OPTIMISATION OF DESIGN OF SPILLWAY GATES

A DISSERTATION

submitted in partial fulfilment of
the requirements for the award of the degree
of
MASTER OF ENGINEERING
in
WATER RESOURCES DEVELOPMENT

By
AM BORO

WATER RESOURCES DEVELOPMENT TRAINING CENTRE
UNIVERSITY OF ROORKEE
ROORKEE-247 667 (INDIA)

JANUARY, 2000

CANDIDATE'S DECLARATION

I hereby declare that the dissertation entitled, **"OPTIMISATION OF DESIGN OF SPILLWAY GATES"**, being submitted by me in partial fulfillment of the requirement for the award of the degree of **MASTER OF ENGINEERING** in **WATER RESOURCES DEVELOPMENT** at Water Resources Development Training Centre of the University of Roorkee, Roorkee is an authentic record of my own work carried out during the period from July 16, 1999 to 25th January, 2000 under the supervision of Prof. Gopal Chauhan, Professor, WRDTC, University of Roorkee, Roorkee.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree or diploma.

Place: Roorkee
Dated: 25th January, 2000

(JANI RAM BORO)

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

(GOPAL CHAUHAN)
PROFESSOR, WRDTC
University of Rookee
Roorkee-247 667 (U.P.)

ACKNOWLEDGEMENT

I wish to express my deep sense of gratitude to Prof. Gopal Chauhan, Professor, WRDTC, University of Roorkee, Roorkee for his able and excellent guidance and constant encouragement during this study. I feel indebted to him for his acceptance to guide me for this study and in fact I could finish it due to his inspiration and timely help.

I am grateful to Prof. Devadutta Das, Director, and all faculty members of WRDTC, University of Rookee for providing me an opportunity to study in this widely recognized Centre and to accomplish this work. I sincerely acknowledge the cooperation and suggestion given by Dr. B. N. Asthana, Visiting Professor, WRDTC in particular.

I am also grateful to my parent department, Central Water Commission, Govt. of India, for deputing me to WRDTC to acquire higher knowledge in the field of Water Resources.

Thanks are due to all authors, institutions and publishers whose books and papers have been used during the course of study.

I am very much thankful to all others who have helped in bringing out this work in the present shape.

In the last but not least, I express my deep gratitude to my parents who always inspired me and encouraged to do something more and more, my wife and my son for forbearance and necessary help.

Roorkee
Dated: 25th January, 2000

(JANI RAM BORO)
WRDTC, UOR

LIST OF SYMBOLS

The important symbols used in denotation of variables are as follows:

Common Symbols:

A :: Angle between the center line of TL making with the radius to Sill Beam, radian

Aa :: Length between bottom of radial/vertical gate and girder ‘a’, m

A1 :: Angle of radius the girder ‘a’ making with TL, radian

AB :: Location of arm joint to the horizontal girder (left), m

ac :: (subscript) Air compressor

AD :: Arc length from bottom of gate to TL, m

AE :: Parameter $b^2hH/1000$, m^4., where, b, h and H are span, height and head of water

Abay :: Area of spillway bay, m^2

AG :: Area of gate, m^2

Arc_AB :: Arc of the radial gate, m

Arc_Tim :: Arc time of the specified electrodes, minute

B :: Angle between the center line of TL making with the radius to FRL, radian

B1 :: Angle of radius the girder ‘b’ making with TL, radian

BC :: Span between the two joints of arm to girder, m

BD :: Arc length from top of gate to TL, m

BE :: Inclined length of arm, m

BMarm :: Highest bending moment out of four BMs in arm, t-m

BMcentre :: Total moment distributed to mid-span of girder section due to water load, t-m/m

BSa/BSb /BSc/BSd :: Bending stress at ‘a’, ‘b’, ‘c’ and ‘d’ resulting from MmaxGA, kg-cm

C :: Total angle of the radial gate, radian

CG :: Centre of gravity

CAWspab :: Co-acting width w.r.t. span 'ab', m

CAWxa :: Co-acting width w.r.t. support point 'a', m

CAWxb :: Co-acting width w.r.t. support point 'b', m

CAWxalow :: Least of CAWs of CAWspab and Cawxa at 'a', m

CAWxblow :: Least of CAWs of CAWspab and CAWxb at 'b', m

CD :: Location of arm joint to the horizontal girder (right), m

CG :: Centre of gravity of radial gate, m

CG1 :: Assumed center of gravity (CG) of radial gate, m

CL :: Crest Level, m

CS :: Clear span of the spillway, m

Cdril :: Drilling cost, lakh Rs.

Cpaints :: Cost of painting with material, lakh Rs.

Ctrans :: Transportation cost, lakh Rs.

crn :: (subscript) Crane

Cerect :: Erection cost, lakh Rs.

Choist :: Cost of hoist, lakh Rs.

Cinsp :: Inspection and design cost, lakh Rs.

Ctotal :: Total cost of gate, lakh Rs.

Cut_spl :: Cutting length in skin plate welding (edge preparation), m

Cut_vs :: Cutting length in vertical stiffener, m

Cut_tot :: Total cutting length for edge preparation, m

Cut_cost :: Cutting cost, Rs.

Cep :: Edge preparation cost, lakh Rs.

C_elect :: Cost of electrode for welding, Rs.

Cwel :: Welding cost, lakh Rs.

conflxabl :: Contra flexure point at left of span 'ab', m

conflxabr :: Contra flexure point at right of span 'ab', m

darm :: CG of arms, m

dbrc :: CG of bracing, m

dhg :: CG of horizontal girders, m

dm :: (subscript) Drilling machine

Dep_cost :: Depreciation cost of equipment, Rs/hour

Dslg_Tim	::	Deslag time for the specified electrodes, minute
dsp	::	CG of skin plate, m
dvs	::	CG of vertical stiffeners, m
D, E, F	::	Arcs, radian
E	::	Young's modulus.
Faxmax	::	Highest axial load on arm, tonne
f1	::	Bending stress on skin plate side, kg/cm^2
f2	::	Bending stress on opposite side of skin plate, kg/cm^2
f3	::	Bending stress in web of stiffener section, kg/cm^2
fbG	::	Bending stress at girder section, kg/cm^2
fc	::	Direct compressive stress in arm section, kg/cm^2
fbc	::	Bending stress in arm section, kg/cm^2
fbsp	::	Bending stress in skin plate, kg/cm^2
Fcomp_a/b	::	Direct compressive force due to direct thrust Wthr, tonne
flgLG	::	Length of flange of girder section, cm
flgWG	::	Width of flange of girder section, cm
flgL	::	Length of flange of arm section, cm
flgW	::	Width of flange of arm section, cm
flgLVS	::	Length of flange of vertical stiffener section, cm
flgWVS	::	Width of flange of vertical stiffener section, cm
FF	::	Seal friction while lifting the radial gate, t-m
FFl	::	Face to face length of skin plate, m
FFw	::	Length between wheels of fixed wheel gate, m
FRL	::	Full Reservoir Level, meter (m)
fT	::	Total stress in arm section, kg/cm^2
fxa	::	Total stress in x-direction at 'a', kg/cm^2
fya	::	Total stress in y-direction at 'a', kg/cm^2
gen	::	(subscript) Generator set
gm	::	(subscript) Grinding machine
Gri_cost	::	Grinding cost, Rs.
Hb	::	Hydrostatic pressure at the bottom of pressure triangle, kg/cm^2
HC1	::	Assumed Hoisting Capacity of the radial gate, tonne

HC :: Actual Hoisting Capacity, tonne

HD :: Head of water, m

HDA :: Index for analysis with a specific area of spillway

HDx :: Number of welding joints

HG :: Horizontal girder

hel :: Number of helper

KBC :: Distribution factor of girder section 'BC'

KBE :: Distribution factor of arm section 'BE'

lcon_spab :: Addition of contra flexure point (lengths) of span 'ab', m

LA :: Actual arm length after correction, m

lab_cost :: Cost of man-power, Rs/hour

lab :: Number of labourer

Lconn :: Arm and Trunnion connection in proportion to 'HD/12', m

LarmCor :: Length deducted for computing Arm length, m

Lev_arm :: Distance between two adjacent joints of arms, m

le :: Arm length from trunnion to girder joint, m

lr :: Slenderness ratio (SlRatio)

Lopt :: Optimal spacing of vertical stiffener, cm

LoptFinal :: Final optimal spacing after analysis of stresses in skin plate as a plate, cm

Lst :: Hor'tal length between Sill Beam and center line of TL, m

ms :: (subscript) Mild steel

misc_cost :: Miscellaneous cost, Rs/hour

marm :: Bending moment due to weight of arms, t-m

mbrc :: Bending moment due to weight of bracing, t-m

mhg :: Bending moment due to weight of horizontal girders, t-m

msp :: Bending moment due to weight of skin plate, t-m

mvs :: Bending moment due to vertical stiffeners, t-m

Ma :: Total bending moment at girder 'a', t-m/m

Mas :: Bending moment due to Wrad at girder 'a', t-m/m

Maw :: Bending moment due to water load at 'a', t-m/m

Marm :: Moment at location where arm is connected with fabricated portion of Trunnion assembly, t-m

Mat_cost :: Cost of steel, lakh Rs.

Mb :: Total bending moment at girder ‘b’, t-m/m

Mbs :: Bending moment due to Wrad at girder ‘b’, t-m/m

Mbw :: Bending moment due to water load at ‘b’, t-m/m

MBA :: Cantilever bending moment distributed to section ‘AB’ due to water load (McantG), t-m/m

MbeamR :: Total bending moment distributed to girder section , t-m/m

MC :: Material cost, lakh Rs.

MCB :: Bending moment distributed to mid-span of section ‘BC’ due to water load (-MbeamG), t-m/m

McantR :: Cantilever bending moment due to rope tension distributed to the girder section (McanTR), t-m/m

MFrmax :: Maximum bending moment due to max. axial force, t-m

MGmax : Maximum bending moment in girder section, t-m

MG1 :: Maximum bending moment at ‘B’ or ‘C’ due to water load and sill pressure, t-m

MG_BC1 :: Maximum span moment at ‘BC’ due to water load and sill pressure, t-m

MG2 :: Maximum bending moment at ‘B’ or ‘C’ due to water load and rope tension, t-m

MG_BC2 :: Maximum span moment at ‘BC’ due to water load and rope tension, t-m

MG :: Total moment due to weight of gate components, t-m

MLopt :: Bending moment on skin plate for a spacing of Lopt, tonne-meter (t-m)

MmaxGA :: Greater of Mpo and Mpq, kg-cm

MN :: Level of girder ‘b’ from TL, m

Mpo :: Cantilever bending moment at girder location, kg-cm

Mpq :: Span bending moment between two stiffeners, kg-cm

N :: Life of equipment, hour

Nvs :: Number of vertical stiffeners
OC :: Operating cost, lakh Rs.
P :: Total pressure on the Radial gate, tonne and Initial cost/capital of equipment, Rs
Pbc :: Allowable bending stress in arm section, kg/cm^2
pcm :: (subscript) Pug cutting machine
Pd :: Perpendicular distance of resultant from trunnion, m
PQ :: Level of girder 'a' from TL, m
R :: Radius of the radial gate, m
R1 :: Angle of rotation of lifted gate, radian
Ra :: Total reaction at girder 'a', t/m
Ras :: Reaction due to Wrad at girder 'a', t/m
RA1 :: Assumed inclination of hoisting rope to horizontal, radian
Rb :: Total reaction at girder 'b', t/m
Rbs :: Reaction due to Wrad at girder 'b', t/m
Raw :: Reaction due to water load at girder 'a', tonne/m
Rbw :: Reaction due to water load at girder 'b', tonne/m
Rep_cost :: Repair cost of equipment, Rs/hour
Rep_Pro :: Repair provision as percentage of initial cost, %
POL_cost :: Energy (fuel or electricity) cost, Rs/hour
Rf :: Radius factor, non-dimensional constant
RT :: Rope tension , tonne
RTh :: Rope tension in x-x direction, tonne
Rvt :: Distance from FRL to TL, m
Rvb :: Distance from TL to SL, m
TF :: Trunnion friction while lifting the radial gate, t-m
TS :: Radial distance of lifting point/pulley from trunnion, m
TT1 :: Vertical distance from TL to lifting point, m
Sa/SA :: Shear stress on the stiffener section, kg/cm^2
Scomb :: Combined stress in skin plate at girder location at 'a', kg/cm^2
Seal_Tim :: Sealing time for the specified electrodes, minute
SFbot :: Negative shear force at girder location at 'a', tonne/m

SFtop :: Positive shear force at girder location at ‘a’, tonne/m
SFbot1 :: Negative shear force due to water and sill pressure, tonne
SFtop1 :: Positive shear force due to water and sill pressure, tonne
SFbot2 :: Negative shear force due to water and rope tension, tonne
Sftop2 :: Positive shear force due to water and rope tension, tonne
Sh :: Horizontal distance from CL to the Sill Beam, m
SL :: Sill Level, m
ss :: (subscript) Stainless steel
SSmax :: Shear stress at girder section, kg/cm^2
ST1 :: Horizontal distance from TL to lifting point, m
Sv :: Vertical distance from CL to the Sill Beam, m
t :: Thickness of skin plate, centimeter (cm)
TA :: Total area of water load in radial gate, m^2
Taxmax :: Highest axial force(~SFmax) out of four SFs in arm, tonne
TL :: Trunnion Level, m
Tim_cut :: Cutting time, hour
Tim_gri :: Grinding time, Hour
tr :: (subscript) Truck
trl :: (subscript) Trailor
Tss/Tsl :: Side seal thickness, millimeter (mm)
Use_Rate :: Hourly use rate of equipments, Rs./hour
vs :: (subscript) Vertical stiffener
veg :: (subscript) Vertical end girder
wa :: Water load at girder ‘a’. t/m^2
wb :: Water load at girder ‘b’, t/m^2
wA :: Water load at bottom of pressure triangle, t/m^2
webLG :: Length of web of girder section, cm
webWG :: Width of web of girder section, cm
WG1 :: Assumed weight of radial gate, tonne
WG :: Weight of radial gate, tonne
Wrad :: Radial load per meter of width of gate due to Sill Beam, t/m
Wthr :: Direct thrust/meter of width of gate due to Sill Beam, t/m
webLVS :: Length of web of vertical stiffener section, cm

webWVS :: Width of web of vertical stiffener section, cm
wVSa :: Weight of vertical stiffener section, kg/m
wHG :: Weight of girder section , kg/m
webL :: Length of web of arm section, cm
webW :: Width of web of arm section, cm
wArm :: Weight of radial arm section, kg/m
wsp :: Weight of skin plate, tonne
wvs :: Weight of vertical stiffeners, tonne
whg :: Weight of horizontal girders, tonne
warm :: Weight of Arms, tonne
wTrAssm :: Weight of trunnion assembly , tonne
wbrc :: Weight of bracing, tonne
Wel_Tim_tot :: Total welding time, minute
Wel_fil :: Total length of weld to be filled in fillet welding, m
Wel_spl :: Total length of weld in skin plate, m
win :: (subscript) Winch
Wor_Hor :: Working hours, hour
wm :: (subscript) Welding machine
Zsp :: Section modulus of skin plate, cm^3

Symbols in Radial Gate with 2 horizontal girders:

bB :: Length between top of gate and girder 'b', m
fb_2_3x :: Bending stress corresponding to panel 'PM*Lopt', kg/cm^2
fb_5_8x :: Bending stress corresponding to panel 'Aa*Lopt', kg/cm^2
fb_11x :: Bending stress corresponding to panel 'PM*LoptPM', kg/cm^2
PM :: Length of arc between horizontal girder 'a' and 'b', m
R2PAa :: Hydrostatic pressure at mid-point of skin plate panel 'Aa*Lopt', kg/cm^2
R2PPM :: Hydrostatic pressure at mid-point of skin plate panel 'PM*Lopt', kg/cm^2
RemPM :: Dividend of CS to Lopt, m

LoptPM :: Width of the side panel 'PM*LoptPM (~RemPM), m

Symbols in Fixed wheel Vertical Lift Gate with 2 horizontal girders

ab :: Length between horizontal girder 'a' and 'b', m
bB :: Length between top of gate and girder 'b', m
fb_2_3x :: Bending stress corresponding to panel 'ab*Lopt', kg/cm^2
fb_5_8x :: Bending stress corresponding to panel 'Aa*Lopt', kg/cm^2
fb_11x :: Bending stress corresponding to panel 'ab*Loptab', kg/cm^2
Loptab :: Width of the side panel 'PM*LoptPM(~RemPM), m
V2PAa :: Hydrostatic pressure at mid-point of skin plate panel 'Aa*Lopt', kg/cm^2
V2Pab :: Hydrostatic pressure at mid-point of skin plate panel 'PM*Lopt', kg/cm^2
Remab :: Dividend of CS to Lopt, m

Symbols in Radial Gate with 3 horizontal girders:

CAWxclow :: Lowest co-acting width at support point 'c', m
cB :: Length between top of gate and girder 'c', m
fb_2_3xPX :: Bending stress corresponding to panel 'PX*Lopt', kg/cm^2
fb_5_8xAa :: Bending stress corresponding to panel 'Aa*Lopt', kg/cm^2
fb_11xPX :: Bending stress corresponding to panel 'PX*LoptPX', kg/cm^2
LoptPX :: Width of the side panel 'PX*LoptPX(~RemPX), m
lcon_b :: addition of two contra flexure points of adjacent spans m
Mcw :: Bending moment at girder 'c' due to water load, t-m
Mc :: Bending moment at 'c' due to water and sill beam, t-m
R3PPX :: Hydrostatic pressure at mid-point of skin plate panel 'PX*Lopt', kg/cm^2
R3PXM :: Hydrostatic pressure at mid-point of skin plate panel 'XM*Lopt', kg/cm^2
R3PAa :: Hydrostatic pressure at mid-point of skin plate panel 'Aa*Lopt', kg/cm^2

RemPX :: Dividend of CS to Lopt, m
PX :: Length of arc between horizontal girder ‘a’ and ‘b’, m
Rcw :: Reaction at girder ‘c’ due to water load, tonne
Rc :: Reaction at girder ‘c’ due to water and sill beam load, t-m
XM :: Length of arc between horizontal girder ‘b’ and ‘c’, m
XY :: Vertical distance from girder ‘b’ to TL, m
wc :: Water load at girder ‘c’, t/m

Symbols in Fixed wheel Vertical Lift Gate width 3 horizontal girders

ab :: Length between horizontal girder ‘a’ and ‘b’, m
bc :: Length between horizontal girder ‘b’ and ‘c’, m
CAWxclow :: Lowest co-acting width at support point ‘c’, m
‘Aa*Lopt’, kg/cm^2
cB :: Length between top of gate and girder ‘c’, m
fb_2_3xab :: Bending stress corresponding to panel ‘ab*Lopt’, kg/cm^2
fb_5_8xAa :: Bending stress corresponding to panel ‘Aa*Lopt’, kg/cm^2
fb_11xab :: Bending stress corresponding to panel ‘ab*Loptab’, kg/cm^2
lcon_b :: addition of two contra flexure points of adjacent spans, m
Loptab :: Width of the side panel ‘ab*Loptab(~Remab), m
fb_2_3xab :: Bending stress corresponding to panel ‘ab*Lopt’, kg/cm^2
fb_5_8xAa :: Bending stress corresponding to panel ‘Aa*Lopt’, kg/cm^2
fb_11xab :: Bending stress corresponding to panel ‘ab*Loptab’, kg/cm^2
fb_2_3xab :: Bending stress corresponding to panel ‘ab*Lopt’, kg/cm^2
fb_5_8xAa :: Bending stress corresponding to panel ‘Aa*Lopt’, kg/cm^2
fb_11xab :: Bending stress corresponding to panel ‘ab*Loptab’, kg/cm^2
Mc :: Bending moment at girder ‘c’ due to water load, t-m
Remab :: Dividend of CS to Lopt, m
Rc :: Reaction at girder ‘c’ due to water load, tonne
V3Pab :: Hydrostatic pressure at mid-point of skin plate panel
‘ab*Lopt’, kg/cm^2
V3Pbc :: Hydrostatic pressure at mid-point of skin plate panel
‘bc*Lopt’, kg/cm^2

V3PAa :: Hydrostatic pressure at mid-point of skin plate panel
XY :: Vertical distance from girder ‘b’ to TL, m
wc :: Water load at girder ‘c’, t/m

Symbols in Radial Gate with 4 horizontal girders:

CAWxdlow :: Lowest co-acting width at support point ‘d, m
CAWxclow :: Lowest co-acting width at support point ‘c’, m
dB :: Length between top of gate and girder ‘d’, m
fb_2_3x PR :: Bending stress corresponding to panel ‘PR*Lopt’, kg/cm^2
fb_5_8x Aa :: Bending stress corresponding to panel ‘Aa*Lopt’, kg/cm^2
fb_11x PR :: Bending stress corresponding to panel ‘PR*LoptPR’, kg/cm^2
lcon_b :: addition of two contra flexure points of adjacent spans at ‘b’, m
lcon_c :: addition of two contra flexure points of adjacent spans at ‘c’, m
LoptPR :: Width of the side panel ‘PR*LoptPR(~RemPR), m
Mcw :: Bending moment at girder ‘c’ due to water load, t-m
Mc :: Bending moment at ‘c ’due to water and sill beam, t-m
Mdw :: Bending moment at girder ‘d’ due to water load, t-m
Md :: Bending moment at ‘d’ due to water and sill beam, t-m
MN :: Vertical distance from girder ‘d’ to TL, m
PR :: Length of arc between horizontal girder ‘a’ and ‘b’, m
Rdw :: Reaction at girder ‘d’ due to water load, tonne
Rc :: Reaction at girder ‘c’ due to water and sill beam load, t-m
Rcw :: Reaction at girder ‘c’ due to water load, tonne
Rd :: Reaction at girder ‘d’ due to water and sill beam load, t-m
RemPR :: Dividend of CS to Lopt, m
RS :: Vertical distance from girder ‘b’ to TL, m
RX :: Length of arc between horizontal girder ‘b’ and ‘c’, m

R4PPR :: Hydrostatic pressure at mid-point of skin plate panel 'PR*Lopt', kg/cm^2

R4PRX :: Hydrostatic pressure at mid-point of skin plate panel 'RX*Lopt', kg/cm^2

R4PAa :: Hydrostatic pressure at mid-point of skin plate panel 'Aa*Lopt', kg/cm^2

XM :: Length of arc between horizontal girder 'c' and 'd', m

XY :: Vertical distance from girder 'c' to TL, m

wc :: Water load at girder 'c', t/m

wd :: Water load at girder 'd', t/m

Symbols in Fixed wheel Vertical Lift Gate with 4 horizontal girders

ab :: Length between horizontal girder 'a' and 'b', m

bc :: Length between horizontal girder 'b' and 'c', m

cd :: Length between horizontal girder 'c' and 'd', m

CAWxdlow :: Lowest co-acting width at support point 'd, m

CAWxclow :: Lowest co-acting width at support point 'c', m

dB :: Length between top of gate and girder 'd', m

fb_2_3x ab :: Bending stress corresponding to panel 'ab*Lopt', kg/cm^2

fb_5_8x Aa :: Bending stress corresponding to panel 'Aa*Lopt', kg/cm^2

fb_11x ab :: Bending stress corresponding to panel 'ab*Loptab', kg/cm^2

hc :: Water load at girder 'c', t/m

hd :: Water load at girder 'd', t/m

lcon_b :: addition of two contra flexure points of adjacent spans at 'b', m

lcon_c :: addition of two contra flexure points of adjacent spans at 'c', m

Loptab :: Width of the side panel 'ab*Loptab(~Remab), m

Mc :: Bending moment at girder 'c' due to water load, t-m

Md :: Bending moment at girder 'd' due to water load, t-m

Rc :: Reaction at girder 'c' due to water load, tonne

Rd :: Reaction at girder 'd' due to water load, tonne

Remab :: Dividend of CS to Lopt, m

V4Pab :: Hydrostatic pressure at mid-point of skin plate panel 'ab*Lopt', kg/cm^2

V4Pbc :: Hydrostatic pressure at mid-point of skin plate panel 'bc*Lopt', kg/cm^2

V4PAa :: Hydrostatic pressure at mid-point of skin plate panel 'Aa*Lopt', kg/cm^2

LIST OF FIGURES

LIST OF TABLES

LIST OF CHARTS

LIST OF APPENDICES

SYNOPSIS

Hydraulic gates are essential hydro mechanical control equipment required for spillways in the water resources projects. Several types of gates are developed, out of which vertical lift gate and radial gate are in use in general. Without sacrificing the operational requirements like failure free performance, water tightness, rapidity in operation and convenience in installation and maintenance, it is desired that the cost of the gate should be minimum with lesser weight of gate and hoisting capacity. To achieve this goal, the design of various components of the gates is to be optimized. The number of horizontal girders which controls the skin plate thickness and hence the quantity of steel for the vertical lift gate besides the heads of water, spacing of vertical stiffeners with their size, radius of radial gate which controls the quantity of steel used for radial arms besides the skin plate length and hence the quantity of steel used for the gate are subject to optimization.

In the dissertation, a study has been done for the optimization of spillway crest gates of vertical lift and radial types. A computer program has been developed in 'C++' and adopted for cost analysis of gates of both, fixed wheel vertical lift type and radial type for 2, 3 and 4 number of horizontal girders in each case.

The analysis indicates that radial gate is cheaper than the fixed wheel vertical lift gate. Basically, heads of water govern the numbers of horizontal girders. The optimized number of horizontal girders is found to be 2 up to 8.5m of head, 4 above 13.5m and 3 in between this range for vertical lift gate, while slightly lower values of head have been established for radial gate.

CONTENTS

CHAPTER I

INTRODUCTION

1.1 GENERAL

Spillway crest gates are provided for regulating the floodwater in the reservoir to the downstream without damaging the dam structure or the downstream area. Gates help to store water in the reservoir for its use in the lean period. Spillway gates are normally meant to be fully closed during non-flood season and are partly or fully open during flood season. Vertical lift gate or radial gate is normally used for controlling the flow of water through the surface spillways.

1.2 VERTICAL LIFT GATE

1.2.1 General

Vertical lift gates are rectangular in shape and are supported by guides, in which gates move vertically in their own plane. The closing member of the gate consists of a framework to which a skin plate is attached. The main load of water pressure is transmitted by the framework to the piers. The lifting mechanism of the gate is made strong enough to withstand the weight of the gate as well as to overcome the friction developed due to water pressure and the movement of gate.

Among the various types of vertical lift gate the fixed wheel gates are used normally used. In the fixed wheel gates, they have a series of wheels fixed along each end of gate to transfer the water load to vertical track on the downstream side of the gate groove. These gates are generally arranged to move vertically. The wheels substitute rolling friction to sliding friction which allow a reduction in hoist capacity as well as permit the gate to close under its own weight.

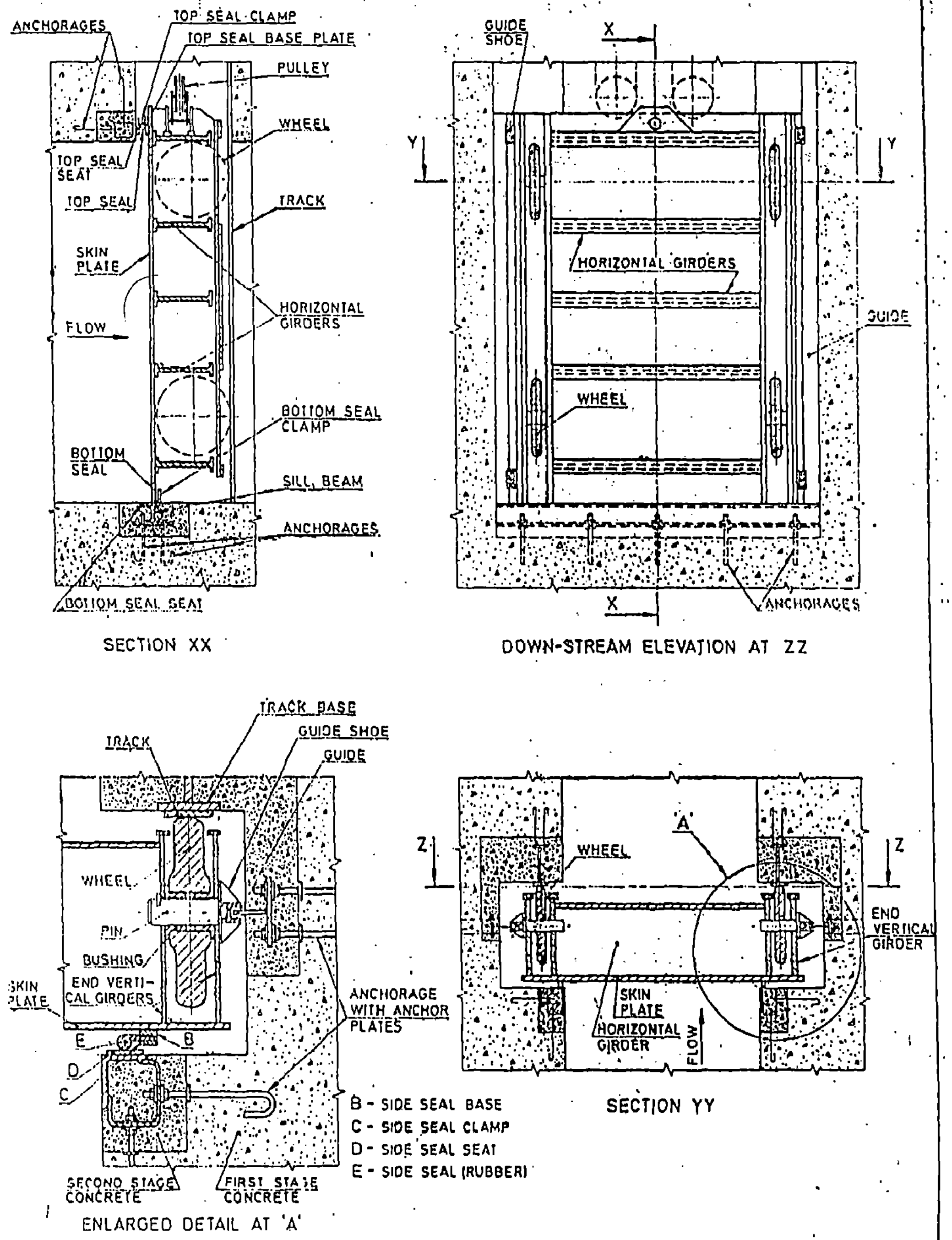


FIG. 1.1: Typical Arrangement of Various Components of Fixed-Wheel Gates

1.2.2 Components of Fixed Wheel Vertical Lift Gate

The closing member of the gate is the gate leaf, which consists of: (1). Skin plate, (2). Vertical stiffeners, (3). Horizontal girders, (4). End girders, (5). Wheels, (6). Pin, (7). Seals and (8). Guide rollers.

The groove embedment on which the gate leaf runs consists of: (1). Wheel track, (2). Seal bases, (3). Guides and (4). Anchor bolts.

FIG-1.1 shows various components of the gate.

1.3 RADIAL GATE

1.3.1 General

Radial gates are most commonly used for controlling discharge from large spillways. The gate leaf consists of a curved skin plate shaped so as to form a sector of the curved surface of a horizontal cylinder. Water is retained on the upstream of the convex surface of the gate. The skin plate is supported by stiffeners. The force exerted by water on gate leaf is passed on to the gate arms, which transmits it further to the trunnion assembly mounted on the trunnion pin or axle. The trunnion pins are located at center of an arc about which the gate rotates. Absence of gate slots is an important feature of these gates. Hence, they are hydraulically more suitable than other type of gates.

1.3.2 Components of Radial Gate

The main components of radial gate are: (1). Skin plate, (2). Vertical stiffeners, (3). Horizontal girders, (4). Arms, (5). Trunnion girders, (6). Trunnion brackets, (7). Trunnion hub, (8). Trunnion pin, (9). Trunnion bushing, (10). Guide rollers, (11). Guide roller pins, (12). Bracings, (13). Anchor girders, (14). Seal seats, (15). Sill beam, (16). Rubber seals, (17). Seal fasteners.

FIG-1.2 shows various components of radial gate.

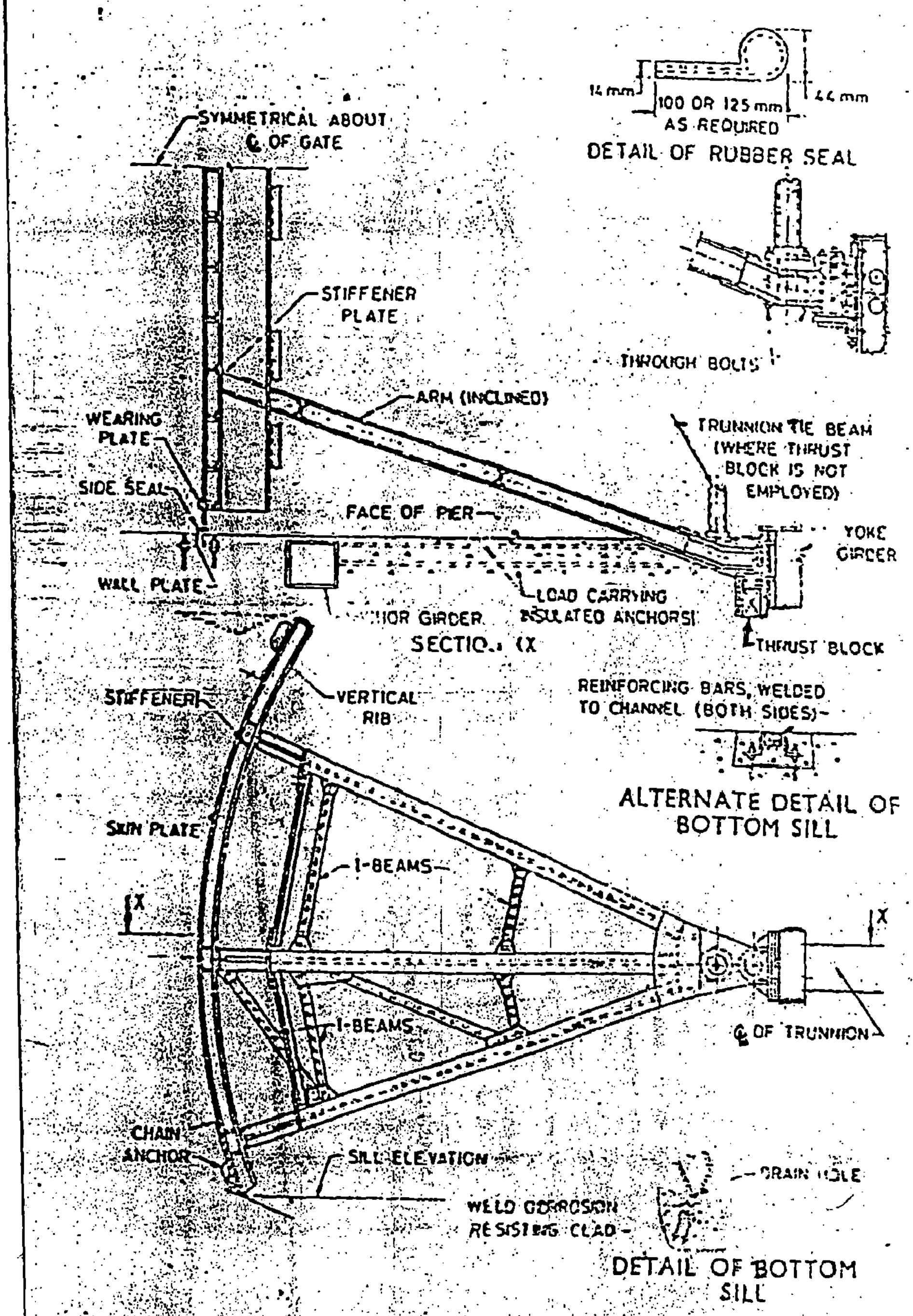


FIG. 1.2: RADIAL GATE WITH INCLINED ARM

(After I.S. 4623)

1.4 SCOPE OF STUDY

The scope of study includes optimization of design of main components of fixed wheel vertical lift gate i.e. design of skin plate, vertical stiffeners, horizontal girders, vertical end girders, wheels, computation of the weight of the gate, center of gravity, hoisting capacity and cost evaluation of the gate with due consideration of material cost and fabrication cost as well as main components of radial gate i.e. skin plate, vertical stiffeners, horizontal girders, arms, computation of the weight of the gate, center of gravity, hoisting capacity and cost evaluation of the gate with due consideration of material cost and fabrication cost.

CHAPTER II

DESIGN OF FIXED WHEEL VERTICAL LIFT GATE

2.1 GENERAL

Structural components of a vertical lift gate of fixed wheel type which transfer the water load acting on the gate include: skin plate, framework of vertical stiffeners supported on main horizontal girders, vertical end girders, wheels, wheel tracks and track base. The structural design of vertical lift gate is based on the principle that the water load is transferred from skin plate to horizontal girders, which further transmit the water load to vertical end girders at two ends. The vertical end girders at ends transmit the load through wheels onto a structural member embedded in concrete, which is termed as track.

2.2 MATERIAL SPECIFICATION

The choice of structural steel for fixed wheel vertical lift gate involves selection of suitable structural steel compatible to welding. The steels selected are as per the IS: 2062-1984. The steel sections required for skin plate vertical stiffeners, horizontal girders, vertical end girders are adopted as per the IS: 808-1964 and weldments made up of plates which may be required for higher heads. The wheel material is taken as per the IS: 1030-1982.

The properties of material conforming to IS: 2062-1984 (Plates & Sections) which decides the permissible stresses in mega pascals (MPa) are as follows:

Grade	Designation	Tensile Strength Min, MPa	Yield Strength Min, MPa			Carbon req'ment, Max
			<20mm	20-40mm	>40mm	
A	Fe 410 WA	410 (4100 kg/cm^2)	250	240	230	0.40
B	Fe 410 WB	410 (4100 kg/cm^2)	250	240	230	0.41

2.3 DESIGN STRESSES

The design stresses are adopted as per IS: 4622-1992 for structural steel as specified in Annex-B of the Code. The permissible stresses based on yield point to wet and accessible conditions have been computed as follows:

Sl. No.	Type of Stress	Limit as per IS: 4622-1992	Permissible Stress as per IS: 2062-1984 (kg/cm^2)		
1	Direct compression and compression in bending	0.45 YP	1125	1080	1035
2	Direct tension and tension in bending	0.45 YP	1125	1080	1035
3	Shear	0.35 YP	875	840	805
4	Combined	0.60 YP	1500	1440	1380
5	Bearing	0.65 YP	1625	1560	1495
6	Bearing stress for Brass and Bronze	0.035 UTS	143.5	143.5	143.5

2.4 DESIGN CONSIDERATIONS

The following design considerations have been adopted:

1. 0.30m is added to the head obtained from full reservoir level (FRL) and sill level (SL) to cater for free board.
2. Spacing of wheel assumed is 5 % of head of water (HD) and equi-distant from girder.
3. Corrosion in regard to skin plate thickness is taken 1.5mm.
4. Co-efficient of axle friction (fa) assumed as 0.015.
5. Co-efficient of rolling friction (fr) assumed as 1.5
6. Co-efficient of guide friction is assumed as 0.5.
7. Weight of wire rope taken as 1.5 % of gate weight.
8. Hoisting capacity is calculated with 20 % extra provision.

