Statically Indeterminate Structures and the Principle of Least Work

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From the author's introductory:

THE subject of statically indeterminate structures has been much neglected in English engineering text-books. Special cases, such as stiffened suspension bridges and rigid arches, have, it is true, been dealt with by more than one writer, but the general question has only been considered in a few scattered papers by a number of different authors. An excellent treatise on the subject was published in Italy by Castigliano in 1879. In this volume the principle of least work was enunciated and its application to determining the stresses in a structure containing superfluous bars explained. These stresses can, it is true, be determined by other methods which Maxwell seems to have originated, but the method of least work has great practical advantages, and will be adopted as the basis of what follows.

Every metallic or wooden structure is elastic, and constitutes a spring. If a spring is loaded by a weight, it elongates, and a certain amount of work is done in this elongation. This work is stored in the spring in the form of potential energy, and can be reconverted into mechanical work, as is commonly done in clocks and watches. The stiffer the spring the less it is deformed by a given weight, and hence less work is stored in a stiff spring loaded with a 1-lb. weight than in a light one loaded by the same weight. Thus if 1 ton is hung from a steel bar of 2 square inches in section, less work is done in deforming the bar than if it was hung on a steel bar of the same length and of 1 square inch section. If a weight lies on a platform supported by four legs of elastic material, work will be done in deforming the platform and in compressing the legs.

If there had been only three legs, the ordinary principles of statics would suffice to determine the weight taken by each leg, which is then quite independent of the comparative stiffness of the legs and the platform. When, however, we have more than three legs, these statical principles no longer suffice, and to determine how much of the weight is carried by each leg it is necessary to introduce other considerations. The one great principle to which such problems can be reduced is known in dynamics as that of least action, and in such problems as we have before us as that of "least work."

That is to say that the work stored in an elastic system in stable equilibrium is always the smallest possible.

As an illustration, suppose a piece of steel ribbon is bent between two stops A and B, Fig. 1, then there are several possible positions of equilibrium for such a spring. For example, the S-shaped curve A D E B is one possible position of equilibrium, and the three-lobed curve A F G B is another, whilst a third possible position of equilibrium is the single-lobed curve A C B. Of these different possible positions of equilibrium some are more stable than others. Thus a slight shock or displacement will cause either the three-lobed curve or the two-lobed one to pass into a single-lobed one like A B, but this latter cannot by a small shock be made to pass into either of the other forms.

Hence it is a case of stable equilibrium whilst the others are unstable. It will be noted that the stable form is the least bent one, and as the work stored in a flat spring increases with the amount of bending, it is obvious that the work stored up as potential energy is less in the stable than in the unstable conditions of equilibrium….

Returning now to our four-legged table, there are an infinite number of ways in which the load could be distributed over the four legs, whilst still maintaining equilibrium. But if the equilibrium is to be stable, the distribution will be such that the worked stored up as potential energy will be as small as possible....

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