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Practical Essay on the Strength of Cast Iron and Other Metals

Although cast iron was used in pagoda construction in ancient China, it was in Britain in the eighteenth century that new methods allowed for its production in quantities that enabled widespread use. An engineer who had educated himself tirelessly in technical subjects from carpentry to architecture, Thomas Tredgold (1788–1829) first published this work in 1822. It served as a standard textbook for British engineers in the early nineteenth century, and several translations extended its influence on the continent. Reissued here in the fourth edition of 1842, edited and annotated by the structural engineer Eaton Hodgkinson (1789–1861), who presents his own research in the second volume, this work addresses both practical and mathematical questions in assessing metallic strength. In Volume 1, wherever progress has been made since the original publication, Hodgkinson adds notes to Tredgold's original text, pointing out certain errors.

Practical Essay on the Strength of Cast Iron and Other Metals

Containing Practical Rules, Tables, and Examples, Founded on a Series of Experiments, with an Extensive Table of the Properties of Materials

Volume 1:
Practical Essay on the Strength of Cast Iron and Other Metals

Thomas Tredgold
Edited by Eaton Hodgkinson

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PRACTICAL ESSAY

ON THE

STRENGTH OF CAST IRON

AND OTHER METALS:

CONTAINING

PRACTICAL RULES, TABLES, AND EXAMPLES, FOUNDED ON A SERIES OF EXPERIMENTS;

WITH AN EXTENSIVE

TABLE OF THE PROPERTIES OF MATERIALS.

BY THOMAS TREDGOLD,

MEMBER OF THE INSTITUTION OF CIVIL ENGINEERS,

AUTHOR OF 'THE HISTORY OF THE STEAM ENGINE,' 'ELEMENTARY PRINCIPLES OF CARPENTRY,' &c., &c.

THE FOURTH EDITION, WITH NOTES BY

EATON HODGKINSON, F.R.S.

TO WHICH ARE ADDED

EXPERIMENTAL RESEARCHES

ON THE

STRENGTH AND OTHER PROPERTIES OF CAST IRON;

WITH

THE DEVELOPEMENT OF NEW PRINCIPLES; CALCULATIONS DEDUCED FROM THEM; AND INQUIRIES APPLICABLE TO RIGID AND TENACIOUS BODIES GENERALLY.

BY THE EDITOR.

LONDON:

JOHN WEALE, 59, HIGH HOLBORN.

MDCCCXLII.

TO

JAMES WALKER, ESQ.,

CIVIL ENGINEER,

FELLOW OF THE ROYAL SOCIETY,
&c., &c., &c.,

PRESIDENT OF THE INSTITUTION OF CIVIL ENGINEERS,

This Essay

ON THE

STRENGTH OF CAST IRON AND OTHER METALS,

RE-EDITED, WITH NOTES, BY

EATON HODGKINSON, ESQ., F.R.S.,

IS INSCRIBED BY

THE PUBLISHER.

PART I.

PRACTICAL ESSAY

ON

THE STRENGTH OF CAST IRON

AND OTHER METALS.

BY THOMAS TREDGOLD.

ADVERTISEMENT TO THE FOURTH EDITION.

In giving a Fourth Edition of Tredgold's 'Essay on the Strength of Cast Iron,' I have made no alteration in the text, but left it as it was in the last edition. The object of the very ingenious Author was to consider the resistances of bodies subjected to small forces, when compared with those necessary to break them; since with the action of small forces, the displacement of the fibres, or particles of bodies, is equal, from equal forces, whether they produce extension or compression. But conclusions drawn from such small strains, when applied to measure the ultimate strength of cast iron, are often much at variance with the results of experiment.

An instance or two may be mentioned: a cast iron beam, to sustain most efficiently a moderate strain, should have equal ribs at top and bottom; but to offer the greatest resistance to fracture, these ribs should be unequal in the proportion of seven to one, nearly; and by this form a great addition of strength is obtained.