9. Wastage of material is assumed as5%.

10. Weight of embedded parts of gate is assumed as 15 %.

11. Hoist cost is taken proportionate to the hoist capacity above Rs.1 lakh.

The sequence of design considerations for various components has been rearranged in a manner so as to facilitate the design process.

2.5 SPACING OF HORIZONTAL GIRDERS

The spacing of horizontal girders is based on criteria of almost equal load on all the girders. Since the water pressure acting on the gate is hydrostatic, the load on the girder will be triangular. The spacing of horizontal girders as shown in **FIG-2.1**, has been determined by analytical method as follows:

- Girder location is computes as:
  $hr=HD*2/3*\{r^{3/2}-(r-1)^{3/2}\}/n^{1/2}$,

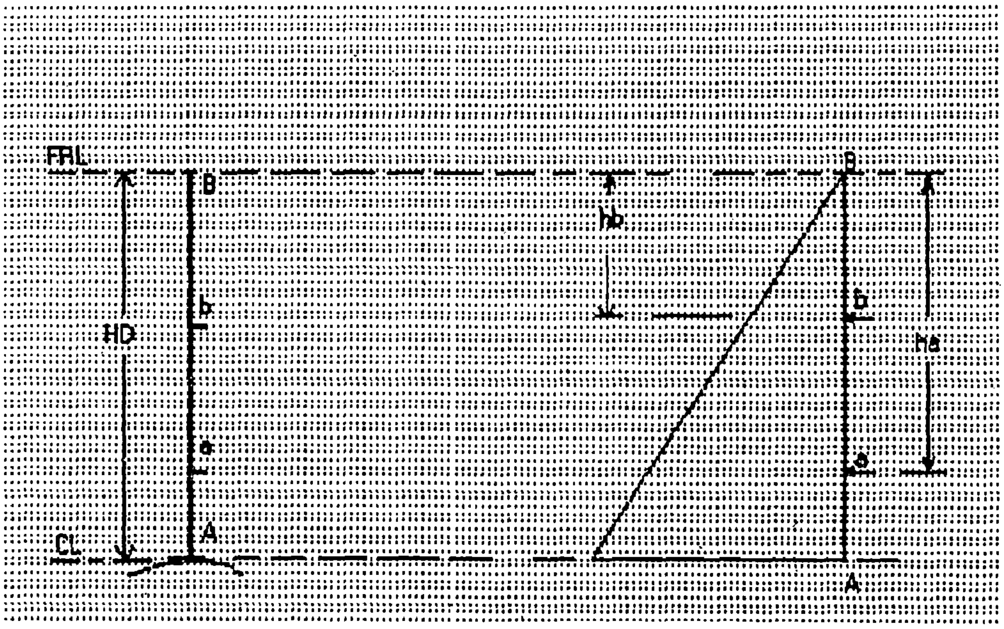
  where, n : number of horizontal girders,
  r : Location of girder
  hr : Depth of the r^th^ girder.

  For fixed wheel gate with 2 horizontal girders & using symbols defined in FIG-2.1, the depth of girders are computed as:

  $ha=HD*2/3*\{2^{3/2}-(2-1)^{3/2}\}/2^{1/2}$

  $hb=HD*2/3*\{1^{3/2}-(1-1)^{3/2}\}/2^{1/2}$

- The fixed end moments are calculated as:
  $Ma=ha*Aa^2/+(HD-ha)*Aa^2/2*2/3$
  $Mb=bB^3/6$
- The reactions at girder locations are computed as:
  $Ra=(HD+ha)*Aa/2+hb*ab/2+(ha-hb)/2*ab*2/3$
  $Rb=bB^2/2+hb*ab/2+(ha-hb)/2*ab/3$
- The span between the wheels is computed as:
  FFw=CS+2*Tsl/1000



Arrangement of Horizontal Girders in Fixed Wheel Vertical Lift Gate.

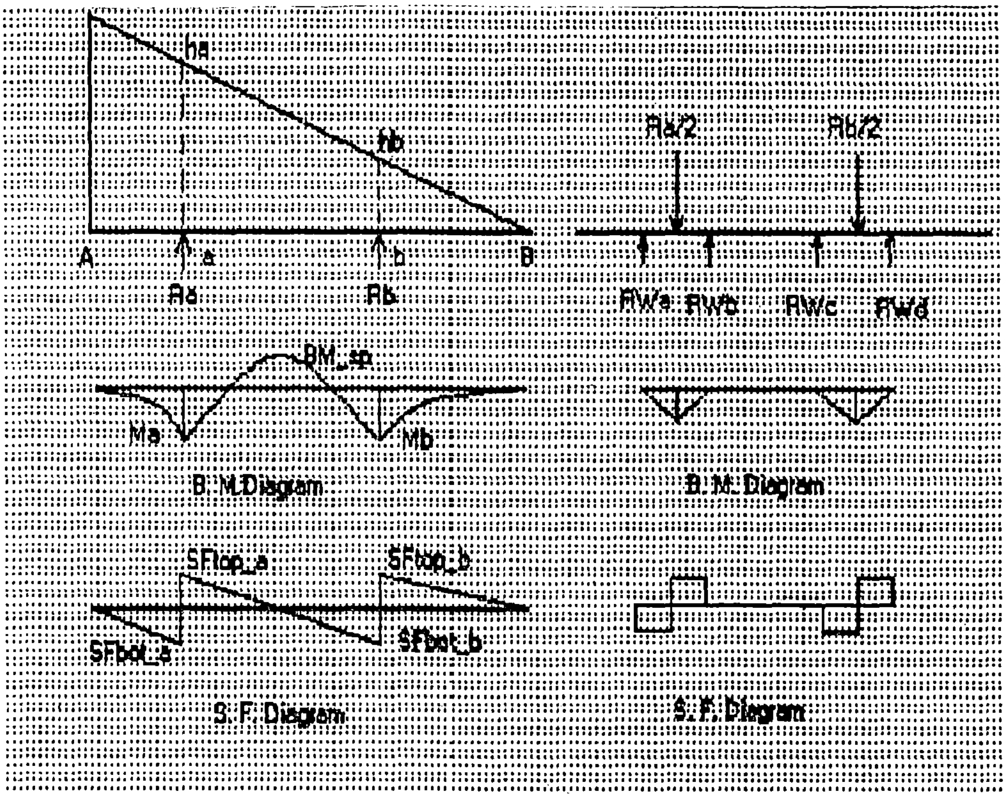


FIG- 2.1: Loads, Forces, Bending Moment and Shear Force Diagrams for Fixed Wheel Vertical Lift Gate.

2.6 DESIGN OF SKIN PLATE AND VERTICAL STIFFENERS

2.6.1 Selection of Skin Plate Thickness and Spacing of Vertical Stiffener

The thickness of the skin plate has been subjected to change when the head of water changes beyond 10m. Vertical stiffeners are provided spaced at optimum distance (Lopt). The thickness of skin plate and the spacing of vertical stiffeners are selected according to head of water and permissible bending stress across the skin plate. The range of Skin plate thickness (t) is taken from 10mm to 20mm and the range of spacing (Lopt) is taken from 40cm to 47cm.

Lopt and t are determined by computing bending moment in skin plate as follows:

$MLopt=Hb*Lopt^2/12$

The bending stress in skin plate is determined as:

$fbsp=MLopt/Zsp$

2.6.2 Varying Thickness of Skin Plate

The thickness of skin plate is assumed to be varying, which is adopted to reduce the cost of skin plate. The necessary analysis has been given to determine the location where the skin plate thickness is changed.

2.6.3 Check for Skin Plate as Panel

The skin plate has been checked as per recommendations laid down in IS: 4622 and IS: 5620 in composite manner for the following conditions:

a. In bending across the stiffeners (or horizontal girders) or as panels.
b. In bending co-acting with stiffeners, (and/or horizontal girders).

The analysis of stresses on the skin plate as panels is done basically for the following conditions:

i. All edges rigidly fixed. This case is analyzed for two variations viz. vertical stiffener sides being shorter than the horizontal girder sides and vice versa.

ii. Two short and one long edge fixed and one long edge simply supported. And two long and one short edge fixed and one edge simply supported.

iii. Three edges fixed and one edge free. This case is also analyzed for two variations comprising two horizontal girders and one vertical stiffener (which is longer or shorter than girder sides) fixed.

The general formula (IS: 4622-1992) for analysis of stresses is:

$b=k/100*h_r*a^2/t^2$ where,

b : bending stress

h_r : hydrostatic pressure at that location

a : width of panel

t : thickness of skin plate

k : non-dimensional factor corresponding to different end conditions. The given values of the Table in the Code are converted into polynomials and then the values of k is obtained from the polynomials.

2.6.4 Check for Stresses in Skin Plate at Girder Locations Co-Acting with Vertical Stiffeners and Combined Stresses

To determine the vertical stiffener section, analysis of stresses at girder locations in skin plate including check for combined stresses, the following procedure is adopted:

a) From the Bending Moment and Shear Force diagrams the equations for change in Shear Force and Bending Moment along the horizontal girder are established. The equation of shear force is a straight line and is represented by a quadratic equation. The bending moment is represented by a cubic equation. The bending moment is maximum at the point where the shear force is zero.

The cubic equation representing the Bending Moment diagram as shown in FIG-2.1 is:

$x^3*(ha-hb)/6/ab-ha/2*x^2+(Ra-(HD+ha)*Aa/2)*x$

$-(ha+2*HD)*Aa^2/6=0$

The quadratic equation representing the Shear Force diagram is:

x^2*(ha-hb)-(2*ha)*x+(2*Ra-(HD+ha)*Aa=0

b) Two contra flexure points where the bending moments are zero occur on the bending moment diagram. Assuming an approximate value, the contra flexure points are determined with the help of Newton-Raphson Method of approximation.

c) The co-acting width (CAW) at support points and at span is calculated as per IS: 4622-1992. The given curves in the Code are converted into polynomials and then the values of L/B are obtained from the polynomials.

d) The water pressure acting at mid point of the skin plate panels is computed as:

V2Pab=(ha+hb)/2/10, for all edges rigidly fixed.

V2PAa=(HD+ha)/2/10, for two short edges and one long edge fixed and one long edge simply supported.

e) The maximum shear force at girder locations (+ve or –ve which is greater) is calculated as:

SFbot_a=Aa*(HD+ha)/2 , bottom shear force at girder 'a'

Sftop_a=Ra-SFbot_a, top shear force at girder 'a'

Similarly the shear force at 'b' is also calculated.

f) The bending moments on skin plate along the girder section for cantilever portion (Mpo) and for Spacing portion (Mpq) are calculated as:

Mpo=HD/10*Loptab^2/2

Mpq=HD/10*Lopt^2/12

The greater of the two is taken for computation of the bending stress (BSa) at 'a' as:

BSa=MmaxGA*ha/HD/(t^2/6), where,MmaxGA: Max. bending moment.

g) Various I-sections and T-sections are taken for analysis of stresses for adoption of vertical stiffener section and the section modulus are computed (with due consideration of co-acting width) to analysis the bending stresses f1, f2 and f3 as:

f1 = M*Lopt/Z1

f2 = M*Lopt/Z2

$f3 = M*Lopt/Z3$

The shear stress is computed as:

$Sa=SFmax*10*Lopt/(a\_web)$

The combined stress is computed as:

$Scomb=(fxa^2+fya^2-fxa*fya)^{1/2}$, where, $fxa = -BSa$, $fya = f3$

h) Weight per meter of vertical stiffener section (wVS) is computed.

2.7 STRUCTURAL DESIGN OF HORIZONTAL GIRDER

2.7.1 General

The spacing of beams has already been decided. To determine the section of the beam to resist the bending moments imposed by the uniformly distributed water load acting on the beam, the skin plate thickness has to be taken into consideration along with the stiffener section. The co-acting width of skin plate has been taken into consideration. While deciding the beam section, the loaded span is taken as center to center of vertical seals at both ends with uniform distributed load of water pressure acting on the beam, which is assumed to be simply supported on vertical end girders at each end of gate. The supporting span is taken as center to center of the wheels.

2.7.2 Design Procedure

To determine the horizontal girder section, analysis of stresses is done with the following procedure:

1) The maximum bending moment, which occurs at mid-span of the horizontal girder, and the maximum shear force (at the two ends) are computed as:

   $MGcentre=1*CS^2/8$

   The bending moment at mid-span is calculated as:

   $MG\_sp=MGcentre*Ra$, Where Ra is UDL in t/m.

   The reactions at end girder location is computed as:

   $RA1=Ra*CS/2$

2) Various I-sections (rolled as well as weldments) are taken and the section modulus computed for analysis with due consideration of co-acting width (CAW) of the skin plate to check bending stress (fbG).

fbG=MG_sp*100*1000/Zxx

3) Shear stress checked with the shear area of the girder section as:

   SSmax=SFmax *1000/Sarea

4) The deflection of the girder beam is checked with the limit of the deflection:

   dlG=CS/8

   $dlmax=5*Ra*10(FFw*100)^4/384/E/Ixx$

5) Weight per meter of the girder section (wHG) is computed.
6) The same procedure is adopted for analysis of stresses at all the girders.

2.8 STRUCTURAL DESIGN OF VERTICAL END GIRDER

2.8.1 General

The vertical end girders are taken as fabricated girders having uniform sections. The girders are designed as a continuous beam having concentrated load coming from horizontal girder beams at points where they meet the vertical end girders supported on the wheels. The bending moments and the shear forces are determined by the method of moment distribution.

2.8.2 Assumptions

The assumptions taken are:

- Normal load is taken. No consideration of possible misalignment of wheels.
- The wheel spacing is taken as 5% of HD i.e. the head of water and each pair of wheels are flanking the horizontal girder symmetrically.
- Two plates of suitable thickness comprise vertical end girder section.
- The hole for wheel pin is taken as 20 % of girder section area.

2.8.3 Design Procedure

The design procedure adopted for design of vertical end girder is:

- The locations of the wheels are determined as:

  Lab=Lcd=5/100*HD

  The reactions on the vertical end girder are:

  RAa=RAmaxa/2 and RAb=Ramaxb/2

  The fixed end moments are:

  MFLab=- (RAa*Lab/8) and MFLcd=- (RAb*Lcd/8)

  The distribution factors taken as:

  kba=(3/Lab)/(3/Lab+4/Lbc) and kcb=(4/Lbc)/(3/Lcd+4/Lbc)

  The bending moment at girder locations, MFb and MFc are computed by the moment distribution method with the fixed end moments and the distribution factors as stated above.

- The bending moment at support points and span have been computed with the help of moment distribution method and then the reactions at each wheel are computed. The reactions at wheel locations are:

  RWa=(RAa/2-MFb/Lab)

  RWb=(RAa*(Lab/2+Lbc)-(MFc-RWa*Lac)Lbc

  RWc=(RAa*(Lab/2+Lbd)-MFd-RWa*Lad-
  RWb*Lbd+RAb*Lcd/2)/Lcd

  RWd=RAa+RAb-(RWa+RWb+RWc)

- The bending moment at mid-span is computed as:

  MG_spa=RWa*Lab/2 and MG_spb=RWd*Lcd/2

- Out of the bending moments and the reactions, the higher values (Mmax and SFmax) are taken for analysis of stresses on the vertical end girder section.
- The section modulus of the section is computed with due consideration of skin plate and the area of wheel pin.
- The section is checked against bending stress and shear stress as:

  fb_sp=(Mmax*Lopt*1000/Zx1)

  fb_opp=(Mmax*Lopt*1000/Zx2)

  SS=SFmax*10*Lopt/(a_web-a_hol)

- The weight per meter of the section (wVEG) is computed.

2.9 DESIGN OF WHEEL

2.9.1 General

The wheels are mounted internally between the webs of the vertical end girders. The internally mounted wheel arrangement is sturdy and better protected against damage as compared to externally mounted wheels. Internally mounted wheels keep alignment better than the cantilevered wheels. The wheels or wheel track or both are suitably curved to avoid any drift or deflection under load. That is why the maximum deflection of gates is kept within the limit of 1/800 of span in accordance with IS: 4622-1992.

2.9.2 Assumptions

The assumptions taken are:

- Normal load is taken. No consideration of possible misalignment of wheels
- All the wheels are in contact with the track.
- All the wheels are designed for same load and hence are of same size.
- Wheel material is made of steel with UTS 9000 kg/cm^2
- BHN of wheel material is taken as 255.
- Radius of crown assumed as 76.8 cm.
- Poisons ratio taken is 0.25.

2.9.3 Design Procedure

The design procedure adopted for design of vertical end girder is:

- The critical stress is calculated with the help of the relation:
  Critical stress=1.72*BHN-154.68
- Allowable stress is computed from the critical stress dividing it by factor of safety
- The projected area is computed from division of normal load by allowable stress
- Net tread width is computed from projected area and assumed radius of wheel

- The curves for determination of stresses in wheels have been represented by polynomials and the stresses are analyzed from the values of the curves corresponding to the ratio of B/A, where B and A are reciprocals of radii in y-direction and x-direction respectively.
- The weight of wheel (wWheel) is computed.

2.10 CALCULATION OF WEIGHT AND CG OF GATE

The weight of gate is calculated with the per meter weight of the sections of the major components of the gate as computed above. The center of gravity (CVG) of the gate from upstream of skin plate is calculated by taking moment about the upstream point.

2.11 CALCULATION OF HOISTING CAPACITY

The hoisting capacity is calculated with the following procedure:

- The total pressure is computed as:

  FFl=CS- 2*12/1000

  $P=1*FFl*HD^2/2$

- Total frictional force is computed with assumptions of seal friction, guide friction etc.

  Ft=F+fg+fs+Wrope

- The hoisting capacity is computed with 20% extra provision:

  WVGt=1.2*(WVGt+Ft)

2.12 DESIGN OF GATES WITH HIGHER NO. OF GIRDERS

The design procedure is basically similar for the design of the gates with more than two horizontal girders as discussed in the above paragraphs for the design of fixed wheel vertical lift gate with 2 horizontal girders except determination of bending moments and reactions at girder locations which are determined by ***Moment Distribution Method.***

CHAPTER III

DESIGN OF RADIAL GATE

3.1 GENERAL

The structural components of a radial gate, which transfers the water load; include: curved skin plate, framework of curved vertical stiffeners, horizontal stiffeners, horizontal girders, radial arms, trunnions, anchorages. The overall design calls for fixing parameters like gate radius, location of sill, location of trunnions and of the hoist. As the gate radius influences the skin plate cost and the arm cost, it has to be optimised. The sill of is located at downstream of the crest to avoid cavitations. The trunnion level is generally placed above the upper nappe profile to avoid corrosion.

3.2 MATERIAL SPECIFICATION

The material specification in structural design of radial gate is also same as that of the design of fixed wheel vertical lift gate. The steels for the design of radial arms are also taken as per IS: 2062-1984. The horizontal girder, radial arms vertical stiffeners are taken both rolled sections and weldments made up of plate, which require in design for higher heads.

3.3 DESIGN STRESSES

The design stresses are adopted as per IS: 4623-1984 for structural steel as specified in Annex-B of the Code. The permissible stresses to wet and accessible conditions are as stated in the design of fixed wheel vertical lift gate. The design stresses for axial compression in arms are taken as steel conforming to IS: 226-1975, IS: 2062-1984 and St. 44-0 of IS: 1977-1962 (IS: 800-1962).

3.4 DESIGN CONSIDERATIONS

The design considerations are as adopted:

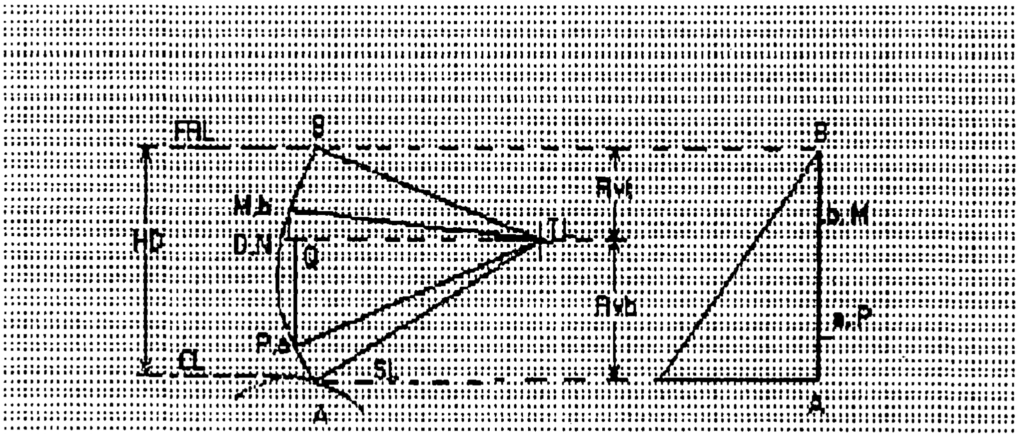
1) The profile of the spillway crest is assumed to be of ogee shaped and the nappe profile is given by the following equation: $Y=0.5*X^{1.85}*(HD)^{-0.85}$
2) Sill of gate is taken at 15% downstream of 'HD'
3) Trunnion is placed at 1.5m above the upper nappe of water profile.
4) 0.30m is added to the head obtained from full reservoir level (FRL) and sill level (SL) to cater for free board.
5) Radius factor is taken as 1.22 for analysis of cost of gate.
6) Side seal length assumed is 12mm each side.
7) Corrosion in regard to skin plate thickness is taken 1.5mm.
8) Co-efficient of axle friction (fa) assumed as 0.015.
9) Co-efficient of rolling friction (fr) assumed as 1.5.
10) Guide friction co-efficient is assumed as 0.5.
11) Weight of wire rope taken as 1.5 % of gate weight.
12) Hoisting capacity is calculated with 20 % extra provision.
13) Wastage of material is assumed as5%.
14) Weight of embedded parts of gate is assumed as 35 %.
15) Hoist cost is taken proportionate to the hoist capacity above Rs.1 lakh.

3.5 SPACING OF HORIZONTAL GIRDERS

As skin plate stiffeners transfer the loading to the horizontal girders, therefore, the spacing of these girders is so arranged that bending moments in the vertical stiffeners, which are considered as continuous beams supported at the horizontal girders, are about equal. The spacing of the horizontal girders as shown in **FIG-3.1,** is fixed by trial and error method so as to have more or less equal bending moment.

The procedure adopted to determine the spacing of horizontal girder is:

1) Radius factor (Rf) assumed as 1.22 and radius of the gate is computed R=1.22*HD



Arrangemnt of Horizontal Girders in Radial Gate.

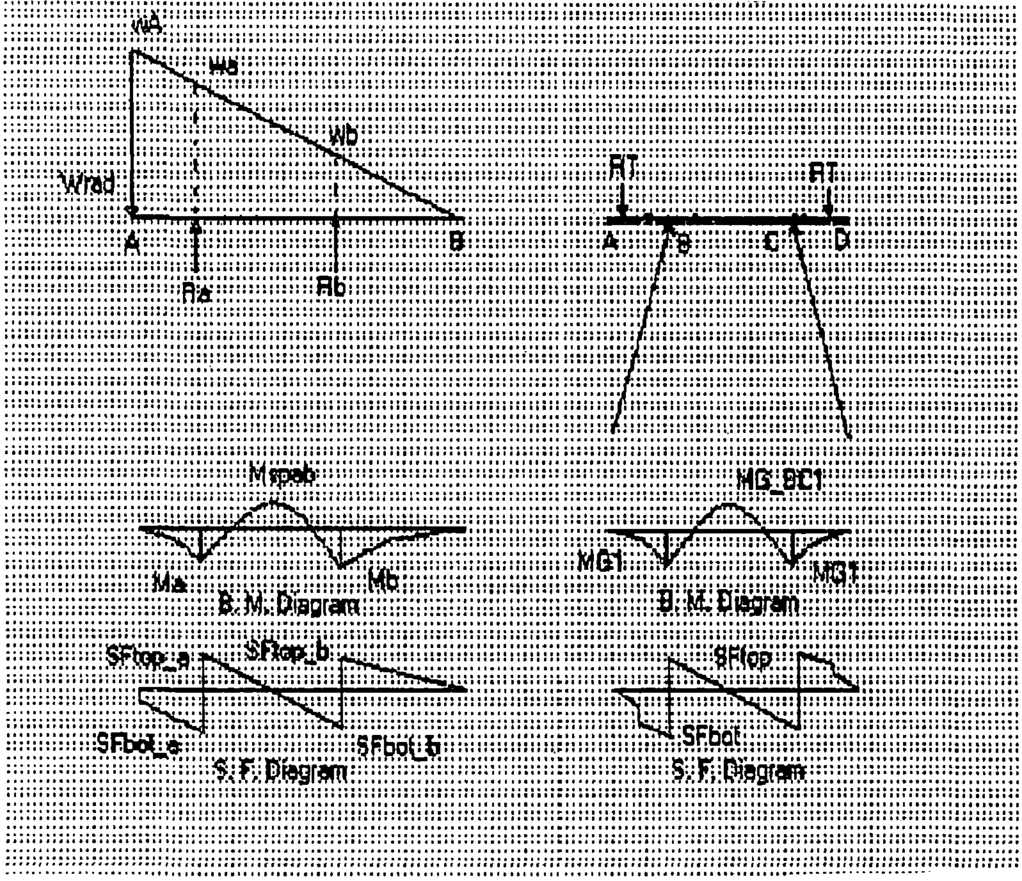


FIG- 3.1: Loads, Forces, Bending Moment and Sher Force Diagrams for Radial Gate.

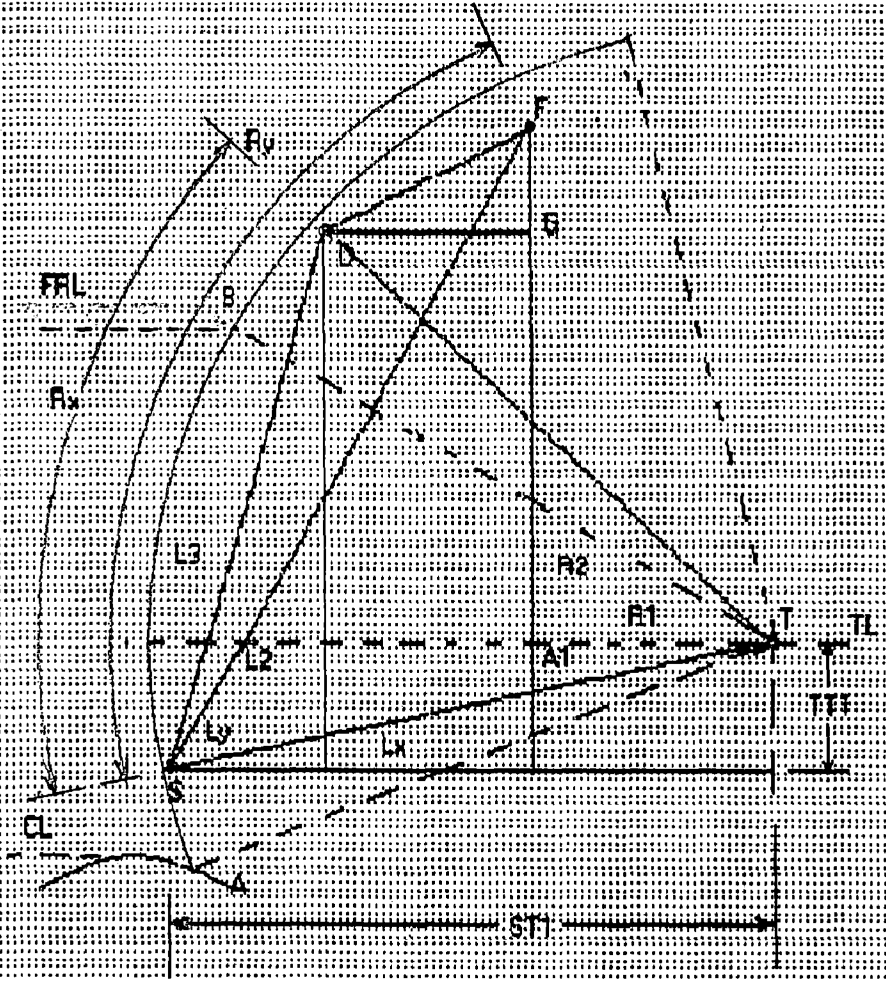


Fig-3.2 Hoisting Arrangement in Radial Gate.

2) The trunnion level (TL) and the inclination (A) of the line joining the Trunnion and the Sill Beam are computed with the consideration of the nappe profile as stated in **para-3.4.**
3) The angles B, C, E, F are computed and then the height of the gate (Arc_AB) is calculated as: Arc_AB=F*R
4) Side seal thickness is assumed as 12mm and the face to face length of the gate is computed:
   FFl=CS-2*Tss/1000
5) Total hydrostatic pressure is computed as:
   P=TA*Rvt+cos(B)*TA*(1-cos(C))-R*TA*sin(B)*sin(C)
6) The spacing of vertical stiffener and the thickness of skin plate are computed by adopting the same procedure as in the case of fixed wheel vertical lift gate.
7) To get desired Bending Moment in skin plate at girder locations, the locations are assumed as:
   PM=0.4912*Arc_AB
   Aa=0.124* Arc_AB
   bB=0.3858* Arc_AB
8) The inclinations of radial arms in elevation (A1, B1 etc.) are computed and depth of girder locations w.r.t. TL (PQ, MN) is computed. The water loads at girder locations are obtained.
9) The bending moment and reactions at girder locations due water load are computed as:
   Maw=Aa^2/2+Aa^2*(wA-wa)/2*2/3 and
   Mbw=bB^2*wb/2/3
   Raw=0.265*Arc_AB*wA and
   Rbw=0.216*Arc_AB*wA
10) With assumed CG1 and WG1, Lst is computed:
    Lst=WG1*CG1/(R*cos(A1))
    Radial load/m width of gate and direct thrust/m width of gate are computed: Wrad=Lst*sin(A1)/CS
    Wthr=Lst*cos(A1)/CS

11)The bending moment and reaction due to sill beam effect are computed:

Mas=Wrad*Aa

Ras=Wrad*(Aa+PM)/PM

Rbs=-Wrad*Aa/PM

12) The total bending moment and reactions are:

Ma=Maw+Mas and Mb=Mbw

Ra=Raw+Ras

Rb=Rbw+Rbs

13) From the Bending Moment and Shear Force diagrams the equations for change in Shear Force and Bending Moment along the horizontal girder are established. The equation of shear force is a straight line and is represented by a quadratic equation. The bending moment is represented by a cubic equation. The bending moment is maximum at the point where the shear force is zero.

The cubic equation representing the Bending Moment diagram is:

$$-x^3*(wa-wb)/6/PM-wb/2*x^2+(Rb-wb*bB/2)*x-wb*Aa^2/6=0$$

The quadratic equation representing the Shear Force diagram is:

$$-x^2\,(wa-wb)/PM-(2*wb)*x+(2*Rb-wb*bB)=0$$

14) The same method is adopted for computing points of contra flexure and co-acting width (CAW) at support points and at span as in design of fixed wheel vertical lift gate.

15) The water pressure acting on the skin plate panels are computed as:

(i) R2PPM=(Rvt+(PQ-MN)/2)/10, kg/cm^2, for all edges rigidly fixed.

(ii) R2PAa=(HD+Rvt+PQ)/2/10, kg/cm^2, for two short edges and one long edge fixed and one long edge simply supported.

16) The calculation of shear forces at girder locations is done with the same procedure as in design of fixed wheel vertical lift gate. Here direct thrust per meter of gate width (Wthr) is also taken into consideration. The direct compressive force, Fcomp is computed as:

Fcomp_a=Fcomp_b=Wthr*Lopt/100/1000

17) The bending moments on skin plate along the girder section for cantilever portion (Mpo) and for Spacing portion (Mpq) are calculated as in design fixed wheel vertical lift gate.

3.6 DESIGN OF SKIN PLATE AND VERTICAL STIFFENERS

The skin plates support the water load on concave side. Suitably spaced vertical stiffeners support the skin plate. In design of skin plate of radial gate also, the thickness is assumed to be varying, as discussed in design of fixed wheel vertical lift gate. The design procedure is same as that of the design related to fixed wheel vertical lift gate.

3.7 STRUCTURAL DESIGN OF HORIZONTAL GIRDER

3.7.1 General

The spacing of the girders has already been decided by trial and error method. The load transferred on the horizontal girders by the curved stiffeners of the skin plate is assumed as uniformly distributed on the horizontal girders rather than a series of concentrated loads. To determine the section of the beam to resist the bending moments imposed by the uniformly distributed water load acting on the beam, the skin plate thickness has to be taken into consideration along with the stiffener section.

3.7.2 Assumptions

The horizontal girders are supported by radial arms, which are assumed inclined to each other in plan. Inclined radial arms are adopted to reduce the cost. Although, in this case, the girder section is subjected to an axial load and hence that should be checked for shear at points where they are supported by the arms. The checking has not been done.

While deciding the beam section, the loaded span is taken as center to center of vertical seals at both ends with uniform distributed load of water pressure acting on the beam, which is assumed to be simply supported on radial arms at a distance of 0.2071 of clear span (CS) gate.

3.7.3 Design Procedure

To determine the horizontal girder section, analysis of stresses is done with the following procedure:

1) The locations of the joints of girders and arms are determined as discussed in para-3.5.
2) To determine the effect of rope tension (RT), rope inclination (RA1) and hoisting capacity of gate (HC1) are assumed for initial calculation. The x-component of the rope tension (RT) is computed as:

   RT=HC1/2

   RTh=RT*cos(RA1)
3) The ratio of moment of inertia of arm (IA) and girder (IG) is assumed as 25. The distribution factors (KBC and KBE) are computed:

   KBC=(4*25/LG)/(4*25/LG+3/LA)

   KBE=1-KBC
4) The distributed bending moments and shear forces at both girders and arms are computed with due consideration two conditions such as water and sill load and water and rope tension. The bending moment (FEM) due to water load and sill pressure is computed as:

   $MBA=1*AB^2/2$ and $MCB=1*BC^2/12$

   The moment distributed to girder section (MbeamG) is computed by the moment distribution method and the bending moment at mid-span is computed as:

   $BMcentre=1*BC^2/8+MbeamG$
5) The moment due to the effect of rope tension distributed to the beam (MbeamR) is computed by adopting the same procedure as in calculation of bending moment distribution due to water load.
6) The bending moment and shear force are computed for two conditions:
   (i) water load and sill pressure
   (ii) water load and rope tension

   For the first condition, the parameters are computed as:

   MG1=-(MbeamG*Ra)

   MG_BC1=BMcentre*Ra, where Ra is uniformly distributed load

   Ra1=Ra*CS/2

   SFbot1=AB*Ra

SFtop1=RA1-SFbot1

For the second condition, the parameters are computed as:

MG2=(-MbeamG*Raw)+(-MbeamR*RTh)

MG-BC2=BMcentre*Raw+MbeamR*RTh

RA2=Raw*CS/2+RTh

SFbot2=Raw*AB

SFtop2=RA2-SFbot2

7) Out of the bending moment and shear forces, maximum value (MGmax and SFmax) are decided and taken for analysis of stresses in horizontal girders and arms.
8) The bending moment distributed to the arm section is computed for further requirement in design of arm section later.

   BMarm=Raw*McanTG+RTh*McanTR
9) Various I-sections (rolled as well as weldments) are taken and the section modulus computed for analysis with due consideration of co-acting width (CAW) of the skin plate to check bending stress (fbG).

   fbG=MGmax*100*1000/Zxx
10) Shear stress checked with the shear area of the girder section.

    SSmax=SFmax*1000/Sarea
11) Weight of girder section (wHG) is computed.
12) The same procedure is adopted for analysis of stresses at all the girders.
13) Length of arm section (effective length), axial force and bending moment induced are used for further analysis of stresses in arm section.

3.8 DESIGN OF RADIAL ARMS

3.8.1 General

The radial arms or end frames as they are sometimes called, serve as columns transferring the water load to the trunnion. As already stated, the arms are inclined to each other in plan. Inclined arms reduce the bending moment in horizontal girders. To get maximum economy, the arms are placed at 0.2071 of span (CS) from the ends, which results in almost equal bending moments at the center of horizontal girder and the points of support. However, the resulting thrust at the trunnions is ignored for simplicity of calculations.

3.8.2 Assumptions

As stated above, the design stresses for axial compression in arms are taken as steel conforming to IS: 226-1975, IS: 2062-1984 and St. 44-0 of IS: 1977-1962 (IS: 800-1962). Arms are assumed to be braced, without any analysis. The slenderness ratio is taken same for longitudinal and transverse directions. No snapping of rope is considered for the analysis of stresses in the arm section.

3.8.3 Design Procedure

To determine the arm section, analysis of stresses is done with the following procedure:

1) The bending moment induced in the arm section due to load transferred from the horizontal girder and frictional forces is computed as:

   MFrmaxa=Faxa*0.2*0.200, Faxa: RA1

   Assuming lever arm action at arm joints near the trunnion, the extra shear force is added to the shear force transferred from the horizontal girder and the maximum shear force (Faxmaxa) is determined.
2) Slenderness ratio is computed with radius of gyration and effective length of arm, which is already computed.
3) Allowable compressive stress (Pbc) is determined from the table (IS: 800-1962) corresponding to the slenderness ratio.
4) Various I-sections (rolled and weldments) are taken for analysis.
5) Section modulus, radius of gyration and shear area are computed.
6) Checked for direct compressive stress (fc), bending stress (fbc) and total stress (fT).

   fc=Faxmax/SA*1000

   fbc=BMarma/Zxx*100*1000

fT=fc+fbc

Weight per meter of arm section (wArm) is computed.

3.9 CALCULATION OF WEIGHT AND CG OF GATE

The weight of gate is calculated with the per meter weight of the sections of the major components of the gate computed above. The center of gravity (CG1) of the gate from the trunnion is calculated by taking moment about the trunnion.

3.10 CALCULATION OF HOISTING CAPACITY

The hoisting arrangement is assumed to have rope wires with 5 pulleys with downstream arrangement. The location of the rope drum and lift of gate are assumed and the perpendicular distance (Pd) from trunnion to the resultant force in rope is computed. By computing the seal friction (FF) and trunnion friction (TF), the hoisting capacity is calculated as follows:

Pd=TS*sin(RA+L2)

FF=2*0.025*FFl*HD/2*1.5

TF=P*0.2

HC=(FF*R+(RT*cos(L2)+WG1)*CG1+TF*0.2)/Pd

3.11 DESIGN OF GATES WITH HIGHER NO. OF GIRDERS

The design procedure is same for the design of the gates with higher number of horizontal girders as discussed in the above paragraphs for the design of radial gate with 2 horizontal girders except that the bending moment and reactions at girder locations are determined by ***Moment Distribution Method***.

CHAPTER IV

COST OF GATE

4.1 GENERAL

Cost of gate is a function of weight of the material and fabrication cost. Cost analysis of gate involves cost of welding, machining and sitting of the gate. Cost of gate include:

1. Material cost
2. Fabrication cost
3. Transportation cost
4. Erection cost
5. Hoist cost

4.2 MATERIAL COST

Materials for the components of fixed wheel gate are as follows:

- Skin plate, vertical stiffeners, horizontal girders, vertical end girders etc. which are used for design of the gate involve structural steel conforming to IS: 226-1975, IS: 2062-1984, IS: 808-1964.
- Wheel involving cast steel conforming to IS: 1030-1982.

