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978-1-108-07042-3 - A History of the Theory of Elasticity and of the Strength of Materials: Volume 1: From Galilei to Saint-Venant

Isaac Todhunter Edited by Karl Pearson

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### A History of the Theory of Elasticity and of the Strength of Materials

A distinguished mathematician and notable university teacher, Isaac Todhunter (1820–84) became known for the successful textbooks he produced as well as for a work ethic that was extraordinary, even by Victorian standards. A scholar who read all the major European languages, Todhunter was an open-minded man who admired George Boole and helped introduce the moral science examination at Cambridge. His many gifts enabled him to produce the histories of mathematical subjects which form his lasting memorial. First published between 1886 and 1893, the present work was the last of these. Edited and completed after Todhunter's death by Karl Pearson (1857–1936), another extraordinary man who pioneered modern statistics, these volumes trace the mathematical understanding of elasticity from the seventeenth to the late nineteenth century. Volume 1 (1886) begins with Galileo Galilei and extends to the researches of Saint-Venant up to 1850.

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# A History of the Theory of Elasticity and of the Strength of Materials

VOLUME 1:  
FROM GALILEI TO SAINT-VENANT

ISAAC TODHUNTER  
EDITED BY KARL PEARSON



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A HISTORY  
OF  
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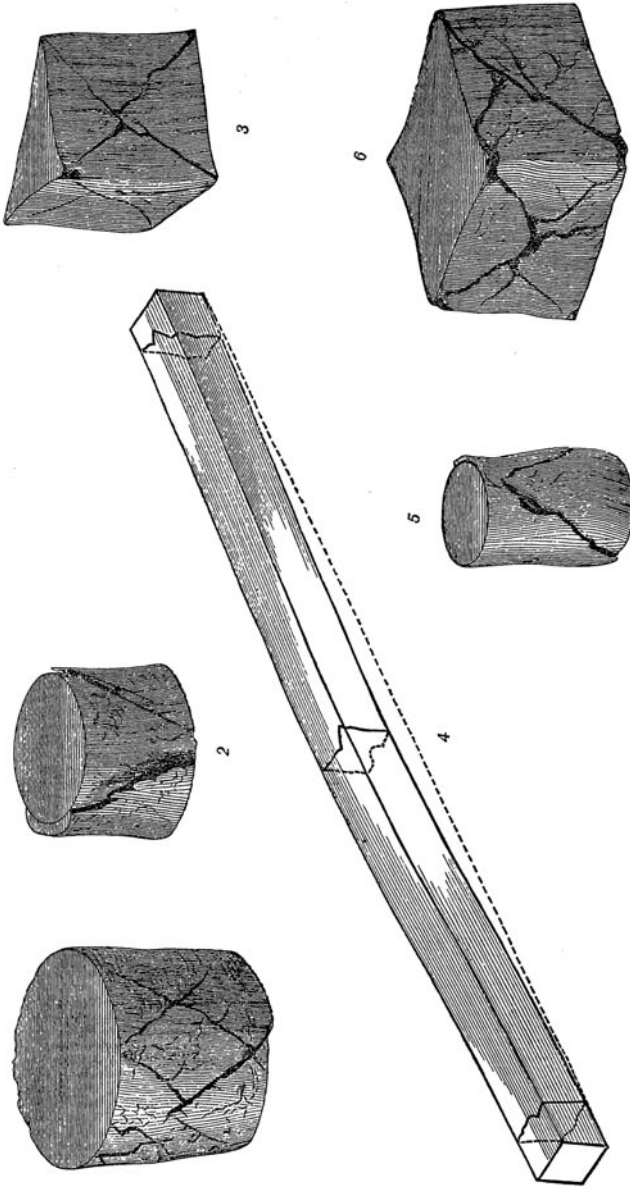
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Rupture-Surfaces of Cast-Iron

*Frontispiece*



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A HISTORY OF  
THE THEORY OF ELASTICITY

AND OF

THE STRENGTH OF MATERIALS

*FROM GALILEI TO THE PRESENT TIME.*

BY THE LATE

ISAAC TODHUNTER, D. Sc., F. R. S.

