NEW FORMULAS FOR THE LOADS AND DEFLECTIONS OF SOLID BEAMS AND GIRDERS

Published @ 2017 Trieste Publishing Pty Ltd

ISBN 9780649330348

New formulas for the loads and deflections of solid beams and girders by William Donaldson

Edited by Trieste Publishing Pty Ltd.
Cover @ 2017

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BY

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LONDON:
E. & F. N. SPON, 48, CHARING CROSS.
NEW YORK:
446, BROOME STREET.
1872.

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INTRODUCTION.

THE aim of the Author, when he commenced the Essay which he now ventures to submit to the criticism of his fellow-engineers, was to obtain a set of formulas for the loads and deflections of solid beams, strictly based on the assumption *ut tensio sic vis*, but not vitiated by the absurd restriction to the full meaning of the maxim, which seems hitherto to have been the stumbling-block in the way of any honest investigation of the subject, *viz.* that the neutral surface must in all cases pass through the centre of gravity of every section of the beam.

The clear and simple meaning of the maxim is, that if any given force is capable of producing a certain amount of extension or compression, double the force would produce double the amount of extension or compression; not that the absolute amounts of extension or compression produced by the same force would be equal—an assumption which is identical with the assumption that the neutral surface passes through the centre of gravity of each section.

The earlier efforts of the scientific men who undertook the investigation of this subject, were simply directed to find out formulas for the loads which beams are capable of supporting without injuring the elasticity of the materials of which they are composed, and the amount of deflection due to those loads; in other words, to find out the intensity of the internal molecular forces without troubling themselves about theories, as the way in which these molecular forces acted and reacted upon each other—a plan which the Author feels sure the practical sound common sense of all engineers speaking the English language, whether English or American, will acknowledge to

be the only one worthy the consideration of men who have real work to do.

During the last few years the *savants*, who still continue these investigations, seem to have left the beaten track, and not content with ascertaining what loads beams of certain sections can support, or perhaps, to speak more correctly, not troubling themselves with that phase of the question at all, have endeavoured to find out, not what the beams can do, but how they do it. Several papers, written apparently with this object in view, have been read at the Institution of Civil Engineers, and have obtained the most honourable recognition of their merits which the Council have it in their power to bestow, although their investigations have neither led to any practical results, nor advanced the subject under discussion one whit further than the stage at which it was left by Barlow, Hodgkinson, Fairbairn, and those who preceded them.

The other extreme into which those who devote their attention to the subject might rush, would be simply to content themselves with ascertaining the breaking loads of various sections of beams of different materials by actual experiments, and determining by this means the value of certain constant factors involved in empirical formulas, based loosely on the assumption *ut tensio sic vis*. The proof and working loads would then be assumed to be equal to some fraction of this load taken sufficiently small to assure the present safety of the beam. This is an error more dangerous than the former, since it leads to the practical adoption of formulas which are erroneous, and may eventually lead to failure, if the beams are repeatedly subjected to the load which they are supposed to be able to bear, whilst the other merely affords occupation to theorists, whose investigations have no influence on the practice of engineering.

Steering midway between these two courses, the Author has worked out with strict accuracy formulas based on the assumption *ut tensio sic vis*, and afterwards tested their approximate truth by comparing the breaking weights calculated from them with the actual breaking weights of beams of various sections

and lengths ascertained by experiment. The results of these investigations are given in Chapters II., III., and IV., which are devoted to the consideration of beams of cast iron, wrought iron, and timber respectively.

With respect to cast iron, the conclusions which the Author has drawn from his investigations, are—

1st. That the maxim *ut tensio sic vis* is not exactly true, whatever may be the absolute magnitude of the stress, but that within certain limits of stress, beyond which the molecular forces cannot be exerted without impairing the elasticity, the maxim is practically correct, and the modulus of elasticity in compression equal to the modulus in extension.

2nd. That the proof tensile and compressive stresses to which it is safe to subject cast iron, do not bear to each other the same ratio as the ultimate tensile and compressive stresses do, inasmuch as whilst the ultimate compressive strength is to the ultimate tensile strength as 6 : 1, the proof compressive strength is to the proof tensile strength as 3 : 1 only. With respect to wrought iron, they are—

1. That the maxim *ut tensio sic vis* is absolutely true within certain limits of stress, the modulus of elasticity in extension being equal to 28,000,000 lbs. per square inch, and in compression to 22,000,000 lbs. per square inch, but that beyond these limits the maxim no longer holds true, even approximately.

2. That the proof tensile and compressive stresses to which it is safe to subject wrought iron do not bear to each other the same ratio as the ultimate tensile and compressive stresses do, inasmuch as whilst the ultimate compressive strength is to the ultimate tensile strength as 4 : 5 only, the proof compressive strength is to the proof tensile strength as 3 : 2.

It follows, from these deductions, that the repeated applications of the working load on cast-iron beams, designed according to the rules of construction at present recognized, must repeatedly subject the material in the upper flange to its proof stress, and therefore ultimately cause failures. Again in wrought-iron beams, although a greater stress than the working

stress in either the upper or lower flange will never be caused by a working load, fully one-sixth part of the whole weight of iron used has been wasted, considerations which the Author hopes will secure for his Essay either a prompt refutation, if the principles inculcated in it are wrong, or a silent acknowledgment of their truth evinced in the altered practice of engineers.