



MODIFIED HAZEN-WILLIAMS FORMULA

THESIS

Submitted in partial fulfilment of the requirements

for the degree of

DOCTOR OF PHILOSOPHY

by ,

D.M. MOHAN

CENTRE FOR ENVIRONMENTAL SCIENCE AND ENGINEERING

. INDIAN INSTITUTE OF TECHNOLOGY , BOMBAY

1986

90029



Abstract

A dimensionally homogeneous and accurate formula has been derived in this research for the estimation of surface resistance in pipes based on explicit friction factor relationship and Darcy-Weisbach equation. The new relationship has been designated as Modified Hazen-Williams formula. The values of coefficient of roughness for commercial pipes have been estimated experimentally and a rational approach put forth to account for reduction in carrying capacity of pipes with age.

Chapter 1 delineates the goals of Government of India in water supply and sanitation sectors along with concomitant investments during the International Drinking Water Supply and Sanitation Decade. The need for and scope of present research are also brought out in this chapter.

Chapter 2 critically reviews pipe friction formulae in respect of their utility to Environmental Engineers.

Chapter 3 brings forth the limitations of widely used Hazen-Williams and Manning's formulae and quantifies errors in the estimation of frictional resistance through these formulae.

Chapter 4 presents a dimensionally homogeneous and accurate Modified Hazen-Williams formula, similar in form to that of Hazen-Williams, based on explicit friction factor relationship and Darcy-Weisbach equation. A nomograph for the solution of water supply and wastewater systems design and analysis problems is also presented.

Chapter 5 demonstrates the applicability of Modified Hazen-Williams formula to the design and analysis of rural and urban water supply systems.



Chapter 6 deals with the application of Modified Hazen-Williams formula, through the development of hydraulic elements for partful conditions, to design and analysis of wastewater collection systems.

Chapter 7 presents the details of experimental estimation of C_R values for commonly used commercial pipes. A comparison of C and C_R values on f - R diagram is also provided.

Chapter 8 reviews prevalent practices for the reduction in carrying capacity of pipes with age. The data on existing systems in some cities is analysed alongwith experimental information gathered during this research to bring out a rational approach to the reduction in carrying capacity of pipes *over* design period.

Chapter 9 underscores salient conclusions and recommendations drawn from the present research.

Appendix I presents a rationale for ascertaining dimensional homogeneity of empirical formulae.

Appendix II provides the derivation for explicit equations for pipe diameter and velocity.

Appendix III presents a case study on the application of Modified Hazen-Williams formula to the design of a real-life rural water supply system.

Appendix IV presents the derivation of hydraulic elements for partful conditions in wastewater lines based on Modified Hazen-Williams formula.

Appendix V provides derivation of Modified Shields equation for the estimation of self cleansing velocity in wastewater lines incorporating Modified Hazen-Williams formula.



Appendix VI describes the procedure adopted in this research for calibration of pitotmeters for experimental estimation of values for coefficient of roughness.

The thesis concludes., with a list of references on researches and articles relevant to the present research.

LB/MOHAN/02/108

39

MODIFIED HAZEN-WILLIAMS FORMULA

THESIS

Submitted in partial fulfilment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations

by
www.lib.library.lk
UNIVERSITY OF MORATUWA, SRI LANKA
MORATUWA

D.M. MOHAN

624 "86"
504 (043)

90023

DONATED BY
PROF. D.C.H. SENARATH

CENTRE FOR ENVIRONMENTAL SCIENCE AND ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY, BOMBAY

1986

90023

THESIS APPROVAL SHEET

Thesis entitled 'MODIFIED HAZEN-WILLIAMS FORMULA'
by D.M. MOHAN is approved for the degree of DOCTOR OF
PHILOSOPHY.

