Or that a 12° curve doubles the level resistance, or that a 1° curve is equal in train resistance to a .025%g rade; strictly, therefore, we should lessen gradients on curves by .025 for each degree of curve, to compensate for curve resistance, but this would be scarcely enough, for whenever a train is nearly stalled, curve resistances due to low speed will be much higher, and if the train is once stalled it will be hard to start again on a curve just barely compensated. For this reason it is customary to compensate for curves at a higher rate than is theoretically necessary, the usual amounts being .04 to .05 per degree of curve, depending on how valuable a few feet are, in elevation, on maximum grades.

ART. 7.—THE COST OF TRAIN RESISTANCES.

It must not be supposed that the expenses of operating a road vary with the total train resistances found according to the rules given in Art. 6. Even the fuel consumed is only affected partially by variation in train resistances; some are affected very much, as car repairs and rail wear, while others, such as maintenance, general expenses, etc., are hardly affected at all.

(*A*) *Cost of Curve Resistances.*—It is estimated that 36 per cent. of the working expenses vary with the curve resistances, and taking the cost of a train mile at 90 cents, and a continuous 12° curve for a mile = 633° curvature, = one mile of level tangent resistances; then, the cost of operating a train each way for a year around 1° of curvature $= 365 \times 2 \times \frac{90}{633} \times 36$ per cent. $= 37\frac{3}{10}$ cents, therefore, we are justified in spending $\frac{100}{5} \times 37.3$ cents = $7.46 per daily train, during construction, in eliminating each degree of curvature with money at 5 per cent., any number of trains per day, or degrees of curve in direct proportion, from which it is evident that the worst features of sharp and heavy curves are more questions of appearance, comfort and safety, than of actual cost in operating, especially as the case is always one of more or less curvature only, and not a question of curves or no curves.

With roads expecting light traffic and heavy grading, it is evident that a very great amount of curvature will be justified; and then, too, it must be remembered, that it is the total angle of a curve and not its sharpness that counts in the total train resistances; the only objections to sharp curves are the slightly increased danger of derailment, the necessary slackening down from very high speeds, the slight lengthening in distance, and the sentiment of the public against them.

(*B*) *The Cost of Grade Resistances.*—Grades must be viewed from two standpoints: first, as so many feet of rise and fall, up and down which the trains must be carried; and second, as the limiting features to the maximum load which a given engine can haul at a low speed over a freight engine division. Under the first heading Wellington divides them into three classes:

(1) Those which are so light or short as to be passed over with uniform steam on and no brakes, the speed only fluctuating. Such grades cost nothing appreciable more to operate than level grades, as the trains going each way in a day gain as much energy as they lose. These grades would be, roughly, anything less than 0.5 per cent.

(2) Those in which steam is cut off in descending, but which do not need brakes in descending nor sand in ascending. It is estimated that one foot of rise and fall, per daily train per year on this class of grade, costs:

Eighty-four cents, if a minor grade, which equals $16.80 capitalized; $1.67, if a maximum grade, which equals $33.40 capitalized. These may be taken roughly as grades between 0.5 per cent. and 0.8 per cent.

(3) Those on which brakes are needed in descending and sand used in ascending. These are estimated to cost per daily train per year, per foot of rise and fall, $3.50, which equals $70, capitalized at 5 per cent. These may be taken as any grades over 0.8 per cent., unless of very short length. By multiplying the above sums ($16.80, $33.40, or $70) by the number of daily trains expected, we can arrive at the total expenditure justifiable to save each foot of rise and fall.

TABLE IX.

(*See Wellington, page 544, for larger table.*)

NET TRAIN LOADS OF VARIOUS ENGINES ON VARIOUS GRADES TAKING 25 PER CENT. AS THE RATIO OF ADHESION.

Grade.	Resistance per ton (in lbs.)	Passenger.		Mogul and 10-wheel			Consolidation.			Mastodon.
		Total Wt.		Total Wt.			Total Wt.			Total Wt.
		52 tons.	58 tons.	60 tons.	64 tons.	67 tons.	70 tons.	75 tons.	80 tons.	87 tons.
		Weight on drivers.		Weight on drivers.			Weight on drivers.			Weight on drivers.
		20 tons.	24 tons.	28 tons.	32 tons.	36 tons.	40 tons.	44 tons.	48 tons.	52 tons.
Level	9	1,198	1,442	1,690	1,938	2,163	2,430	2,675	2,920	3,163 tons
1/10 per cent. ...	10	918	1,142	1,340	1,536	1,733	1,930	2,125	2,320	2,513 "
3/10 " ...	14	662	799	940	1,079	1,219	1,359	1,496	1,634	1,770 "
5/10 " ...	18	504	609	718	825	933	1,041	1,147	1,253	1,357 "
1 " ...	28	305	371	440	507	576	644	711	777	842 "
1½ " ...	38	211	258	308	357	407	456	504	552	597 "
2 " ...	48	156	192	232	269	308	347	383	420	455 "
2½ " ...	58	120	149	181	212	243	275	304	334	361 "
3 " ...	68	95	118	146	171	198	224	249	273	295 "
4 " ...	88	62	78	99	118	138	157	175	193	208 "
5 " ...	108	41	53	70	84	100	115	129	142	151 "
10 "	208	0	0	7	13	20	26	31	35	38 "

Remember the above sums are not supposed to be precise, but to be as near as it is possible to arrive at the truth. These figures refer to the cost of grades regarded merely as so many feet of rise and fall, and are entirely independent of and distinct from the effect which the maximum grade has on the train load, which is a far more important matter. In special cases, as on the N. Y. C. and H. R. Railway, where the grades are very light, the curves are the limiting features, but usually grades limit and determine the load which a given engine can haul. The hauling capacity usually depends on the weight on the drivers, and the ratio of adhesion, although for high speeds the limits of boiler capacity or cylinder power may be reached first; for freight work, however, the former are all we need to consider. The ratio of adhesion varies from 20 per cent. on slippery rails to 25 per cent. in ordinary weather, and to 33 per cent. where sand is used, but falls at once to about 10 per cent. when the driving wheels begin to slip. For any assumed ratio of adhesion it is easy to compute the load which an engine of known weight on drivers can haul up any grade. The total load includes the engine itself, but on light maximum grades it is not usual to haul maximum loads because of the difficulty in handling long trains and making couplings strong enough to transmit a very heavy pull when combined with the severe jerks caused by the great amount of slack in link and pin couplers. The increasing use of automatic vertical plane couplers having very little slack will soon do away with this difficulty and enable longer trains to be handled with facility. Table IX. enables us to compute the increased or decreased engine mileage due to a change in maximum grades, for any given amount of traffic. For light traffic such calculations must be modified, as more trains will be run to accommodate traffic than are strictly required to carry it, and only as traffic increases so as to afford at least two or three fully-loaded freight trains per day will such calculations be rigidly true—even