Materials relating to track base, bushing, wheel pin or axle, seal seat, seal base, anchorages are not calculated in the cost analysis, as they are not designed. A percentage over the total weight has been assumed and added.

Skin plate weight is computed from volume of steel and assuming the weight of steel as 7.850 tonne/m^3. The weight per meter of section has been computed in each case of vertical stiffeners, horizontal girders, vertical end girders while designing and the weight is calculated by computing the total length of the sections. In case of wheel, the weight per wheel is computed while designing and then multiplying by the number of wheels. The embedded parts are added with 15 percentage of the total weight. The material cost of gate is determined by assuming a cost of Rs.25000 per tonne as a rate of steel.

4.3 FABRICATION COST

The main components of fabrication cost are:

- Edge preparation cost
- Welding cost
- Drilling cost
- Painting cost
- Inspection and design cost

4.3.1 Edge Preparation Cost

4.3.1.1 Calculation of use rate

Edge preparation cost includes cutting cost and grinding cost before welding. In edge preparation cost, the use rate of Pug Cutting Machine, generally used for cutting of the skin plate etc., has been calculated by the modified straight line method as described below:

- Depreciation cost is computed by the relation:
  Dep_cost=5/4*0.9*P/N
- Repairing cost is computed by the relation:
  Rep_cost=0.1*Rep_Prov*P/Wor_Hor
- Energy cost is computed by the relation:
  POL_cost=POL, POL may be cost of fuel or electricity (Rs.2.5/unit)
- Cost of man power is computed by assuming daily wages of Rs.250 per labour and Rs.200 per helper
- Miscellaneous cost is taken as 10% of Repair Cost
- Use rate is determined adding all the above costs with 10% extra for overhead cost

The use rate of the Pug Cutting Machine is calculated with the assumptions that:

- Capital cost of machine (P): Rs.20, 000
- Repair provision: 80% of capital cost
- Life of machine (N): 16,000 hours
- Consumption rate: 0.5 units/hour

- Manpower: 2 labour and 2 helpers
- Working hour: 2000 hours

Similarly the use rate of Grinding Machine for grinding after cutting is calculated with the assumptions that:

- Capital cost of machine (P): Rs.12, 000
- Repair provision: 80% of capital cost
- Life of machine (N): 16,000 hours
- Consumption rate: 0.25 units/hour
- Manpower: 2 labours
- Working hour: 2200 hours

Similarly the use rate of Welding Machine for grinding after cutting is calculated with the assumptions that:

- Capital cost of machine (P): Rs.45, 000
- Repair provision (Rep_Pro): 80% of capital cost
- Life of machine (N): 16,000 hours
- Consumption rate: 20 units/hour
- Manpower: 2 labours and 2 helpers
- Working hour: 2200 hours

4.3.1.2 Calculation of cutting length

The assumptions for computing cutting/grinding/welding are taken as:

- Skin plate is having welding joints in every 2.5m.
- Cutting time 20 minutes/meter
- Grinding time 10 minutes/meter

4.3.1.3 Calculation of edge preparation cost

After computing use rates of cutting and grinding, cutting and grinding times, and cutting/grinding lengths, with the use rates concerned, the edge preparation cost is calculated.

4.3.2 Welding Cost

4.3.2.1 General

In fabrication of gate, we have to use butt as well as fillet welding. Butt weld is usually made convex on either side. Butt weld may be single V, single U, double V or double U etc. When the lapped plates are joined, fillet welds are used. These are generally of right angled triangle shaped. The outer surface is generally made convex. Fillet welding is usually done by fusion of electrode.

Fusion welding requires the application of heat which in this case is supplied by the arc. The rate at which heat is put into joint depends on the welding current, arc voltage and the speed of travel. Increased current is required for larger electrodes and the electrode diameter and arc length (voltage) influence the joint preparation required to obtain a full penetration weld.

Deep penetration in fillet welding in flat and horizontal may be done as per IS: 814 -1991. The thickness of the thinner plates in the design of the gates is below 20mm. So, the minimum fillet weld size is 6mm.

Inspection of the welding may be done as per IS: 822-1970.

4.3.2.2 Calculation of welding time

The procedure for calculation of welding time is taken from the Report of a Special Problem for ME (WRD), 1987, on 'Cost Analysis of Vertical Gates' by Sri Amulya Kumar Das. The calculation of welding is done with determination of the welding elements and the metal removal elements in welding. These are taken from standard data for arc welding. The welding elements are shown in **Table-4.1**. The **Table-4.2** shows the metal removal elements. The cost of electrode per meter of butt-welding is shown in **Table-4.3**. The **Table-4.4** shows calculation of welding time for butt welds. Similarly The **Table-4.5** and **Table-4,6** show the cost of electrode per meter of fillet welds and welding time thereof. The IS: 814 – 1991is also referred to for specifications used for calculation of welding time.

Table-4.1: Welding time for welding elements

Sl. No	Welding Elements	MMA per joint (min)	Per elect-rode	CO_2 per joint (min)	Per 8m wire
1	Pick up and put on gloves etc.	0.085	-	0.085	-
2	Pick up electrode and holder etc.	0.056	-	-	-
3	Pick up hand shield etc.	0.077	-	-	-
4	Aside hand shield	-	0.025	-	-
5	Change electrode	-	0.062	-	-
6	Pick up hand shield etc.	-	0.077	-	-
7	Aside hand shield	0.025	-	-	-
8	Aside stub end etc.	0.031	-	-	-
9	Pick up head shield etc.	-	-	0.045	-
10	Pick up MIG gun and position etc.	-	-	0.057	-
11	Raise head shield	-	-	-	0.012
12	Pick up enters, trim etc.	-	-	-	0.077
13	Ream nozzle etc.	-	-	-	0.085
14	Pick up MIG gun and position etc.	-	-	-	0.057
15	Lower head shield	-	-	-	0.012
16	Raise head shield	-	-	0.012	-
17	Remove head shield etc.	-	-	0.085	-
18	Pick up anti-spatter can etc.	-	-	0.081	-
19	Remove gloves etc.	0.062	-	0.062	-
	TOTAL:	0.0336	0.164	0.377	0.243

Metal removal elements/joint is:

Table-4.2: Welding time for metal removal elements

Sl. No.	Metal removal elements	Per joint (min)
1	Pick up face mask etc.	0.045
2	Pick up grinder etc.	0.058
3	Lower face mask	0.012
4	Aside grinder	0.026
5	Remove and aside face mask	0.035
	TOTAL:	0.176

Therefore, ancillaries, welding per joint = 0.164+0.176
= 0.34

DEPOSITION DATA (butt welding)

Table-4.3: Calculation of cost of electrodes in butt-welding

Electrode size (millimeter)	3.15	4.0	5.0	6.3	Total
Current (Amp)	110	180	210	290	
Arc time/meter (minute)					35.26
Weight of weld/meter (kg)					0.88
Length of electrode consumed per meter of weld (meter)	3.94	1.03	0.85	1.93	
No. of electrodes/meter of weld (assuming 50mm stub)	9.9	2.6	2.1	4.8	
No. of electrode changes per joint i.e. (length of joint)*(No. of electrode/m)	39	10	8	19	76
Cost of electrode/m (butt weld):	(9.9*3+2.6*4+2.1*5+4.8*6)*Wel_spl				

Synthesis of times/joint (minute)

Table-4.4: Total welding time in butt-welding

Ancillaries, welding per joint	0.34
Metal removal	0.18
Per electrode change	76*0.164 = 12.46
Arc time:	35.26*Wel_spl
Deslag time:	3.88* Wel_spl
Sealing time:	11.88* Wel_spl
Total welding (skin plate) time (minute):	(Arc time+ Deslag time + Sealing time)

DEPOSITION DATA (fillet welding)

Table-4.5: Calculation of cost of electrodes in fillet welding

Electrode size (millimeter)	5.0
Current (Amp)	220
Arc time/meter (min)	14.36
Weight of weld/meter (kg)	0.44
Length of electrode/m of weld (meter)	3.08
No. of electrode consumed/m of weld (assuming 50mm stub)	7.7
No. of electrode changes /joint i.e. (length of joint)*(no. of electrode/m)	40
Cost of electrode/m (fillet weld):	(7.7*3)*(Wel_fil_vs +Wel_fil_veg +Wel_fil_ms +Wel_fil_ss)

Synthesis of times/joint (minute)

Table-4.6: Total welding time in fillet welding

Ancillaries, welding per joint	0.34
Metal removal	-
Per electrode change	40*0.164 = 6.56
Arc time:	14.36*(Wel_fil_vs +Wel_fil_veg +Wel_fil_ms +Wel_fil_ss)
Deslag time:	3.35*(Wel_fil_vs +Wel_fil_veg +Wel_fil_ms +Wel_fil_ss)
Sealing time:	-
Total welding (vertical stiffener, horizontal girder, vertical end girder) time: (minute)	(0.34 +6.56 +Arc time + Deslag time)

4.3.2.2 Calculation of Welding Cost

The welding cost is calculated by multiplying the welding time and the use rate of welding machine.

4.3.3 Drilling Cost

Drilling cost include labour charges of drillings, which are required to fix the seal in the gate. To ascertain the cost of drilling the drilling time is assumed as 20% of welding time. The use rate of drilling machine is computed with the following assumptions:

- Capital cost of machine (P): Rs.12, 000

- Repair provision: 80% of capital cost
- Life of machine (N): 16,000 hours
- Consumption rate: 0.25 units/hour
- Manpower: 2 helpers
- Working hour: 1200 hours

Drilling cost is obtained by multiplying the use rate of drilling machine with the assumed drilling time.

4.3.4 Painting Cost

The painting of the gate and embedded parts are most essential so as to save the gate and embedded parts from corrosion. Water resistant primer and paints have to be applied minimum in three coats to the parts. Air compressor is required for painting. The use rate of air compressor has been computed with the following assumptions:

- Capital cost of machine (P): Rs.100, 000
- Repair provision: 100% of capital cost
- Life of machine (N): 12,000 hours
- Consumption rate: 0.15 liters/hp (130 HP) with 75% load factor
- Manpower: 1 labour and 1 helper
- Working hour: 1200 hours

The painting time is assumed as 11 hours for painting 100 m^2 for 3 coats (Report on special problem by A. K. Das, 1987). The cost of paint is assumed by taking primer cost of Rs. 75 and paint cost of Rs.100. The painting cost is computed by multiplying the use rate of the air compressor and the assumed painting time, proportional to the weight obtained in that case.

4.3.5 Calculation of Fabrication Cost

The fabrication cost is calculated with addition of the edge preparation cost, the welding cost, the drilling cost and painting cost, which are determined in the above paragraphs. The inspection & design cost is added as percentage of total cost.

4.4 TRANSPORTATION COST

The cost incurred for transporting material from store to the workshop and workshop to the work site is required to be covered. The calculation of the transportation cost requires the determination of the use rates of truck and trailer, which are required in the transportation of materials. The use rates are computed with the following assumptions:

The use rate of truck (1210 SE, TATA)

- Capital cost of machine (P): Rs.600, 000
- Repair provision: 140% of capital cost
- Life of machine (N): 20,000/40 hours
- Consumption rate: 0.15 liters/hp (98 HP) with 75% load factor
- Manpower: 1 labour and 1 helper
- Working hour: 600000*2/10/40 hours

15% of the depreciation cost of the truck is taken extra for depreciation of tyres. Kilometer use rate (Use_ratkm) is computed by dividing the hourly use rate.

The use rate of trailer

- Capital cost of machine (P): Rs.10, 00, 000
- Repair provision: 140% of capital cost
- Life of machine (N): 20,000/40 hours
- Consumption rate: 0.15 liters/hp (200 HP) with 75% load factor
- Manpower: 1 labour and 1 helper
- Working hour: 1200 hours

The assumptions of working time of truck (8 hour and 50km) and trailer (16 hour) are made as in the case of the special problem and the transportation cost is computed proportionately to the gate weight in that case. The transportation cost is:

(8*Use_Ratetr+50*Use_Ratekm+16*Use_Ratetrl)*WG1/9.2

4.5 ERECTION COST

The cost of placing the gate including the embedded parts in proper places with accuracy is the erection cost. For calculation of erection cost, a 10-ton mobile crane, a hand operated winch and a diesel generating set are considered. The use rates of the required machines are computed with the following assumptions:

The use rate of Crane (diesel)

- Capital cost of machine (P): Rs.8, 00, 000
- Repair provision: 120% of capital cost
- Life of machine (N): 15000 hours
- Consumption rate: 0.15 liters/hp (280 HP) with 60% load factor
- Manpower: 1 labour and 1 helper
- Working hour: 1200 hours

The use rate of Winch (diesel)

- Capital cost of machine (P): Rs.1, 50, 000
- Repair provision: 80% of capital cost
- Life of machine (N): 15,000 hours
- Consumption rate: 0.5 (cost for grease only)
- Manpower: 6 helpers
- Working hour: 2000 hours

The use rate of Generator set (diesel)

- Capital cost of machine (P): Rs.6, 00, 000
- Repair provision: 100% of capital cost
- Life of machine (N): 20,000 hours
- Consumption rate: 0.15 liters/hp (200 HP) with 60% load factor
- Manpower: 2 labours
- Working hour: 2000 hours

The assumptions of working time of crane (16 hour), winch (24 hour) and generator set (30 hour) are made as in the case of the special problem and the erection cost is computed proportionately to the gate weight in that case. The erection cost is:

(16*Use_Ratecrn+24*Use_Ratewin+30*Use_Rategen)*WG1/9.2

4.6 HOIST COST

The hoist cost includes the cost of motor, reduction gearbox with gears, electrical materials required for the hoist, wire ropes, pulleys/falls etc. The hoist cost is assumed as Rs.1 lakh with proportionate increase for hoisting capacity of the gate as follows:

Hoist cost = 1+HC1/100

4.7 INSPECTIONS AND DESIGN COST

The inspections and design cost is taken as 10 % of the total cost computed.

4.8 TOTAL COST

The total cost of the gate is obtained by adding all the above costs viz. material cost, fabrication cost, transportation cost, erection cost, inspection and design cost and hoist cost.

CHAPTER V

FORMULATION OF PROGRAM IN 'C++'

5.1 GENERAL

The design of hydraulic gates involves enormous calculations. Specially, while computing the load on the radial gate, the consideration of radial load due to rope tension necessitates calculations again and again. To select the safe steel sections in each case of vertical stiffener, horizontal girder, vertical end girder and radial arm and to follow other safe design considerations, it is required to go for several calculations until the desired result. Therefore, a computer program is most essential for optimization of design process. For this purpose, 'C++' language is used to formulate the necessary program.

5.2 FORMULATION OF PROGRAM

The main program is developed in 'TURBO C++'. A general 'C++' program consists of the following:

- # include statements: preprocessor directive, which tells the compiler to insert another source file.
- Declarations of Functions: functions (called sub-programs in other languages), which are called as and when required.
- main( ): main function, which executes the statements including other functions in it.
- Body of main program: statements relating to main program.
- Definitions of functions: bodies of the functions are placed.

In the present program, the include files are:

- **iostream.h** to include 'cout' identifier and '<<' operator etc.
- **conio.h** to include functions getch( ), clrscr( ) etc.
- **math.h** to include functions sqrt( ), sin ( ), cos( ), asin( ), acos( ), pow( ) etc.

- **process.h** to include functions exit( ) etc.
- **iomanip.h** to include functions setw( ) etc.

The functions developed for assisting the main program and their explanations are stated as under:

- **void Rvv(float [ ], float *, float *, float *, float *)**

  This function determines the trunnion level (TL) and the angle A1 the TL making with the sill of gate.
- **float xsqrt(float [ ], float)**

  This function computes the roots of quadratic equation representing the shear force diagram.
- **float xcube(float [ ], float [ ], float, float, int)**

  This function computes the contra flexure points on the Bending Moment diagram.
- **float polym(float [ ], float [ ], int, float)**

  This function formats polynomials up to 8 order with 9 numbers of data.
- **float caw1(float, float, float)**

  This function computes co-acting width (CAW) of span.
- **float caw2(float, float, float)**

  This function computes co-acting width (CAW) support points.
- **float big(float [ ], int)**

  This function computes the biggest of the given set.
- **float small(float [ ], int)**

  This function computes the smallest of the given set.
- **void k_nondim(float, int, float)**

  This function computes the non-dimensional constant required in the analysis of skin plate as panels.
- **void Stress_VS(float[ ], float, float, float, float, float, float*, float*, float*, float*, float*, float*, float*, float*, float*, float*, float*)**

  This function is used to analysis the stresses for selecting the vertical stiffener section.

- **void Stress_HG(float[ ], float, float, float, float, float, float*, float*, float*, float*, float*, float*, float*)**

  This function is used to analysis the stresses for selecting the horizontal girder section in radial gate.

- **void Stress_VHG(float[ ], float, float, float, float*, float*, float*, float*, float*, float*, float*)**

  This function is used to analysis the stresses for selecting the horizontal girder section in fixed wheel vertical lift gate.

- **void Stress_VEG(float, float, float, float, float*, float*, float*, float*, float*, float*)**

  This function is used to analysis the stresses for selecting the vertical end girder section in fixed wheel vertical lift gate.

- **void Pbc_all(float, float*, char)**

  This function is used to compute the allowable compressive stress in column for a given slenderness ratio.

- **void Stress_Arm(float, float, float, float*, float*, float*, float*)**

  This function is used to analysis the stresses for selecting the arm section in radial gate.

- **void Wheel(float, float, float, float*, float*, float*, float*)**

  This function is used for design of wheel in fixed wheel vertical lift gate.

- **void Stress_SP(float, float, float, float, int, float*)**

  This function is used for analysis of stresses in skin plate.

- **void Use_Rat(float, float, float, float, float, int, int, float*)**

  This function computes the use rates of equipments.

- **void COST(float, float, float, float, float, float, char, float, float, float*)**

  This function is used to calculate the cost of gate.

5.3 GENERAL STRUCTURE OF PROGRAM

The sequence of execution of the program for radial gate is as stated under:

- Include statements
- Function declarations

- Main program starts
- FRL, CL, CS are initialized
- Calculation of SL, HD
- Initialization of radius factor (Rf) and side seal (Tss)
- Calculation of Trunnion Level (TL) and Rvt, Rvb and A with the function **void Rvv( )**.
- Calculation of gate height (Arc_AB) and total hydrostatic pressure on the gate (P)
- Selection of skin plate thickness (t) and optimal spacing of vertical stiffener (Lopt) with due consideration of corrosion allowance.
- Arrangement of horizontal girders by trial and error method so as to have almost equal bending moment at supports.
- Water load(Raw, Rbw etc.) and bending moments (Maw, Mbw etc.) are computed.
- CG1, HG1 are assumed for initial calculations.
- Radial load due to sill beam (Ras, Rbs etc.) and bending moments (Mas, Mbs etc.) are computed and then total load (Ra, Rb etc.) and Total bending moments (Ma, Mb etc.) are determined.
- Shear force diagram along the vertical stiffener at girder locations is represented by a quadratic equation and the co-efficient of the equation between two girders are computed.
- Bending moment diagram along the vertical stiffener is represented by a cubic equation and the co-efficients of the equation between two girders are computed.
- The contra flexure points are computed with the help of function **float xcube( )**
- Co-acting width (CAW)s are computed by the functions **float caw1( )** and **float caw2( )**
- Analysis of stresses in skin plate as a panel with the function **void Stress_SP( )**
- Check for stresses in skin plate at girder locations including combined stresses and selection of vertical stiffener section and its

weight per meter(wVS) with the help of the function **void Stress_VS( )**

- Initial assumption of HC1, RA1 the hoist capacity and rope inclination
- Analysis of stresses and selection of girder section and its weight per meter (wHG) with the help of the function **void Stress_HG( )**
- Assumptions for trunnion friction, seal friction etc. and computation of load on the arm
- Analysis of stresses in arm section and selection of arm section and Its weight per meter (wArm) with the help of the function **void Stress_Arm( )**
- Calculation of CG1, weight of gate (WG1)
- Calculation of hoisting capacity (HC1)
- Calculation of cost of material (Mat_cost)
- Calculation of fabrication cost (Cwel, Cdril, Cpaints), transportation cost (Ctrans), erection cost (Cerect) etc. and then the total cost of gate (Ctotal) assuming hoist cost (Choist), inspections and design cost (Cinsp) with the help of the function **void COST( )**
- Main program ends
- Function definitions

Similarly, The sequence of execution of the program for fixed wheel vertical lift gate is as stated under:

- Include statements
- Function declarations
- Main program starts
- FRL, CL, CS are initialized
- Calculation of SL, HD
- Initialization of side seal (Tss)
- Selection of skin plate thickness (t) and optimal spacing of vertical stiffener (Lopt) with due consideration of corrosion allowance.
- Arrangement of horizontal girders analytical method so as to have almost equal load at supports.

- Water load(Ra, Rb etc.) and bending moments (Ma, Mb etc.) are computed.
- Shear force diagram along the vertical stiffener at girder locations is represented by a quadratic equation and the co-efficients of the equation between two girders are computed.
- Bending moment diagram along the vertical stiffener is represented by a cubic equation and the co-efficients of the equation between two girders are computed.
- The contra flexure points are computed with the help of function **float xcube( )**
- Cc-acting width (CAW)s are computed by the functions **float caw1( )** and **float caw2( )**
- Analysis of stresses in skin plate as a panel with the function **void Stress_SP( )**
- Check for stresses in skin plate at girder locations including combined stresses and selection of vertical stiffener section and its weight per meter(wVS) with the help of the function **void Stress_VS( )**
- Analysis of stresses and selection of girder section and its weight per meter (wVHG) with the help of the function **void Stress_VHG( )**
- Analysis of stresses and selection of vertical end girder section and its weight/m (wVEG) with the help of the function **void Stress_VEG( )**
- Design of wheel and calculation of weight per meter (wWheel) with the help of the function **void Wheel ( )**
- Assumptions for axle friction (fa), guide friction, rolling friction (fr) etc. and computation of load on the gate
- Calculation of CVG, weight of gate (WVG)
- Calculation of hoisting capacity (WVGt)
- Calculation of cost of material (Mat_cost)
- Calculation of fabrication cost (Cwel, Cdril, Cpaints), transportation cost (Ctrans), erection cost (Cerect) etc. and then the

total cost of gate (Ctotal) assuming hoist cost (Choist), inspections and design cost (Cinsp) with the help of the function **void COST( )**

- Main program ends
- Function definitions

5.4 PROGRAM EXECUTION

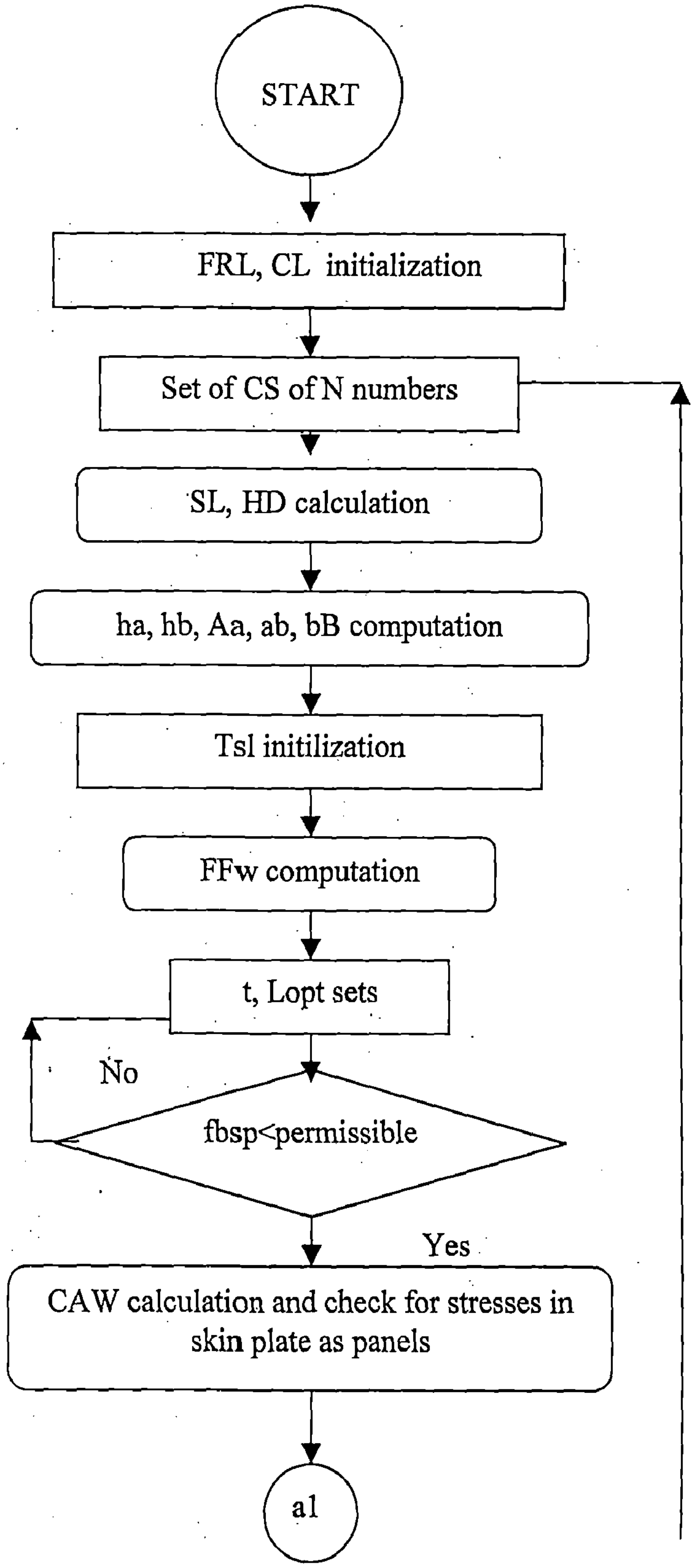
It was intended to frame the whole program having 2,3 and 4 horizontal girders in each case of fixed wheel vertical lift gate and radial gate. But, the text volume of the program exceeds 64 KB and hence it cannot be run. So, the program has been divided into separate programs for each case of different number of horizontal girders for both fixed wheel vertical lift gate and radial gate. Six separate programs are framed to analysis the cost of gate. The programs are named as under:

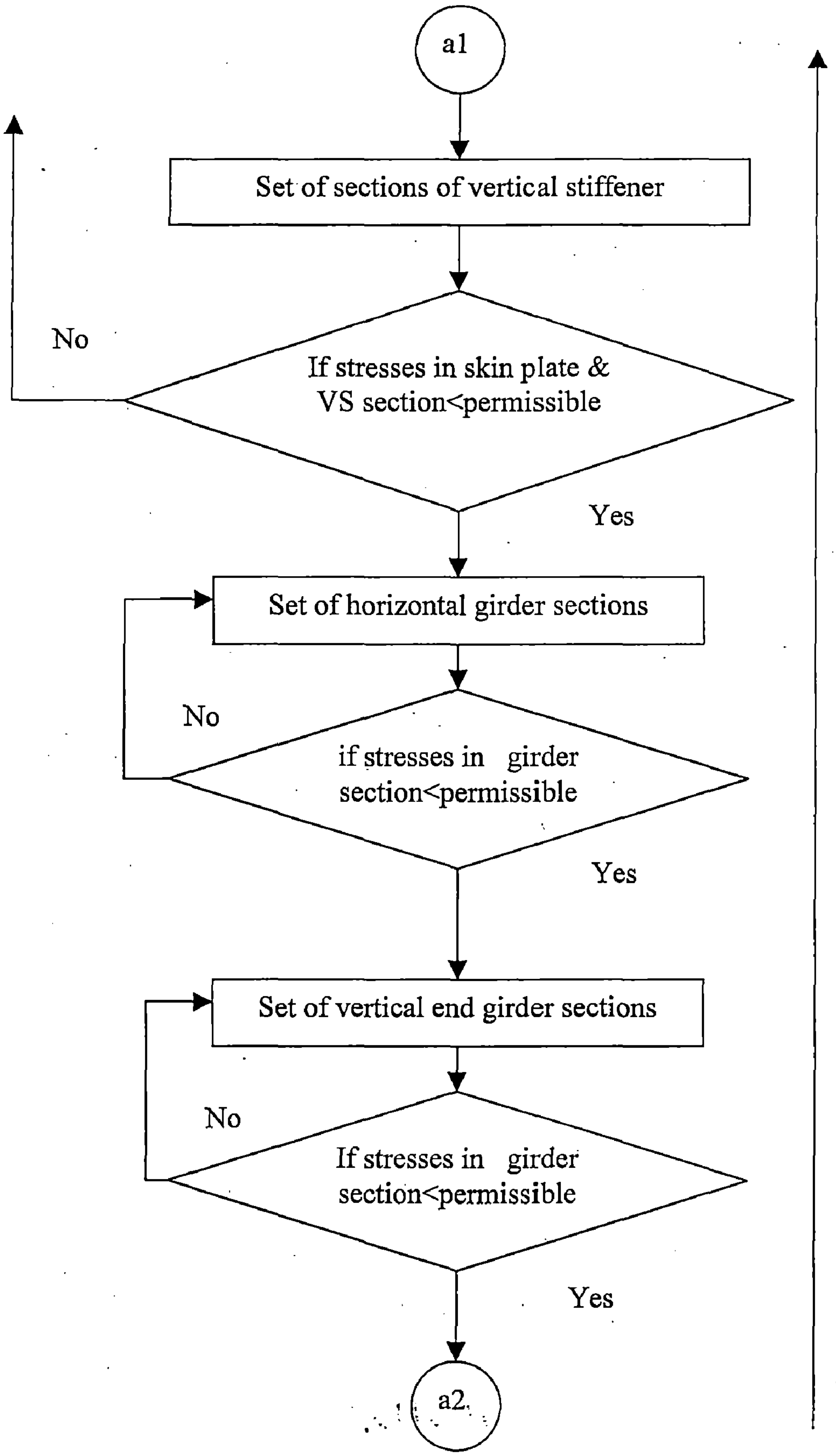
1.	**OPTGATV2.CPP**	Program for cost analysis of fixed Wheel vertical lift gate with 2 horizontal girders.
2.	**OPTGATV3.CPP**	Program for cost analysis of fixed Wheel vertical lift gate with 3 horizontal girders.
3.	**OPTGATV4.CPP**	Program for cost analysis of fixed Wheel vertical lift gate with 4 horizontal girders.
4.	**OPTGATR2.CPP**	Program for cost analysis of radial gate with 2 horizontal girders.
5.	**OPTGATR3.CPP**	Program for cost analysis of radial gate with 3 horizontal girders.
6.	**OPTGATR4.CPP**	Program for cost analysis of radial gate with 4 horizontal girders.

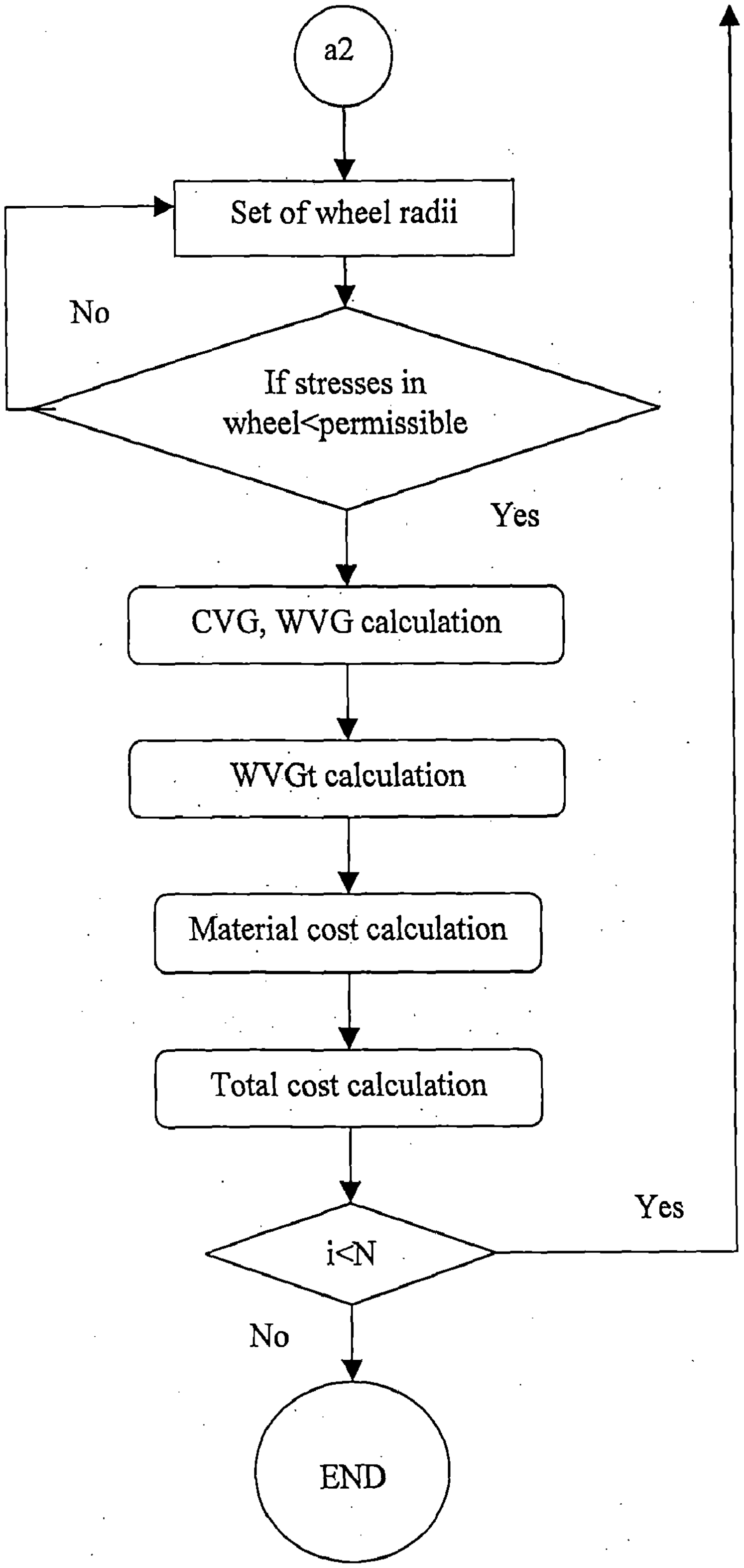
The function definitions are required to be included in each program. These are attached with the program 'OPTGATR2.CPP', but not attached in rest of the programs enclosed in the Annexure to reduce the volume of the dissertation report. These are to be added while running each program.

