Essentials of Engineering Hydraulics

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Essentials of Engineering Hydraulics

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Foreword to the First Edition

by

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Imperial College of Science and Technology, London

It is a pleasure to have the opportunity of commending this book. The author, a friend and former student of mine, has attempted to bring out the principles of physics which are likely to be of future importance to hydraulic engineering science, with particular reference to water resources problems. With the greater importance and complexity of water resource exploitation likely to occur in the future, our analysis and design of engineering problems in this field must become more exact, and there are several parts of Dr. Dake's book which introduce new ideas. In the past half-century, the science of fluid mechanics has been largely dominated by the demands of aeronautical engineering; in the future it is not too much to believe that the efficient supply, distribution, drainage and re-use of the world's water supply for the benefit of an increasing population will present the most urgent of problems to the engineer.

I feel particularly honoured, too, in that this book must be among the first technical texts to come from a young and flourishing university, and is, I think, the first in hydraulic engineering to come from Africa. Over many years, academics in Britain and elsewhere have attempted, with varying success, to help the establishment of degree courses at Kumasi, and to produce skilled technological manpower. That a book of this standard should now come forward is a source of pleasure to all those who have helped, and an indication of future success.

J. R. D. FRANCIS
1972

Preface to the Second Edition

The Second Edition of *Essentials of Engineering Hydraulics* has retained the primary objectives and structure of the original book. However, the rational metric system of units (Système International d'Unités) has been adopted generally although a few examples and approaches have retained the imperial units.

The scope of the book has been increased by inclusion of section 1.8, '*Fluids in Static Equilibrium*' and sub-sections 8.7.3 and 9.3.5 '*Routeing of Floods in River Channels*' and '*The Transient State of the Well Problem*', respectively. There has been general updating.

A guide to the solution of the tutorial problems at the end of the book is available for restricted distribution to lecturers upon official request to the publisher.

Jonas M. K. Dake
Nairobi 1982

Preface to the First Edition

Teaching of engineering poses a challenge which, although also relevant to the developed countries, carries with it enormous pressures in the developing countries. The immediate need for technical personnel for rapid development and the desire to design curricula and training methods to suit particular local needs provide strong incentives which could, without proper control, compromise engineering science and its teaching in the developing world.

The generally accepted role of an engineering institution is the provision of the scientific foundation on which the engineering profession rests. It is also recognized that the student's scientific background must be both basic and environmental. In other words, engineering syllabuses must be such that, while not compromising on basic engineering science and standards, they reflect sufficient background preparation for the appropriate level of local development.

This text has been written to provide in one volume an adequate coverage of the basic principles of fluid flow and summaries of specialized topics in hydraulic engineering, using mainly examples from African and other developing countries.

A survey of fluid mechanics and hydraulics syllabuses in British universities reveals that the courses are fairly uniform up to second year level but vary widely in the final year. This book is well suited to these courses. Students in those universities which emphasize civil engineering fluid mechanics will also find this book useful throughout the whole or considerable part of their courses of study.

Essentials of Engineering Hydraulics can be divided into two parts. Part I, Elementary Fluid Mechanics, emphasizes fundamental physical concepts and details of the mechanics of fluid flow. A good knowledge of general mechanics and mathematics as well as introductory lectures in fluid mechanics covering hydrostatics and broad definitions are assumed. Coverage in Part I is suitable up to the end of the second year (3-year degree courses) or third year (4-year degree courses) of civil and mechanical engineering undergraduate studies. Part II on Specialized Topics in Civil Engineering is meant mainly for final-year civil engineering degree students. Treatment is concentrated on discussions of the physics and concepts which have led to certain mathematical results. Equations are generally not derived but discussions centre on the merits and limitations of the equations.

The general aim of the book is to emphasize the physical concepts of fluid flow and hydraulic engineering processes with the hope of providing a foundation which is suitable for both academic and non-academic postgraduate work. To-

wards this end, serious efforts have been made to steer a middle course between the thorough mathematical approach and the strictly down-to-earth empirical approach.

Chapter 11 gives an introduction to the fundamental economics of water resources development which is a very important topic at postgraduate level. I feel that economics and decision theory must be given more prominence in undergraduate engineering curricula especially in countries where young graduates soon find themselves propelled to positions of responsibility and decision making.

In an attempt to make this book comprehensive and yet not too bulky and expensive, I have resorted to a literary style which uses terse but scientific words with the hope of putting the argument in a short space. I have also followed rather the classroom 'hand-out' approach than the elaborate and sometimes long-winded approach found in many books.