Examiners



University of Moratuwa, Sri Lanka
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

Supervisor


Co-supervisor

Chairman

Date:

ABSTRACT

A dimensionally homogeneous and accurate formula has been derived in this research for the estimation of surface resistance in pipes based on explicit friction factor relationship and Darcy-Weisbach equation. The new relationship has been designated as Modified Hazen-Williams formula. The values of coefficient of roughness for commercial pipes have been estimated experimentally and a rational approach put forth to account for reduction in carrying capacity of pipes with age.

 University of Moratuwa, Sri Lanka.
Chapter 1 delineates the goals of Government of India in water supply and sanitation sectors alongwith concomitant investments during the International Drinking Water Supply and Sanitation Decade. The need for and scope of present research are also brought out in this chapter.

Chapter 2 critically reviews pipe friction formulae in respect of their utility to Environmental Engineers.

Chapter 3 brings forth the limitations of widely used Hazen-Williams and Mannings formulae and quantifies errors in the estimation of frictional resistance through these formulae.

Chapter 4 presents a dimensionally homogeneous and accurate Modified Hazen-Williams formula, similar in form

to that of Hazen-Williams, based on explicit friction factor relationship and Darcy-Weisbach equation. A nomograph for the solution of water supply and wastewater systems design and analysis problems is also presented.

Chapter 5 demonstrates the applicability of Modified Hazen-Williams formula to the design and analysis of rural and urban water supply systems.

Chapter 6 deals with the application of Modified Hazen-Williams formula, through the development of hydraulic elements for particular conditions, to design and analysis of wastewater collection systems.

Chapter 7 presents the details of experimental estimation of C_R values for commonly used commercial pipes. A comparison of C and C_R values on f - R diagram is also provided.

Chapter 8 reviews prevalent practices for the reduction in carrying capacity of pipes with age. The data on existing systems in some cities is analysed alongwith experimental information gathered during this research to bring out a rational approach to the reduction in carrying capacity of pipes over design period.

Chapter 9 underscores salient conclusions and recommendations drawn from the present research.

Appendix I presents a rationale for ascertaining dimensional homogeneity of empirical formulae.

Appendix II provides the derivation for explicit equations for pipe diameter and velocity.

Appendix III presents a case study on the application of Modified Hazen-Williams formula to the design of a real-life rural water supply system.

Appendix IV presents the derivation of hydraulic elements for partful conditions in wastewater lines based on Modified Hazen-Williams formula.

Appendix V provides derivation of Modified Shields equation for the estimation of self cleansing velocity in wastewater lines incorporating Modified Hazen-Williams formula.

Appendix VI describes the procedure adopted in this research for calibration of pitotmeters for experimental estimation of values for coefficient of roughness.

The thesis concludes with a list of references on researches and articles relevant to the present research.

CONTENTS

		<u>PAGE NO.</u>
	LIST OF TABLES	..
	LIST OF FIGURES	..
	NOMENCLATURE	..
CHAPTER 1	INTRODUCTION	..
	1.1 Need for this Research	..
	1.2 Limitations of Hazen-Williams and Mannings Formulae	..
	1.3 Roughness Coefficients	..
	1.4 Reduction in Carrying Capacity of Pipes with Age	..
	1.5 Scope of Present Research	..
CHAPTER 2	REVIEW OF PIPE FRICTION FORMULAE	..
	2.1 Empirical Formulae	..
	2.2 Implicit Rational Formulae	..
	2.3 Explicit Formulae	..
	2.4 Discussions	..
CHAPTER 3	LIMITATIONS OF HAZEN-WILLIAMS AND MANNINGS FORMULAE	..
	3.1 Limitations of Hazen-Williams Formula	..
	3.2 Limitations of Mannings Formula	..
	3.3 Limitations of Crimps and Burges Formula	..
	3.4 Discussions	..