CHART-5.FC.V.1

FLOW CHART OF THE PROGRAM FOR FIXED WHEEL VERTICAL LIFT GATE



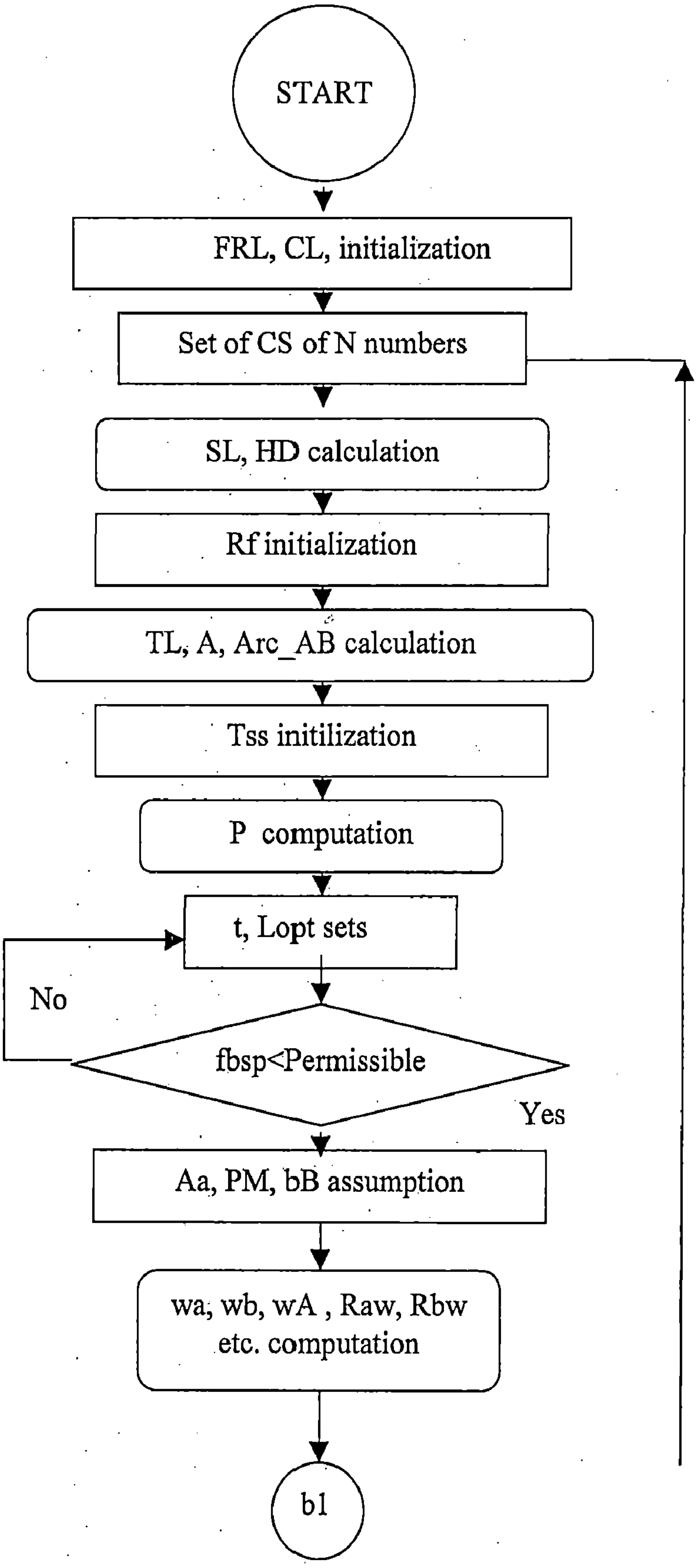

a1
Set of sections of vertical stiffener
If stresses in skin plate & VS section<permissible
No
Yes
Set of horizontal girder sections
if stresses in girder section<permissible
No
Yes
Set of vertical end girder sections
If stresses in girder section<permissible
No
Yes
a2

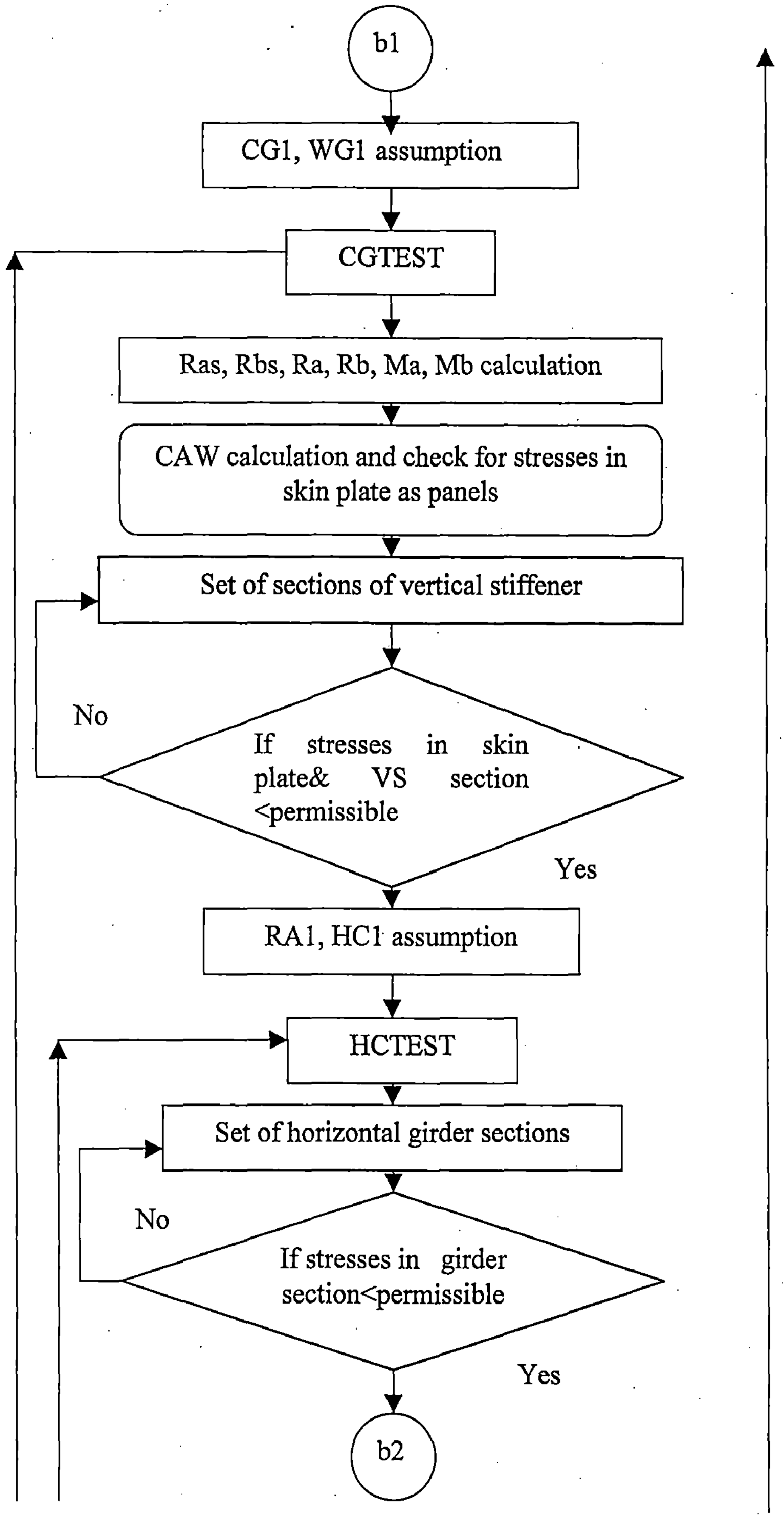

a2
Set of wheel radii
No
If stresses in wheel<permissible
Yes
CVG, WVG calculation
WVGt calculation
Material cost calculation
Total cost calculation
Yes
i<N
No
END

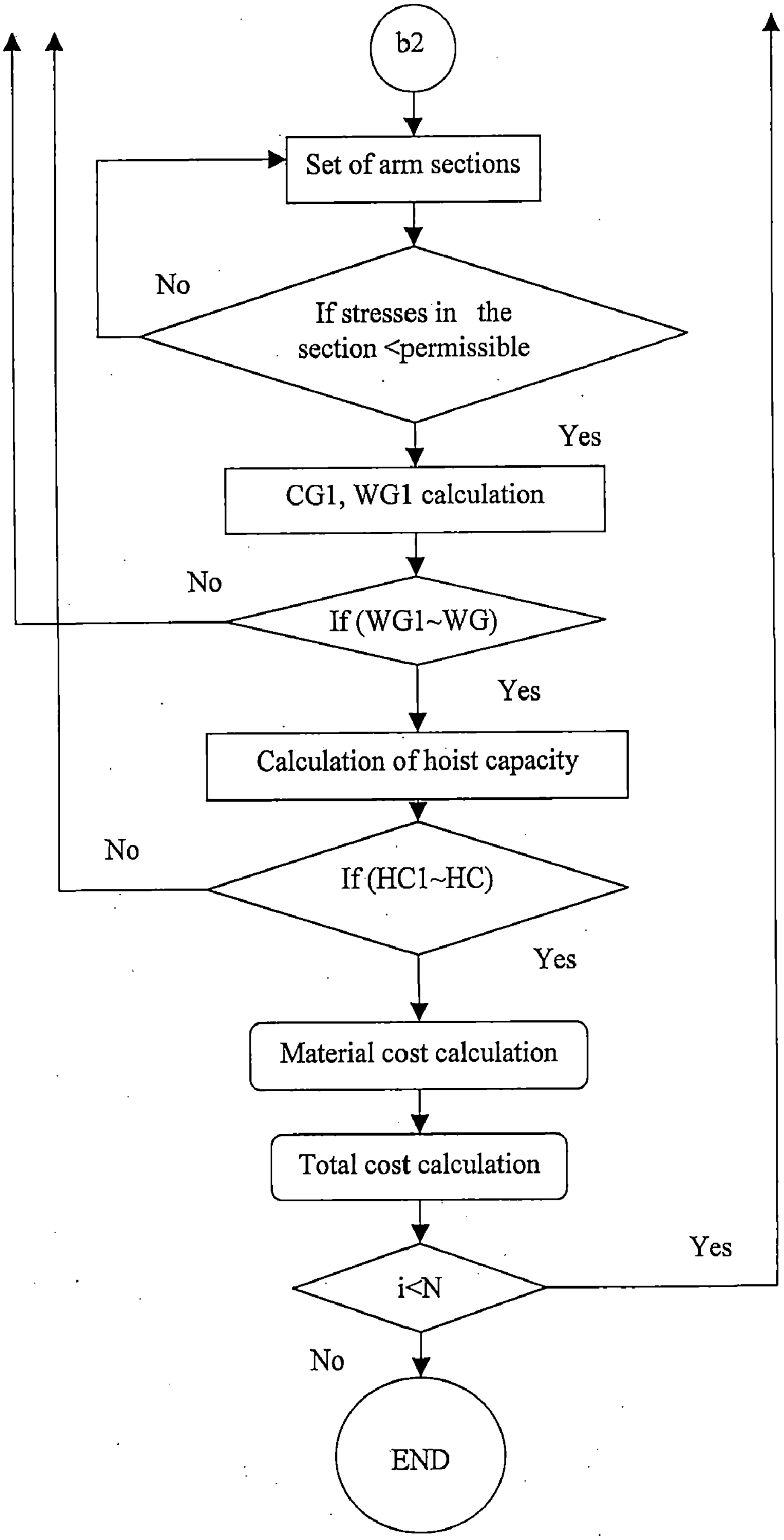
610,119.

CHART-5.FC.R.1

FLOW CHART OF THE PROGRAM FOR RADIAL GATE




b1
CG1, WG1 assumption
CGTEST
Ras, Rbs, Ra, Rb, Ma, Mb calculation
CAW calculation and check for stresses in skin plate as panels
Set of sections of vertical stiffener
No
If stresses in skin plate& VS section <permissible
Yes
RA1, HC1 assumption
HCTEST
Set of horizontal girder sections
No
If stresses in girder section<permissible
Yes
b2


b2
Set of arm sections
No
If stresses in the section <permissible
Yes
CG1, WG1 calculation
No
If (WG1~WG)
Yes
Calculation of hoist capacity
No
If (HC1~HC)
Yes
Material cost calculation
Total cost calculation
Yes
i<N
No
END

CHAPTER VI

ANALYSIS AND RESULTS

6.1 GENERAL

The optimization of design of spillway gate is basically aimed at the following aspects:

- Radius of radial gate depends on the radius factor by which the head of water is multiplied to get the radius of gate. Radius of gate controls the quantity of steel used for radial arms and the skin plate. It is intended to analyze the cost of radial gate to obtain a radius factor for which the cost is minimum.
- The number of horizontal girders for both fixed wheel vertical lift gate and radial gate influences the weight of gate and hence the cost of steel. This is a most important optimization criterion.
- The variation of cost with respect to span is also an optimization criterion.
- The weight of fixed wheel vertical lift gate and radial gate comprises the steel used in the gate, which comprises the principal cost of gate. This can be an optimization criterion for selection of gate among these two.
- Cost analysis can also be done w.r.t. a specific area of spillway bay.
- Hoist capacity of fixed wheel gate and radial gate can be compared.
- Material cost and operating cost may be taken for analysis of cost.
- The relationship of head of water and area of gate can also be analyzed.
- The relationship of height and span of gate bay also be optimized.

6.2 COST ANALYSIS

6.2.1 Radius Factor Analysis

The costs of radial gate for each case of radial gates having various numbers of horizontal girders have been computed with the help of the general computer program. The radius factor is taken from 1 to 2 and respective costs are analyzed. The results obtained thus, have been reproduced by the curves, which are drawn with the help of 'MICROSOFT EXCEL'.

- **Radial Gate with 2 Horizontal Girders**

The analysis of the costs of radial gate with 2 horizontal girders is done and two Charts plotted are CHART-6.1.R2.1 and CHART-6.1.R2.2. The Charts are self-explanatory. Costs of gate are lowest for radius factor of 1.15 in the first Chart and 1.2 in case of the second Chart.

The Charts CHART-6.1.R2.3 and CHART-6.1.R2.4 are plotted with the radius factors obtained from the relationship of head of water and clear span of gate, when the cost of gate is lowest. The variation of radius factor for different spans with head of water is seen in CHART-6.1.R2.3 and in CHART-6.1.R2.4, the variation for head of water to span is seen. The trends of the curves show that radius factor converges to about 8.5m of head of water. For heads of water lower than 8.5m, higher radius factor can be used.

- **Radial Gate with 3 Horizontal Girders**

In the analysis of radius factor in radial gate with 3 horizontal girders is shown in the Charts CHART-6.1.R3.1 to CHART-6.1.R3.4. In CHART-6.1.R3.1 and CHART-6.1.R3.2 the radius factor corresponding to lowest costs occurs at 1.2 and 1.1 respectively.

The relationships of head of water and span with radius factor show that the lower radius factor is required for lowest cost of gate for heads ranging from about 8.5m to 12.5m.

- **Radial Gate with 4 Horizontal Girders**

In case of radial gate with 4 horizontal girders, the Charts CHART-6.1.R4.1 and CHART-6.1.R4.2 show that radius factors corresponding to global lowest cost of gate occur at 1.25 and 1.2 respectively.

In the trend of radius factors for variation of head of water and clear span, the radius factor corresponding to lowest cost of gate occurs at 14m head.

- **Conclusion**

From the above analysis, it is observed that:

a) The radius factor varies between 1.05 and 1.45.

b) Minimum radius factor for radial gate with 2 horizontal girder occurs at 8.5m head, it is 14m head in case of gate with 4 horizontal girder and in the case of gate with 3 horizontal girder, the head of water for minimum radius factor varies from about 8.5m to 13.5m approximately.

c) In average, the radius factor can be taken as 1.25.

6.2.2 Optimisation of No. of Horizontal Girders in Fixed Wheel Vertical Lift Gate

The optimization of number of horizontal girders in fixed wheel vertical lift gate as well as in radial gate may be done as follows:

(1) Cost analysis with respect to head of water.

(2) Cost analysis with respect to clear span of gate.

(3) Cost analysis with respect to head for a specific area of spillway bay

For optimization of number of horizontal girders in fixed wheel vertical lift gate is done as under:

- **Analysis with respect to Head (HD)**

The costs of fixed wheel gate with 2, 3 and 4 numbers of horizontal girders have been plotted against head of water. The curves are shown in the Charts CHART-6.2.HD.V.1 to CHART-6.2.HD.V.8.

The curves shown in CHART-6.2.HD.V.1 reveals that gate with 2 numbers of horizontal girders is always cheaper for heads below 9.5m and gate with 4 number of horizontal girder is always cheaper above 13.5m of head. The gate with 3 horizontal girders is cheaper in the range of head from 9.5m to 13.5m for a clear span of 12m. The other curves also show that the upper and lower cutting point for cheaper gate with 3 horizontal girders are about 13m and 8m respectively.

- **Analysis with respect to Span (CS)**

The cost analysis with respect to clear span of gate is shown in the curves plotted in CHART-6.2.CS.V.1 to CHART-6.2.CS.V.4. The variation in cost is noticed to be related to the head of water significantly. For 6.4m head, the gate with 2 horizontal girders is always cheaper while it is always costlier for 10.5m and 12m head. In case of 8.4m head, it becomes costlier above 17.5m approx.

- **Analysis with respect to Head (HD) for a Specific Area of Spillway Bay**

Analysis is also done for a specific area of spillway bay for variation of cost with respect to head of water. CHART-6.2.HDA.V.1 to CHART-6.2.HDA.V.4 show the head-cost relationships for various areas of spillway bays. These curves indicate that the gate with 2 numbers of horizontal girders is cheaper below 8-9m of head and the gate with 4 numbers of girders is cheaper above 13-14m while the gate with 3 girders remains in between these limits.

- **Analysis of Gate Weight**

The gate weights computed for different heads and spans are compared. The obtained results are reproduced by curves. The gate weight is analyzed with respect to a parameter '$b^2hH/1000$' (AE) which is generally taken for analysis of gate weight. The gate weights obtained from the empirical relations given by **Erbiste** (1984) are taken for comparison. In the analysis the value of the parameter is limited to greater than 2000 m^4. Here b, h and H are clear span, height and head of gate.

The comparisons of gate weight with **Erbiste**'s formula reveal that the trends of the curves are more or less compatible.

- **Conclusion**

For lower heads of water below 8m or so, the cost of gate with 4 number of girders is a bit unpredictable. However, from the above analysis, it is observed that:

(1) The optimum no. of horizontal girder up to a head of 8.5m is 2

(2) The optimum no. of horizontal girder below a head of 13.5m and above 8.5m is 3.

(3) The optimum no. of horizontal girder above 13.5m head is 4.

6.2.3 Optimisation of No. of Horizontal Girders in Radial Gate

Cost analysis has been done for optimization of number of horizontal girders in radial gate with 2, 3 and 4 numbers of girders in the same procedure as discussed in para-6.2.2. The curves are shown in Charts from CHART-6.2.HD.R2.1 to CHART-6.2.HD.R.4.

- **Conclusion**

The cost of gate with 4 numbers of girders in case of radial gate is also a bit unpredictable. But, the observation is that:

(1) The optimum no. of horizontal girder up to a head of 7m is 2

(2) The optimum no. of horizontal girder below a head of 13.5m and above 7m is 3.

(3) The optimum no. of horizontal girder above 13.5m head is 4.

6.2.4 Optimisation of Type of Gate

For optimization of type of gate between fixed wheel vertical lift gate and radial gate, comparison can be done for the following:

a) Hoisting capacity of the gates
b) Total cost of gates
c) Material cost and operating costs of gates

The parameters mentioned above are analyzed and the respective curves are shown in CHART-6.3.HC.1, CHART-6.3.COST.1, CHART-6.3.MC.1 and CHART-6.3.OC.1. From the above curves it is clearly evident that the radial gate is cheaper than the fixed wheel vertical lift gate.

Table-6.1.R2.1 Rf for 6.4m head				**Table-6.1.R3.1** Rf for 9m head				**Table-6.1.R4.1** Rf for 12m head			
CS=6m		CS=10m		CS=9m		CS=12m		CS=12m		CS=15m	
Rf	Cost	Rf	Cost	Rf	Cost	Rf	Cost	Rf	Cost	Rf	Cost
1.05	5.89	1.05	8.07	1.05	11.86	1.05	15.65	1.05	24.24	1.05	29.9
1.1	5.87	1.1	8.1	1.1	11.63	1.1	16.2	1.1	22.92	1.1	30.1
1.15	5.55	1.15	8.14	1.15	11.69	1.15	16.38	1.15	23.84	1.15	31
1.2	5.55	1.2	7.93	1.2	11.71	1.2	16.45	1.2	23.96	1.2	29.4
1.25	5.55	1.25	7.93	1.25	11.88	1.25	16.48	1.25	22.86	1.25	29.9
1.3	5.55	1.3	7.93	1.3	12.28	1.3	16.64	1.3	23.38	1.3	30.8
1.35	5.56	1.35	7.98	1.35	12.37	1.35	16.71	1.35	23.49	1.35	31.4
1.4	5.56	1.4	7.98	1.4	12.52	1.4	16.86	1.4	24.08	1.4	31
1.45	5.57	1.45	7.99	1.45	12.94	1.45	17.13	1.45	23.44	1.45	29.9
1.5	5.56	1.5	8.04	1.5	13.01	1.5	17.3	1.5	23.4	1.5	30.2
1.55	5.57	1.55	8.05	1.55	13.21	1.55	17.3	1.55	23.53	1.55	30.3
1.6	5.58	1.6	8.06	1.6	13.39	1.6	17.37	1.6	23.84	1.6	30.9
1.65	5.59	1.65	8.12	1.65	12.87	1.65	16.93	1.65	24.28	1.65	31.3
1.7	5.62	1.7	8.14	1.7	13.11	1.7	17.09	1.7	24.64	1.7	31.9
1.75	5.63	1.75	8.16	1.75	12.77	1.75	17.19	1.75	25.06	1.75	32.3

Table-6.1.R2.2

Rf for minimum cost

CS	HD		
(m)	6.4m	7.4m	8.4m
4	1.25	1.15	1.05
6	1.2	1.1	1.05
8	1.2	1.05	1.05
10	1.25	1.05	1.05
12	1.25	1.1	1.2
15	1.25	1.35	1.2

Table-6.1.R2.3

Rf for minimum cost w.r.t. Head

HD	CS					
(m)	4m	6m	8m	10m	12m	15m
6.4	1.25	1.2	1.2	1.25	1.25	1.25
7.4	1.15	1.1	1.05	1.05	1.1	1.35
8.4	1.05	1.05	1.05	1.05	1.2	1.2
9	1.25	1.05	1.05	1.15	1.15	1.15
12	1.05	1.05	1.1	1.05	1.05	1.05

Table-6.1.R3.2

Rf for minimum cost w.r.t. Head

HD	CS					
(m)	5m	7m	9m	12m	15m	20m
7	1.35	1.3	1.2	1.1	1.1	1.1
9	1.2	1.05	1.1	1.05	1.05	1.05
12	1.15	1.05	1.05	1.05	1.05	1.05
14	1.15	1.1	1.4	1.25	1.05	1.35

Table-6.1.R3.3

Rf for minimum cost

CS	HD			
(m)	7m	9m	12m	14m
5	1.35	1.2	1.15	1.15
7	1.3	1.05	1.05	1.1
9	1.2	1.1	1.05	1.4
12	1.1	1.05	1.05	1.25
15	1.1	1.05	1.05	1.05
20	1.1	1.05	1.05	1.35

Table-6.1.R4.2

Rf for minimum cost w.r.t. Head

HD	CS					
(m)	7m	9m	12m	15m	20m	25m
9	1.4	1.3	1.2	1.2	1.2	1.05
12	1.3	1.3	1.25	1.2	1.15	1.15
14	1.05	1.05	1.05	1.05	1.05	1.05
16	1.1	1.05	1.3	1.45	1.1	1.45

Table-6.1.R4.3

Rf for minimum cost

CS	HD			
(m)	9m	12m	14m	16m
7	1.4	1.3	1.05	1.1
9	1.3	1.3	1.05	1.05
12	1.2	1.25	1.05	1.3
15	1.2	1.2	1.05	1.45
20	1.2	1.15	1.05	1.1
25	1.05	1.15	1.05	1.45

Table-6.2.HD.V.1:

Cost and weight of fixed wheel vertical lift gate w.r.t. head for 8m span

Height	AG	HD	Cost (lakh Rs.)				AE	Weight (tonne)			
(m)	(m2)	(m)	V4	V3	V2		(m4)	V4	V3	V2	WE
14.5	145.1	14.5	25.8	28.5	31.3		21.1	55.1	62.6	62.6	56
12.5	124.8	12.5	22	21.2	25.8		15.6	46.8	45.1	45.1	45.3
10.5	104.5	10.5	17.2	16.9	18.7		10.9	35.2	34.2	34.2	35.4
8.4	84.2	8.4	13.6	13	12.7		7.1	27.1	25.7	25.7	26.1
6.4	63.9	6.4	10.6	9.9	9.6		4.1	20.5	18.5	18.5	17.8
4.4	43.6	4.4	6.5	6.5	6.3		2	10.6	10.7	10.7	10.4

Table-6.2.HD.V.2:

Cost and weight of fixed wheel vertical lift gate w.r.t. head for 10m span

Height	AG	HD	Cost (lakh Rs.)				AE	Weight (tonne)			
(m)	(m^2)	(m)	V4	V3	V2		(m^4)	V4	V3	V2	WE
16.5	165.4	16.5	42.1	43.5			27.4	93.8	97.2		91.8
14.5	145.1	14.5	33.7	34.8	40		21.1	74.2	77.4	89.9	76.5
12.5	124.8	12.5	30.2	27.5	31.8		15.6	66.8	60.1	71	61.9
10.5	104.5	10.5	22.5	22.3	23		10.9	47.6	47.4	48.5	48.3
8.4	84.2	8.4	16.9	16.9	16.5		7.1	35	35.1	33.9	35.7
6.4	63.9	6.4	13.4	12.3	11.9		4.1	27.1	24.2	23.5	24.3
4.4	43.6	4.4	10	9.3	8.1		2	19.5	17.6	15.2	14.2

Table-6.2.HD.V.3:

Cost and weight of fixed wheel vertical lift gate w.r.t. head for 12m span

Height	AG	HD	Cost (lakh Rs.)				AE	Weight (tonne)			
(m)	(m^2)	(m)	V4	V3	V2		(m^4)	V4	V3	V2	WE
16.5	198.5	16.5	51.7	57.8			39.4	116.4	132.1		118.6
14.5	174.2	14.5	41.5	42.7	51.3		30.3	92.5	96.1	117.3	98.7
12.5	149.8	12.5	35.3	33.9	39.3		22.4	78.4	75.3	89.2	80
10.5	125.4	10.5	30.6	26.9	27.9		15.7	67.6	58.2	60.2	62.4
8.4	101.1	8.4	21.7	20.8	20.1		10.2	46.6	44.3	42.1	46.1
6.4	76.7	6.4	16.5	15.7	14.6		5.9	34.7	32.6	29.9	31.3
4.4	52.3	4.4	12.6	11.1	9.6		2.7	25.8	22	18.6	18.3

Table-6.2.HD.V.3:

Cost and weight of fixed wheel vertical lift gate w.r.t. head for 15m span

Height	AG	HD	Cost (lakh Rs.)				AE	Weight (tonne)			
(m)	(m^2)	(m)	V4	V3	V2		(m^4)	V4	V3	V2	WE
16.5	248.1	16.5	77.7	82.9			61.6	179.8	193.1		162.1
14.5	217.1	14.5	60.8	62.9	70.9		47.4	139.1	145.7	165	134.9
12.5	187.2	12.5	47.3	47	55.7		35.1	107.2	107.5	129.3	109.3
10.5	156.8	10.5	38.2	35.1	38.7		24.6	85.4	77.5	86.4	85.2
8.4	126.3	8.4	31.8	27.9	25.8		16	71.6	61.5	55.7	63
6.4	95.9	6.4	23.6	23.4	19.9		9.2	52.4	51.8	43.1	42.8
4.4	65.4	4.4	15.9	15.5	13.1		4.3	33.9	32.9	27.3	25.1

Table-6.2.CS.R.1:

Cost and weight of radial gate w.r.t. span for 6.4m head

Height	AG	CS	Cost (lakh Rs.)				AE	Weight (tonne)			
(m)	(m2)	(m)	R4	R3	R2		(m4)	R4	R3	R2	WE
6.6	118.5	18	13.2	13.7	14.9		13.6	25.7	27.0	30.5	43.1
6.6	105.4	16	11.7	12.2	13.4		10.8	22.2	23.5	26.9	36.8
6.6	92.2	14	10.4	10.8	11.5		8.3	19.1	20.1	22.3	30.8
6.6	79.0	12	9.2	9.4	9.4		6.1	16.4	16.8	16.8	25.0
6.6	65.9	10	7.9	8.0	7.9		4.2	13.6	14.0	13.6	19.6
6.6	52.7	8	7.1	6.9	6.7		2.7	12.0	11.3	10.7	14.5

Table-6.2.CS.R.2:

Cost and weight of radial gate w.r.t. span for 8.4m head

Height	AG	CS	Cost (lakh Rs.)				AE	Weight (tonne)			
(m)	(m2)	(m)	R4	R3	R2		(m4)	R4	R3	R2	WE
8.7	156.2	18	23	22.2	23.8		13.6	51.7	49.3	53.2	62.5
8.7	138.8	16	19.2	19.5	20.5		10.8	41.9	42.5	44.9	53.4
8.7	121.5	14	14.9	16.8	17.6		8.3	30.2	35.7	37.8	44.6
8.7	104.1	12	13	13.9	15.1		6.1	25.8	28.4	31.4	36.2
8.7	86.8	10	10.8	11.9	12.2		4.2	20.6	23.7	24.5	28.4
8.7	69.4	8	9	9.9	10.2		2.7	16.5	19	19.6	21

Table-6.2.CS.R.3:

Cost and weight of radial gate w.r.t. span for 10.5m head

Height	AG	CS	Cost (lakh Rs.)				AE	Weight (tonne)			
(m)	(m2)	(m)	R4	R3	R2		(m4)	R4	R3	R2	WE
10.8	193.8	18	32.4	31.0	32.3		36.5	75.3	72.3	73.9	83.6
10.8	172.3	16	28.5	27.2	27.2		28.8	65.6	62.6	60.7	71.4
10.8	150.8	14	24.6	23.2	23.4		22.1	55.8	52.4	51.3	59.6
10.8	129.2	12	20.7	19.3	19.9		16.2	45.9	42.3	42.7	48.5
10.8	107.7	10	16.8	16.1	16.6		11.3	36.2	34.6	34.8	37.9
10.8	86.2	8	13.5	12.9	13.7		7.2	27.8	26.7	27.7	28.1

Table-6.2.CS.R.4:

Cost and weight of radial gate w.r.t. span for 10.5m head

Height	AG	CS	Cost (lakh Rs.)				AE	Weight (tonne)			
(m)	(m2)	(m)	R4	R3	R2		(m4)	R4	R3	R2	WE
12.1	224	18	38	37.7	37.6		48.7	89.5	88.6	88.7	101.6
12.1	199.1	16	32.2	32.6	33.6		38.5	74.8	76	79	86.7
12.1	174.2	14	27.6	27.8	28.2		29.5	63	63.9	65	72.4
12.1	149.3	12	22.7	23.5	23.7		21.6	50.7	52.9	53.8	58.9
12.1	124.4	10	20.1	19.3	19.7		15	44.7	42.5	43.8	46.1
12.1	99.5	8	16.2	15.7	15.6		9.6	35	33.5	33.5	34.1

Table-6.2.HDA.V.1:

Cost and weight of fixed wheel vertical lift gate for area of spillway bay of 75m^2

CS	HEAD	Cost (lakh Rs.)				AE	Weight (tonne)			
(m)	(m)	V4	V3	V2		(m^4)	V4	V3	V2	WE
4	18.6	20.8	23.1			5.6	42.8	49.8		30.4
4.5	16.5	19.3	19.9			5.6	39.2	42.1		30.4
5.2	14.5	17.6	18.5	20.9		5.6	35.3	38.7	44.8	30.4
6	12.5	16.7	16	20		5.6	33.3	32.6	43	30.4
7.2	10.5	15.7	14.8	16.2		5.6	30.9	29.3	33	30.4
8.9	8.4	15	14.3	14.7		5.6	29.7	28.7	29	30.4
11.7	6.4	16.2	15.4	14.1		5.6	33	31.9	38.6	30.4
17.2	4.4	12.1	18.2	17.6		5.6	45.9	39.5		30.4

Table-6.2.HDA.V.1:

Cost and weight of fixed wheel vertical lift gate for area of spillway bay of 100m^2

CS	HEAD	Cost (lakh Rs.)				AE	Weight (tonne)			
(m)	(m)	V4	V3	V2		(m^4)	V4	V3	V2	WE
5.4	18.6	27	29.8			10	56.7	65.5		45.1
6	16.5	24.5	25.8			10	51.1	55.9		45.1
6.9	14.5	23.1	23.6	27		10	47.8	50.9	39.5	45.1
8	12.5	22.6	21.2	25.8		10	46.8	45.1	56.9	45.1
9.6	10.5	21.6	20.2	21.5		10	44.6	42.2	45.5	45.1
11.9	8.4	21.5	20.3	20.3		10	44.9	43.4	43.4	45.1
15.7	6.4	25.1	24.1	20.5		10	54.5	53.6	44.5	45.1
22.9	4.4	36.7	29.3	24.2		10	84.3	67.2	54.8	45.1

Table-6.2.HDA.V.1:

Cost and weight of fixed wheel vertical lift gate for area of spillway bay of 150m^2

CS	HEAD	Cost (lakh Rs.)				AE	Weight (tonne)			
(m)	(m)	V4	V3	V2		(m^4)	V4	V3	V2	WE
8.1	18.6	40.5	43.4			29.5	87.6	97.5		80.1
9.1	16.5	37.9	39.1			29.5	81.7	87.1		80.1
10.3	14.5	36.2	36.2	40.6		29.5	77.9	80.8	91.5	80.1
12	12.5	36.3	33.6	39.3		29.5	78.5	74.7	89.2	80.1
14.4	10.5	36.2	33.2	34.6		29.5	78.5	73.2	76.2	80.1
17.8	8.4	39.5	34.9	33.8		29.5	87.7	78.7	75.7	80.1
23.5	6.4	47.4	39.2	35.6		29.5	108	90	81.4	80.1
34.4	4.4	63.9	55.1	54.8		29.5	150.1	131.7	132.2	80.1

Table-6.2.HDA.V.1:

Cost and weight of fixed wheel vertical lift gate for area of spillway bay of 175m^2

CS	HEAD	Cost (lakh Rs.)				AE	Weight (tonne)			
(m)	(m)	V4	V3	V2		(m^4)	V4	V3	V2	WE
9.4	18.6	47.6	50.7			30.6	104	114.3		99.4
10.6	16.5	44.9	46.8			30.6	98.1	105.3		99.4
12.1	14.5	43.3	42.8	50.7		30.6	94.7	96.3	116.1	99.4
14	12.5	44.5	41.3	50.5		30.6	97.6	93.4	116.6	99.4
16.7	10.5	45.1	42	45.6		30.6	99.2	94.2	103.2	99.4
20.4	8.4	47.4	44.9	46.4		30.6	106.1	102.9	107.2	99.4
27.4	6.4	58	55.7	53.3		30.6	133.2	131.4	126.1	99.4
40.1	4.4	94.8	88.9	85		30.6	226.3	218.1	209.5	99.4

Table-6.2.HD.R.1:

Cost and weight of radial gate w.r.t. head for 8m span

Height	AG	HD	Cost (lakh Rs.)				AE	Weight (tonne)			
(m)	(m^2)	(m)	R4	R3	R2		(m^4)	R4	R3	R2	WE
17	136.4	16.5	26.4	30.2	39.6		18.1	60.9	71.8	99.3	52.1
15	119.6	14.5	21	22	23		13.9	46.6	49.4	53	43.7
12.9	102.9	12.5	16.8	16.2	16.7		10.3	36.6	34.7	36.2	35.7
10.8	86.2	10.5	13.5	13	13.7		7.2	27.8	27	27.7	28.1
8.7	69.4	8.4	9	9.9	10.2		4.7	16.5	19	19.6	21
6.6	52.7	6.4	7.1	6.9	6.7		2.7	12	11.3	10.8	14.5
4.5	35.9	4.4		5.1	4.9		1.3		7.3	6.7	8.7

Table-6.2.HD.R.2:

Cost and weight of radial gate w.r.t. head for 10m span

Height	AG	HD	Cost (lakh Rs.)				AE	Weight (tonne)			
(m)	(m^2)	(m)	R4	R3	R2		(m^4)	R4	R3	R2	WE
17	170.5	16.5	32.6	39.7	48.3		28.2	76.3	97	121.7	70.3
15	149.5	14.5	26	28.5	29.2		21.7	58.8	66.1	68.9	59
12.9	128.6	12.5	20.9	20.1	20.3		16.1	46.6	44.2	45	48.1
10.8	107.7	10.5	16.8	16.2	16.6		11.3	36.2	34.9	34.8	37.9
8.7	86.8	8.4	10.8	11.9	12.2		7.3	20.6	23.7	24.5	28.4
6.6	65.9	6.4	7.9	8	7.9		4.2	13.6	14	13.6	19.6
4.5	44.9	4.4		5.8	5.6		2		8.9	8.2	11.7

Table-6.2.CS.V.1:

Cost and weight of fixed wheel vertical lift gate w.r.t. span for 6.4m head

Height	AG	CS	Cost (lakh Rs.)				AE	Weight (tonne)			
(m)	(m^2)	(m)	V4	V3	V2		(m^4)	V4	V3	V2	WE
6.4	115	18	32.9	27.3	24.5		13.2	75.8	60.9	54	55.3
6.4	102.3	16	26.2	24.7	20.9		10.5	58.7	54.9	45.3	46.9
6.4	89.5	14	20.7	19.1	19		8	45.1	40.9	40.8	38.9
6.4	76.7	12	16.5	15.7	14.6		5.9	34.7	32.6	29.9	31.3
6.4	63.9	10	13.4	12.3	11.9		4.1	27.1	24.2	23.5	24.3
6.4	51.1	8	10.6	9.9	9.6		2.6	20.5	18.5	18.1	17.8

Table-6.2.CS.V.2:

Cost and weight of fixed wheel vertical lift gate w.r.t. span for 8.4m head

Height	Abay	CS	Cost (lakh Rs.)				AE	Weight (tonne)			
(m)	(m^2)	(m)	V4	V3	V2		(m^4)	V4	V3	V2	WE
8.4	151.6	18	39	35.4	36.6		23	88.9	79.9	82	81.3
8.4	134.7	16	33.5	30.4	27.7		18.2	75.5	67.7	59.9	68.9
8.4	117.9	14	29.8	26.8	23.8		13.9	66.9	59.2	50.8	57.2
8.4	101.1	12	21.7	20.8	20.1		10.2	46.6	44.3	42.1	46.1
8.4	84.2	10	16.9	16.9	16.5		7.1	35	35.1	33.9	35.7
8.4	67.4	8	13.6	13	12.7		4.5	27.1	25.7	24.6	26.1

Table-6.2.CS.V.3:

Cost and weight of fixed wheel vertical lift gate w.r.t. span for 10.5m head

Height	Abay	CS	Cost (lakh Rs.)				AE	Weight (tonne)			
(m)	(m^2)	(m)	V4	V3	V2		(m^4)	V4	V3	V2	WE
10.5	188.1	18	48.9	48.8	53.4		35.4	111	110.9	122.2	110
10.5	167.2	16	41.6	38.1	42.9		28	93.7	84.5	96.3	93.3
10.5	146.3	14	34.7	32.4	34.1		21.4	77.1	71.1	74.8	77.4
10.5	125.4	12	30.6	26.9	27.9		15.7	67.6	58.2	60.2	62.4
10.5	104.5	10	22.5	22.3	23		10.9	47.6	47.4	48.5	48.3
10.5	83.6	8	17.2	16.9	18.7		7	35.2	34.2	38.6	35.4

Table-6.2.CS.V.4:

Cost and weight of fixed wheel vertical lift gate w.r.t. span for 12m head

Height	Abay	CS	Cost (lakh Rs.)				AE	Weight (tonne)			
(m)	(m^2)	(m)	V4	V3	V2		(m^4)	V4	V3	V2	WE
12	217.4	18	61.4	63.5	70.1		47.3	141.6	146	164.4	134.7
12	193.2	16	47.3	52.6	56.5		40	106.9	119.6	131.2	114.2
12	169.1	14	40.4	39.9	44.9		30.5	90.3	88.3	102.5	94.7
12	144.9	12	33.3	33.5	35.4		22.4	73.7	73.1	79.4	76.3
12	120.8	10	27.6	27.7	28.7		15.6	60.3	59.8	63.1	59.1
12	96.6	8	20.3	21.4	23.3		10	42.3	44.6	50.5	43.3

Table-6.2.HDA.R.1:

Cost and weight of radial gate for area of spillway bay of 75m^2

CS	HD	Cost (lakh Rs.)				AE	Weight (tonne)			
(m)	(m)	R4	R3	R2		(m^4)	R4	R3	R2	WE
4.5	16.5	16.8	19.1	17.4		5.8	37.5	43.9	39.4	24.3
5.2	14.5	14.9	15.1	15.4		5.8	32.1	32.5	33.7	24.3
6	12.5	13.1	13.2	13.1		5.8	27.3	27.4	27.4	24.3
7.2	10.5	12.2	11.8	12.3		5.8	24.7	24	24.5	24.3
8.9	8.4	9.9	10.8	11.2		5.8	18.4	21.3	22	24.3
11.7	6.4	9	9.2	9.1		5.8	16	16.4	16.3	24.3
17.2	4.4		8.7	8.6		5.8		15	14.6	24.3

Table-6.2.HDA.R.2:

Cost and weight of radial gate for area of spillway bay of 100m^2

CS	HD	Cost (lakh Rs.)				AE	Weight (tonne)			
(m)	(m)	R4	R3	R2		(m^4)	R4	R3	R2	WE
6	16.5	20.7	23.9	22.1		10.3	47.1	56	51.1	35.7
6.9	14.5	18.3	18.8	20.5		10.3	40.3	41.6	46.5	35.7
8	12.5	16.8	16.2	16.7		10.3	36.6	34.7	36.2	35.7
9.6	10.5	16.2	15.3	15.8		10.3	34.8	32.6	33.2	35.7
11.9	8.4	12.8	13.7	14.8		10.3	25.3	27.9	31.2	35.7
15.7	6.4	11.5	11.9	13.1		10.3	21.5	22.9	26.3	35.7
22.9	4.4		11.1	11.2		10.3		20.3	20.6	35.7

Table-6.2.HDA.R.3:

Cost and weight of radial gate for area of spillway bay of 125m^2

CS	HD	Cost (lakh Rs.)				AE	Weight (tonne)			
(m)	(m)	R4	R3	R2		(m^4)	R4	R3	R2	WE
7.6	16.5	24.9	28.4	40.2		16.1	57.5	111.4	67.6	48.2
8.6	14.5	22.2	23.1	25.7		16.1	49.5	93.4	52.3	48.2
10	12.5	20.9	20.1	20.3		16.1	46.6	79.7	44.2	48.2
12	10.5	20.6	19.4	19.6		16.1	45.9	79.6	42.6	48.2
14.8	8.4	17.8	18	18.8		16.1	38.1	78.9	38.9	48.2
19.6	6.4	14.5	16.7	17.8		16.1	28.7	75.2	35	48.2
28.7	4.4		13.4	17.5		16.1		77.6	25.3	48.2

Table-6.3.HC.1: Comparison of hoisting capacity of radial gate and fixed vertical lift gate