EDITED AND COMPLETED

FOR THE SYNDICS OF THE UNIVERSITY PRESS

BY

KARL PEARSON, M.A.

PROFESSOR OF APPLIED MATHEMATICS, UNIVERSITY COLLEGE, LONDON.

VOL. I. GALILEI TO SAINT-VENANT

1639—1850.

CAMBRIDGE:

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1886

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TO THE MEMORY OF

M. BARRÉ DE SAINT-VENANT

THE FOREMOST OF MODERN ELASTICIANS

THE EDITOR DEDICATES HIS LABOUR

ON THE PRESENT VOLUME.

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Si ces imperfections sont malheureusement nombreuses cela vient de ce que la science appliquée est jeune et encore pauvre ; avec ses ressources actuelles, elle peut déjà rendre de grands services, mais ses destinées sont bien plus hautes : elle offre un champ immense au zèle de ceux qui voudront l'enrichir, et beaucoup de parties de son domaine semblent même n'attendre que des efforts légers pour produire des résultats d'une grande utilité.

*Saint-Venant.*

Jedenfalls sieht man aus den angeführten Thatsachen, dass die Theorie der Elasticität noch durchaus nicht als abgeschlossen zu betrachten ist, und es wäre zu wünschen, dass recht viel Physiker sich mit diesem Gegenstande beschäftigten, um durch vermehrte Beobachtungen die sichere Grundlage zu einer erweiterten Theorie zu schaffen.

*Clausius.*

Ceux qui, les premiers, ont signalé ces nouveaux instruments, n'existeront plus et seront complètement oubliés ; à moins que quelque géomètre archéologue ne ressuscite leurs noms. Eh ! qu'importe, d'ailleurs, si la science a marché !

*Lamé.*

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## PREFACE.

IN the summer of 1884 at the suggestion of Dr Routh the Syndics of the University Press placed in my hands the manuscript of the late Dr Todhunter's History of Elasticity, in order that it might be edited and completed for the Press. That the publication might not be indefinitely delayed, it was thought advisable to print off chapter by chapter as the work of revision progressed. That this arrangement has accelerated the publication of the first volume is certain, but at the same time it has introduced some disadvantages to which it is necessary for me to refer. In the first place it was impossible to introduce in the earlier cross-references to later portions of the work; this I have endeavoured to rectify by adding a copious index to the whole volume. In the next place I must mention, that it was not till I had advanced some way into the work that I felt convinced that the reproduction in the analysis of a memoir of the individual writer's terminology and notation must be abandoned and a uniform terminology and notation adopted for the whole book. This was absolutely needful if the book was to be available for easy reference, and not merely of interest to the historical student. The choice, however, of such terminology and notation—considering the enormous diversity, I will even say confusion, on this point to be found in the writings of British and continental elasticians—was an extremely venturesome task. To evolve a really scientific terminology which shall stand any chance of universal adoption from a number of words, which

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each individual writer has used in his own sense, is no easy matter. If I have in some cases dispensed with such well-worn words as tension, pressure, extension, contraction and so forth, it has been from no desire for novelty, but in order to avoid a conflict of definitions. That the notation and terminology proposed in this work will extend beyond it I hardly venture to hope, I shall be content if they be intelligible to those who may consult this book. They will be found fully discussed in Notes B—D of the Appendix, which I would ask the reader to examine before passing to the text. As I have said, it was unfortunately only after I had made some progress in the work, that I became convinced of the need of terminological and notational uniformity. I think, however, consistency in these points will be found after the middle of the chapter devoted to Poisson. The introduction of this uniform system of symbols and terms has itself involved a considerable amount of additional work on the manuscript. The symbols and terms used in the manuscript are occasionally those of the original memoirs, occasionally those of Lamé or of Saint-Venant. The want of uniformity in the first two chapters will perhaps not be considered a disadvantage, the memoirs being of historical rather than scientific interest, and their language often the most characteristic part of their historical value.

