

mile running with steam shut off can be read directly from the diagrams. By multiplying each of these costs by its respective distance and adding the two products together we have the cost of motive power per round trip. The fuel used when running down hill with steam shut off is taken at 10 per cent. of the maximum (see Wellington), and the same percentage is used for helpers returning down grade light. The problem of finding the motive-power cost for any case is thus reduced to the determination of the number of miles run under steam, and also with steam shut off, and the average speed for each condition.

The type and tractive power of the locomotive being determined, its rating and the make-up of trains in each direction are calculated for ten miles per hour on the ruling grades. Helpers are estimated for steeper grades when by their use the total annual cost of motive power is reduced by increasing the length and weight of the trains. For this purpose the tractive power of the engine is taken at nine-fortieths of the weight on the drivers, which can be depended upon at the low speed of ten miles per hour. The train-resistance is taken at 7.31 lb. per ton of 2,000 lb.; the safe average of several experiments at slow speeds. The grade-resistance in pounds per ton of 2,000 lb. is 0.3788 times the rise in feet per mile. Diagram 7 gives the total train and grade resistance for any grade. Dividing the resistance for the ruling grades from Diagram 7 into the tractive power of the engine, and deducting from the result the weight of the engine and tender, gives the weight of the train behind the tender that can be hauled up these grades. Dividing the total weight of the train by the tractive power of the engine, both in pounds, gives the number of miles of 1,000 lb. each per unit of tractive power of 1,000 lbs. This is calculated for trains in each direction and for each helper run, and for the Arthur's Pass lines is shown in Table 3.

As stated above, the engines are supposed to develop their entire steaming-capacity all the time, except when running down grades steep enough to maintain the maximum speed, assumed at sixteen miles per hour, without steam. When the capacity of the engine is not all consumed in overcoming train and grade resistances, the balance is expended in accelerating speed. The momentum or velocity head acquired at the foot of a down-grade is absorbed in overcoming a part of the grade-resistance of the succeeding up-grade. The effect of this is to reduce all of the grades, except long-ruling and helper grades, opposed to trains moving in the direction under consideration.

Having found the miles per unit of tractive power for the several cases required, we next require a table showing the speed in miles per hour that an engine so rated can attain on any grade. It is evident that in all cases no grades steeper than the ruling or rating grade need be considered, because the entire adhesion is used in rating. For convenience the same table should give the momentum of velocity heads in feet corresponding to each speed in miles per hour, from ten miles per hour, the minimum speed on ruling and helper grades up to the maximum speed permissible, in this case sixteen miles per hour down hill and twenty miles per hour up hill or on level track. Such a table, which we will call a "Speed-rating table," was prepared by the late Mr. W. G. Curtis, of the Southern Pacific Company, and published in the "Bulletin of the American Railway Engineering and Maintenance-of-way Association," by Mr. John D. Isaacs, of the same company. It was prepared for rating purposes. This table is computed by dividing the total resistance in pounds per mile for each combination of speed and grade into the tractive power of the engine at the same speed, and dividing the result by the units of tractive power of the engine at ten miles per hour. Table 4 is a similar table which I have computed for the conditions of the Arthur's Pass problem.

The velocity head in feet of any speed is the vertical fall down grade through which a train would have to run by gravity and without frictional resistance to attain that speed. Conversely, it is the vertical rise in feet through which a train running at a given speed, without either friction or motive power, would have to pass to come to rest. The grade of double power is about 20 ft. per mile (see Wellington), and therefore a train running down a 20 ft.-to-the-mile grade, without the use of either power or brakes, will have the same velocity at the bottom that it had at the top, and the speed will be uniform all the way. Trains running down grades steeper than 20 ft. per mile without either power or brakes gain in velocity head the actual fall less 20 ft. per mile. When the maximum permissible speed is attained on such grades brakes must be set. On grades less than the ruling and helper grades, for which the power has been rated at ten miles per hour, the surplus power will accelerate the speed until a balance is effected between the tractive effort and the resistance. This is attained when the velocity heads in feet, corresponding to the respective speeds in miles per hour at the beginning and end of the run under consideration, measured vertically upward from the track profile, give a new grade on which, at the speed corresponding to the velocity head at the end of the run, these forces will be in balance. These new grades are called the velocity or "virtual grades," and are the true grades governing the average speed and cost of motive power for any line. If the velocity heads for the speeds at every point are laid off on ordinates to the track-profile, lines connecting the upper ends of these ordinates are the virtual grades, and we then have the virtual or "operating profile." The operating profile thus gives the speed at every point of the line, in terms of the velocity head at which an engine can haul the given number of miles per unit of tractive power. It also gives the distance run down grade accelerating speed with steam shut off and also under brakes. The distances run under brakes in stopping are also given. The virtual or operating profile eliminates all sags of 20 ft. or less in the track-profile and improves all heavy grades except *long* ruling or helper grades.

If, now, we take the half sum of the velocity heads at two adjacent points of change of virtual grades on the operating profile, we have the velocity head of the average speed between these points. Then multiplying these average speeds by their respective running distances and dividing the sum of these results by the total distance run, all under steam, we have the average speed for the distance run under steam. In like manner we find the average speed for the distance run with steam shut off. These computations and results are given in Table 5. Having found the average