CHAPTER 4	MODIFIED HAZEN-WILLIAMS FORMULA	..
4.1	Explicit Relationships for Diameter and Velocity	..
4.2	Modified Hazen-Williams Formula	..
4.3	Coefficient of Roughness, C_R	..
4.4	Effect of Viscosity on C_R Values	..
4.5	Nomograph Based on Modified Hazen-Williams Formula	..
4.6	Discussions	..
CHAPTER 5	APPLICATION OF MODIFIED HAZEN-WILLIAMS (MHW) FORMULA IN DESIGN AND ANALYSIS OF WATER SUPPLY SYSTEMS	..
5.1	Rural Water Supply Systems	..
5.2	Urban Water Supply Systems	..
5.3	Discussions	..
CHAPTER 6	APPLICATION OF MODIFIED HAZEN-WILLIAMS (MHW) FORMULA IN DESIGN AND ANALYSIS OF WASTEWATER SYSTEMS	..
6.1	Partful Flow Conditions in Wastewater Lines	..
6.2	Hydraulic Elements for Partful Conditions in Wastewater Lines	..
6.3	Modified Shields Equation	..
6.4	Applicability of Modified Hazen-Williams Formula in Design and Analysis of Wastewater Collection Systems	..
6.5	Discussions	..

CHAPTER 7	EXPERIMENTAL ESTIMATION OF C_R VALUES ..	
7.1	Need for Updating of Roughness Co- efficients of Commonly Used Commercial Pipes ..	
7.2	Experimental Procedure for Estimation of Roughness Coefficients of Commonly Used Commercial Pipes ..	
7.3	Estimation of C_R Values for Small Diameter Pipes ..	
7.4	Estimation of C_R Values for Large Diameter Pipes ..	
7.5	Review of Experimental Results ..	
7.6	Comparison of C_R and C Values on f-R Diagram ..	
7.7	Discussions ..	
CHAPTER 8	REDUCTION IN CARRYING CAPACITY OF PIPES WITH AGE ..	
8.1	Practice in Vogue for Water and Wastewater Lines ..	
8.2	Considerations for Rational Reduction in Carrying Capacity in Cast Iron and Steel Pipes ..	
8.3	Considerations for Rational Reduction in Carrying Capacity in Cementi- ferrous and HDPE Pipes ..	
8.4	Considerations for Rational Reduction in Carrying Capacity in Wastewater Lines ..	
8.5	Experimental Estimation of C_R Values of Aged Pipes Used in Water Supply ..	
8.6	Analysis of Data on Existing Water Supply Systems in Some Cities ..	
8.7	Comparison of C and C_R Values for Design Period on f-R Diagram ..	
8.8	Discussions ..	

CHAPTER 9	CONCLUSIONS	..
APPENDIX I	DEVELOPMENT OF CRITERIA FOR DIMENSIONAL HOMOGENEITY OF EXPONENTIAL PIPE FLOW FORMULAE	..
APPENDIX II	DERIVATION OF EXPLICIT EQUATIONS FOR PIPE DIAMETER AND VELOCITY	..
APPENDIX III	DESIGN OF RURAL WATER SUPPLY SYSTEM USING MODIFIED HAZEN-WILLIAMS FORMULA	..
APPENDIX IV	HYDRAULIC ELEMENTS FOR PARTFUL CONDITIONS IN WASTEWATER LINES	..
APPENDIX V	DERIVATION OF MODIFIED SHIELDS EQUATION	..
APPENDIX VI	CALIBRATION OF PITOTMETERS	..
	REFERENCES	..
	ACKNOWLEDGEMENTS	..
	SUMMARY	..