'The author of any textbook depends largely upon his predecessors' — Francis. Existing books and other publications from which I have benefited are listed at the end of each chapter in acknowledgement and as further references for the interested reader. The tutorial problems have been derived from my own class exercises, homework and class tests at M.I.T. and from other sources, all of which are gratefully acknowledged. In the final chapter, problems 3.18, 4.23, 4.24, 5.18, 5.19, 6.3, 6.14, 8.1, 8.2 and 8.3 have been included with the kind permission of the University of London. All statements in the text and answers to problems, however, are my responsibility.

I wish to thank Prof. J. R. D. Francis of Imperial College, London and Dr. J. O. Sonuga of Lagos University and other colleagues who read the manuscript in part or whole and made many useful suggestions. The encouragement of Prof. Francis, a former teacher with continued interest in his student and the external examiner in Fluid Mechanics and Hydraulics as well as the moderator for Civil Engineering courses at U.S.T., has been invaluable. Mr. D. W. Prah of the Department of Liberal and Social Studies, U.S.T., made some useful comments on the use of economic terms in Chapter 11. The services of the clerical staff and the draughtsmen of the Faculty of Engineering, U.S.T., especially of Messrs. S. K. Gaisie and S. F. Dadzie during the preparation of the manuscript and drawings are also gratefully acknowledged.

Finally, I wish to express my sincere gratitude to the University of Science and Technology, Kumasi, whose financial support has made the production of this book possible.

University of Science and Technology, Kumasi, Ghana

Jonas M. K. Dake
1972

List of Principal Symbols

A_j	cross-section area of a jet (L^2)
A	area (L^2)
a	acceleration (L/t^2), area (L^2), wave amplitude (L)
a_b	amplitude of wave beat envelope (L)
B	top width of a channel (L)
b	bottom width of a channel (L)
C	Chezy coefficient ($L^{1/2}/t$); wave velocity (L/t)
C_G	group velocity (waves) (L/t)
C_p	specific heat at constant pressure (L^2/Tt^2)
C.R.F.	Capital Recovery Factor
C_v	specific heat at constant volume (L^2/Tt^2)
c	concentration of mass, surge wave speed (L/t), speed of sound (L/t)
C_D	coefficient of drag
C_d	coefficient of discharge
c_f	coefficient of drag (friction)
c.s.	control surface
c.v.	control volume
C_v	coefficient of velocity
D	molecular mass conductivity (M/Lt), pipe diameter (L), drag (ML/t^2)
D_N	sieve diameter which pass $N\%$ of soil sample (L)
D_{50}	median sand particle size (L)
d	geometric mean size (sand) (L), depth (L), drawdown (L)
d_g	geometric mean size (sand) (L)
d_n	diameter of a nozzle (L)
E	energy (ML^2/t^2), specific energy (L), Euler number, rate of evaporation (L/t); wave energy (M/t^2), modulus of elasticity (M/Lt^2)
$\dot{E}$	rate of transmission of wave energy (ML/t^3)
E_h	thermal eddy diffusivity (L^2/t)
E_m	mass eddy diffusivity (L^2/t)
E_k	kinetic energy (ML^2/t^2)
E_p	potential energy (ML^2/t^2)
e	exponential constant ($=2.71828$)
e	vapour pressure (mmHg), void ratio
F	force (ML/t^2), Froude number, fetch (L)
F'	densimetric Froude number
f	friction factor
f_p	infiltration capacity (L/t or L^3/t)
f_s	silt factor
g	acceleration due to gravity (L/t^2)
g_o	constant – 32.174 lbfm/slug
H	enthalpy (L^2/t^2), total head (L), wave height (L)
H_m	head developed or consumed by a rotodynamic machine (L)
H_p	pump head (L)
H_t	theoretical head of a rotodynamic machine (L)