The disadvantages which I have pointed out in this first volume will I trust be obviated in the second by the revision and completion of the whole manuscript before the work of printing is commenced. The second volume will contain an analysis of all researches in elasticity from 1850 to the present time. From 1850 to 1870 most but not all of the chief mathematical memoirs have been already analysed by Dr Todhunter; there is but little of a later date completed. Considering the amount of work to be done, considering that it is advisable to avoid revision and printing being carried on simultaneously, and finally noting the very limited time, which the teaching duties of my present post allow me to spend in a library where it is possible to carry on historical work of this kind, I fear the publication of the second volume would be much delayed were the task of editing it entrusted to me. I lay

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stress upon this point as, although I have endeavoured to make the first volume complete in itself, much of its usefulness will be realised only on the appearance of the second. Indeed, in the interests of the reader as well as of the work, I think the Syndics will have to consider the question of appointing another editor, who has more of the needful leisure.

It is proper that I should explain with some detail the manner in which I have performed my task as editor. Dr Todhunter's manuscript consists of two distinct parts, the first contains a purely mathematical treatise on the theory of the 'perfect' elastic solid; the second a history of the theory of elasticity. The treatise based principally on the works of Lamé, Saint Venant and Clebsch is yet to a great extent historical, that is to say many paragraphs are composed of analyses of important memoirs. Thus in the History-manuscript after the title of a memoir there is occasionally only a mere reference to the paragraph of the Theory-manuscript, where it will be found discussed. Certain portions also of the manuscript have inscribed upon them in Dr Todhunter's handwriting 'History or Theory?' The Syndics having determined to publish in the first place the History only, it became necessary to determine how the gaps in the 'History' which were covered by mere reference to the 'Theory' should be filled up. With the sanction of the Syndics I have adopted the following principle: the analysis of a memoir wherever possible is to be Dr Todhunter's. Thus certain, on the whole not very considerable, portions of the Theory-manuscript are incorporated in the History, while all portions of the manuscript marked doubtful have been made use of when required.

Dr Todhunter's manuscript contains two versions, a first writing and a revision. The revision has been again read through by the author, but the principal alterations made are notes or suggestions for further consideration; in some cases the note is merely a statement that a criticism must be either modified or entirely reconstructed, in other cases, it involves a valuable cross-reference. One of the most important of these notes is that

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referred to in my footnote on p. 250; it led to the only considerable excision which I have thought it proper to make before printing Dr Todhunter's manuscript.

The changes I have made in that manuscript are of the following character; the introduction of a uniform terminology and notation, the correction of clerical and other obvious errors, the insertion of cross-references, the occasional introduction of a remark or of a footnote. The remarks are inclosed in square brackets. With this exception any article in this volume the number of which is *not included in square brackets* is due entirely to Dr Todhunter. So far as the arrangement of the memoirs is concerned there was little if anything to guide me in the manuscript. Dr Todhunter had evidently intended to give each of the principal elasticians chapters to themselves, and to group the minor memoirs together into periods. This method although it destroys the strict chronological treatment, and to some extent obscures the order of development, yet possesses such advantages, in that it groups together the researches of one man following his own peculiar lines of thought, that I have followed it without hesitation as the best possible. I even regret that I have not devoted special chapters to such elasticians as Hodgkinson, Wertheim and F. E. Neumann; in the latter case the regret is deepened by the recent publication of his lectures on elasticity.

Turning to my own share in the completing of the work, I fear that at first sight I may appear to have exceeded the duty of an editor. For all the Articles in this volume whose numbers are enclosed in square brackets I am alone responsible, as well as for the corresponding footnotes, and the Appendix with which the volume concludes. The principle which has guided me throughout the additions I have made has been to make the work, so far as it lay in my power, a standard work of reference for its own branch of science. The use of a work of this kind is twofold. It forms on the one hand the history of a peculiar phase of intellectual development, worth studying for the many side lights it throws on



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general human progress. On the other hand it serves as a guide to the investigator in what has been done, and what ought to be done. In this latter respect the individualism of modern science has not infrequently led to a great waste of power; the same bit of work has been repeated in different countries at different times, owing to the absence of such histories as Dr Todhunter set himself to write. It is true that the various *Jahrbücher* and *Fortschritte* now reduce the possibility of this repetition, but besides their frequent insufficiency they are at best but indices to the work of the last few years; an enormous amount of matter is practically stored out of sight in the *Transactions* and *Journals* of the last century and of the first half of the present century. It would be a great aid to science, if, at any rate, the innumerable mathematical journals could be to a great extent specialised, so that we might look to any one of them for a special class of memoir. Perhaps this is too great a collectivist reform to expect in the near future from even the cosmopolitan spirit of modern science. As it is, the would-be researcher either wastes much time in learning the history of his subject, or else works away regardless of earlier investigators. The latter course has been singularly prevalent with even some first-class British and French mathematicians.

