainty which hangs about the question of curve resistance, it is a wiser way of attaining the same end than to reduce the nominal tangent grade, especially in the vicinity of stations.

Conclusions.—1. With short grades or under favoring topographical conditions compensate as liberally as possible up to a maximum at special points of 0.10% per degree.

2. Where speed may sometimes be very low, and hence invariably on or very near to known stopping places, this maximum rate appears, with our present knowledge, none too much. In general, however, 0.05% per degree (= 1 lb. per ton) is an ample equivalent for curve resistance, and for fast trains alone probably 0.02 to 0.03% (= 0.4 to 0.6 lb. per ton) is sufficient to balance the resistance.

3. On sections where curves largely predominate over tangents it is particularly desirable to have ample compensation, and, if excessive, it will do least harm.