Under small strains beams of any particular form offer the same resistance, whether they are turned their proper way up or the reverse; but I have shown that a cast iron beam may be constructed to resist fracture with four times as much force one way up as the opposite.

The line bounding the extended and compressed fibres of a bent beam, called the neutral line, is in the middle of a square beam subjected to a small strain; but in a cast iron beam of this form, the neutral line has, at the time of fracture, removed near to the compressed side, and the strength is considerably increased by the change.

These results, with respect to fracture, arise from the circumstance that cast iron resists fracture in crushing with many times the force that it does in tearing asunder; the mean being about seven times, nearly.

The preceding facts show an essential difference in the laws which regulate moderate and ultimate strains; and the latter will be considered in the Second Part of this Work.

The experiments from which Mr. TREDGOLD had to draw his conclusions, respecting the transverse strength of cast iron, had not been observed with sufficient accuracy to enable him to determine when the elasticity first became injured; and accordingly he concludes that beams

retain their elasticity unimpaired till nearly one-third of the breaking weight is laid on; but I have shown that beams, whose section is T, and which bear so much more one way up than the other, will retain a perceptible deflexion, and not recover their original form, after as little as $\frac{1}{52}$d, or even $\frac{1}{80}$th of the breaking weight is laid on. In other words, there is no elastic limit, a set taking place with the smallest flexure. From this cause, and others, Mr. TREDGOLD has drawn some erroneous conclusions, of which a few are pointed out in the Notes to the body of his Work.

In a material so much used as cast iron, it is of great consequence to the founder to know whence he can obtain the irons best suited for different purposes. The experiments of Mr. Fairbairn on the transverse strength of cast iron bars, of which I have given an abstract, contain, with a few experiments made by myself, examinations, similarly conducted, of most of the irons used in this country: they will be consulted with interest for the purpose above mentioned; and his experiments on bars loaded for an indefinite time show that cast iron may be trusted far beyond what has generally been conceived.

The strength of pillars is a subject on which there has confessedly been a great want of experimental information: I therefore recently undertook an extensive series of experiments upon pillars, comparing the results

with the theoretical conclusions of Euler and Lagrange upon the matter. With the reception by the Royal Society of the Paper containing these experiments, and still more with the honourable mark of distinction awarded to it, I have the fullest reason to be gratified; and I am indebted to the Council for the privilege of giving an abstract of it in this Work.

EDITOR.

ADVERTISEMENT TO THE THIRD EDITION.

PUBLIC approbation of 'THE PRACTICAL ESSAY ON THE STRENGTH OF CAST IRON, &c.' having made a new Edition necessary, it may be proper to state, that it is printed from a copy corrected by Mr. TREDGOLD'S own hand, and to which nothing has been added; its progress through the press has been kindly superintended by the Author's friend, Professor Barlow, of Woolwich; its correctness cannot therefore be reasonably questioned.

The utility and importance of this Practical Essay have been acknowledged by the most unqualified approbation of the scientific of all countries, and it has accordingly been printed in the French, Italian, and Dutch languages. To the clear and practical demonstrations set forth in this Work, of the superiority of iron for supports, as well perpendicular as horizontal, may be attributed the present almost universal adoption of this material in buildings, as a substitute for wood; and, in reference to this particular subject, the Author was frequently consulted by the most eminent Architects and Engineers. His many other valuable works, of which a list is subjoined, more particularly the 'History of the Steam Engine,' have also experienced a similar liberal patronage both at home and abroad; and it is not, we think, presuming too much to say, that these Works have had an important influence in promoting the present advanced state of mechanical and scientific knowledge,—and to this honour the Author ardently aspired, as he considered it of the highest value.

Of Mr. Tredgold it may be stated, that from his earliest

years his mind was ever occupied by the most intense desire for information. Being altogether *self-taught*, it will not be difficult to form some idea of the great labour and fatigue which he must have necessarily undergone, in the acquirement of that correct and extensive knowledge of the various sciences of which he has so ably treated; and in his high attainments in mathematical demonstration, which he has so ingeniously and successfully applied in the many useful investigations exhibited in his Works.

