curve would be 1.76%. The amount of elevation lost by compensating the grade is found by multiplying the degree of central angle of the curve by the rate of compensation; and this elevation divided by the length of grade will give the rate by which the maximum grade on tangent must be increased to avoid a final loss in elevation.

"The change in grade may commence at the nearest even station, and not necessarily at the P.C. The reduced grade extends usually beyond the curve. To avoid too great a loss in elevation or too heavy a grade on the tangent, it may be necessary to modify the rate of compensation, but this will depend largely upon traffic conditions. In general, the compensation should be introduced even upon easy grades, especially those which approach the rate of ruling grade, in order to provide for future increase in train loads or reductions in grades. For curves of 10 deg. or over, the rate of compensation may be reduced (as curve resistance does not increase with the degree of curve). There is a great diversity of practice which is based largely upon opinion and experience, and there is much need for careful experiments in order to give some definite knowledge as to the requirements under modern conditions of rolling-stock and traffic."

The following quotation is from Webb's "Railway Construction" (1909):

On minor grades the addition [of resistance due to curvature] is of little importance, but when the grade is nearly or quite the ruling grade of the road, then the additional resistance induced by a curve will make that curve a place of maximum resistance, and the real maximum will be a virtual grade somewhat higher than the nominal maximum.

The proper rate of compensation evidently is the rate of grade of which the resistance just equals the resistance due to the curve. But such resistance is variable. It is greater as the velocity is lower; it is generally about 2 lb. per ton (equal to a grade of 0.1%) per degree of curve when starting a train. On this account the compensation for a curve which occurs at a known stopping place for the heaviest trains should be 0.1% per degree of curve. The resistance is not even strictly proportioned to the degree of curvature, although it is usually considered to be so. On this account the compensation per degree of curve may be made less on a sharp curve than on an easy curve. The compensation actually required for very fast trains is less than for slow trains, say 0.02 or 0.03% per degree of curve. But since the comparatively slow and heavy freight trains are the trains which are chiefly limited by the ruling grade, the compensation would be made with respect to those trains. From 0.04 to 0.05% per degree is the rate of compensation most usually employed for average conditions.

1. On the upper side of a stopping place for the heaviest trains, compensate 0.10% per degree of curvature.

2. On the lower side of such a stopping place do not compensate at all.

3. Ordinarily compensate about 0.05% per degree of curve.

4. Reduce this rate to 0.04 or even 0.03% if the grade on tangents must be increased to reach the required summit.

5. Reduce the rate somewhat for curvature above 8 or 10 deg.

6. Curves on minor grades need not be compensated, unless the minor grade is so heavy that the added resistance of the curve would make the total resistance greater than that of the ruling grade, or unless there is some ground to believe that the ruling grade may be reduced some time below that of the minor grade under consideration.

The American Railway Engineering Association, through its standing committees, has given a considerable amount of attention to this subject. It is to be noted that the committees which have reported upon it have been of a rather exceptionally high character as to the members and their work, and for this reason their statements deserve careful consideration. Extracts from the several reports, covering practically all that is said on this particular subject, are given below:

1901—In connection with a complete change of location or a modification of the existing location, the maximum grade and curvature should be decided and the necessary compensation calculated for the curves, to make the resistance on curves equal to that on a straight line. On lines where tests have been carried out on an extensive scale, it has been found that it is good practice to use 0.03% for each degree of curvature for all curves up to and including 2 deg., and 0.04% above that to 4 deg (Committee on Grading.)

1902—From the result of the committee's inquiries it would seem that the practice in this country at present favors compensation proportioned to degree of curve, and 0.04% per degree represents average practice. The observation of the effect of compensation, however, seems on the whole not to have been critical enough to determine definitely whether or not it should be proportional to the degree of curve, and further experiment and critical observation are needed. The effect of curves, as shown on a speed recorder capable of recording slight changes in speed, is suggested as a desirable method of experimenting. (Committee on Roadway.)

1907—Curve resistance is estimated by different engineers at different values. The compilation made by the Committee on Roadway (1902), showed that 0.8 lb. per ton per degree on central angle, or 0.04% for compensation per degree, well represented average practice. (Committee on Economics of Railway Location.)

1908—An inquiry was made by the above committee as to whether any experiments had been made in recent years which confirm or modify the commonly accepted value of 0.04% per degree of curve as the rate of compensation for curvature. Although independent experimental work was referred to, many of the answers merely stated the practice regarding curve compensation. There was a remarkable amount of unanimity in saying that 0.04% was a little higher than necessary, that 0.03% was too small and that 0.035% seemed the proper figure. The variations ranged from 0.02 to 0.08%. In investigating the accuracy of allowance for compensation, the widening of gauge on curves should be tested.

1910—We are interested in curve resistance chiefly from the standpoint of its compensation. In the location of a railway, curvature evils may be eliminated partially by reducing grade on the curve by such an amount as to make the engine effort the same on curve as on tangent. Tests made on the Baltimore & Ohio R.R. (1904), show that on the portion compensated 0.03%, the resistance on curve was greater than on tangent, and on the portion compensated 0.04% the resistance on curve was less than on tangent. In replies to a circular sent out in 1907, the consensus of opinion was that 0.035% per degree gave the best results. (Committee on Economics of Railway Location.)

The committee's recommendation, as adopted by the association, reads: "In order to equalize resistance on curve and tangent, curves ordinarily should be compensated 0.035% per degree of curvature. The effect of curve resistance is dispelled more slowly at slow speed than at high speed."

In the discussion, some of the speakers proposed to substitute 0.04%. Further it was pointed out (following the Wellington line of reasoning) that the rate of compensation should never be made absolutely constant, as the effect of the compensation on construction and on the ruling grade