Head	R4	R3	R2	V4	V3	V2
16.5	61	73.1	92.1	99	102.3	
14.5	49.4	53.6	57.5	79	82.2	94.4
12.5	41.5	40.8	42.7	70.2	63.7	74.3
10.5	35.1	34.5	35.6	50.6	50.5	51.5
8.4	24.7	27.2	28.2	37.5	37.5	36.4
6.4	19.7	20.3	20.4	28.7	25.8	25.1
4.4	16.3	16	16	20.2	18.4	16

Table-6.3.COST.1: Comparison of total cost of radial gate and fixed wheel vertical lift gate

Head	R4	R3	R2	V4	V3	V2
16.5	32.6	39.7	48.3	42.1	43.5	
14.5	25.9	28.5	29.2	33.7	34.8	40
12.5	20.9	20.1	20.3	30.2	27.5	31.8
10.5	16.8	16.2	16.6	22.5	22.3	23
8.4	10.8	11.9	12.2	16.9	16.9	16.5
6.4	7.9	8	7.9	13.4	12.3	11.9
4.4		5.8	5.6	10	9.3	8.1

Table-6.3.MC.1: Comparison of material cost of radial gate and fixed wheel vertical lift gate

Head	R4	R3	R2	V4	V3	V2
16.5	19.6	24.9	31.2	24.7	25.6	
14.5	15.1	17	17.7	19.5	20.4	23.7
12.5	12	11.4	11.6	17.6	15.9	18.7
10.5	9.3	9	9	12.6	12.5	12.8
8.4	5.3	6.1	6.3	9.3	9.3	9
6.4	3.5	3.6	3.5	7.2	6.4	6.2
4.4	2.5	2.3	2.2	5.2	4.7	4

Table-6.3.OC.1: Comparison of operating cost of radial gate and fixed wheel vertical lift gate

Head	R4	R3	R2	V4	V3	V2
16.5	13	14.8	17	15.4	15.8	
14.5	10.8	11.4	11.5	12.6	12.7	14.4
12.5	8.9	8.7	8.7	11.2	10.3	11.6
10.5	7.4	7.2	7.6	8.9	8.8	9.1
8.4	5.5	5.7	5.9	6.9	6.9	6.9
6.4	4.4	4.4	4.4	5.6	5.4	5.2
4.4	3.5	3.5	3.4	4.4	4.2	3.7

CHART-6.1.R2.1

Optimisation of radius factor in radial gate with 2 HG for 6.4m head and 6m span

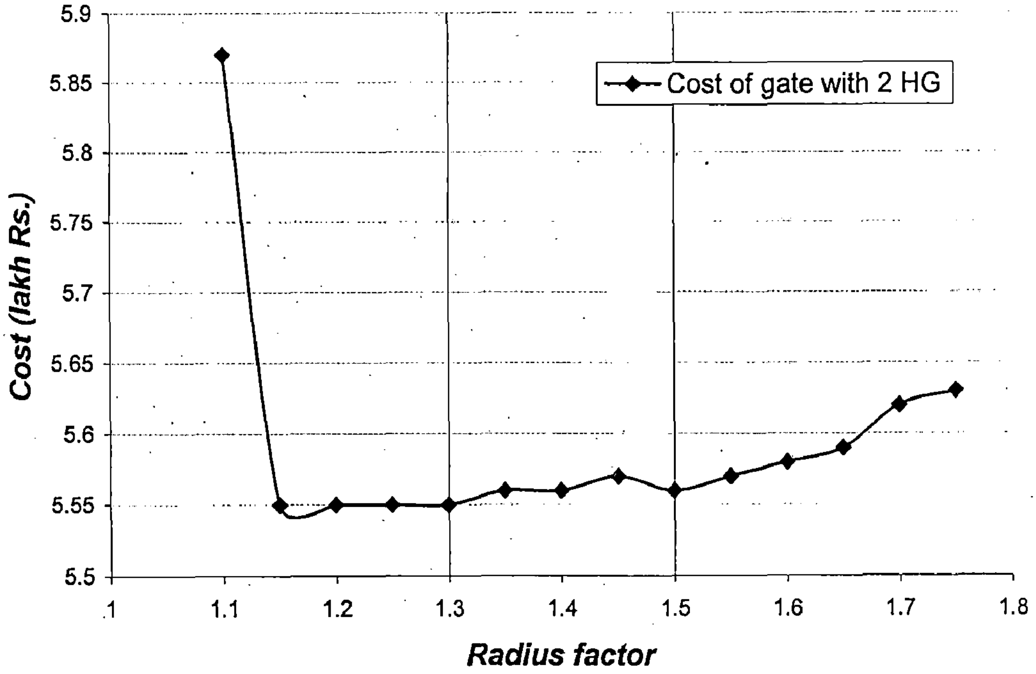


CHART-6.1.R2.2

Optimisation of radius factor in radial gate with 2 HG for 6.4m Head and 10m Span

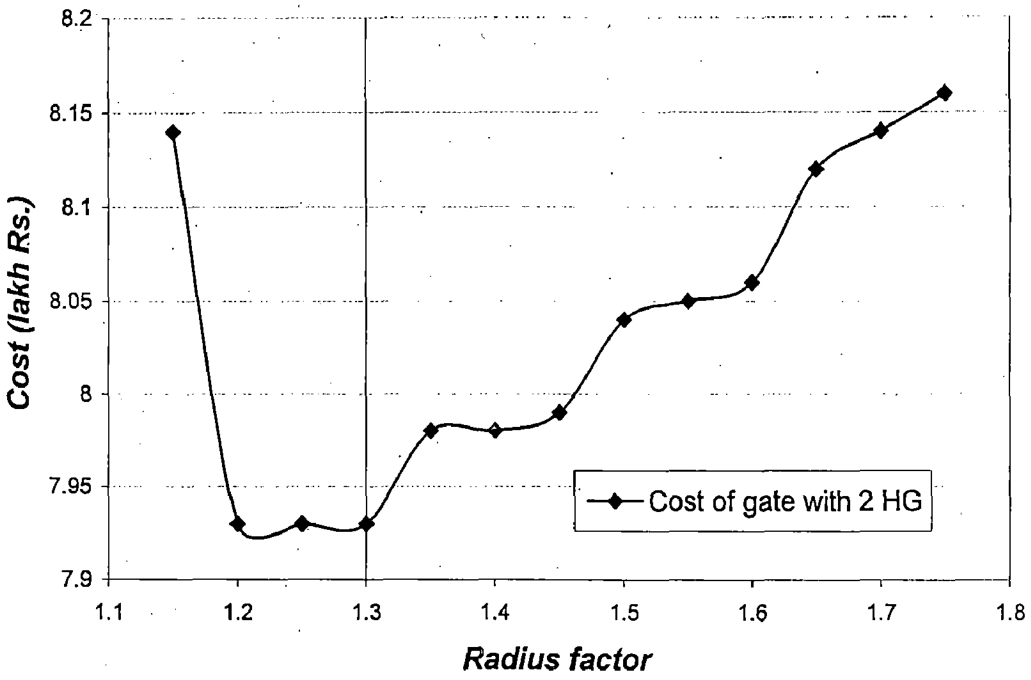


CHART-6.1.R2.3

Radius factors in radial gate with 2 HG w.r.t. head for lowest cost of gate

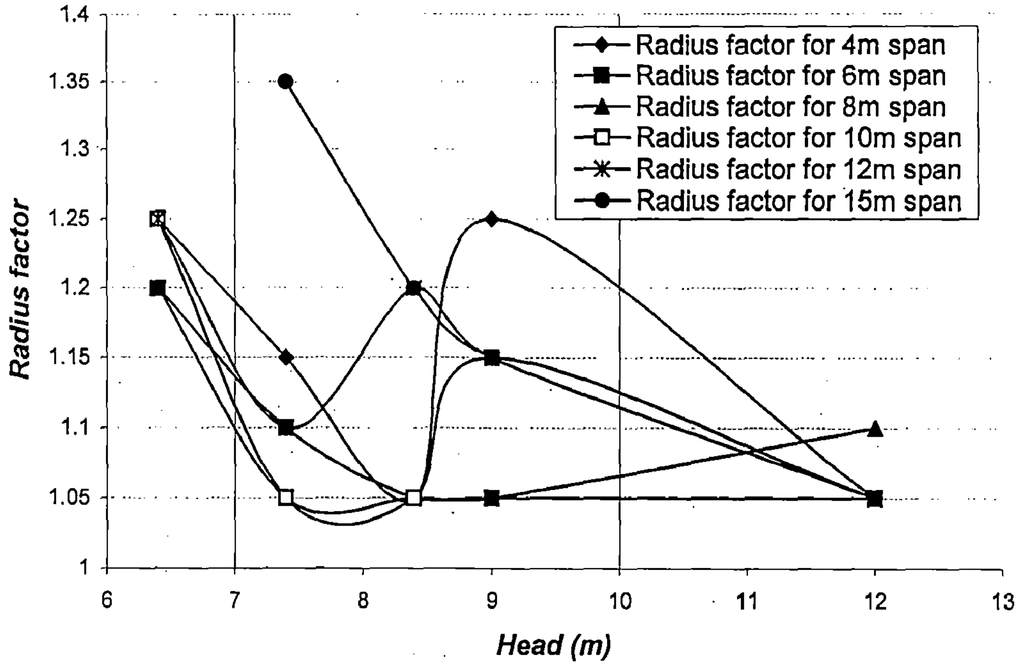


CHART-6.1.R2.4

Radius factors in radial gate with 2 HG w.r.t. span for lowest cost of gate

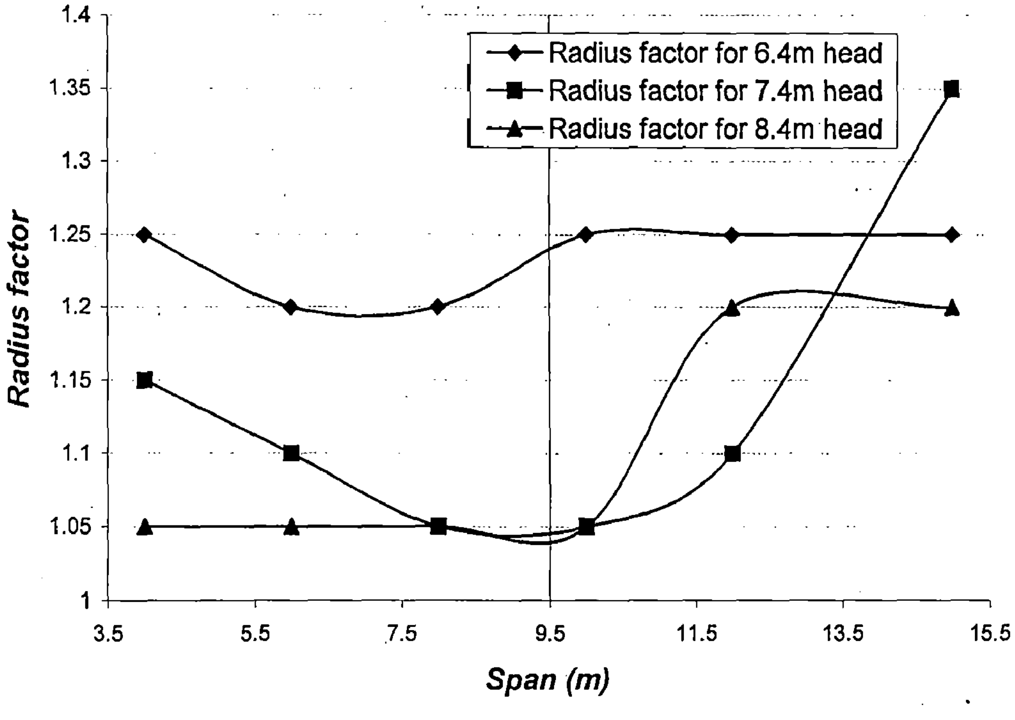


CHART-6.1.R3.1

Optimisation of radius factor in radial gate with 3 HG for 9m head and 5m span

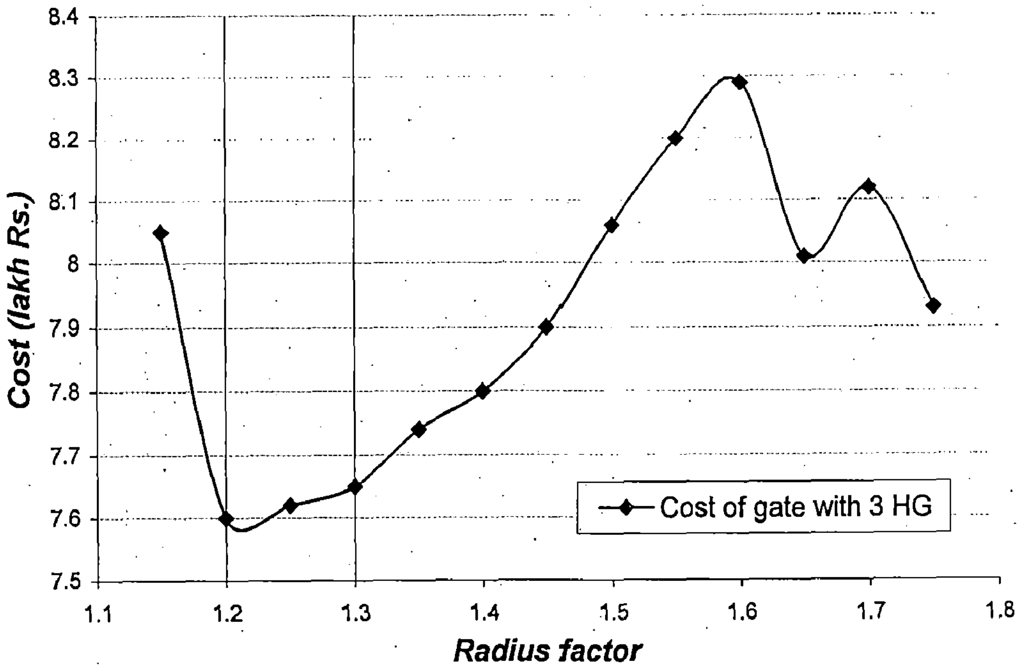


CHART-6.1.R3.2

Optimisation of radius factor in radial gate with 3 HG for 9m head and 9m span

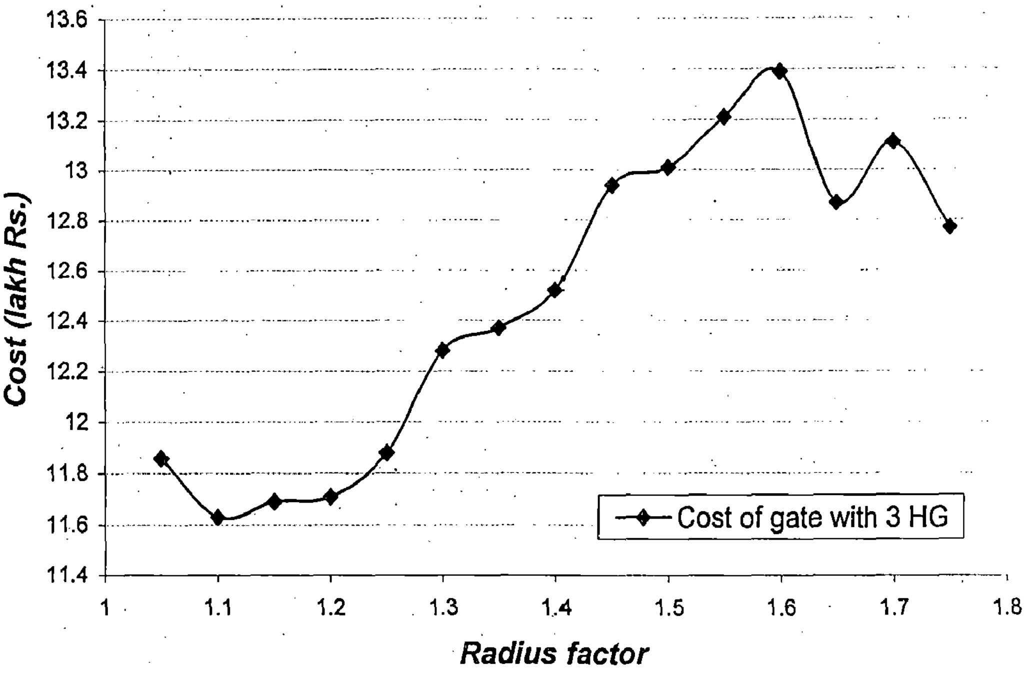


CHART-6.1.R3.3

Radius factors in radial gate with 3 HG w.r.t. head corresponding to lowest cost of gate for various spans

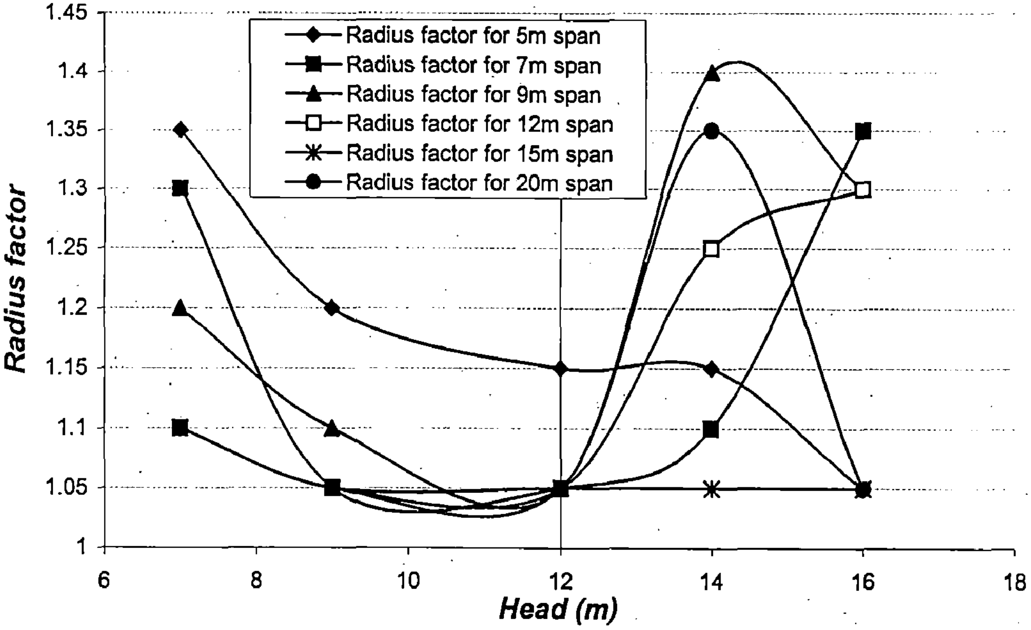


CHART-6.1.R3.4

Radius factor in radial gate with 3 HG corresponding to lowest cost of gate w.r.t. span for various heads

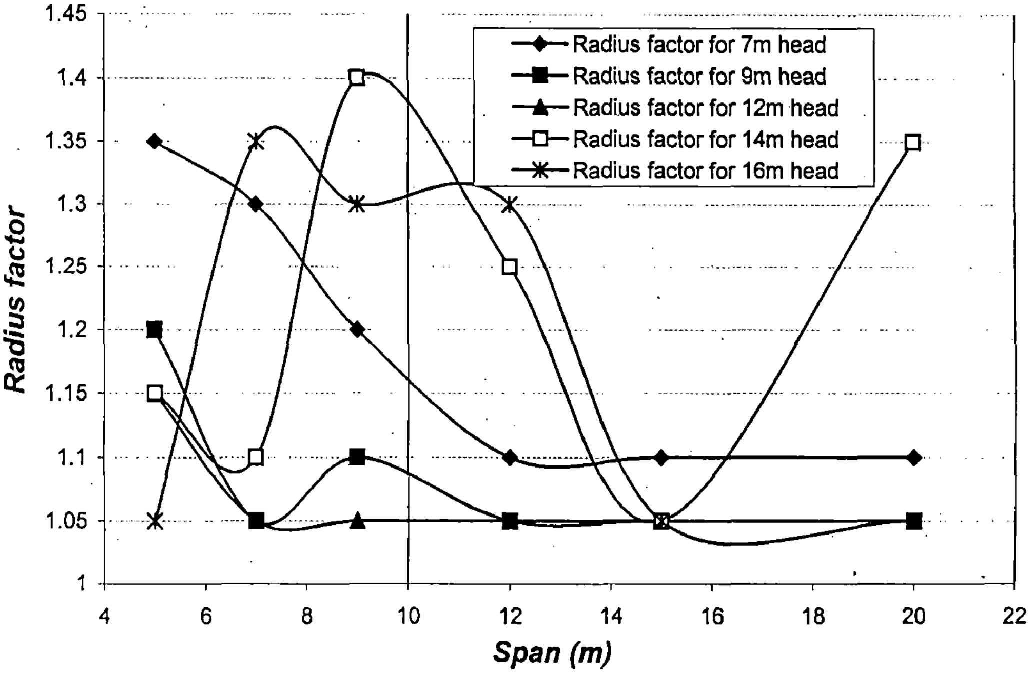


CHART-6.1.R4.1

Optimisation of radius factor in radial gate with 4 HG for 12m head and 12m span

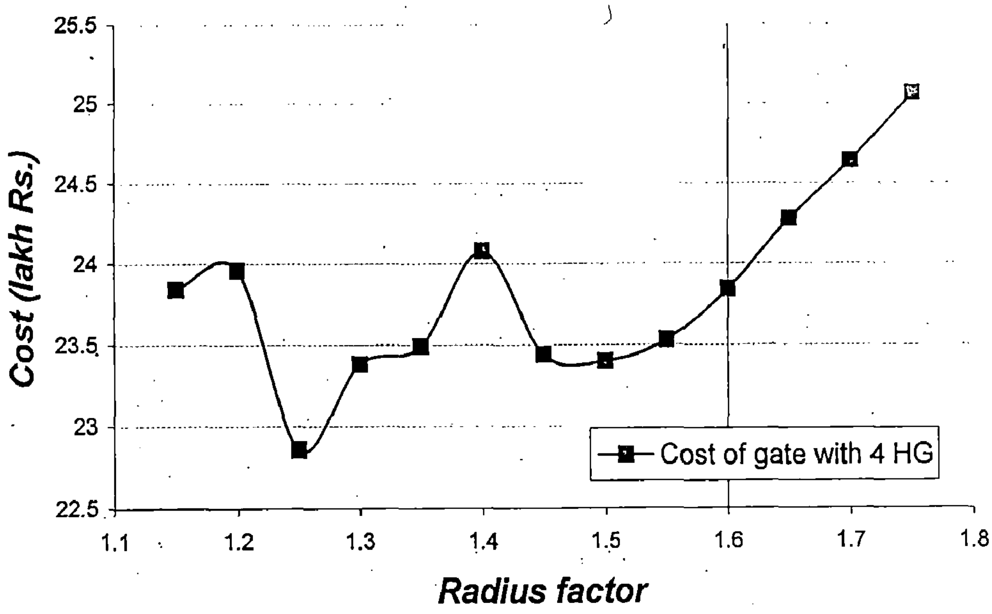


CHART-6.1.R4.2

Optimisation of radius factor in radial gate with 4 HG for 12m head and 15m span

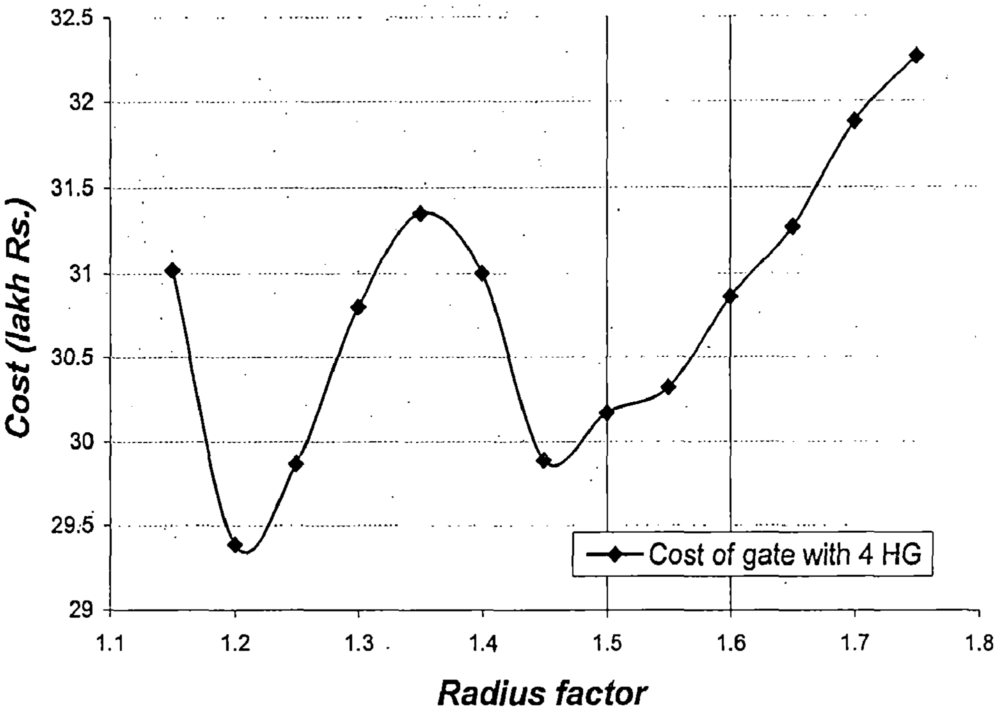


CHART-6.1.R4.3

Radius factors in radial gate with 4 HG w.r.t. head correspnding to lowest cost of gate for various spans

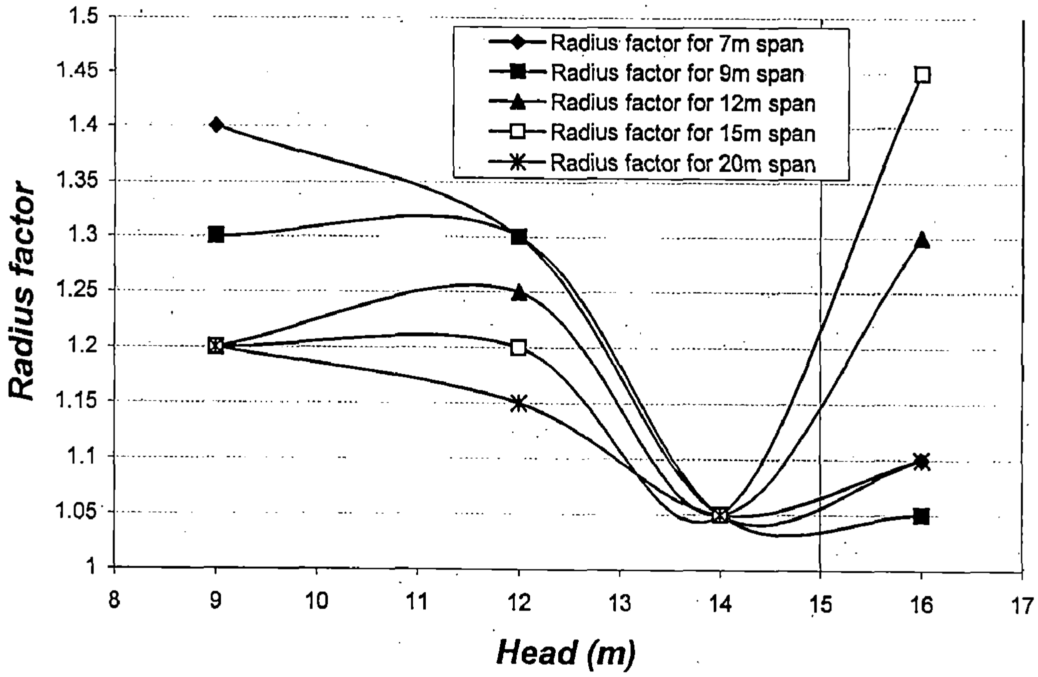


CHART-6.1.R4.4

Radius factors in radial gate with 4 HG w.r.t. span correspnding to lowest cost of gate for various heads

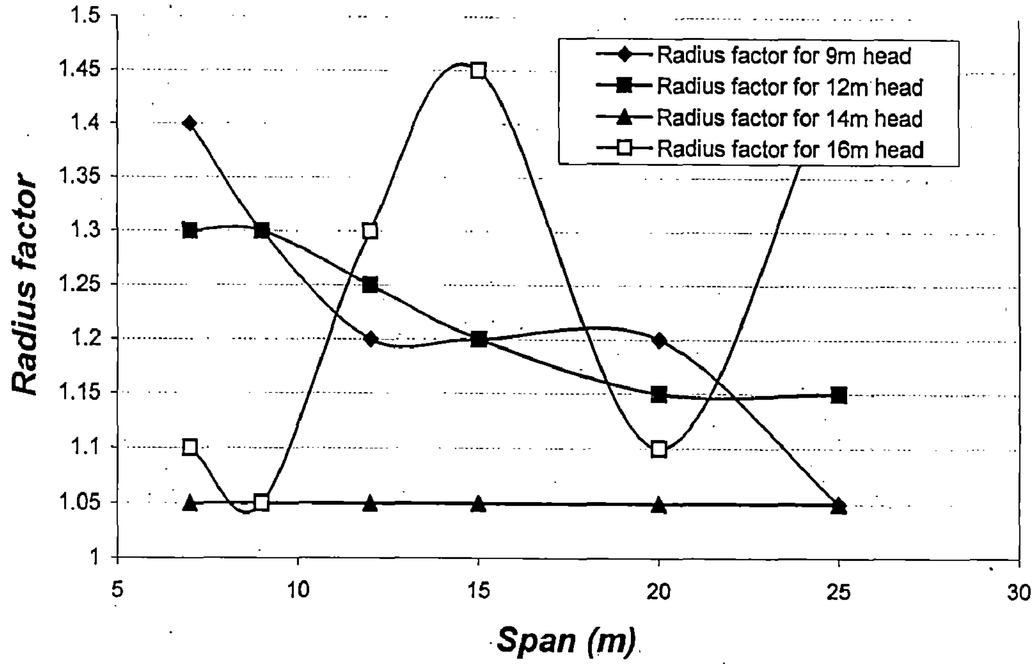


CHART-6.2.HD.V.1:

Optimisation of number of horizontal girders in fixed wheel vertical lift gate w.r.t. head for 12m span

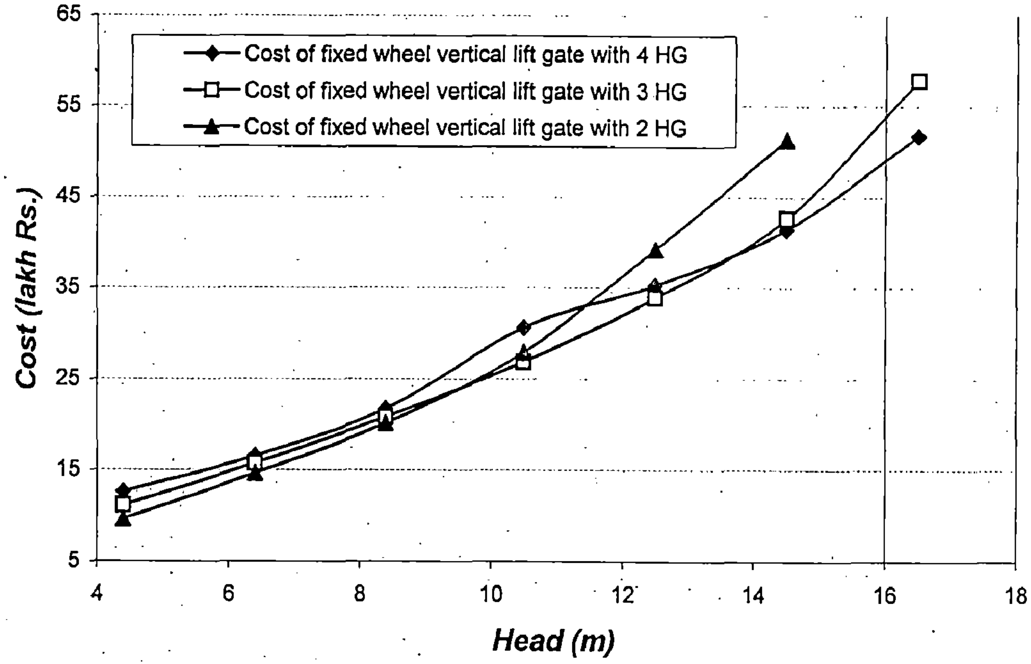


CHART-6.2.HD.V.2:

Optimisation of number of horizontal girders in fixed wheel vertical lift gate w.r.t. head for 15m span

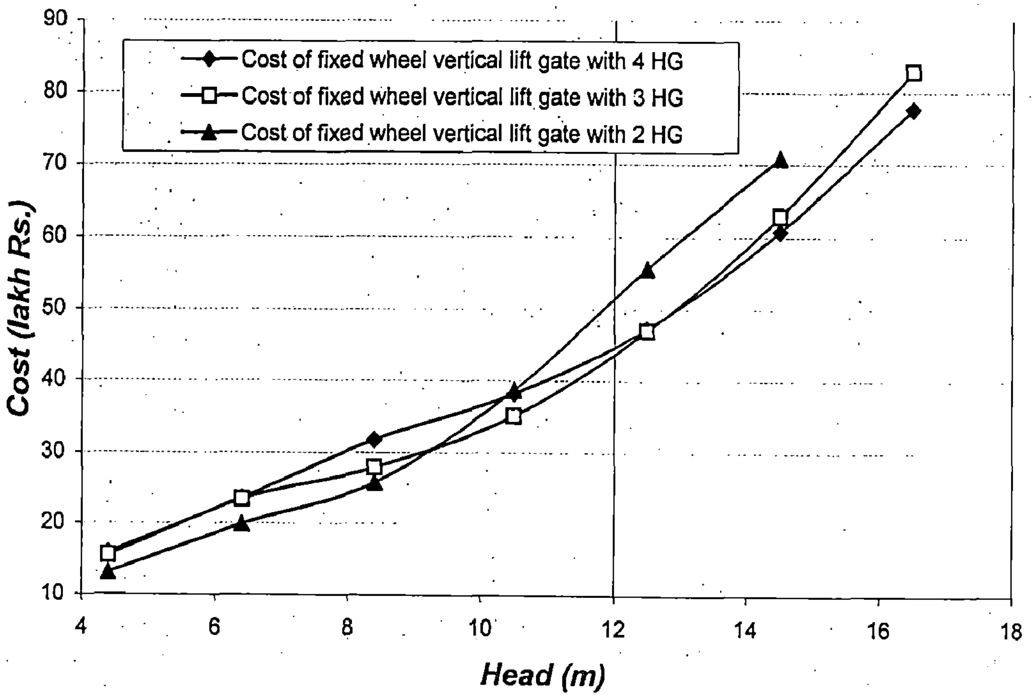


CHART-6.2.HD.V.3:

Optimisation of number of horizontal girders in fixed wheel vertical lift gate w.r.t. head for 8m span

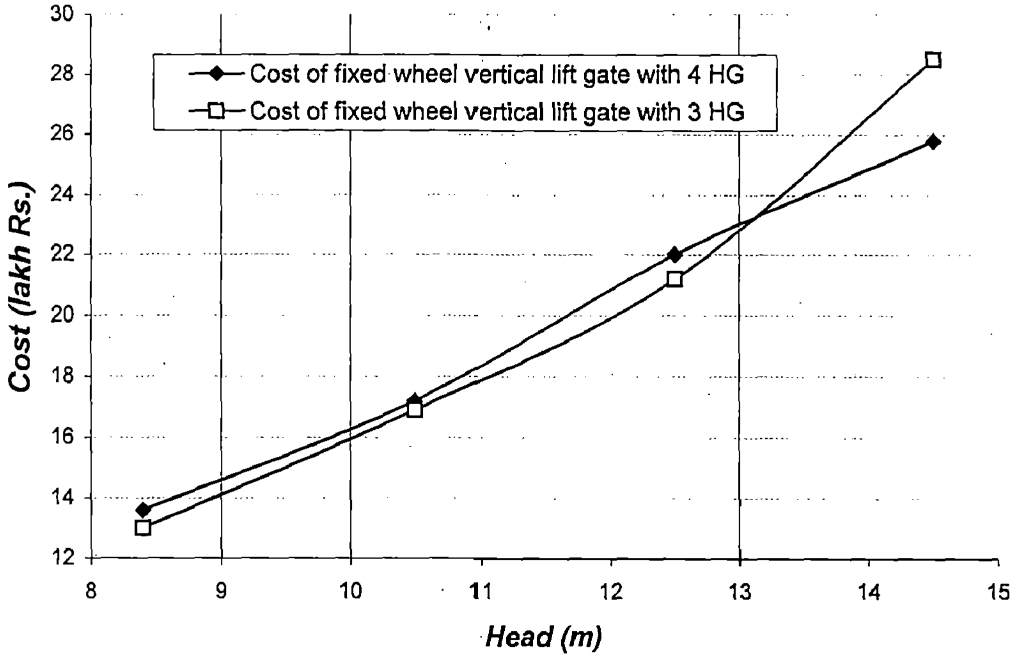


CHART-6.2.HD.V.4:

Optimisation of number of horizontal girders in fixed wheel vertical lift gate w.r.t. head for 8m span

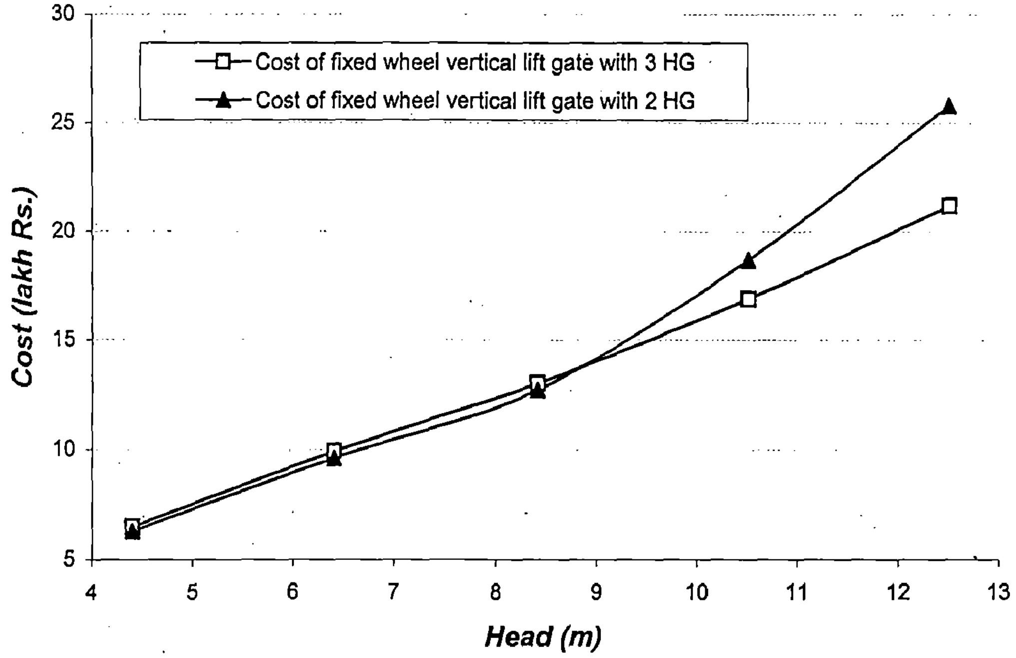


CHART-6.2.HD.V.5:

Optimisation of number of horizontal girders in fixed wheel vertical lift gate w.r.t. head for 12m span