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

LIST OF TABLES

<u>TABLE NO.</u>		<u>PAGE NO.</u>
3.1	Percentage Errors Implicit in Hazen-Williams Formula	..
3.2	Percentage Errors in Estimation of Darcys f by Hazen-Williams Formula	..
3.3	Percentage Errors in Estimation of Darcys f by Mannings Formula	..
4.1	C_R Values for Cast Iron (New) at 20°C	..
4.2	C_R Values for Concrete (New) at 20°C	..
4.3	C_R Values for Steel (New) at 20°C	..
4.4	C_R Values for Glazed Stoneware (New) at 20°C	..
4.5	C_R Values for GI (New) at 20°C	..
4.6	C_R Values for PVC/HDPE (New) at 20°C	..
4.7	C_R Values for AC (New) at 20°C	..
4.8	C_R Values for Cast Iron (Old) at 20°C	..
5.1	Analysis of Rural Water Supply System Using Hazen-Williams Formula, $C = 150$ for HDPE Pipes	..
5.2	Analysis of Rural Water Supply Systems Using Modified Hazen-Williams Formula, $C_R = 1$ for HDPE Pipes	..
5.3	Analysis of Rural Water Supply System Using Hazen-Williams Formula, $C = 120$ for HDPE Pipes	..
6.1	Hydraulic Elements for Circular Wastewater Lines (Modified Hazen-Williams Formula)	..
7.1	Pipe Materials and Diameters Used in Experimental Estimation of C_R Values	..

TABLE NO.

PAGE NO.

7.2	Details of Transmission Lines Used for Experimental Estimation of C_R Values in Large Diameter Pipes (New) at Hyderabad	..
7.3	Range of Application of Pitotmeters, Manometers and Pressure Gauges	..
7.4	Establishment of Traversing Points for Velocity Distribution in Large Diameter Pipes	..
7.5	Velocity Distribution Pattern for the Experimental Estimation of C_R Values	..
7.6	Experimental Results of C_R Values for Small Diameter RCC (New) Pipes	..
7.7	Experimental Results of C_R Values for Small Diameter AC (New) Pipes	..
7.8	Experimental Results of C_R Values for Small Diameter CI (New) Pipes	..
7.9	Experimental Results of C_R Values for Large Diameter (New) Pipes	..
8.1	Recommended C Values (CPHEEO)	..
8.2	Recommended n values (CPHEEO)	..
8.3	Details of Transmission Lines Used in Experimental Estimation of C_R Values for Aged Pipes at Hyderabad	..
8.4	Experimental Determination of C_R Values for Aged Pipes at Hyderabad	..
8.5	Analysis of Data on Existing Water Supply Systems in Some Indian Cities for CI Pipes	..
8.6	Analysis of Data on Existing Water Supply Systems in Some Cities for Steel Pipes	..

TABLE NO.

PAGE NO.

8.7	Analysis of Data on Existing Water Supply Systems of Some Cities for Concrete Pipes	..
III.1	Discharge in Each Section of Rural Water Supply Case Study	..
III.2	Calculation of Multiplication Factors for Each Branch of Rural Water Supply Case Study	..
III.3	Summary of Design for Rural Water Supply Case Study	..



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

LIST OF FIGURES

<u>FIGURE NO.</u>		<u>PAGE NO.</u>
2.1	Variation of f with R for Artificially Roughened Pipes (Nikuradse)	..
4.1	Effect of Temperature on C_R Values	..
4.2	Nomograph for Modified Hazen-Williams Formula; $C_R = 1, 20^{\circ}\text{C}$..
5.1	Single Branch Dead End System	..
5.2	Multibranch Dead End System	..
5.3	Multibranch Rural Water Supply System in Case Study	..
7.1	Schematic of Experimental Rig Used for Experimental Estimation of C_R Values in Small Diameter Pipes	..
7.2	Index Plan Showing the Details of Transmission Lines Used for Experimental Estimation of C_R Values in Large Diameter Pipes	..
7.3	Relationship Between Ratio of Mean Velocity to Centre Velocity in a Circular Pipe with Reynolds Number (Straight Smooth Pipes)	..
7.4	f - R Relationship for Commercial Pipes	..
8.1	Relationship Between Age of Pipes and C_R Values for Old CI Pipes	..
8.2	Relationship Between Age of Pipes and C_R Values for Old Steel Pipes (for Corrosive Water)	..
8.3	Trend Curves for Head Loss Tests in Seven U.S. Cities	..
8.4	f - R Relationship for CI and Steel Pipes	..

FIGURE NO.