To such ardent and unremitted application, the naturally feeble constitution of Mr. TREDGOLD eventually gave way, and after a protracted series of suffering terminated in his death on the 28th of January, 1829, in the 41st year of his age,—to the great loss of the public at large, and which an amiable wife and young family have seriously to deplore;[1] whose slender circumstances call

[1] The widow lived but a short time after the death of her husband, leaving three daughters and a son on the scanty subsistence afforded by a subscription set on foot by some benevolent Members of the Profession of Civil Engineering and Architecture: subsequently the two elder daughters died. The son is now articled to Mr. Bryan Donkin, of Rotherhithe, and the only daughter is living under the protection of Mrs. Urquhart, her aunt, who is herself in straitened circumstances from the recent loss of her husband, on whom she wholly depended for support. At no time nor in any place can it be improper, in the cause of humanity, to mention the fact that Mrs. Urquhart, as a measure of relief from the heavy burden upon her hand, is now endeavouring to procure a presentation for one of her children to Christ's Hospital. Besides the strong claim before referred to, she has the following certificate from Dr. Reid, who testifies to her respectability and merit:

"I hereby certify that the late John Urquhart, who attended to the Warming and Ventilating of the present Houses of Parliament under my direction, conducted himself with the greatest propriety, steadiness, and attention to all the duties intrusted to

for the kind aid of all benevolent persons, in behalf of these representatives of a truly worthy and scientific man, who devoted his whole life to the promotion and general diffusion of the most useful knowledge, with scarcely an ordinary attention to his own personal emolument.

As a philosopher and author, Mr. TREDGOLD contributed to many of the scientific publications of the day, to which his name was not always added. The following List of his Works will serve to evince his great industry, and will show the extensive range of studies with which his mind was successively occupied, and the important results he ever had in view:

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him, and that the zeal and intelligence with which he directed the operations he had to conduct gave the highest satisfaction. In the prime of his life, and when he was beginning to emerge from the difficulties with which he had long struggled, he was suddenly cut off, and has left a wife and family to deplore his loss. From the high character which he always had, and from the difficulties and embarrassments in which his widow (a near relative of the late Mr. Tredgold, to whose family she still devotes the care and anxiety of a mother,) is necessarily placed, and the exemplary manner in which she continues to bear up against the adversity with which she has been nearly overwhelmed, I have thought it incumbent on me to bear testimony to the circumstances I have now stated, and shall merely add that her case demands the sympathy and consideration of those who have the means of assisting her, and who will find on inquiry that her conduct has been such as to call for the most liberal assistance that her wants and necessities require.

"D. B. REID."

It is therefore hoped that some benevolent individual will endeavour to procure from a trustee or subscriber the required presentation; and in the true spirit of a grateful remembrance of the talent of the late Mr. Tredgold, who did so much for his succeeding age, this case is earnestly placed before the Architectural and Engineering Profession by the Publisher.—1842.

1. Elementary Principles of Carpentry, 4to. 22 Plates. (Re-edited by Professor Barlow in 1838, and containing 28 additional Plates and an Appendix.)
2. A Treatise of Joinery, in the Encyclopædia Britannica.
3. Essay on the Strength of Cast Iron and other Metals, 8vo. 4 Plates.
4. Additions to Buchanan's Essays on Mill-work, 2 vols. 8vo. 20 Plates. (Re-edited, with much additional matter, principally treating of Tools, Machines, &c., by George Rennie, C. E., F.R.S. 74 Plates, in 2 vols.)
5. A Treatise on Stone Masonry, for Supplement to Encyclopædia Britannica.
6. Principles of Warming and Ventilating Public Buildings, Hothouses, &c., 8vo. 9 Plates. (Re-edited by Mr. Bramah in 1838.)
7. A Treatise on Rail-roads and Carriages, &c., 8vo. 4 Plates.
8. A Letter to Mr. Huskisson on Steam Navigation, 8vo.
9. Additions and Notes to Tracts on Hydraulics, by Smeaton, Venturi, Dr. Young, &c. 8vo. 7 Plates.
10. Practical Rules, with Diagrams, for Barlow's Essay on the Strength of Timber, 8vo.
11. The Steam Engine; comprising an account of its Invention, Progressive Improvement, &c., 4to. 20 Plates. (This Work has been much extended to all the practical improvements of the last ten years, and particularly as regards Steam Navigation and Locomotive Engines, in 2 large volumes, with 125 Plates. 2300 copies of this edition have been sold in three years.—Publisher.)