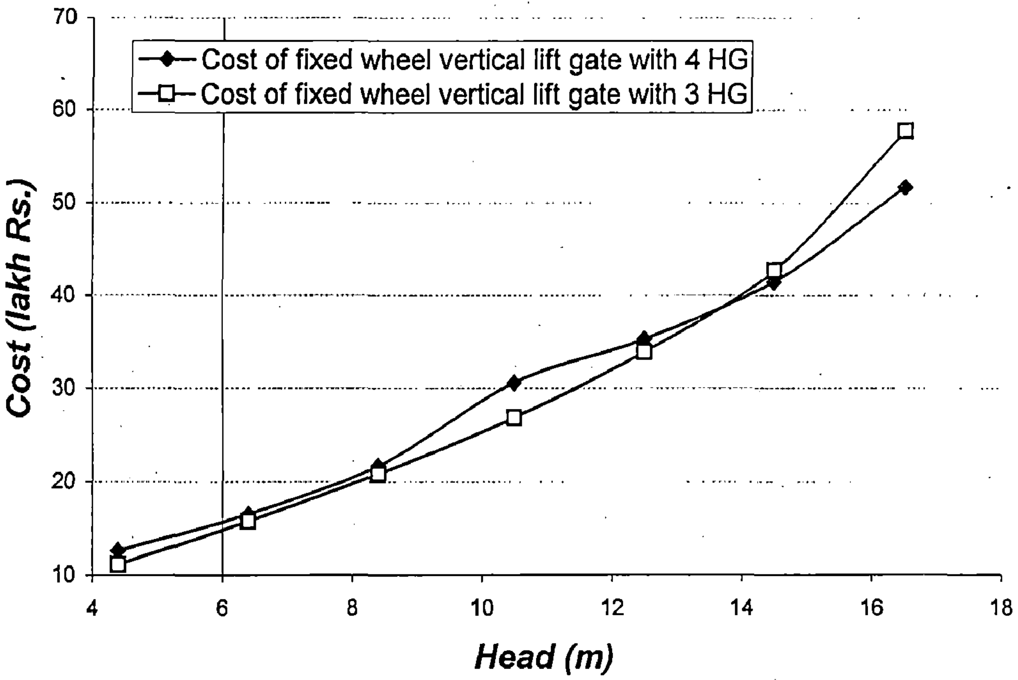


CHART-6.2.HD.V.6:

Optimisation of number of horizontal girders in fixed wheel vertical lift gate w.r.t. head for 12m span

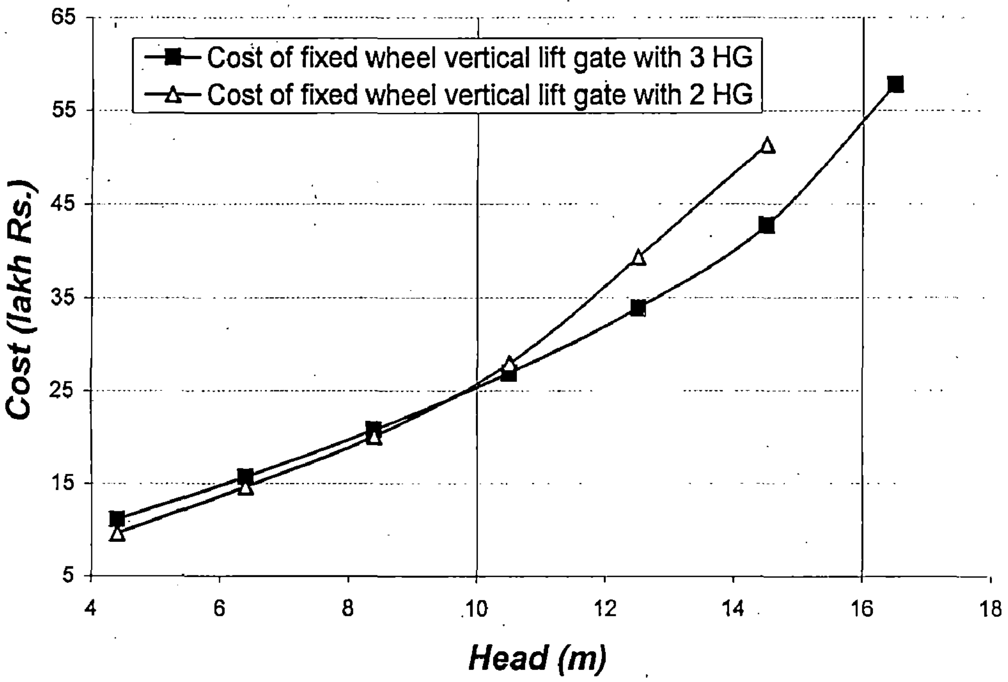


CHART-6.2.HD.V.7:

Optimisation of number of horizontal girdres in fixed wheel vertical lift gate w.r.t. head for 15m span

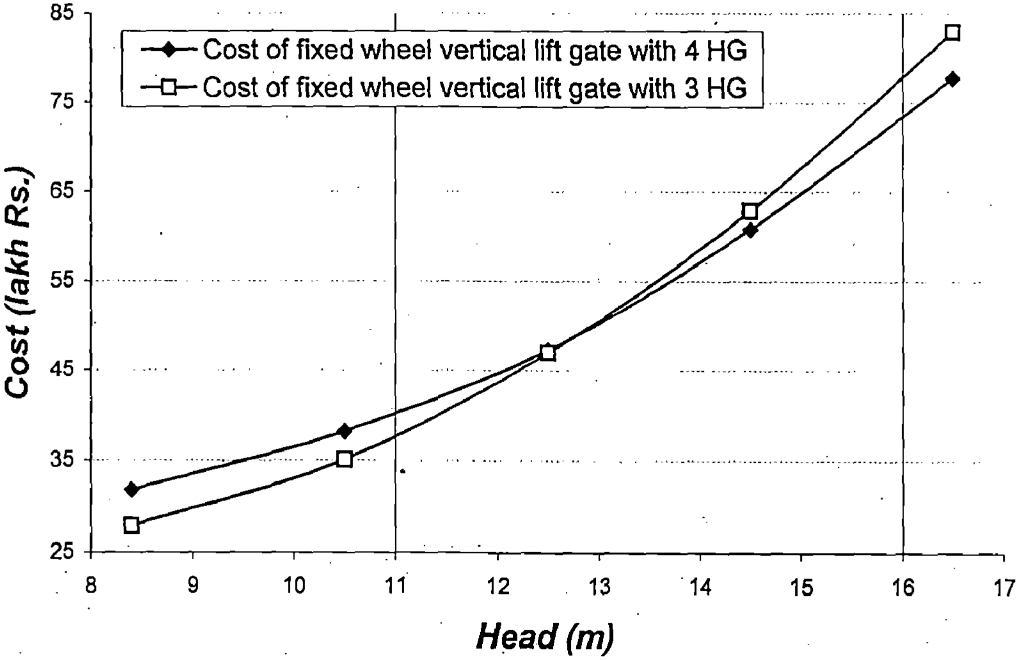


CHART-6.2.HD.V.8:

Optimisation of number of horizontal girders in fixed wheel vertical lift gate w.r.t. head for 15m span

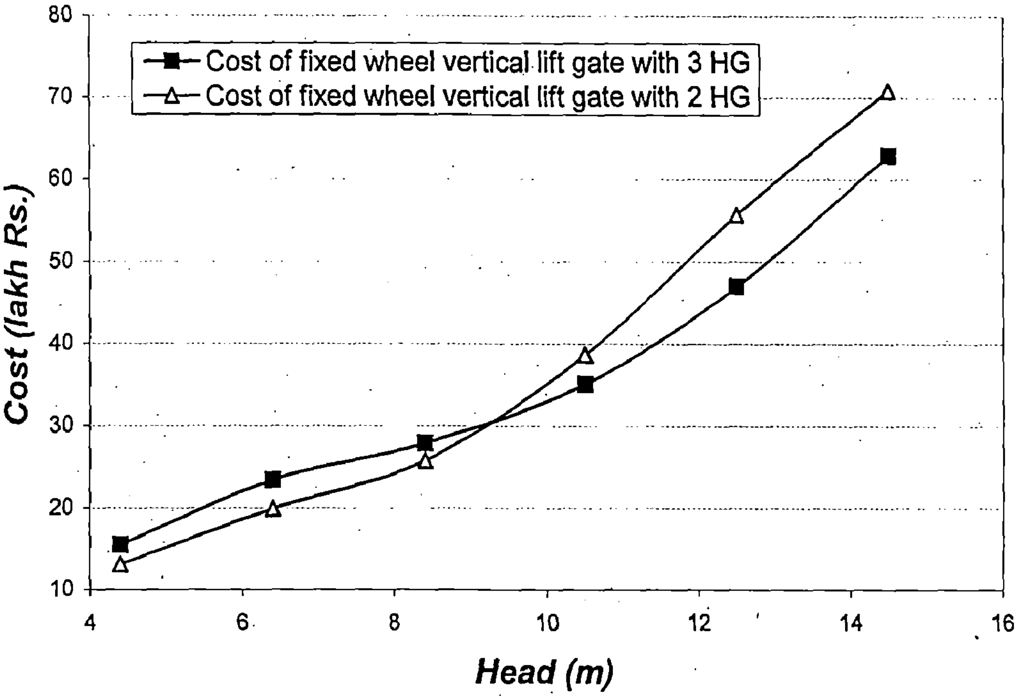


CHART-6.2.CS.V.1:

Optimisation of number of horizontal girders in fixed wheel vertical lift gate w.r.t. span for 6.4m head

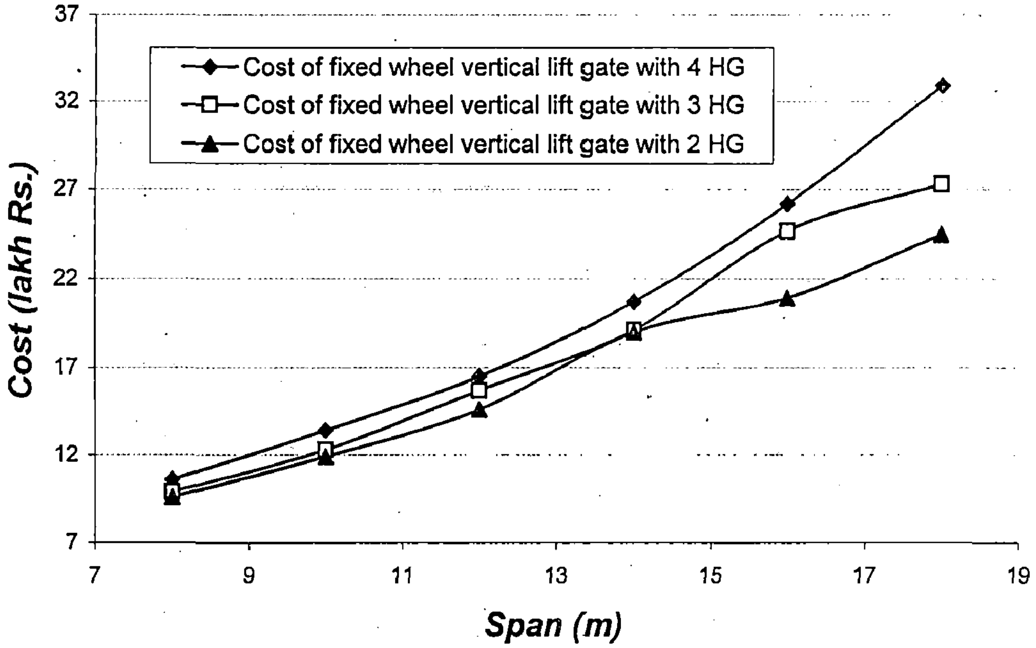


CHART-6.2.CS.V.2:

Optimisation of number of horizontal girders in fixed wheel vertical lift gate w.r.t. span for 8.4m head

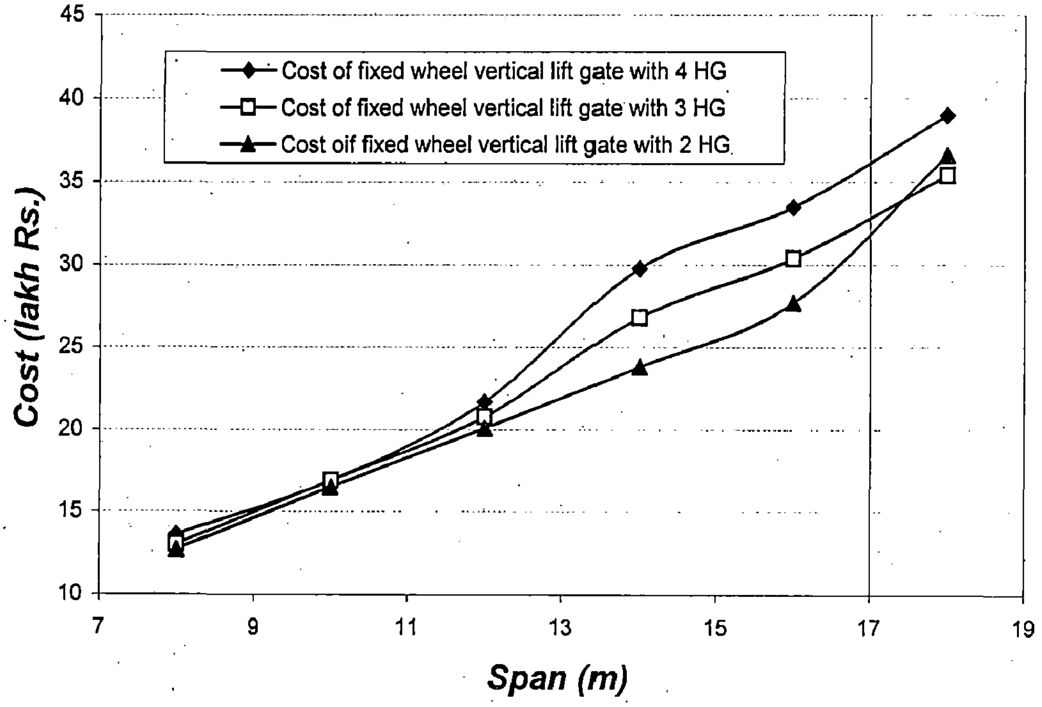


CHART-6.2.CS.V.3:

Optimisation of number of horizontal girders in fixed wheel vertical lift gate w.r.t. span for 10.5m head

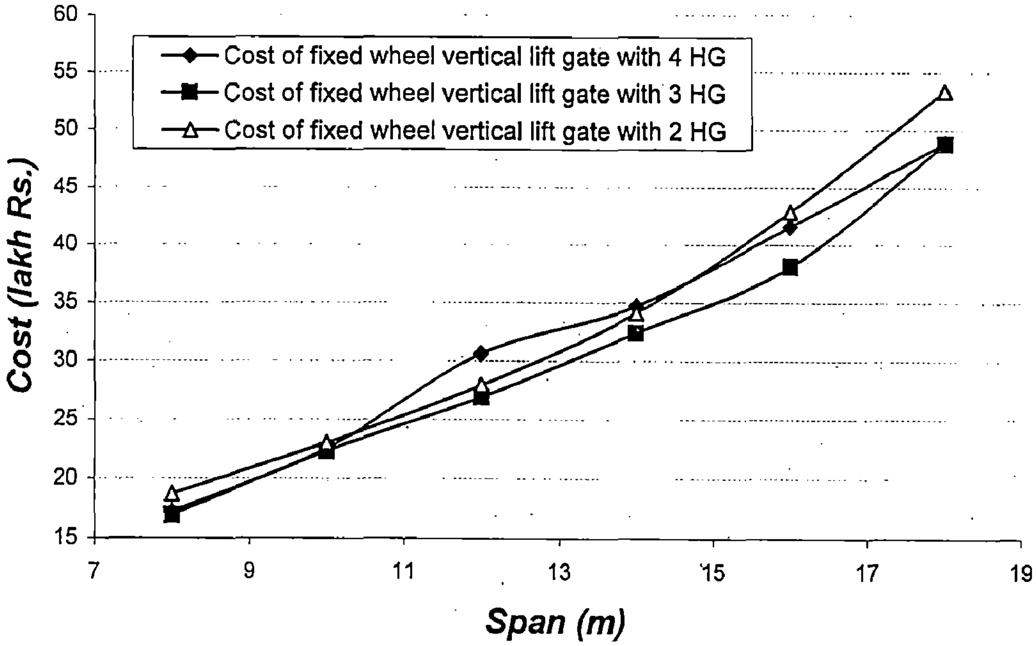


CHART-6.2.CS.V.4:

Optimisation of number of horizontal girders in fixed wheel vertical lift gate w.r.t. span for 12m head

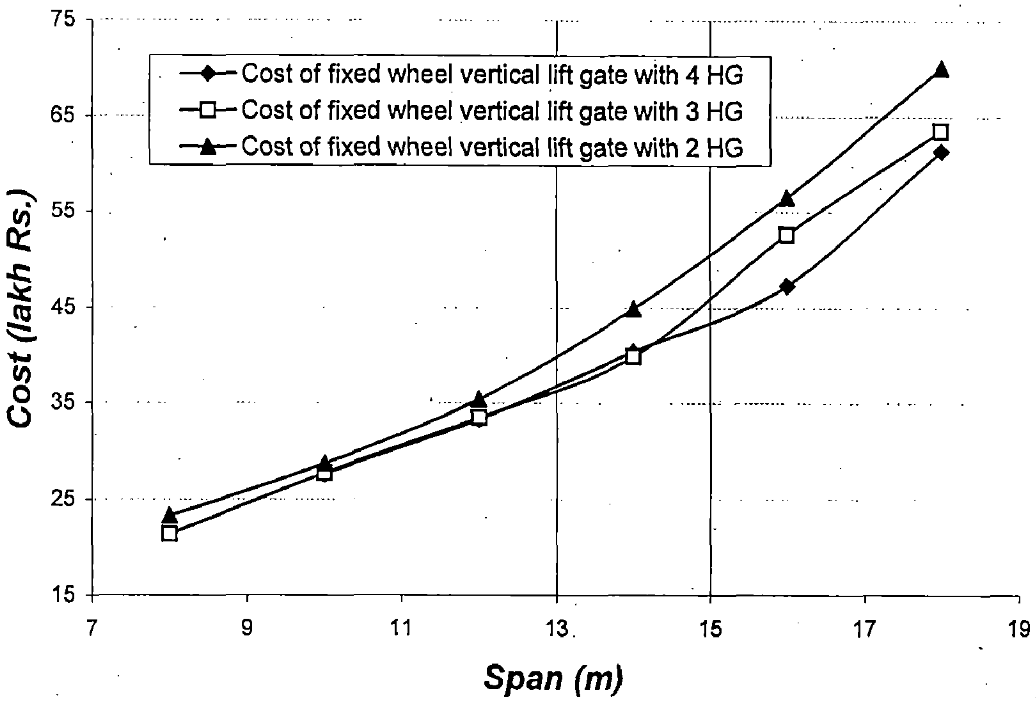


CHART-6.2.HDA.V.1:

Cost analysis of fixed wheel vertical lift gate for area of spillway bay of 75m^2

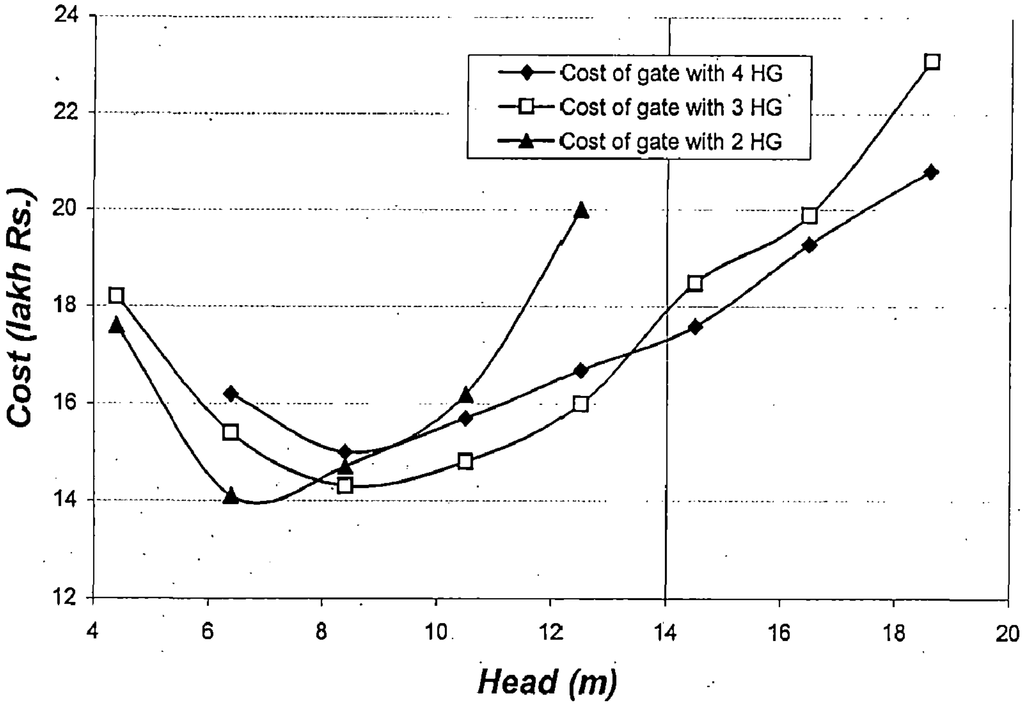


CHART-6.2.HDA.V.2:

Cost analysis of fixed wheel vertical lift gate for area of spillway bay of 100m^2

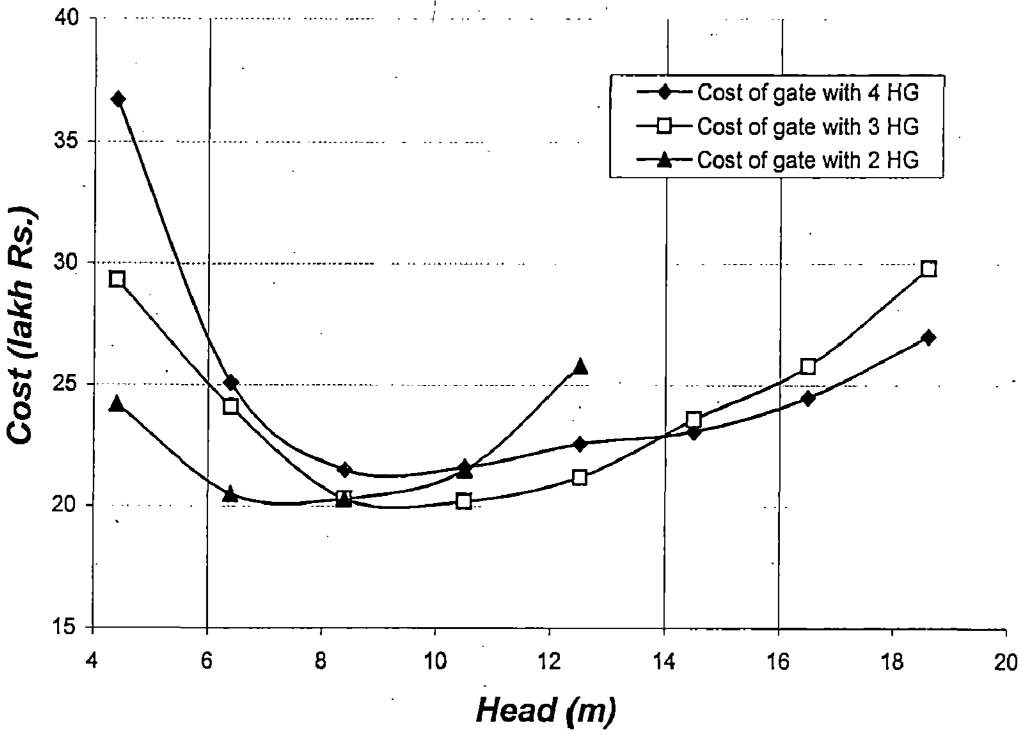


CHART-6.2.HDA.V.3:
Cost analysis of fixed wheel vertical lift gate for area of spillway bay of 150m^2

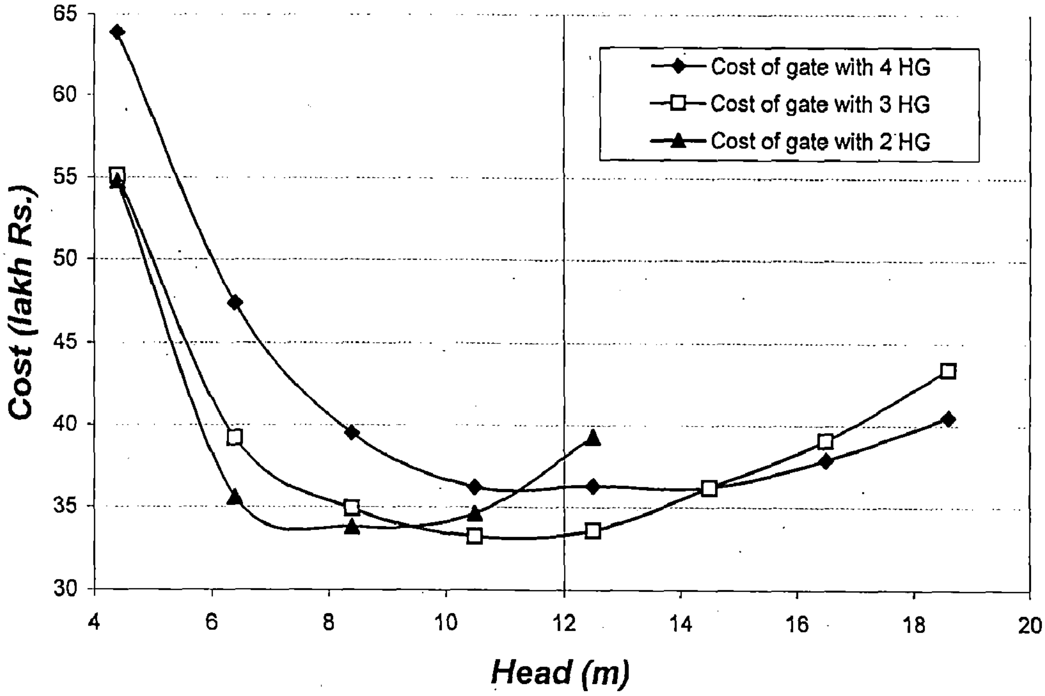


CHART-62.HDA.V.4:
Cost analysis of fixed wheel vertical lift gate for area of spillway bay of 175m^2

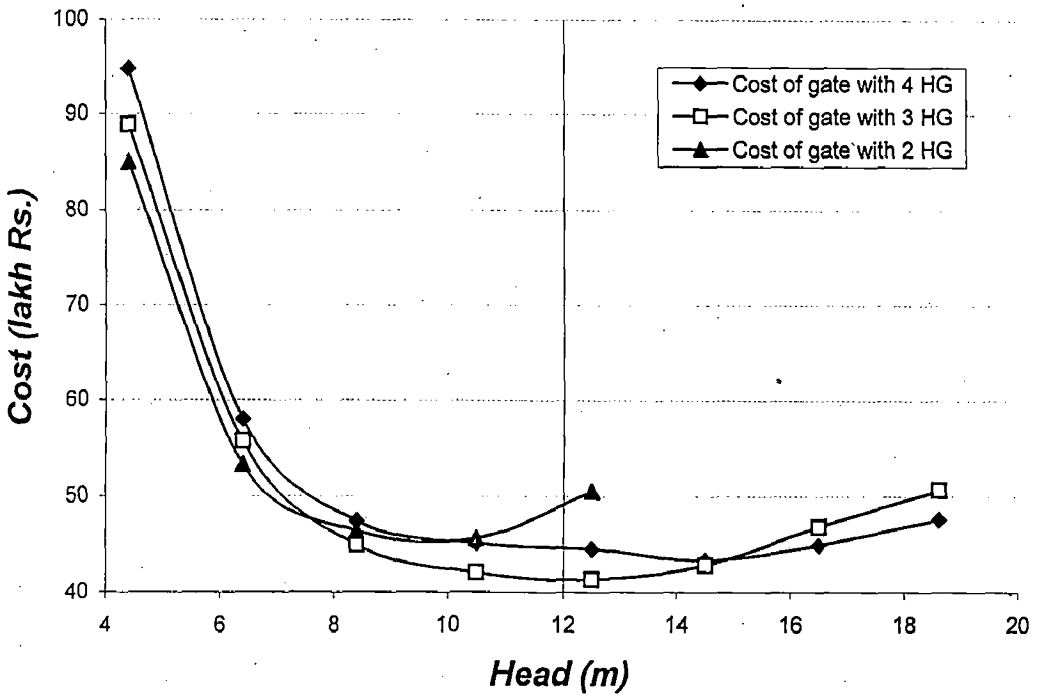


CHART-6.2.WG.V.1:

Comparison of weight of fixed wheel vertical lift gate with Erbiste's formula for 6.4m head

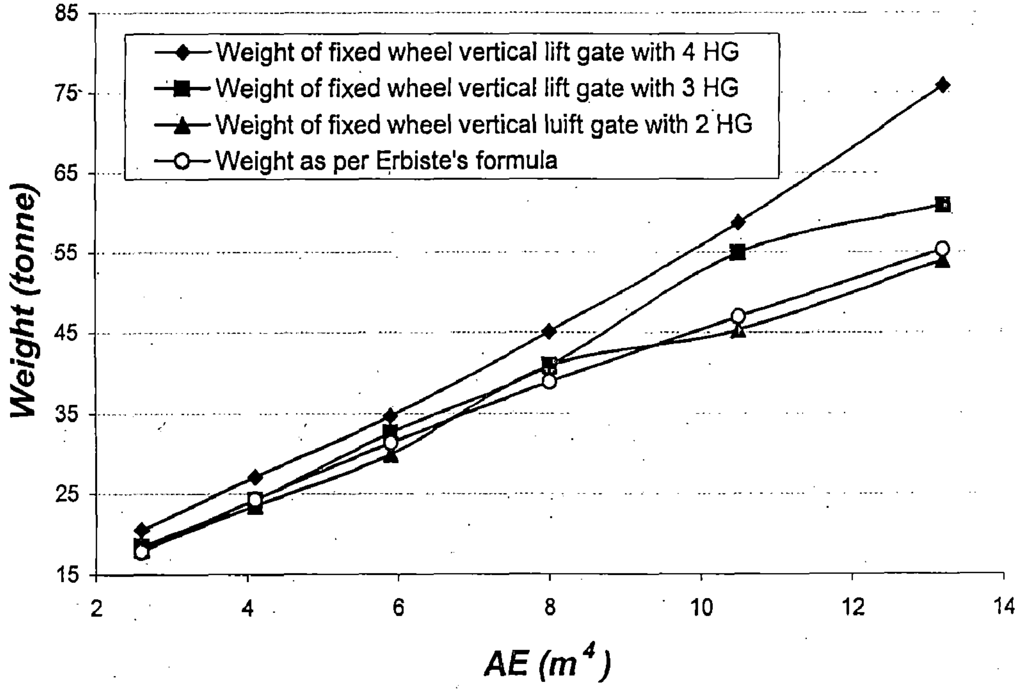


CHART-6.2.WG.V.2:

Comparison of weight of fixed wheel vertical lift gate with Erbiste's formula for 8.4m head

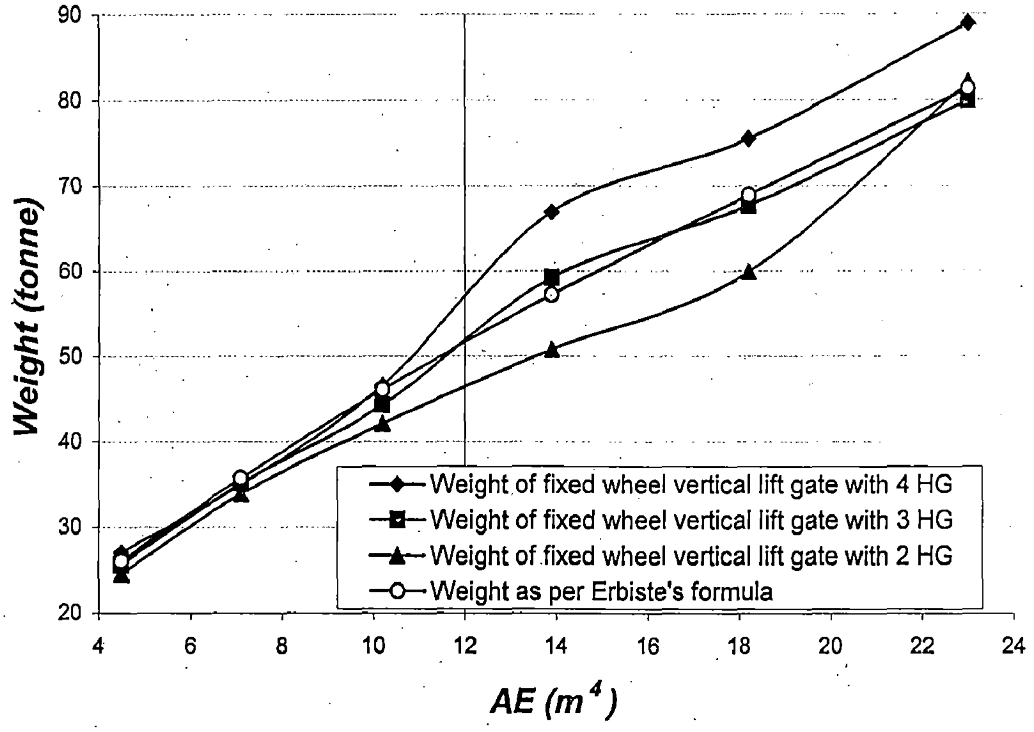


CHART-2.WG.V.3:
Comparison of weight of fixed wheel vertical lift gate with Erbiste's formula for 10.5m head

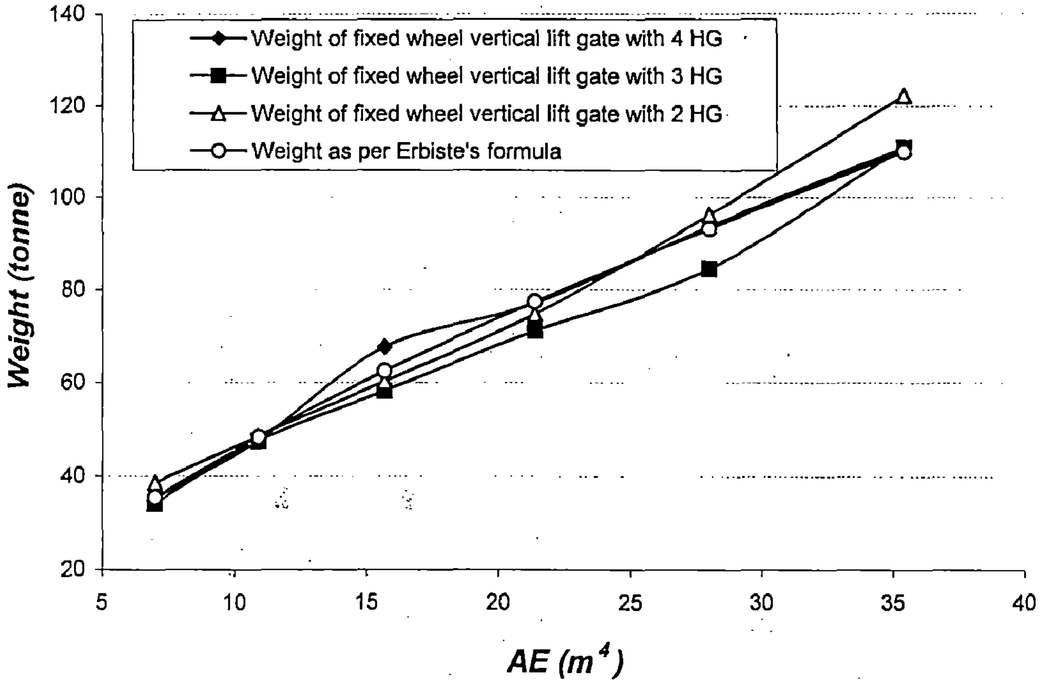


CHART-2.WG.V.4:
Comparison of weight of fixed wheel vertical lift gate with Erbiste's formula for 12m head

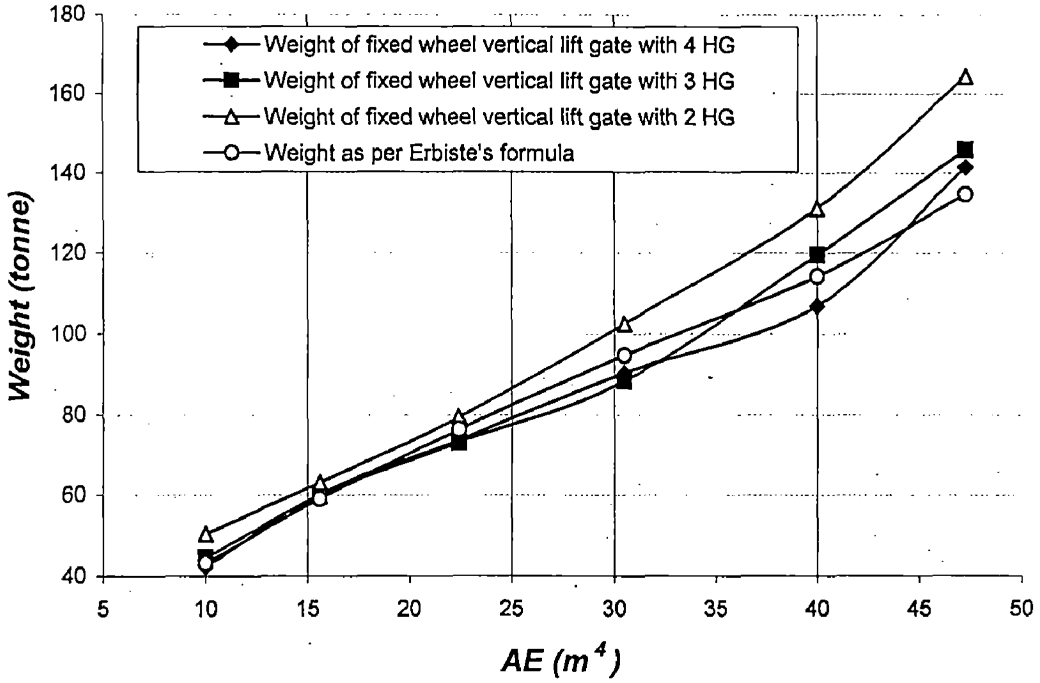


CHART-6.2.HD.R.1:

Optimisation of number of horizontal girders in radial gate with 4 and 3 HG for 8m span