List of Principal Symbols

H_s	static lift (L)
H_{sv}	net positive suction head (NPSH) (L)
H_T	turbine head (L)
h	head of water above spillway crest (L), hydraulic head (L)
h_f	friction head loss (L)
I	moment of inertia (ML^2), infiltration amount (L^3), rate of interest
i	seepage (hydraulic) gradient (L/L)
i_o	rainfall intensity (L/t)
J	mechanical equivalent of heat, (ML^2/t^2)
K	thermal molecular conductivity (ML/Tr^3), coefficient of hydraulic resistances, modulus of compressibility (M/Lt^2)
K_n	nozzle (loss) coefficient
K_r	coefficient of wave refraction
k	coefficient of permeability (superficial) (L/t); wave number ($2\pi/L$)
k_s	size of roughness (L)
L	length (L), wavelength (L)
L_o	wavelength in deep water (L)
l	length (L)
lbm	pound mass (M)
lbf	pound force (ML/t^2)
M	mass (M), Mach number
MB	marginal benefit
MC	marginal cost
MP	marginal productivity
MRS	marginal rate of substitution
MRT	marginal rate of transformation
m	mass (M), mass rate of flow (M/t), hydraulic mean depth or radius (L)
N	speed of rotation (rev/min)
N_s	specific speed (turbines)
N_u	unit speed (rotodynamic machines)
n	porosity, ratio of wave group velocity to phase velocity (C_G/C)
n_s	specific speed (pumps)
O	outflow (L^3/t)
$\bar{O}$	average outflow (L^3/t)
OMR	operation, maintenance and repairs
P	force (ML/t^2), wetted perimeter (L), power (ML^2/t^3), principal investment, precipitation (rainfall)
P_u	unit power
p	pressure (M/Lt^2)
ppm	parts per million
p_{at}	atmospheric pressure (M/Lt^2)
p_v	vapour pressure (M/Lt^2)
Q	discharge rate (L^3/t), heat (ML^2/t^2)
Q_u	unit discharge
q	discharge per unit width (L^2/t)
$\mathbf{q}$	velocity vector (L/t)
q_b	rate of bed load transport per unit width (L^2/t)
q_s	rate of suspended load transport per unit width

List of Principal Symbols

xv

R	universal gas constant ($L^2/t^2 T$), Reynolds number, rainfall amount (L^3)
R'	Reynolds number based on shear velocity ($v'd/v$)
R_i	Richardson number
$^{\circ}R$	degrees Rankine
r	radius (L), (suffix) ratio of model quantity/prototype quantity
S	specific gravity, storage (L^3), degree of saturation, storage constant
S_f	slope of energy grade line (L/L)
S_F	shape factor (sand grains)
S_F	flow net shape factor
S_o	bed slope (L/L)
S_s	specific gravity of solids
T	temperature (T), wave period (t), torque (ML^2/t^2), transmissibility (L^2/t)
t	time (t), wind duration (t)
t_c	time of concentration (t)
t_p	recurrence interval (t)
t_r	duration of rainfall (t)
U	internal energy (ML^2/t^2), wind speed (L/t)
u	specific internal energy (L^2/t^2)
V	volume (L^3)
V_v	volume of voids (L^3)
v	velocity (L/t)
$\bar{v}$	time average velocity (turbulent flow) (L/t) (sections 1.5.4, 4.1.3, 7.2.3); sectional average velocity (sections 3.1, 3.2, 3.3, 3.4.1, 3.4.2)
v_f	radial (flow) component of velocity in a rotodynamic machine (L/t)
v_n	velocity of nozzle jet (L/t)
v_s	seepage velocity (ch. 9) (L/t)
v_s	shear velocity $\sqrt{(T_o/\rho)}$ (L/t)
v_w	absolute surge wave speed (L/t), rotodynamic whirl component of velocity (L/t)
W	weight (ML/t^2), Weber number, work (ML^2/t^2)
W_p	work against pressure (ML^2/t^2)
W_s	work against shear (ML^2/t^2)
W_{sh}	shaft work (ML^2/t^2)
w	settling velocity (sand particles) (L/t)
y	distance measured from wall (L)
y_c	critical depth (L)
y_n	uniform (normal) depth (L)
y_o	depth (generally) in an open channel (L)
$\bar{y}$	centroid of section measured from water surface (L)
y'	centre of pressure measured from water surface (L)
ΔZ or Z_o	height of weir (L)
Σ	summation of
$\rightarrow$	approaches (equivalent or equal to)
α	thermal molecular diffusivity (L^2/t), angle
α_m	mass molecular diffusivity (L^2/t)
β	angle, constant of proportionality in $\epsilon_s = \beta\epsilon$
γ	specific (unit) weight ($M/L^2 t^2$)
γ_s	specific weight of solid matter ($M/L^2 t^2$)
δ	boundary layer thickness (L)
ϵ	eddy kinematic viscosity (L^2/t)
ϵ_s	eddy diffusivity for suspended load (L^2/t)
θ	angle, temperature (T)

List of Principal Symbols

η	efficiency, small amplitude wave form (L)
η_h	hydraulic efficiency
η_m	mechanical efficiency
μ	dynamic molecular viscosity (M/Lt), discharge factor
ν	kinematic molecular viscosity (L^2/t)
ρ	density (M/L^3)
ρ_s	density of solid matter (M/L^3)
σ	surface tension (M/t^2), standard deviation, wave number ($2\pi/\tau$)
σ_c	critical cavitation number
σ_g	geometric standard deviation
τ	shear stress (M/Lt^2)
τ_c	critical shear stress (M/Lt^2)
τ_0	wall shear stress (M/Lt^2)
ω or Ω	angular velocity (rad/t)
$\mathcal{C}$	Cauchy number