On recording Mr. Tredgold's death, the Editor of the Literary Gazette well observes, "The numerous and excellent publications of Mr. Tredgold will ever hold the first place among the elementary compendiums of Civil Engineering, and must ever insure him the lively gratitude of the cultivators of general knowledge."

J. T.

August, 1831.

PREFACE TO THE SECOND EDITION.

In the following pages I have attempted to supply a 'Practical Treatise on the Strength of Cast Iron:' the use and advantage of such a Work will be best appreciated by those who consider the serious consequences of a failure in the application of this material. It is used for the principal supports of Churches, Theatres, Dwelling-houses, Manufactories, and Warehouses; for Bridges, Roofs, and Floors; and for the moving parts of the most powerful Engines. If a failure take place, from want of strength, it will most probably happen at that moment when its consequences will be most serious: hence, I think I may venture to say, without giving any undue importance to the object of this Work, that, if there be one subject which requires the aid and assistance of science more than another, it is the application of supports of cast iron.

The very considerable improvements that have been made in the manufacture of iron, have, undoubtedly, chiefly arisen out of the peculiar advantages derived from its use, in the mining and manufacturing districts of Britain; and the immense quantities of it employed in these districts is one of the most satisfactory proofs of its utility and value.

These improvements in the manufacture of iron have

also enabled the manufacturers to reduce its price; so far indeed that it now can be employed, instead of foreign timber, for many important purposes in buildings and machines, at a very small additional expense, with a considerable addition of soundness and durability. It is not, however, fitted for every purpose; for example, if it be desirable that a house should exclude the cold of winter, and the heat of summer, it certainly would not be advisable to form the roof, or any other considerable part of it, wholly of iron; as you could not easily find another substance for the purpose, that suffers heat to pass through it so rapidly as iron does. But it is more imprudent to build heavy brick or stone walls upon timber supports, a material which is so subject to decay, and so easily destroyed by fire; and yet nearly half the houses in London are partly sustained by wooden posts. If you use timber to prevent settlements where a foundation is soft or irregular, the timber decays, and worse settlements take place than those it was intended to avoid:[1] in all such cases iron might be used with success.

I think it will appear, on an accurate survey of the present state of the mechanical arts, that the physical and mechanical properties of matter are not sufficiently studied. If such knowledge were cultivated, if it formed a part of a young mechanic's education,—that is, if he were prepared by a regular course of experimental study respecting the nature and properties of materials,—would not his progress in any particular art be greatly facilitated? Experience, "slow preceptress," furnishes a practical mechanic with some share of this knowledge, but such experience is always limited to a particular

[1] See Napier's Supplement to Encyclo. Brit. art. 'Stone Masonry,' § 60.

range of objects, and it engenders prejudice in favour of particular things, and particular modes of operation. Lord Bacon's idea of a Mechanical History,[2] which Diderot attempted to realize,[3] is not so well calculated to fulfil his own view as a well-directed course of experiments on the nature, forms, and properties of materials, illustrated by a reference to the manner of applying them in the arts. In Chemistry much has been already done; but an Experimental School of Mechanical Science remains to be formed.

Having briefly alluded to this deficiency in the experimental investigation of the mechanical properties of bodies, I must proceed to inform the reader of the nature of the Work now offered to his notice, as improved by the addition of another year's collection of experience, and much experimental research.

