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IMPACT FORMULAS FOR HIGHWAY BRIDGE DESIGN

PART I.

A BRIEF HISTORY OF TWO RAILWAY BRIDGE IMPACT FORMULAS, SHOWING THAT THEY ARE UNSUITED FOR HIGHWAY BRIDGE DESIGN.

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OVER a hundred years ago, in 1807, Thomas Young first announced the general principle of the properties of bodies "to resist impulse." This property, to which he gave the name "Resilience," is the capacity of a body to endure, absorb, or store up the work which may be done on it and give it out again under proper conditions.

As a simple example of this, when a tensile force is applied to a bar of steel, the bar is extended and work is done by the force. The work is absorbed by the bar and by the law of conservation of energy the internal work in the bar must equal the applied external work. When the external force is removed the bar assumes its original length, giving out as it does so the stored-up work which is, by definition, the resilience. Wherever in engineering structures there is compression, extension or deflection (provided the elastic limit of the material has not been exceeded) we have examples of resilience.

This property is of the utmost practical importance in engineering. Were it not for it a structure, no matter how strong under static loads, would be liable to be shattered by a light blow. Glass is an example of a material with low resilience and we are quite familiar with its "brittleness" and its inability to withstand a shock. But even a bar of iron or steel can be broken with a surprisingly small amount of work. A bar of steel having one square inch section area and a modulus of elasticity of 29,000,000 will require only 17.6 foot-pounds of work to stretch it to its elastic limit of 32,000 lbs.

If the bar were 10 feet long or 10 square inches in section it would take ten times as much work to stress it to the same point. So that the resilience of a bar or a bridge member varies as its section and length, or, which is the same thing, as its volume.

But the absorption of work is not quite instantaneous, although very rapid. Stress is said to travel in steel at the rate of about 17,000 feet per second—the same rate as sound. Rapid as it is, it is still slow enough to make it an important consideration. If the force be applied to the bar instantaneously by striking it a blow it is possible to stress the metal at the point of contact beyond the elastic limit or even the breaking point before the rest of the bar can absorb the work.

After Young, there was considerable investigation and discussion of the subject, but it was first put into practical form, as far as the engineering profession is concerned, in 1849, when an extensive series of tests was made in England by a "commission appointed to inquire into the application of iron to railway structures." The result of their report was that the British Board of Trade established the rule that for cast iron the factor of safety for live loads should be double that for dead loads. This rule was largely used for many years and became accepted as a general principle to be applied to live loads of any kind or however applied. It is based on the fact that a suddenly applied load, *i.e.*, one which reaches its maximum value the instant it is applied, does produce twice the stress in a structure that it would if it were applied gradually.

If a tensile force p be applied suddenly to a bar and extend it a length λ the work performed on the bar will be $p\lambda$. But in absorbing this work the stress in the bar increases from zero to p_b so that the work absorbed equals $\frac{p_b \lambda}{2}$.

As the internal work equals the applied work

$$p\lambda = \frac{p_b \lambda}{2} \text{ or } p_b = 2p$$

If the force were applied gradually p_b would equal p.

All the experiments of the above-mentioned commission were performed on cast iron and the experimenters failed to detect the elastic limit of the metal, as in this material it is so near the breaking strength. Besides, testing machines did not reach a sufficient degree of refinement to permit an accurate study of materials under stress until thirty years later. The commission, however, detected a phenomenon in materials subjected to repeated stresses which was called "fatigue." This subject was carefully investigated by Woehler between the years 1859-1870, and he established the principle that when a bar iron was subjected to a varying stress a number of times (sometimes it took an enormous number) it broke at a stress less than its maximum strength, as shown by a static test. This stress he expressed as a function of the ratio of the maximum and minimum stresses.

His principle was at once adopted in the design of iron bridges and was made applicable by suitable formulas by Launhardt and Weyranch. These formulas replaced the simple method of doubling the live load stress and they persist to this day in one form or another.

The fallacy of this method lies in the fact that Woehler's principle applies only to materials stressed beyond the elastic limit and it does not apply, and has no meaning, if the stress is below this point. As some one has said: "If we were designing a structure so that it would *fail*, then Woehler's formulas would be the correct