Keeping the twofold object of this work in view I have endeavoured to give it completeness (1) as a history of development, (2) as a guide to what has been accomplished.

Taking the first chapter of this History the author has discussed the important memoirs of James Bernoulli and some of those due to Euler. The whole early history of our subject is however so intimately connected with the names of Galilei, Hooke, Mariotte and Leibniz, that I have introduced some account of their work. The labours of Lagrange and Riccati also required some recognition, so that these early writers form the basis of a chapter, which I believe the reader will not find without interest, whether judged from the special standpoint of the elastician or from the wider footing of insight into the growth of human ideas. With a similar aim I have introduced throughout the volume a number of

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memoirs having purely historical value which had escaped Dr Todhunter's notice.

Another class of memoirs which I have inserted are memoirs of mathematical value, omitted apparently by pure accident. For example all the memoirs of F. E. Neumann, the second memoir of Duhamel, those of Blanchet etc. I cannot hope that the work is complete in this respect even now, but I trust that nothing of equal importance has escaped the author or editor<sup>1</sup>

My greatest difficulty arose with regard to the rigid line which Dr Todhunter had attempted to draw between mathematical and physical memoirs. Thus while including an account of Clausius' memoir of 1849, he had omitted Weber's of 1835, yet the consideration of the former demands the inclusion of the latter, were it not indeed required by the long series of mathematical memoirs which have in recent years treated of elastic after-strain. What seemed to me peculiarly needful at the present time was to place before the mathematician the results of physical investigations, that he might have some distinct guide to the direction in which research is required. There has been far too much invention of 'solvable problems' by the mathematical elastician; far too much neglect of the physical and technical problems which have been crying out for solution. Much of the ingenuity which has been spent on the ideal body of 'perfect' elasticity ideally loaded, might I believe have wrought miracles in the fields of physical and technical elasticity, where pressing practical problems remain in abundance unsolved. I have endeavoured, so far as lay in my power, to abrogate this divorce between mathematical elasticity on the one hand, and physical and technical elasticity on the other. With this aim in view I have introduced the general conclusions of a considerable body of physical and technical memoirs, in the hope that by doing so I may bring the mathematician closer to the physicist and both to the practical engineer. I trust that in doing so I have rendered this History of value to a wider range of

<sup>1</sup> I should be very glad of a notification of any omissions, so that some reference might be made to them in the second volume.

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readers, and so increased the usefulness of Dr Todhunter's many years of patient historical research on the more purely mathematical side of elasticity. In this matter I have kept before me the labours of M. de Saint Venant as a true guide to the functions of the ideal elastician.

It remains for me to thank those friends who have so readily given assistance and sympathy in the labour of editing. Only those, who have undertaken a task of similar dimensions can fully appreciate the value of such help. The aid of two men, strangely alike in character though diverse in pursuit, who exhibited a keen interest in the progress of this work, has been lost to me during its passage through the press. To the late Mr Henry Bradshaw I owe assistance in procuring scarce memoirs, pamphlets, and dissertations, as well as many valuable suggestions on typographical and bibliographical details. To the late M. Barré de Saint Venant I am indebted for the loan of several works, for a variety of references and facts bearing on the history of elasticity, as well as for a revision of the earlier pages of Chapter IX. The later pages of that chapter were revised after the death of M. de Saint-Venant by his friend and pupil M. Flamant, Professeur à l'Ecole Centrale; whom I have likewise to thank for disinterested assistance in the revision of other portions of the work relating to French elasticians.