This Work is divided into eleven Sections:—The First Section consists of introductory remarks on the use and the qualities of cast iron; and of cautions to be observed in employing it. This section includes three extensive Tables, which will often save the practical man a considerable share of trouble in calculation.

The Second Section explains the arrangement and use of the Tables which precede it; and in this edition the number of popular examples is much increased.

It is a common and a well understood fact, that an uniform beam is not equally strained in every part, and therefore may be reduced in size, so as to lessen both the strain and the expense of material.

The Third Section points out the value of cast iron in

[2] Of the Advancement of Learning. Book II. Bacon's Works, vol. i. p. 79.

[3] French Encyclopédie.

this particular, and the forms to be adopted for different cases.

The Fourth Section contains a popular explanation of the strongest forms for the sections of beams; the construction of open beams; and the best form for shafts. A due consideration of these two sections will enable the young mechanic to guard against some common errors in attempting to apply these things to practice. They are much augmented, and a new principle of constructing bridges is explained in the fourth section.

The Fifth Section is wholly devoted to experiments on cast iron: it will be found to contain, in addition to my own experiments, almost all of the experiments that have been described by preceding writers. Those I have tried for the purpose of establishing rules, to apply in practice, have been made with a different view of the subject from that entertained by preceding experimentalists; one better adapted for practical application, one which shows that, within the proper limits, our theory of the strength of materials is to be depended upon; but that beyond these limits materials should never be strained in constructions of any kind whatever.[4] Nevertheless it would be extremely desirable that some accurate experiments on the extension of bodies should be made, when the strain exceeds the elastic force; as by that means something important regarding the ductility of matter might be discovered; and perhaps they might throw some light on the nature and arrangement of the ultimate particles of bodies.

[4] To Dr. T. Young we are chiefly indebted for showing the necessity of attending to the strain which produces permanent alteration: Nat. Phil. vol. i. p. 141. To that valuable Work I am most indebted for assistance in this Essay.

To this section a great many new experiments have been added, to show the relative strength of iron of different qualities; and also seven new experiments on torsion, made by Messrs. Bramah. The section concludes with the result of my observations on the relation between the appearance of the fracture and the strength of cast iron, as determined by experiment.

The Sixth Section contains experiments on malleable iron and other metals, and is entirely new. The effect of hammering, and the decrease of force by heat, are experimentally examined; and the cause of English iron being inferior to Swedish, for particular purposes, is pointed out.

In the Seventh Section I have shown how to obtain some of the most useful practical rules from the first principles that are furnished by experience. I have conducted the investigation of these rules in a manner somewhat different from other writers, and I have avoided the use of fluxions.[5] Several new cases are investigated,

[5] I have avoided fluxions in consequence of the very obscure manner in which its principles have been explained by the writers I have consulted on the subject. I cannot reconcile the idea of one of the terms of a proportion vanishing for the purpose of obtaining a correct result; it is not, it cannot be good reasoning; though, from other principles, I am aware that the conclusions obtained are accurate. If the doctrine of fluxions be freed from the obscure terms, limiting ratios, evanescent increments and decrements, &c., it is in reality not very difficult. If you represent the increase of a variable quantity by a progression, (as is done in art. 295, Section XI.,) any term of that progression (except the last) corresponds with what is called a fluxion; and the sum of the progression is the same as a fluent. A fluxion is, therefore, the velocity of increase of an increasing variable quantity; or of decrease of a decreasing one; on the supposition that we take the velocity at any point and consider it uniform. But

and some addition is made to the theory of resistance: the reader will find examples of this in treating of the strength of beams, art. 108 to 119; the deflexion of beams, art. 124 to 130; the strain upon beams, art. 133 to 141; and in the ninth and tenth sections.

The Eighth Section treats of the stiffness to resist lateral strains, with its application to some interesting practical cases.