PAGE NO.

8.5	f-R Relationship for RCC, AC and HDPE Pipes	..
VI.1	Schematic for Calibration of Pitotmeter	..
VI.2	Estimation of Pitotmeter Coefficient (for Small Diameter Pipes)	..
VI.3	Estimation of Pitotmeter Coefficient (for Large Diameter Pipes)	..



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

NOMENCLATURE

A	=	area of pipe
A_1	=	constant for power cost
a	=	partful area of pipe
a_r	=	constant dependent on depth of flow
B_r	=	constant for rough turbulent flow equation
b	=	multiplication factor in Hazen-Williams formula
C or C'	=	Chezys or Hazen-Williams constant
\bar{C}	=	constant for a pipe of known length, C_R and flow
C_i	=	consumption at node i
\bar{C}_i	=	constant C for ith pipe
C_R	=	coefficient of roughness
C_{Rf}	=	coefficient of roughness for full flow condition
C_{Rp}	=	coefficient of roughness for partful conditions
D	=	diameter of pipe
D/K	=	relative roughness
D_i	=	diameter of ith element
D_t	=	distance travelled
d	=	partful depth
d_p	=	diameter of grit particle
f	=	Darcys friction factor
f'	=	porosity ratio
f_f	=	friction factor at full flow condition
f_p	=	friction factor at part flow conditions

GL	=	ground level
g	=	acceleration due to gravity
H	=	head loss due to friction in pipe line
HGL	=	hydraulic grade line
H_j	=	head at node j
HW	=	Hazen-Williams
h	=	head measured in manometer
h_f	=	head lost due to friction in meters
h_j	=	head loss over j pipes
h_n	=	friction head loss in n pipes
h_o	=	input head
h_r	=	constant dependent on depth of flow
h_t	=	desired terminal head required at withdrawal point
I	=	Langeliers saturation index
K	=	roughness of pipe material
K'	=	peaking factor in wastewater flow
\bar{K}' , K_1 and K_2	=	regression analysis constants
K_o	=	initial roughness
K_s	=	sediment characteristic
K_T	=	roughness at end of T years
L	=	length of pipe line
MF	=	multiplication factor
MHW	=	Modified Hazen-Williams

m, m_1	=	regression analysis exponents
N	=	$[1.8099/4.8099 + m]$
n	=	Mannings coefficient
n_f	=	Mannings coefficient for full flow condition
n_p	=	Mannings coefficient for partful conditions
Q	=	flow in pipe
Q_{av}	=	average flow
Q_i	=	flow in i th element
Q_{peak}	=	peak flow in wastewater lines
q	=	partful flow in wastewater lines
R	=	Reynolds number
R_R	=	Reynolds number based on $(gDS)^{\frac{1}{2}}$ as velocity
r	=	hydraulic radius of pipe
r_f	=	hydraulic radius at full flow condition
r_p	=	hydraulic radius at partful conditions
S	=	slope of hydraulic gradient line
S_s	=	specific gravity of sediment
SGSW	=	salt glazed stoneware
T	=	time in years
t_t	=	time of travel
V	=	velocity of flow
V_A	=	actual velocity
V_c	=	centre velocity
V_f	=	velocity at full flow condition



University of Moratuwa, Sri Lanka
 Electronic Theses & Dissertations
www.lib.mrt.ac.lk

V_m	=	mean velocity
V_p	=	velocity at partful conditions
V_{Th}	=	theoretical velocity
W	=	weight of sediment in water
*	=	subscript for nondimensional parameter
α	=	exponent of r in exponential formulae
α_f	=	friction angle of sediment
α_r	=	growth rate of roughness
β	=	exponent of s in exponential formulae
ρ	=	specific weight of water
ρ_s	=	specific weight of sediment
τ	=	intensity of tractive force
ν	=	kinematic viscosity



University of Moratuwa, Sri Lanka.
 Electronic Theses & Dissertations
 www.lib.moratuwa.lk