The assistance of two other friends has left its mark on nearly every article I have contributed to the work. My colleague, Professor A. B. W. Kennedy, has continually placed at my disposal the results not only of special experiments, but of his wide practical experience. The curves figured in the Appendix, as well as a variety of practical and technical remarks scattered throughout the volume I owe entirely to him; beyond this it is difficult for me to fitly acknowledge what I have learnt from mere contact with a mind so thoroughly imbued with the concepts of physical and technical elasticity. Mr W. H. Macaulay, University Lecturer in Applied Mechanics, Cambridge, has given me repeated aid in the discussion of mathematical difficulties, and has

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saved me from many errors of interpretation, and several of judgment. I have to thank Mr C. Chree of King's College, Cambridge for a very careful revision of the proofs subsequent to Chapter IV., and for a variety of suggestions. Mr T. H. Beare of the Engineering Department, University College, has prepared the copious Index to this volume, upon which much of its usefulness will depend. To Mr R. J. Parker of Lincoln's Inn I owe frequent linguistic assistance and revision. While to Professor Callcott Reilly of Cooper's Hill, to my colleague Professor M. J. M. Hill and to Mr R. Tucker of the London Mathematical Society I am indebted for aid in a variety of ways.

In conclusion I can only hope that this first volume of Dr Todhunter's work will fulfil the object which he had designed for it, that—notwithstanding the want of the author's own revision and the many editorial failings—it may still take its place as a standard work of reference, worthy alike of its author and of the University which publishes it.

KARL PEARSON.

UNIVERSITY COLLEGE, LONDON.

June 23, 1886.

## ERRATA.

- p. 100, line 4 for  $d^2x/dx^2$  read  $d^2y/dx^2$ .  
 p. 142, last line for Poisson read Poincot.  
 p. 217, *dele* footnote.  
 p. 317, line 5 from bottom for VII. read VIII.  
 p. 327, footnote for confusing  $f(r)$  read confusing  $f(r)$   
 p. 359, line 1 for  $xx$  read  $xx$ .  
 p. 368, line 24 for Art. 659 read Art. 661.  
 p. 391, line 5 for horizontal read vertical.  
 p. 438, line 14 for  $\frac{1}{E_2}$  read  $\frac{1}{E_r}$   
 p. 446, first line for  $P\omega$  read  $P/\omega$ .  
 p. 523, line 17 for 2·04 read 2·047.  
 p. 705, line 15 for Art. 366 read Art. 365.  
 p. 855, line 16 for 1239 read 1240.

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## CHIEF ELASTICIANS BEFORE 1850.

ARRANGED IN THE ORDER OF THEIR CHIEF MEMOIRS  
ON ELASTICITY.

	<i>Birth.</i>	<i>Death.</i>
Galilei . . . . .	. 1564—	1642
Hooke . . . . .	. 1635—	1702
Mariotte . . . . .	. 1620 (?)—	1684
James Bernoulli . . . . .	. 1654—	1705
Musschenbroek . . . . .	. 1692—	1761
Daniel Bernoulli . . . . .	. 1700—	1782
Euler . . . . .	. 1707—	1783
Coulomb . . . . .	. 1736—	1806
Girard . . . . .	. 1765—	1836
Young . . . . .	. 1773—	1829
Tredgold . . . . .	. 1788—	1829
Hodgkinson . . . . .	. 1789—	1861
Navier . . . . .	. 1785—	1836
Germain . . . . .	. 1776—	1831
Savart . . . . .	. 1791—	1841
Poisson . . . . .	. 1781—	1840
Cauchy . . . . .	. 1789—	1857
W. Weber . . . . .	. 1804—	*
Vicat . . . . .	. 1786—	1861
Piola . . . . .	. 1791—	1850
F. E. Neumann . . . . .	. 1798—	*
Gerstner . . . . .	. 1756—	1832
Duhamel . . . . .	. 1797—	1872
Green . . . . .	. 1793—	1841
Poncelet . . . . .	. 1788—	1867
Lamé . . . . .	. 1795—	1870
Clapeyron . . . . .	. 1799—	1864
Stokes . . . . .	. 1819—	*
Wertheim . . . . .	. 1815—	1861
Blanchet . . . . .	. 1813—	*
Maxwell . . . . .	. 1831—	1879
Haughton . . . . .	. (?)—	*
Jellett . . . . .	. (?)—	*
Kupffer . . . . .	. 1799—	1865
Saint-Venant . . . . .	. 1797—	1886

\* Living scientists.