The Ninth Section is on the strength and stiffness

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when you use this uniform velocity to represent an accelerated one, and say that the ratio of these velocities approaches to a ratio of equality as its limit, while the space or time of description is diminishing to evanescence, I must be allowed to withhold my assent to your doctrine. For it is clear that the exact ratio of equality can obtain only when the space described is nothing; and consequently, it cannot, with logical accuracy, be employed to compare the spaces generated when they become of finite magnitude. Robins and Maclaurin have shown that their reasoning is agreeable to the practice of the ancient geometers; but to give dignity to their speculations these geometers employed a subtile and metaphysical method, in preference to a candid avowal of a tentative comparison: the same practice there is not now any reason to continue. The science of space, or geometry, is completely distinct from that of number or analysis. They have both been injured by an intermixture, which was begun by the ancients: how they came to conceive that the doctrines of number and space rested on principles common to both, it is not necessary to inquire; but as soon as you commence the fifth book of Euclid you bid adieu to pure geometry; and, in the rest, the aid of a metaphysical method of forcing the assent, rather than of convincing the judgment, is frequently introduced, and reigns through most of the works of the older geometers. The neglect of pure geometry has left ample scope for a display of talent. I am thankful to the kind friends who have taken some pains to correct my notions on this subject; they will see that I have profited in some degree by their remarks.

to resist torsion or twisting, with its application to machinery.

The Tenth Section treats of the strength of columns, pillars, and ties, with some new examples. It may be useful to remark, that the most refined methods of analysis have been applied to the same subjects by Euler, Lagrange, and other continental mathematicians, without arriving at results more accurate, more simple, or more convenient in practice.

In the Eleventh Section I have considered the resistance of beams to impulsive force. In this section will be found many important rules, with examples of their application to the moving parts of engines, bridges, &c., wherein the advantage gained by employing beams of the figures of equal resistance is shown.

The Eleventh Section is followed by an extensive 'TABLE OF THE PROPERTIES OF MATERIALS, AND OTHER DATA, OFTEN USED IN CALCULATIONS,' arranged alphabetically, and in this edition much enlarged. By means of this Table the various rules for the strength of cast iron, contained in this Work, may be applied to several other kinds of materials.

A note, which I have added at the end of the Table, on the chemical action of some bodies on cast iron, will be read with interest by those who employ cast iron where it is exposed to the action of sea-water.

The Plates are accompanied by descriptive letter-press, with references to the articles which the figures are intended to explain.

The Work concludes with an Index,[6] containing copious references to the Practical Rules; and, in general, it will be found that the examples are selected with a view to

[6] A *General Index* will be given at the end of the Work.—ED.

explain the practical application of the rules, and to make the reader aware of the limits and precautions to be attended to. In fact, the want of such information has often brought theory into discredit with some men, whereas the fault ought to have fallen on the person that misapplied it.

I hope there will be few things of any importance found in this Work for which a sufficient reason is not given: sometimes I have been compelled to omit several steps in the investigations, in order to make it as little mathematical as possible; and such omissions the reader must excuse till a larger share of mathematical learning becomes the common lot of every practical mechanic; and I hope that period is not far distant.

The communication of any experiment or observation that is calculated to confirm or correct any thing I have done I shall esteem a favour.

The manner in which my Works have been received has been highly gratifying to my feelings, and has afforded me an early opportunity of rendering my grateful thanks. They are especially due to Messrs. Bramah and Mr. Bevan,—the former, for specimens and an account of experiments,—the latter, for corrections of some press errors.

A Second Part is in progress, on the 'Strength of Pipes, Mains, Tanks, Boilers, &c.; of Chains to resist Impulsion and Pressure; of Suspension and other Iron Bridges; and of Framed Work for Roofs, Bridges, Mills, and Machinery.'

16, *Grove Place, Lisson Grove,*
Nov. 1823.

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SECTION XI.

All the quantities, proportions, &c., are stated in English weights and measures, the pound being the avoirdupois pound, except the contrary be stated.