ones to use." However, the early designers were consistent to this extent, that they worked with the ultimate strength of their materials but took care to apply a sufficiently large factor of safety to bring their working stresses within the elastic limit.

Another fault of this method is that it confuses "fatigue of material" with stresses due to sudden loading. Fatigue is the evidence of "permanent work" done on the material while the impact formula in bridge design is an attempt to express the stresses caused by "temporary work." Impact is a property of the applied force depending on the way the load is applied, and it is only when resilience of the material is destroyed that fatigue appears.

But to return to our history. It was Bauschinger who proved that Woehler's rule did not hold good below the elastic limit, and in 1877 Prof. Winkler, of Berlin, first suggested that the dynamic effect of the live load should be considered in addition to its static effect. (Trans. Am.Soc.C.E., Vol. 41, p. 172-174.) In other words, his suggestion was that the effect of impact should be treated as an increase in the live load rather than a mechanical effect on the material of the structure.

The effect of simple impact on a bridge may be roughly analyzed if the word is used in its correct sense, meaning the effects due to the stopping of a moving body. When such a moving body strikes a bridge the kinetic energy or work stored in it must be dissipated in one way or another. There are three stages in the process. First, the motion of the moving body will be imparted to the particles of the structure and set them in motion. If the structure were free to move and perfectly rigid in itself all the energy would be thus transferred according to the laws of motion. Only such stresses would be developed as would be necessary to transfer the motion to the distant particles of the structure. However, as bridge structures are not rigid and are anchored to their abutments the particles move as far as they can and the total effect is what we recognize as deflection. This is the second stage. Some parts will be compressed and others stretched. Even the abutments are never absolutely rigid and will therefore also be affected. By this action the structure absorbs work and the process goes on until the sum of the internal work equals the work imparted by the moving body. But this is not a state of equilibrium, so a series of oscillations or vibrations begins which lasts until all the surplus energy has been converted into molecular work or heat. If at any instant the stresses in any part of the structure exceed the elastic limit, permanent work will be done and the structure will not regain its original shape. Its capacity to absorb work—its resilience—has been exceeded and it cannot give back all it received.

When a train moving at a high rate of speed passes over a railway bridge there is doubtless increased stresses due to sudden loading as defined above. There are also innumerable blows, shocks, jars, etc., too complicated for analysis. The result is that stresses are produced above those that the train would cause if at rest on the bridge. This difference in stress between what would be the static stresses from the live load at rest and the actual stresses, however produced, is what is covered by the "impact increment" of modern specifications.

Joseph M. Wilson in 1885 first introduced in America the method suggested by Prof. Winkler, but the most widely used formula was first brought into systematic use by the late C. C. Schneider and published in the specifications of the Pencoyd Iron Works in 1887. (Trans. Am. Soc. C.E., Vol. 34, 1895, p. 331-2.) Mr. Schneider had collected some data of experiments on existing bridges to ascertain the effect of passing trains and from this he developed the formula

$$I = L\left(\frac{300}{s + 300}\right)$$

In which I = impact increment to be added to the static live load stress L; s = loaded length of span producing the stress L.

It is an interesting fact that since then the American Railway Engineering Association, after making thousands of measurements on existing bridges, recommended this formula, and it is now widely used in railway work.

It will be noted that in this formula the value of I, the impact increment, depends only on s, the span length, or that part of the span which, when loaded, produces the maximum static stress. For a train moving at a uniform rate of speed the length s will determine the time required for the live load to reach its maximum, so that the value of I really varies inversely as the time required to apply the load and thus takes care of sudden loading. Also, as the longer spans will usually have the longer members this formula may be considered to insure that short members have a larger impact increment than the long ones. No account is taken of the inertia of the structure nor the relative mass of train and bridge since it is used for all types of spans and for this reason many engineers were not satisfied with it but favored a formula developed by Henry S. Prichard.

Mr. Prichard derived his formula by "starting with Launhardt's and modifying it to accord with the results of a study of all data bearing on the subject which was available," and in 1895 published it in the revised specifications of the New Jersey Steel and Iron Company. (Trans. Am. Soc. C.E., Vol. 41, p. 503.) This formula is

$$I = L\frac{L}{L + D}$$

I = impact increment;
L = live load stress;
D = dead load stress.

The impact increment in this formula depends only on the relative magnitudes of the dead and live load or, in other words, the relative mass of the bridge and the train. No account is taken of the speed at which the train is moving, or the length of span. In later specifications which use this formula, such as the Dominion Government, 1908, in order to correct this defect, the live load stress is first multiplied by a factor varying with the length of span and the product is used as L in the above formula. The factor is

$$\left(1.40 - \frac{s}{200}\right)$$

This is only used for spans under 80 feet.

It will be interesting to compare the relative values of the impact increment as obtained from these two formulas. In order to do this the values of I, as given by them, have been plotted as curves in Diagram 1. The ordinates give the values of the impact increment in percentage of the live load for spans up to 200 feet. As the Prichard formula depends only on the ratio of the dead and live load, two curves are shown—for dead load equal to zero, and for dead load equal to live load.

It will be noted that the Schneider formula gives values about an average between the other two curves. In actual design the relation between the dead and live loads is such that the results are about the same whichever formula is used, except for very short spans and heavy loading, under which conditions the Prichard formula gives higher values. The Dominion Government formula gives much higher values for spans under 80 feet.