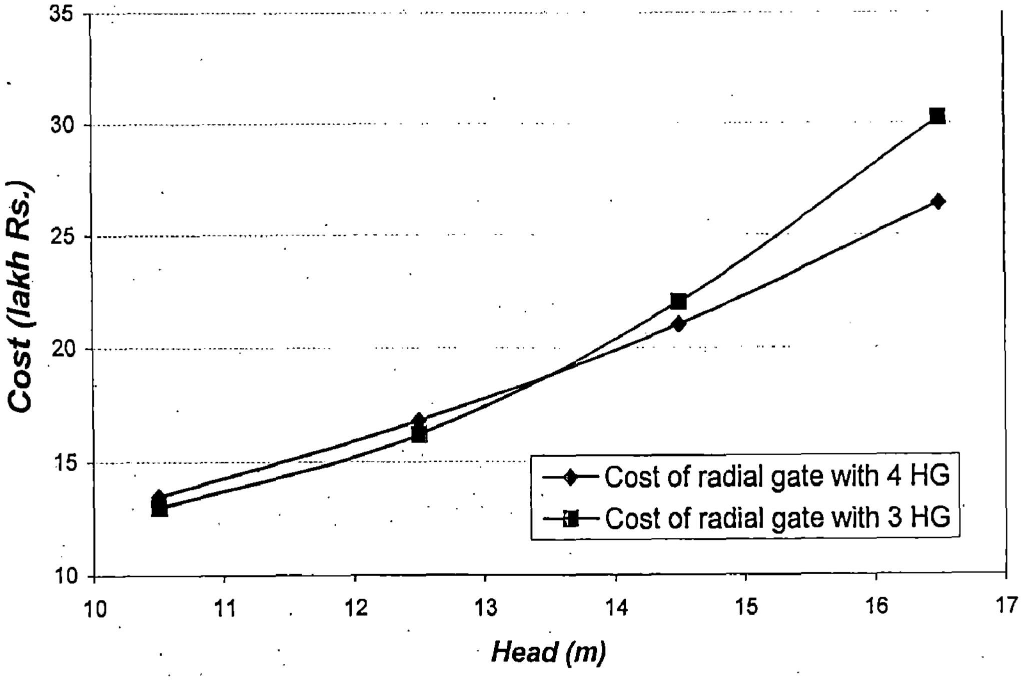


CHART-6.2.HD.R.2:

Optimisation of number of horizontal girders in radial gates with 2 and 3 HG for 8m span

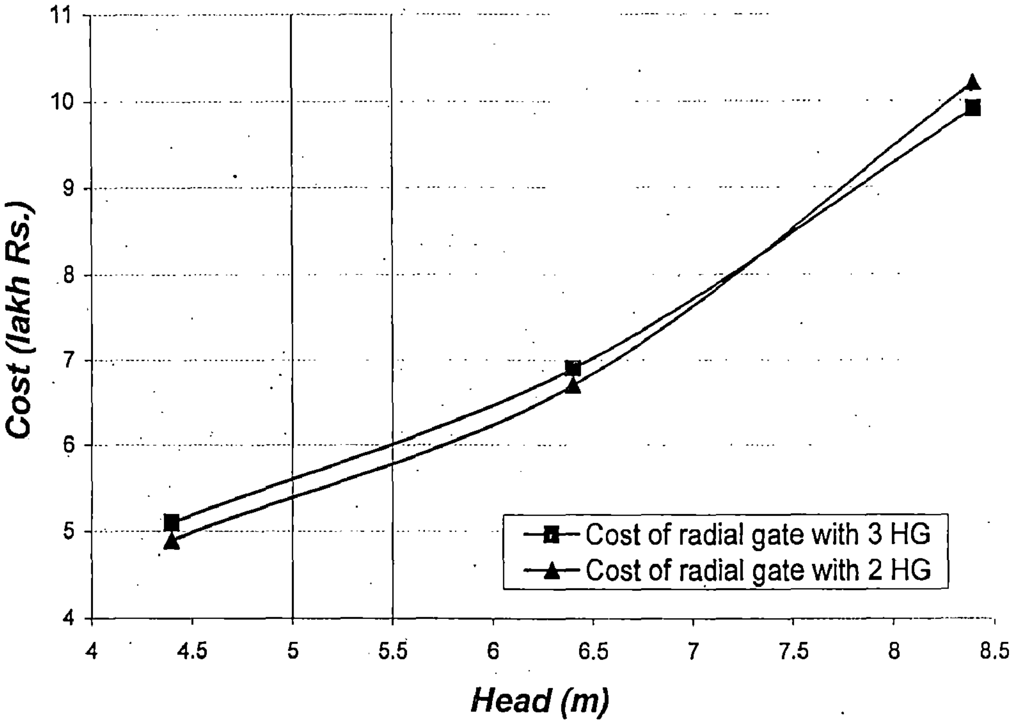


CHART-6.2.HD.R.3:

Optimisation of number of horizontal girders in radial gate with 4 and 3 HG for 10m span

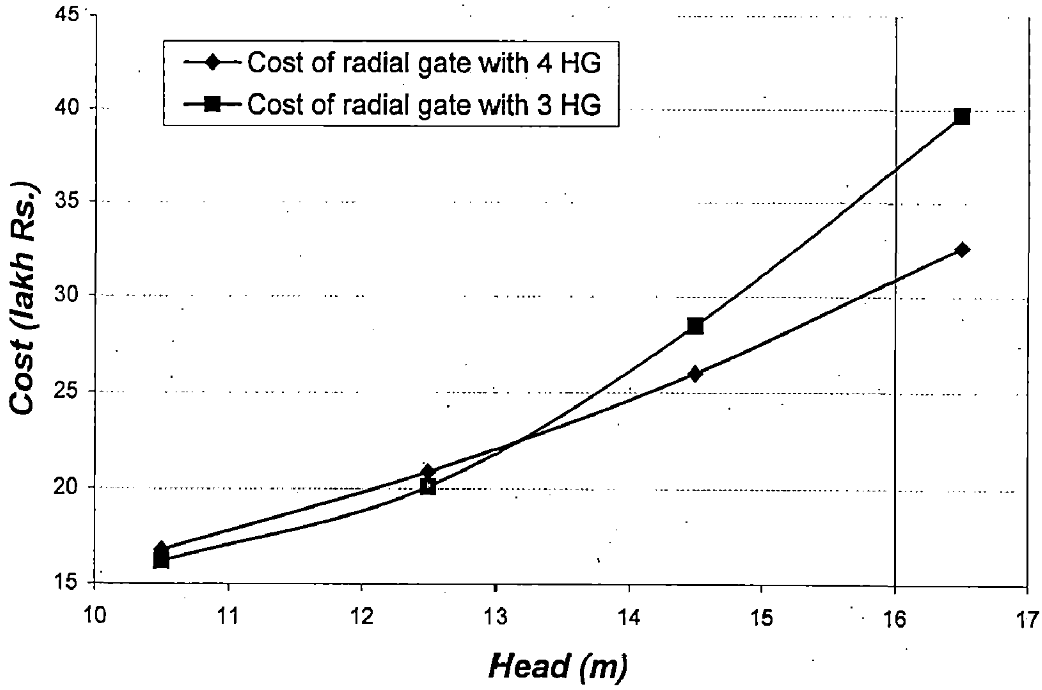


CHART-6.2.HD.R.4:

Optimisation of number of horizontal girders in radial gate with 3 and 2 HG for 10m span

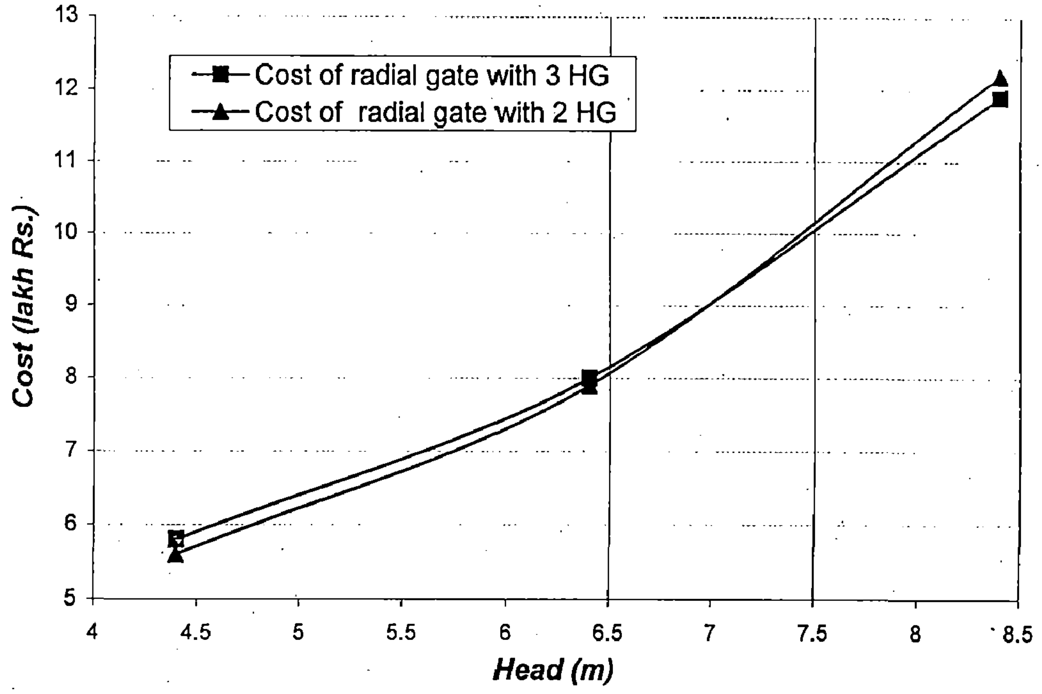


CHART-6.2.CS.R.1:

Optimisation of number of horizontal girders in radial gate w.r.t. span for 6.4m head

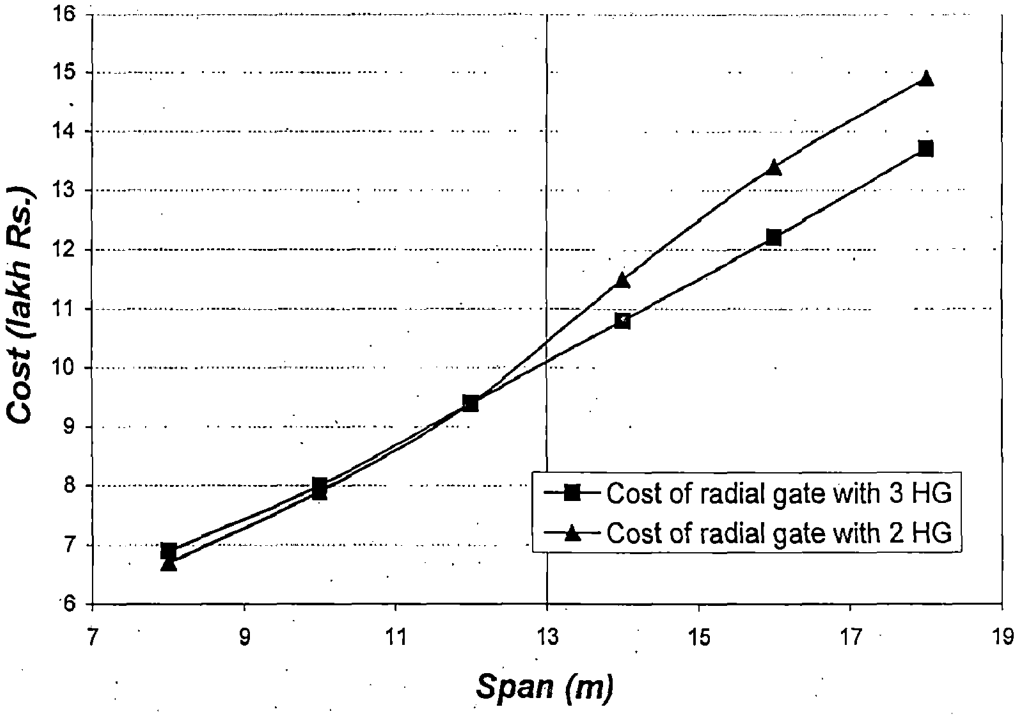


CHART-6.2.CS.R.2:

Optimisation of number of horizontal girders in radial gate w.r.t. span for 8.4m head

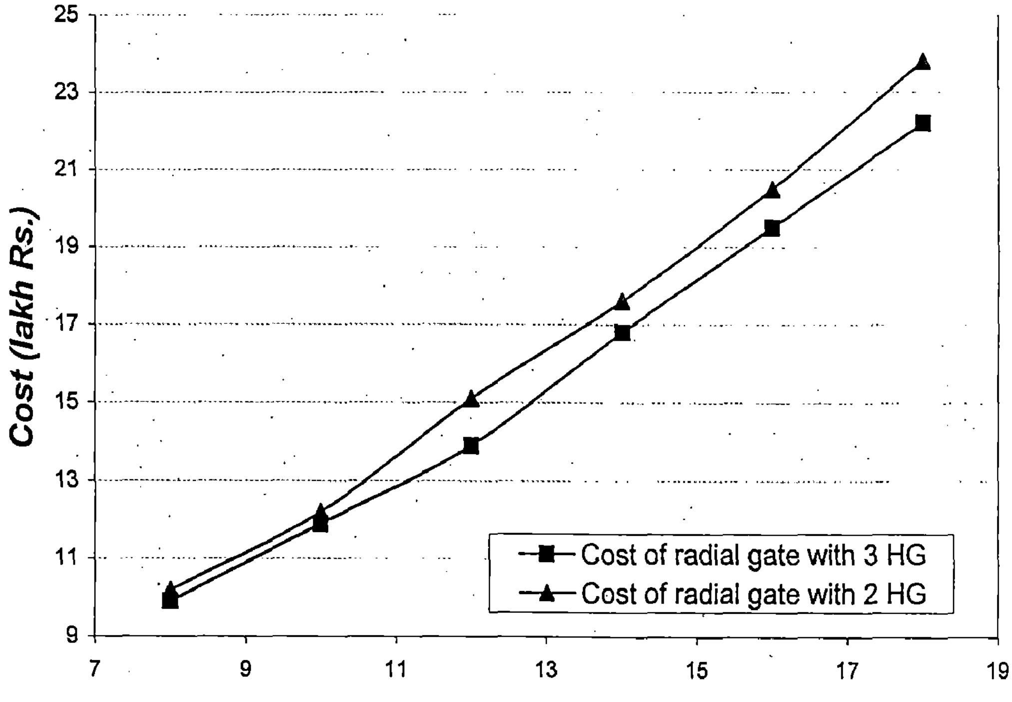


CHART-6.2.CS.R.3:
Optimisation of number of horizontal girders in radial gate w.r.t. span for 10.5m head

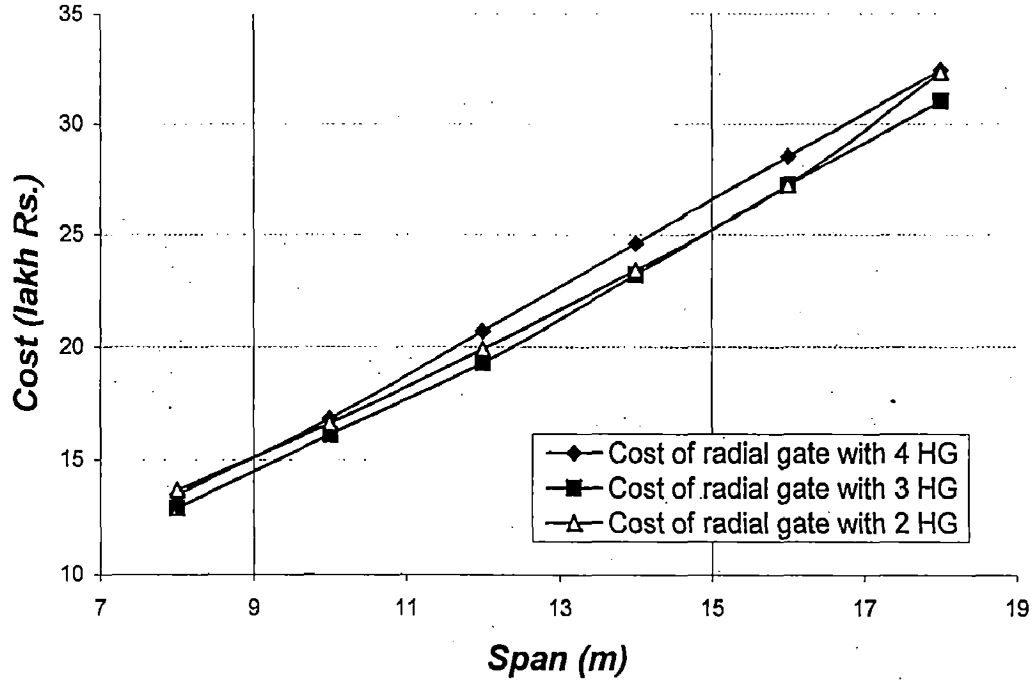


CHART-6.2.CS.R.4:
Optimisation number of of horizontal girders in radial gate w.r.t. span for 12m head

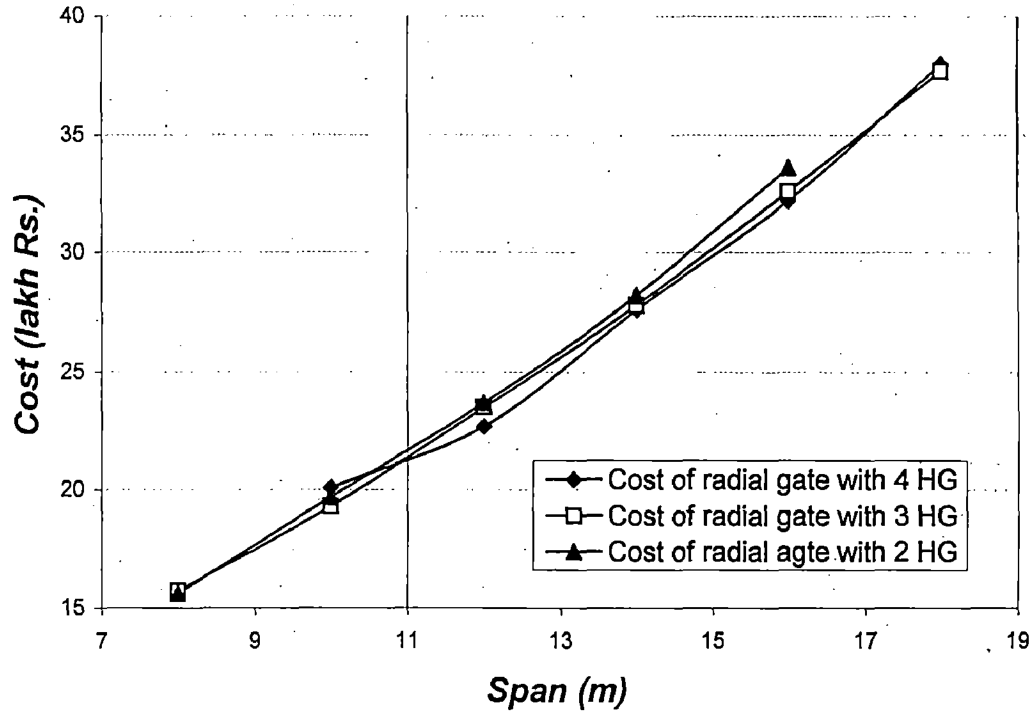


CHART-6.2.HDA.R.1
Optimisation of number of horizontal girders in radial gate (4 & 3 HG) w.r.t. haed for area of spillway bay of $75m^2$

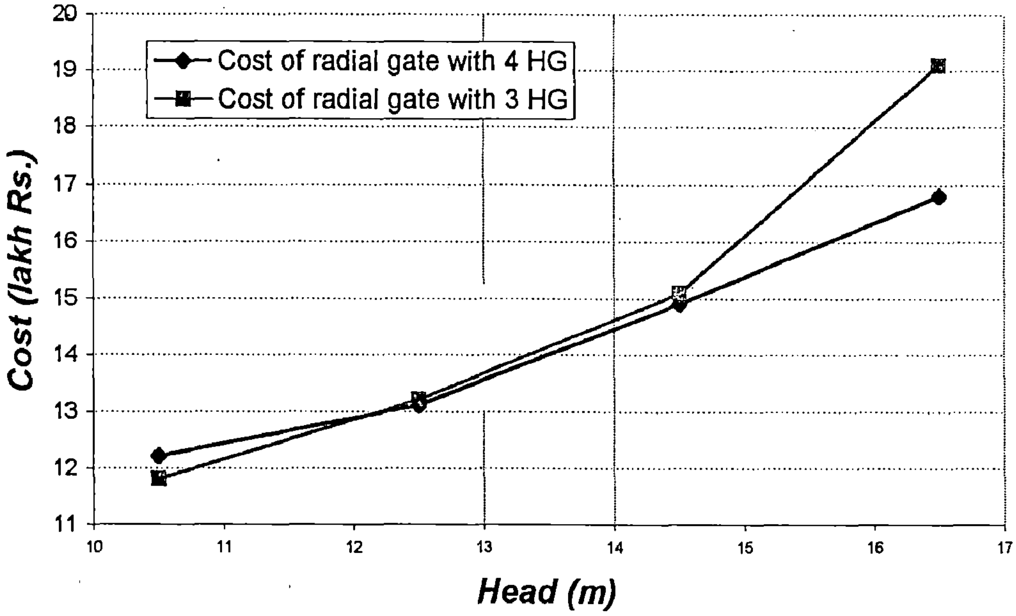


CHART-6.2.HDA.R.2:
Optimisation of number of horizontal girders in radial gate (3 & 2 HG) w.r.t. head for area of spillway bay of $75m^2$

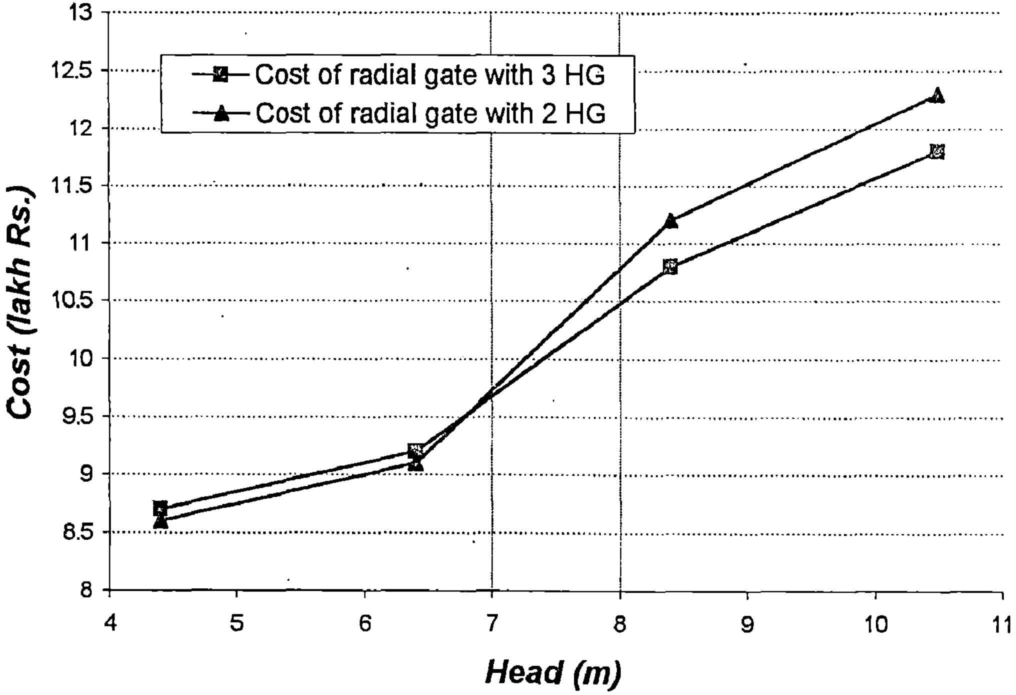


CHART-6.2.HDA.R.3:
Optimisation of number of horizontal girders in radial gate w.r.t. head for area of spillway bay of 100m^2

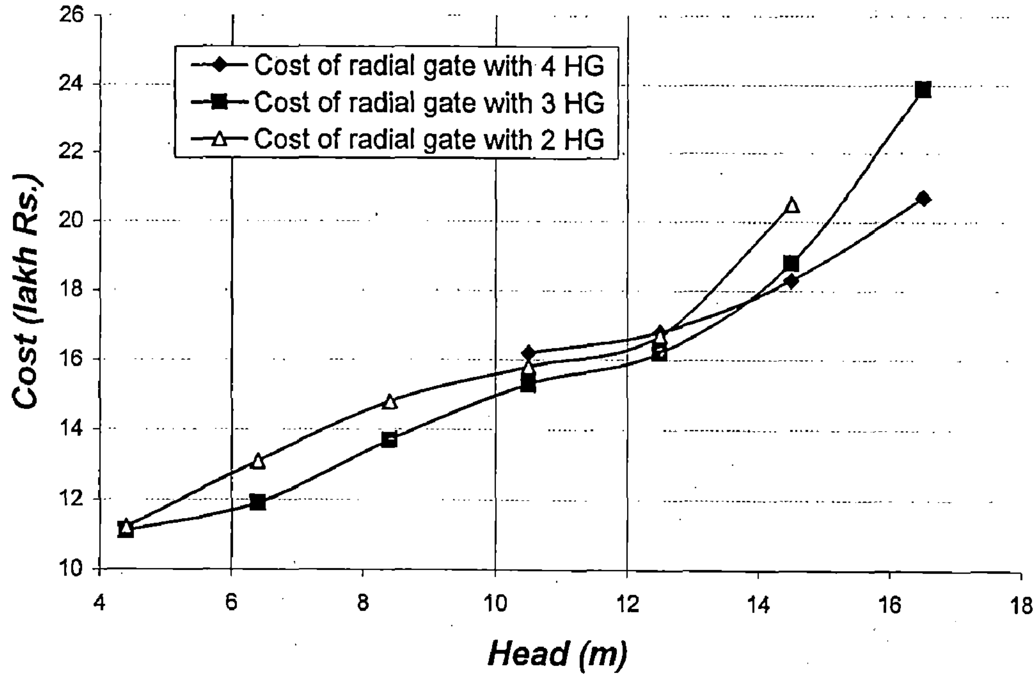


CHART-6.2.HDA.R.4:
Optimisation of number of horizontal girders in radial gate w.r.t. head for area of spillway bay of 125m^2

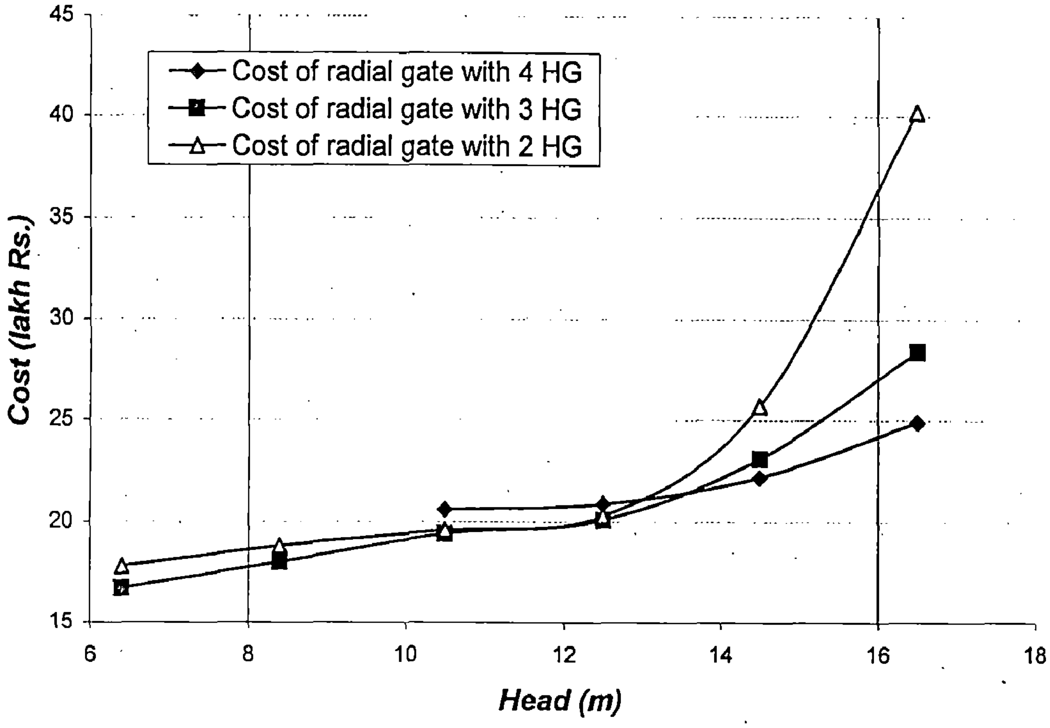


CHART-6.2.WG.R.1:

Comparison of weight of radial gate with Erbiste's formula for 6.4m head (>2000m^4)

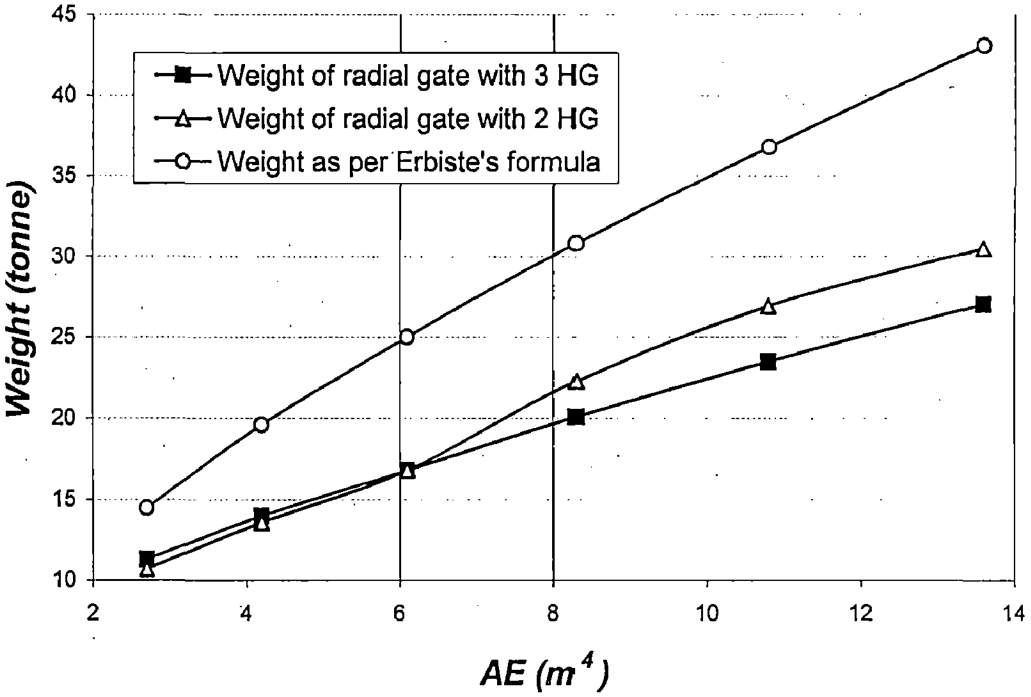


CHART-6.2.WG.R.2:

Comparison of weight of radial gate with Erbiste's formula for 8.4m head (>2000m^4)

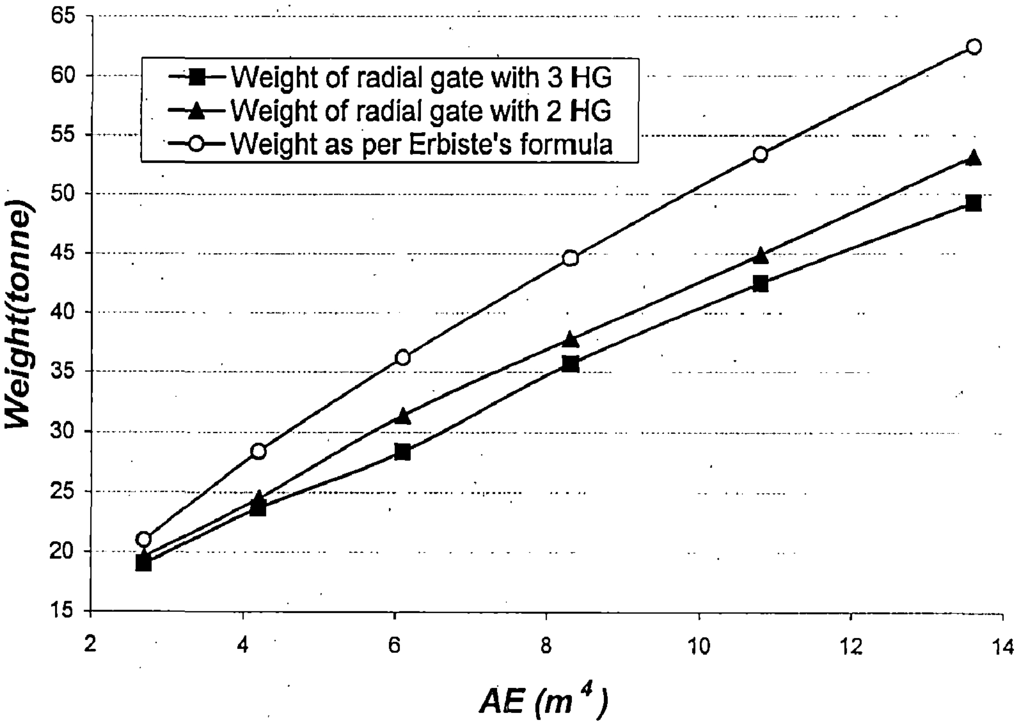


CHART-6.2.WG.R.3

Comparison of weight of radial gate with Erbiste's formula for 10.5m head (>2000m4)

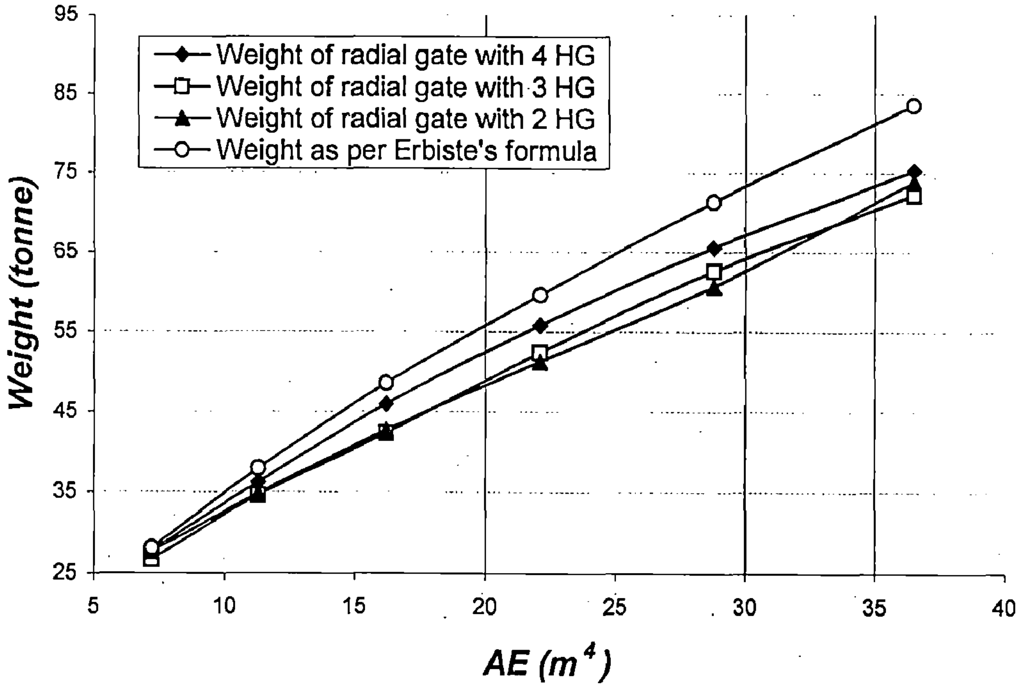


CHART-6.2.WG.R.4

Comparison of weight of radial gate with Erbiste's formula for 12m head (>2000m4)

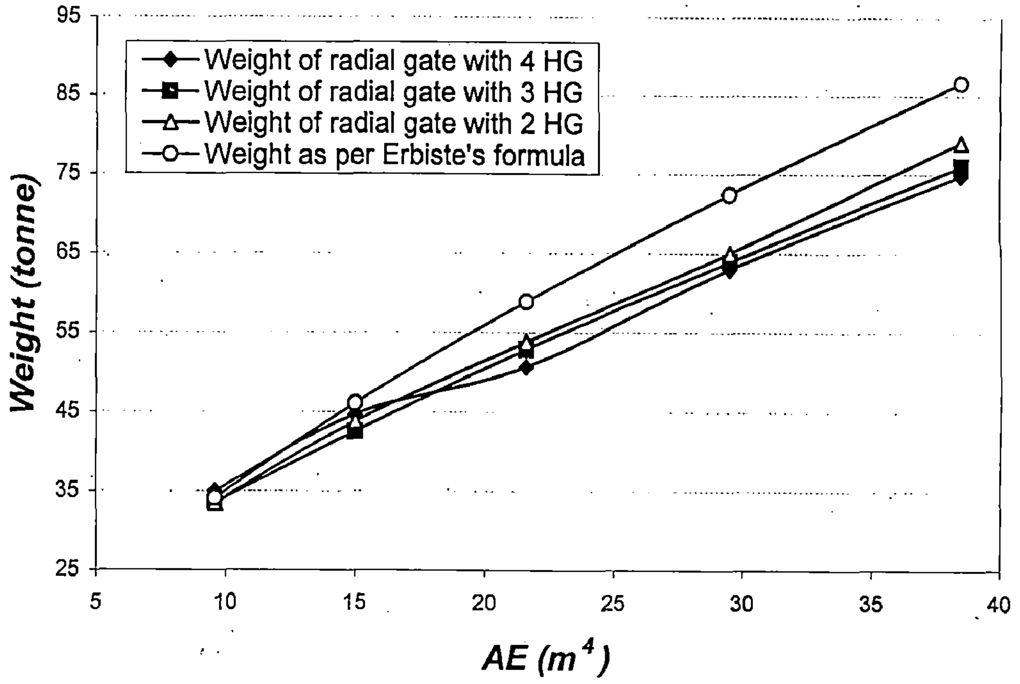


CHART-6.3.HC.1:

Comparison of hoisting capacity of radial and fixed wheel vertical lift gates for 10m span

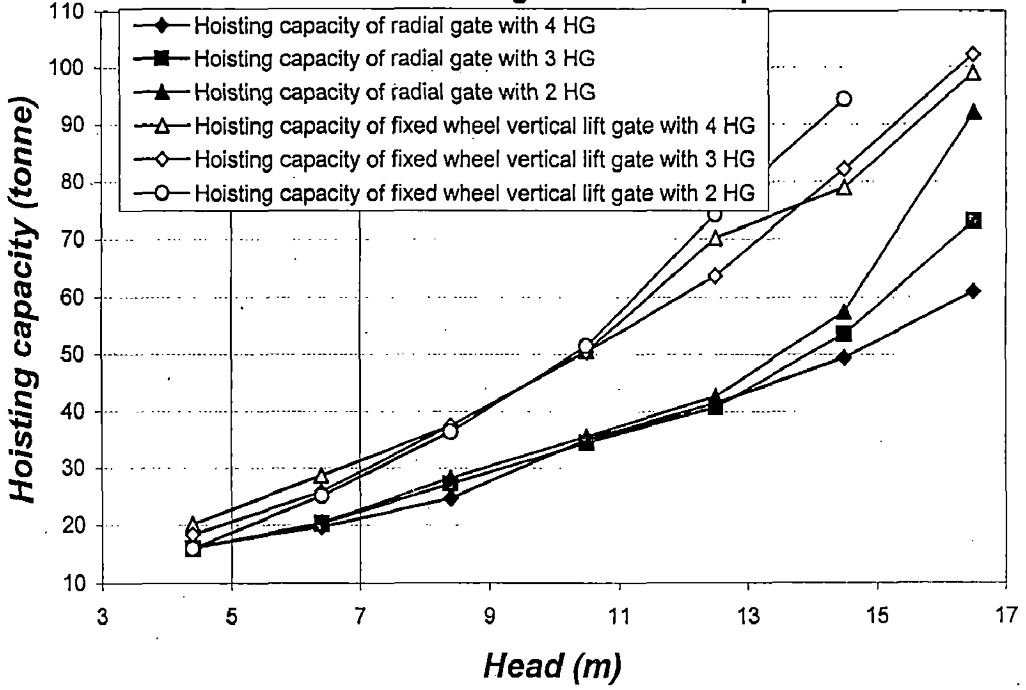


CHART-6.3.COST.1:

Comparison of cost of radial and fixed wheel vertical lift gates for 10m span

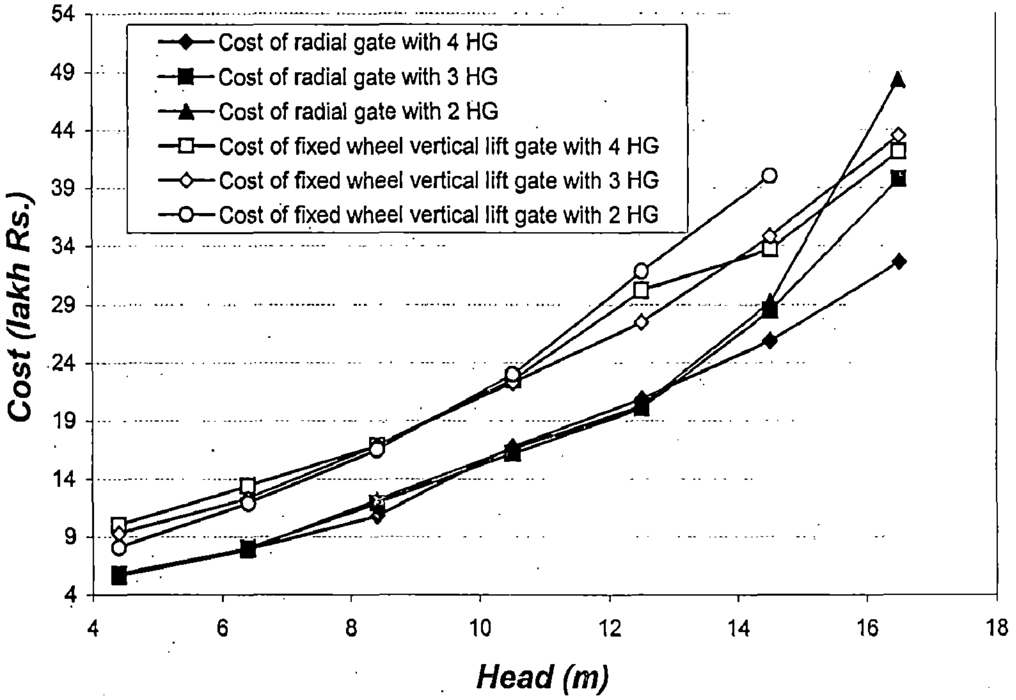


CHART-6.3.MC.1:

Comparison of material costs of radial and fixed wheel vertical lift gates for 10m span

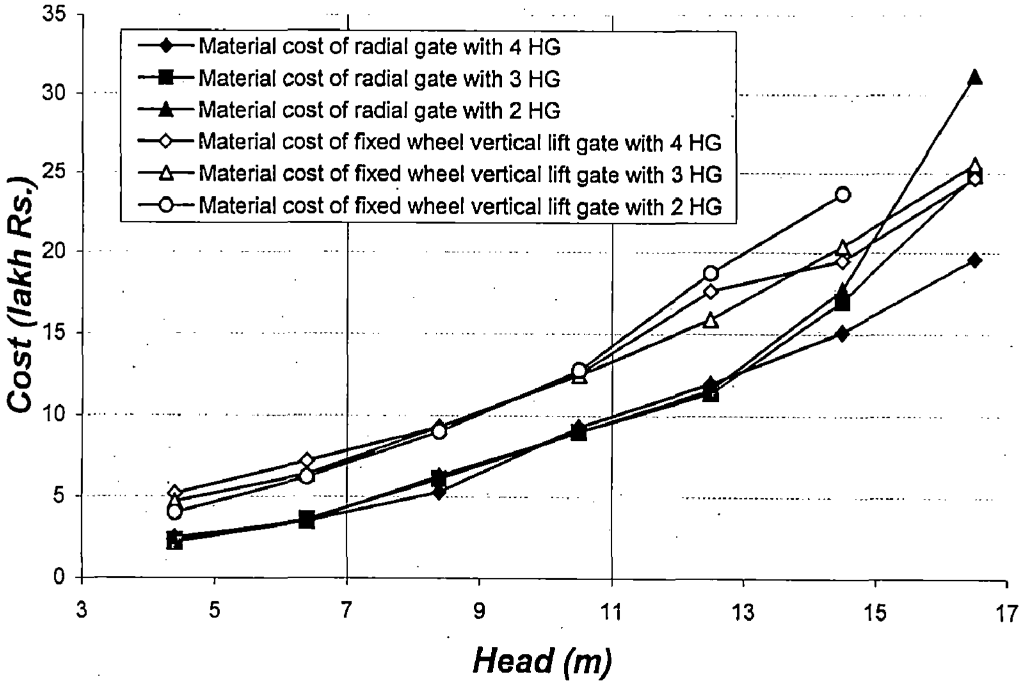
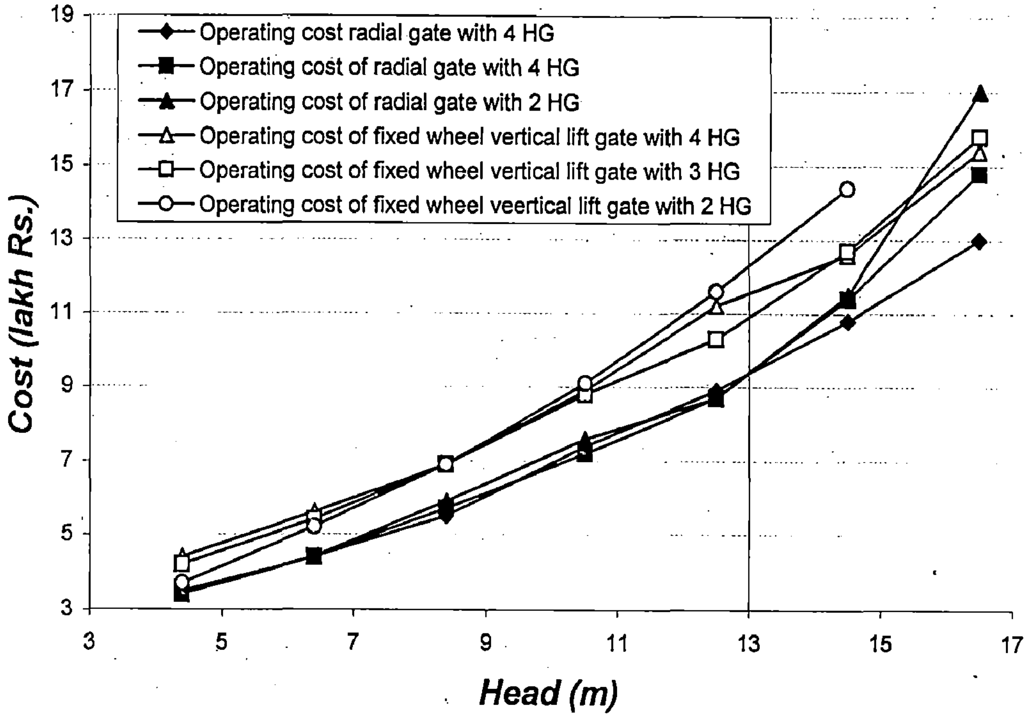


CHART-6.3.OC.1:

Comparison of operating costs of radial and fixed wheel vertical lift gates for 10m span



CHAPTER VII

CONCLUSIONS AND RECCOMMENDATIONS

7.1 GENERAL

The results obtained by computer have been checked in sample cases by doing manual calculations and have been found to tally. However, due to limited data available in IS: 808-1964, for steel sections, it has not been possible to use the computer program for design of gates with 2 horizontal girders, in cases when head of water exceeds 14.5m. Due to paucity of time, the formulation of computer program could not be modified to cover design of gates subject to heads of water less than 4.4m.

7.2 CONCLUSIONS

The cost analysis of fixed wheel vertical lift gate and radial for various parameters as discussed in the above paragraphs, it is concluded that:

- The radius factor of radial gate varies between 1.05 to 1.45 and 1.25 being the average value.
- Number of horizontal girders in both fixed wheel vertical lift and radial gates is primarily based on head of water.
- Number of horizontal girders in fixed wheel vertical lift gate is 2 up to 8.5m of heads, 4 above 13.5m and 3 in between these limits.
- Number of horizontal girders in radial gate is 2 up to 7m of heads, 4 above 13.5m and 3 in between these limits.
- Between these two types of spillway gates, radial gate is cheaper.

7.3 SUGGESTIONS FOR FURTHER WORKS

The scope of future works lies in the following aspects:

- In the above analysis the horizontal stiffeners are not taken for all the panels. Cost analysis of gates can be done with full consideration of horizontal stiffeners also.

- Design of braces is not considered in this analysis. It may be included with detailed design.
- The embedded parts may be fully designed for complete analysis.
- The cause of convergence of radius factor to certain heads as seen in the analysis of radius factor in case of radial gate may also be analyzed.
- The effect of individual components such as skin plate, stiffeners, girders etc. to the overall cost of gate may be taken for sensitivity analysis.

****

APPENDICES

PROGRAMS

```
//------------------------------------------------------------------
//                    :: OPTGATR2.CPP ::
//PROGRAM FOR 'OPTIMISATION OF DESIGN OF SPILLWAY GATES'
//------------------------------------------------------------------

#include<iostream.h>
#include<conio.h>
#include<math.h>
#include<process.h>
#include<iomanip.h>

void main()   //Main program starts.
{
clrscr();

//-----------------------------------------------------------------
//    FUNCTION DECLARATIONS
//-----------------------------------------------------------------

void Rvv(float [], float*, float*, float*, float*);
float xcube(float [], float [], float, float, int);
void nchar(int, char);  long fact(int);
float xsqrt(float [], float);
float polym(float[], float [], int, float);
float caw2(float, float, float);
float caw1(float, float, float);
void k_nondim(float, int, float*);
void Stress_VS(float [], float, float, float, float, float,
             float*, float*, float*, float*, float*, float*,
             float*, float*, float*, float*, float*);
float big(float [],int);      float small(float [], int);
void Stress_HG(float [], float, float, float, float, float,
             float, float*, float*, float*, float*, float*,
             float*, float*);
void Pbc_all(float, float*, char);
void Stress_Arm(float, float, float, float*, float*, float*,
             float*);
void Use_Rat(float, float, float, float, float, int, int,float*);
void Stress_SP(float, float, float, float, int, float*);
void COST(float, float, float, float, float, float, char, float,
            float, float*);

cout.precision(3);

//------------------------------------------------------------------
//    SKIN PLATE AND VERTICAL STIFFENER
//------------------------------------------------------------------

float FRL,CL,HD,SL,Sh,Sv,TL;
float CS; FRL=100; CL=90;
```

```
float CSArr[]={20,18,16,14,12,10,8,6};
cout<<"\nCost analysis of Radial Gate (2 HG) w.r.t. Span "<<endl;
nchar(70,'-');
cout<<"\n"<<setw(8)<<"Head"<<setw(8)<<"Span"<<setw(13)<<"WG"
  <<setw(10)<<"CG"<<setw(17)<<"Hoist capacity"<<setw(13)<<"Cost";
cout<<"\n"<<setw(8)<<"(m)"<<setw(8)<<"(m)"<<setw(13)<<"(tonnes)"
    <<setw(10)<<"(m)"<<setw(17)<<"(tonnes)"<<setw(13)
    <<"(lakh Rs.)"<<endl;
nchar(70,'-');  cout<<endl;
for(int k=0;k<8;k++)
{
CS=CSArr[k];  SL=CL;
for(int i=0;i<5;i++)
      {
      HD=FRL-SL;   Sh=0.15*HD;
      Sv=pow(Sh,1.85)*pow(HD,-0.85)/2.0;  SL=CL-Sv;
      }
      HD=FRL-SL+0.300;
float Rf=1.22;  float R=Rf*HD;  float Rvb,Rvt,A;
float Rvvx[]={R,HD,Sh,Sv,SL};
Rvv(Rvvx,&TL,&Rvb,&Rvt,&A);
float B=asin(Rvt/R);  float C=A+B;  float D=sin(A);
float E=sin(B);       float F=D+E;        F=2*asin(F/2);
float Tss=12;           //Side seal thickness.
float FFl=CS-2*Tss/1000;            //Face to face length.
float TA=FFl*R;                //Total area of water load.
float P=TA*F*Rvt+R*cos(B)*TA*(1-cos(C))
      -R*TA*sin(B)*sin(C);     //Total pr. in tonnes.
float Arc_AB=R*F;              //Arc length of skin plate.
float t, MLopt;  int Lopt;
float Hb=HD/10;  float Zsp;  float fbsp;
float tArr[5]={2.0,1.8,1.4,1.2,1.0};;
int LoptArr[8]={40,41,42,43,44,45,46,47};
for(i=0;i<5;i++)
            {
            t=tArr[i]-0.15; Zsp=1*pow(t,2)/6;
            for(int j=0;j<8;j++)
                  {
                  Lopt=LoptArr[j];
                  MLopt=Hb*pow(Lopt,2)/12; fbsp=MLopt/Zsp;
                  }
            if(fbsp>1125) break; Lopt=Lopt; t=t;
            }

//Arrangement of Horizontal Girders.

Lopt+=1;

LoptFinal : Lopt-=1;

float PM=0.52*Arc_AB; float Aa=0.12*Arc_AB; float bB=0.36*Arc_AB;
float AD=D*R; float DB=E*R; float DM=DB-bB; float PD=AD-Aa;
float A1=PD/R; float B1=DM/R;
float PQ=R*sin(A1); float MN=R*sin(B1);

//Water load at girder locations.

float wa=(Rvt+PQ); float wb=(Rvt-MN); float wA=HD; //in t/sq.m.

//Bending moment at support points (1 m width of load).
```

```
float Maw=pow(Aa,2)*1/2*wA+pow(Aa,2)*(wA-wa)/2*2/3;  // in t.m/m
float Mbw=pow(bB,2)*1/2*1/3*wb;

//Reactions at support points due to water load.

float Raw=0.265*Arc_AB*wA; float Rbw=0.216*Arc_AB*wA; //tonnes/m.
float hg;  float ep=0.1e-5;

//The effect of sill pressure.

float CG1=R*0.7; float WG1=10;

CGTEST:

float Lst=WG1*CG1/(R*cos(A1));//Lst: length from SL to centre
                        //line of Trunnion.
float Wrad=Lst*sin(A1)/CS;      //Radial load/m width of gate, t/m
float Wthr=Lst*cos(A1)/CS;      //Direct thrust/m width of gate,t/m
float Mas=Wrad*Aa;              //t.m.
float Ras=Wrad*(Aa+PM)/PM;    float Rbs=-Wrad*Aa/PM;
float Ra=Raw+Ras;float Rb=Rbw+Rbs;float Ma=Maw+Mas; float Mb=Mbw;

//Maximum bending moment along span ab occurs when shear force
//is zero or shear force equals to Rb. (from 'b')

float R2Qu_ab_a=-(wa-wb)/PM;float R2Qu_ab_b=-(2*wb);
float R2Qu_ab_c=(2*Rb-wb*bB);
float R2Q_ab_Arrb[]={R2Qu_ab_a,R2Qu_ab_b,R2Qu_ab_c};

//Max span BM due to combined load of water and sill pres. at
//dist. x from 'b' in t.m.
//Mspab_b=-wb*bB/2*(bB/3+x)-1/2*(wa-wb)/PM*x*x/2*x/3+Rb*x

//float Mspab_b=-pow(xbl,3)*(wa-wb)/6/PM-wb/2*pow(xbl,2)
//              +(Rb-wb*bB/2)*xbl-(wb*pow(bB,2))/6;
float R2Cu_ab_a=-(wa-wb)/6/PM; float R2Cu_ab_b=-wb/2;
float R2Cu_ab_c=Rb-wb*bB/2; float R2Cu_ab_d=-wb/6*pow(bB,2);
float R2C_ab_Arrb[]={R2Cu_ab_a,R2Cu_ab_b,R2Cu_ab_c,R2Cu_ab_d};
float spbcr=0.2*PM; float spbcl=0.8*PM;
float conflxabr=xcube(R2C_ab_Arrb,R2Q_ab_Arrb,spbcr,PM,1);
float conflxabl=xcube(R2C_ab_Arrb,R2Q_ab_Arrb,spbcl,PM,2);

//Calculation of co-acting width at support points/span.
float conflxabspW=conflxabl+conflxabr;
float CAWspab=caw1(PM,conflxabspW,Lopt);//CAW at span ab
float CAWxa=caw2(Aa,conflxabl,Lopt);      //CAW at support 'a'.
float CAWxb=caw2(bB,conflxabr,Lopt);      //CAW at support 'b'.
float cawArra[]={CAWxa,CAWspab};
float cawArrb[]={CAWxb,CAWspab};
float CAWxalow=small(cawArra,2);
float CAWxblow=small(cawArrb,2);

//Maximum bending moment along span ab occurs when shear force
//is zero or shear force equals to Rb. (from 'a')
//ie. (wa-wb)/PM*x^2-(2*wa)*x+(2*Ra-Wrad)-(wA+wa)*Aa)=0

//Check for skin plate as plate,  all edges rigidly fixed(=R).
//Here s=t,a=Lopt,b=ab=PM.

float t1=0.85;  t=1.05;
float R2PPM=(Rvt+(PQ-MN)/2)/10;  float fb_2_3x,tPM;
```

```
if(R2PPM*10<=10){tPM=t1;}     else tPM=t;
Stress_SP(Lopt,tPM,R2PPM,PM/2,3,&fb_2_3x);
if(fb_2_3x>1125) goto LoptFinal;

//Check for skin plate as plate, for two short and one long edges
//fixed and one long edge simply supported.(=R2sl). b=Lopt, a=Aa.

//Check for skin plate as plate, for two long and one short edges
//fixed and one short edge simply supported.(=R2ls). b=Aa, =Lopt.

float R2PAa=(HD+Rvt+PQ)/2/10;  float fb_5_8x,tAa;
if(R2PAa*10<=10){tAa=t1;}     else tAa=t;
Stress_SP(Lopt,tAa,R2PAa,Aa,3,&fb_5_8x);
if(fb_5_8x>1125)goto LoptFinal;

//Check for skin plate  as plate, for three edges fixed and one
//(longer) edge free(=R3fl1). Here b=Aa, a=Lopt (for Aa>Lopt).

//Check for skin plate  as plate, for three edges fixed and one
//(longer) edge free(=R3fl2). Here b=Lopt, a=Aa (for Aa<Lopt).

float LoptPM;  int CSS=CS*100;  int RemPM=(CSS) % Lopt;
if(RemPM==0) LoptPM=Lopt/5;
      else if(RemPM>(Lopt*0.4))      LoptPM=RemPM/4;
      else if(RemPM<(Lopt*0.4))      LoptPM=(Lopt+RemPM)/5;
float fb_11x;
Stress_SP(LoptPM,tPM,R2PPM,PM/2,11,&fb_11x);
if(fb_11x>1125)goto LoptFinal;

//Check for stresses in skin plate at  girder points co-acting
//with vertical stiffeners  and span.
//v/stiffener selected (1/2 cut ISMB 400 and T-sections).

//At support 'a': sh. force:
float Hax,Hbx,tax,tbx;
      Hax=Rvt+PQ; Hbx=Rvt-MN;
if(Hax<=10){tax=t1;} else tax=t;
float SFbot_a=Aa*(wA+wa)/2+Wrad; float SFtop_a=Ra-SFbot_a;
float SFArr_a[]={SFbot_a,SFtop_a};
float SFmax_a=big(SFArr_a,2);        //in tonnes./m
//dir. comp. force:
float Fcomp_a=(Wthr*Lopt/100/1000);        //in kgf.
float Mpo=wA/10*pow(LoptPM,2)/2; float Mpq=wA/10*pow(Lopt,2)/12;
float MGArrA[]={Mpo,Mpq};
float MmaxGA=big(MGArrA,2);
float BSa=MmaxGA*wa/wA/(pow(tax,2)/6);  //in kgf/sqcm.
float cawa[2]={CAWxalow*100,tax};
float f1a,f2a,f3a,Sa,STspa,STflga,Scomba,wVSa,webLVSa,flgLVSa,
      flgWVSa;
Stress_VS(cawa,Ma,SFmax_a,BSa,Fcomp_a,Lopt,&f1a,&f2a,&f3a,&Sa,
        &STspa,&STflga,&Scomba,&webLVSa,&flgLVSa,&flgWVSa,
        &wVSa);

//At support 'b': sh. force:
if(Hbx<=10){tbx=t1;} else tbx=t;
float SFbot_b=Aa*(wA+wa)/2+Wrad+(wa+wb)/2*PM-Ra;
float SFtop_b=Rb-SFbot_a;
float SFArr_b[]={SFbot_b,SFtop_b};
float SFmax_b=big(SFArr_b,2);        //in tonnes./m
//dir. comp. force:
float Fcomp_b=(Wthr*Lopt/100/1000);        //in kgf.
```

```
float BSb=MmaxGA*wb/wA/(pow(tbx,2)/6);  //in kgf/sqcm.
float cawb[2]={CAWxblow*100,tbx};
float f1b,f2b,f3b,Sb,STspb,STflgb,Scombb,wVSb,webLVSb,flgLVSb,
      flgW9VSb;
Stress_VS(cawb,Mb,SFmax_b,BSb,Fcomp_b,Lopt,&f1b,&f2b,&f3b,&Sb,
        &STspb,&STflgb,&Scombb,&webLVSb,&flgLVSb,&flgWVSb,
        &wVSb);



//-----------------------------------------------------------------
//     HORIZONTAL GIRDERS
//-----------------------------------------------------------------

//Analysis for water load and sill pressure on Horizontal Girders.

float Lconn=HD/12.5 ;   //in metre.
float LarmCor=(webLVSa+flgWVSa)/100+Lconn;

//Effect of Rope Tension .

float RA1=3.14/3;          //RA1 is rope inclination to horizontal.
float HC1=50*cos(RA1);     //HC1 is hoist capacity.

HCTEST:

float RT=HC1/2;            //RT is rope tension in tonnes.
float RTh=RT*cos(RA1);     //RT in x-x direction.
float webLGa,flgLGa,flgWGa,wHGa,Taxmaxa,BMarma,LAa; float Tha=RTh;

//Stresses at H/girder 'a'.

Stress_HG(cawa,R,CS,LarmCor,Ra,Raw,RTha,&webLGa,&flgLGa,&flgWGa,
        &wHGa,&Taxmaxa,&BMarma,&LAa);

//Stresses at H/girder 'b'.

float webLGb,flgLGb,flgWGb,wHGb,Taxmaxb,BMarmb,LAb; float RThb=0;
Stress_HG(cawb,R,CS,LarmCor,Rb,Rbw,RThb,&webLGb,&flgLGb,&flgWGb,
        &wHGb,&Taxmaxb,&BMarmb,&LAb);

//-----------------------------------------------------------------
//    ARMS
//-----------------------------------------------------------------

float Faxa=1*Taxmaxa; float Faxb=Taxmaxb; //Axial load.

//Effect of frictional forces in trunnion.
//Max. BM at 'a'.

float MFrmaxa=Faxa*0.2*0.200; //tm.
float larma=R-(webLVSa+flgWVSa)/100;
float Marma=MFrmaxa*(larma-0.1*larma)/larma;

//Effect of frictional forces in trunnion.
//Max. BM at 'b'.

float MFrmaxb=Faxb*0.2*0.200; //tm.
float Marmb=MFrmaxb*(larma-0.09*larma)/larma;
//Condition for biggest of axial forces.
//Total axial load.
```

```
float Lev_arma=2*0.1*larma*sin(C/2);
float Lev_armb=2*0.09*larma*sin(C/2);
float Faxmaxa=Faxa+Marma/Lev_arma;
float Faxmaxb=Faxb+Marmb/Lev_armb;
float BMarmaa=1*BMarma;  float BMarmbb=BMarmb;
float lea=R-(webLVSa+flgWVSa+(webLGa+2*flgWGa)/2)/100;
float leb=R-(webLVSa+flgWVSa+(webLGb+2*flgWGb)/2)/100;
float webLArma,webWArma,flgLArma,flgWArma,wArma;
Stress_Arm(Faxmaxa,BMarmaa,lea,&webLArma,&flgLArma,&flgWArma,
        &wArma);
float webLArmb,webWArmb,flgLArmb,flgWArmb,wArmb;
Stress_Arm(Faxmaxb,BMarmbb,leb,&webLArmb,&flgLArmb,&flgWArmb,
        &wArmb);

//-----------------------------------------------------
//   CALCULATION OF WEIGHT OF GATE
//-----------------------------------------------------

//Skin plate weight in tonnes.
float WG=0;float DG=0; float MG=0;
float Arc_DB,tb,Lxt,Lxa,Arc_x;  t=0.85;
float Ltb=0;float Lt=Arc_AB;
if(HD>=10){
        Arc_DB=E*R; Lxt=10-Rvt; Lxa=sin(Lxt/R); Arc_x=asin(Lxa);
        Ltb=Arc_AB-(Arc_DB+Arc_x);  tb=t; Lt=Arc_AB-Ltb;
        }
float wsp=(Ltb*(tb+0.15)+(t+0.15)*Lt)/100*CS*7.850;
float dsp=(R+2*R*cos(C/2))/3; //cg. of skin plate.
float Msp=wsp*dsp;   WG+=wsp;DG+=dsp;MG+=Msp;
//V/stiffener weight in tonnes.
float d_VSa=(webLVSa+flgWVSa)/100;
int Nvs;int CS1=CS*100;
if(RemPM==0)Nvs=CS1/Lopt+4;
     else if(RemPM<0.4*Lopt)Nvs=(CS1-CS1 % Lopt)/Lopt+3;
     else if(RemPM>0.4*Lopt)Nvs=(CS1-CS1 % Lopt)/Lopt+4;
float wvs=Nvs*wVSa*Arc_AB/1000;
float dvs=((R-(d_VSa)*2/3+2*(R-(d_VSa)*2/3)*cos(C/2)))/3;
float Mvs=wvs*dvs;  WG+=wvs;DG+=dvs;MG+=Mvs;
//H/Girder weight in tonnes.
float whga=wHGa*CS/1000; float whgb=wHGb*CS/1000;
float whg=whga+whgb;
float d_VSHGa=(webLVSa+flgWVSa+(webLGa+2*flgWGa)/2)/100;
float d_VSHGb=(webLVSa+flgWVSa+(webLGb+2*flgWGb)/2)/100;
float dhga=(R-d_VSHGa)*cos(A); float dhgb=(R-d_VSHGb)*cos(B);
float dhg=dhga+dhgb;
float mhga=whga*dhga; float mhgb=whgb*dhgb; float mhg=mhga+mhgb;
     WG+=whg;DG+=dhg;MG+=mhg;
//Arm weight in tonnes.
float warma=wArma*LAa/1000;float warmb=wArmb*LAb/1000;
float warm=warma+warmb;
float darma=(R-d_VSHGa)*cos(A)/2;float darmb=(R-d_VSHGb)*cos(B)/2;
float darm=darma+darmb;
float marma=warma*darma; float marmb=warmb*darmb;
float marm=marma+marmb;  WG+=warm;DG+=darm;MG+=marm;
float wTrAssm=2.5/100*WG;
          //weight of Trunnion assembly with bushing.
float wbrc=5/100*WG;     //weight of bracing assumed.(in pc)
float dbrc=darm*2/3;   float mbrc=wbrc*dbrc;
     WG+=wTrAssm+wbrc;DG+=dbrc;MG+=mbrc;
float CG=MG/WG;   hg=WG1-WG;
float wg=WG; WG=WG1; WG1=wg; float hg1=CG; CG=CG1; CG1=hg1;
```

```
if(fabs(hg)<ep) goto CGTEST;

//---------------------------------------------------------------
//    CALCULATION OF HOISTING CAPACITY OF THE GATE.
//---------------------------------------------------------------

float TS=R-d_VSHGa;
float TT1=TS*sin(A1); //vertical distance from TL to 'a'.
float ST1=TS*cos(A1); //horizontal dist. from 'a' to c/line of TL.
float Rx=(HD/2+TT1)/R;
float R1=2*asin(Rx);  //angle of rotation of lifted gate.
float R2=R1-A1;
float Ry=(HD+TT1)/(ST1-0.45*R);
float Lx=atan(Ry);
float L2=Lx-A1;
float Rz=(HD+TT1+6/100*R)/(ST1-TS*cos(R2));
float Ly=atan(Rz);
float L3=Ly-A1;
float Rl=(5+sin(L3-L2))/(1+5*cos(L3-L2));
float RA=atan(Rl);     //rope inclination in radians.
float Pd=TS*sin(RA+L2);//perpend'lar dist. of resultant from Trnn.
//Loads & forces.
float FF=2*0.025*FFl*HD/2*1.5;//seal friction.
float TF=P*0.2;                //Trunnion friction, tonnes.
float HC=(FF*R+(RT*cos(L2)+WG1)*CG1+TF*0.2)/Pd;     //HC1/2=RT.
      HC+=5/100*WG1;      //addition for ropes.
      HC+=20/100*HC;         //addition for reserve.
float hc=HC-HC1;
float hh=HC; HC=HC1; HC1=hh; float rr=RA; RA=RA1; RA1=rr;
if(fabs(hc)<ep) goto HCTEST;

//---------------------------------------------------------------
//    COST EVALUATION
//---------------------------------------------------------------

//MATERIAL COST OF GATE (Mat_cost)

float Cspl=1.05*wsp; float Cvs=1.05*wvs; float Chg=1.05*whg;
float Carm=1.05*warm; float Cbrc=1.05*wbrc;
float Css=1.05*2*(Arc_AB+CS)*8*80/1000/1000*7.85;
float Mat_cost=1*(Cspl+Cvs+Chg+Carm+Cbrc+Css)*25000/100000;
cout.precision(1);   float Ctotal;
COST(Arc_AB,CS,Nvs,WG1,HC1,Mat_cost,'R',1,1,&Ctotal);
cout<<setw(8)<<HD<<setw(8)<<CS<<setw(13)<<WG1*1.35<<setw(10)<<CG1
    <<setw(17)<<HC1<<setw(13)<<Ctotal<<endl;
}
nchar(70,'-');
getch();
}    //Main program ends.

//---------------------------------------------------------------
//    FUNCTION DEFINITIONS
//---------------------------------------------------------------

//Function for lines/decoration.

void nchar(int n, char c)
{
int i;  for (i=0;i<n;i++){ cout<<c;}
}
```

```
//Function for factorial.

long fact(int n)
{
if(n==0||n==1) return 1; else return n*fact(n-1);
}

//Function for square root.

float xsqrt(float ab[], float y)
{
float x1, x2, d, ta,x;  d=ab[1]*ab[1]-4*ab[0]*ab[2];  ta=2*ab[0];
if(d>=0){
      d=sqrt(d);     x1=(-ab[1]+d)/ta;    x2=(-ab[1]-d)/ta;
      if((x1>0)&&(x1<y))  x=x1;
      else if((x2>0)&&(x2<y)) x=x2;
      }
      return x;
}

//Function for computing contraflexure points.

float xcube(float p[], float a[], float x, float y, int c)
{
if(c==1)
      {
long f, fd; float h, ep=0.1e-5;
      do
      {
      f=x*(x*(p[0]*x+p[1])+p[2])+p[3];
      fd=x*(x*a[0]+a[1])+a[2];  h=-f/fd;  x=x+h;
      }
      while(fabs(h)>ep); return x;
      }
else if(c==2)
      {
long f,fd; float h,ep=0.1e-5;
      do
      {
      f=x*(x*(p[0]*x+p[1])+p[2])+p[3];
      fd=x*(x*a[0]+a[1])+a[2];  h=-f/fd;  x=x+h;
      }
      while(fabs(h)>ep);
      }
      return (y-x);
}

//Function for formating polynomial of order 8 with 9 nos. data)

float polym(float xf[], float f[], int n, float x)
{
float  d9f0,d8f0,d7f0,d6f0,d5f0,d4f0,d3f0,d2f0,d1f0;
d9f0=d8f0=d7f0=d6f0=d5f0=d4f0=d3f0=d2f0=d1f0=0;
float fxr4,fxr5,fxr6,fxr7,fxr8,fxr9;
d1f0=f[1]-f[0]+d1f0;
d2f0=f[2]-2*f[1]+f[0]+d2f0;
d3f0=f[3]-3*f[2]+3*f[1]-f[0]+d3f0;
d4f0=f[4]-4*f[3]+6*f[2]-4*f[1]+f[0]+d4f0;
d5f0=f[5]-5*f[4]+10*f[3]-10*f[2]+5*f[1]-f[0]+d5f0;
d6f0=f[6]-6*f[5]+15*f[4]-20*f[3]+15*f[2]-6*f[1]+f[0]+d6f0;
```

```
d7f0=f[7]-7*f[6]+21*f[5]-35*f[4]+35*f[3]-21*f[2]+7*f[1]-f[0]+d7f0;
d8f0=f[8]-8*f[7]+28*f[6]-56*f[5]+70*f[4]
      -56*f[3]+28*f[2]-8*f[1]+f[0]+d8f0;
d9f0=f[9]-9*f[8]+36*f[7]-84*f[6]+126*f[5]-126*f[4]+84*f[3]-36*f[2]
      +9*f[1]-f[0]+d9f0;
float h,p,fx;
h=xf[1]-xf[0];
p=(x-xf[0])/h;
fxr4=f[0]+p*d1f0+p*(p-1)*d2f0/fact(2)+p*(p-1)*(p-2)*d3f0/fact(3);
      p*(p-1)*(p-2)*(p-3)*d4f0/fact(4);
fxr5=p*(p-1)*(p-2)*(p-3)*(p-4)*d5f0/fact(5)+fxr4;
fxr6=p*(p-1)*(p-2)*(p-3)*(p-4)*(p-5)*d6f0/fact(6)+fxr5;
fxr7=p*(p-1)*(p-2)*(p-3)*(p-4)*(p-5)*(p-6)*d7f0/fact(7)+fxr6;
fxr8=p*(p-1)*(p-2)*(p-3)*(p-4)*(p-5)*(p-6)*(p-)*d8f0/fact(8)+fxr7;
fxr9=p*(p-1)*(p-2)*(p-3)*(p-4)*(p-5)*(p-6)*(p-7)*(p-)*d9f0/fact(9)
      +fxr8;
if(n==4) fx=fxr4;
      else if(n==5) fx=fxr5;    else if(n==6) fx=fxr6;
      else if(n==7) fx=fxr7;    else if(n==8) fx=fxr8;
      else if(n==9) fx=fxr9;    return fx;
 }

//Function for computing CAW of skin plate at support points (n2).

float caw2(float la, float lcon_abst, float B)
{
float n2,caw,l,xcaw;
float x1[6]={1,2,3,4,5,6};float x2[9]={4,6,8,10,12,14,16,18,20};
float y1[6]={0.15,0.3,0.425,0.53,0.62,0.66};
float y2[9]={0.53,0.66,0.73,0.775,0.795,0.84,0.85,0.87,0.88};
      l=la+lcon_abst;  B=B/2/100;   xcaw=l/B;
if(xcaw<5) n2=polym(x1,y1,6,xcaw);
else if(xcaw>5) n2=polym(x2,y2,9,xcaw); caw=2*n2*B; return caw;
}

//Function for computing CAW of span of skin plate (n1)

float caw1(float ab, float lcon_absp, float B)
{
float n1,caw,l,xcaw;
float x1[]={1,2,3,4,5,6}; float x2[]={4,6,8,10,12,14,16,18,20};
float y1[]={0.195,0.375,0.55,0.7,0.79,0.85};
float y2[]={0.7,0.85,0.915,0.945,0.95,0.96,0.97,0.973,0.975};
      l=ab-lcon_absp;  B=B/2/100;  xcaw=l/B;
if(xcaw<5) n1=polym(x1,y1,6,xcaw);
else if(xcaw>5) n1=polym(x2,y2,9,xcaw); caw=2*n1*B;  return caw;
}

//Function for computing the biggest value.

float big(float a[], int n)
{
float big=a[0];
for(int i=0;i<n;i++) if(a[i]>big)big=a[i]; return big;
}

//Function for computing the smallest value.

float small(float a[], int n)
{
float small=a[0];
```

```
for(int i=0;i<n;i++) if(a[i]<small) small=a[i]; return small;
}


//Function of computing k, the non-dimensional constant.

void k_nondim(float a, int b, float *p)
{
float k_2x,k_2y,k_4y,k_3x,k_5x,k_5y,k_7y,k_6x,k_8x,k_8y,k_10y,
      k_9x,k_11x,k_11y,k_12x,k_12y,k_13x,k_13y,k_14x,k_14y,k_15x;
float y_2xk,y_2yk,y_4yk,y_3xk,y_5xk,y_5yk,y_7yk,y_6xk,y_8xk,y_8yk,
      y_10yk,y_9xk,y_11xk,y_11yk,y_12xk,y_12yk,y_13xk,y_13yk,
      y_14xk,y_14yk,y_15xk;
float kR,kR2sl,kR2ls,kR3fl;
float x[]={1.0,1.5,2.0,2.5,3.0};
float y_2x[]={18.7,22.1,21.7,25.,25.0};   y_2xk=25.0;
float y_2y[]={13.7,12.2,9.5,8.0,7.5};     y_2yk=7.5;
float y_4y[]={30.9,34.3,34.3,31.3,34.3};  y_4yk=34.3;
float y_3x[]={39.9,45.5,49.9,50.0,50.};   y_3xk=50.0;
float y_5x[]={14.2,27.1,33.8,36.6,37.4};  y_5xk=37.5;
float y_5y[]={16.6,18.1,15.5,13.3,12.0};  y_5yk=11.3;
float y_7y[]={36.0,45.5,47.0,47.0,47.1};  y_7yk=47.2;
float y_6x[]={32.8,56.5,68.3,73.2,74.0};  y_6xk=75.0;
float y_8x[]={16.6,23.2,25.0,25.0,25.0};  y_8xk=25.0;
float y_8y[]={14.2,11.4,9.0,8.0,7.6};     y_8yk=7.5;
float y_10y[]={36.0,43.3,50.0,50.0,50.0}; y_10yk=50.0;
float y_9x[]={32.8,34.1,34.2,34.2,34.2};  y_9xk=34.2;
float y_11x[]={17.67,23.5,19.49,18.37,19.78};   y_11xk=22.0;
float y_11y[]={12.29,14.2,6.72,2.88,7.68};      y_11yk=75.0;
float y_12x[]={9.45,20.5,33.98,42.05,44.93};    y_12xk=90.0;
float y_12y[]={31.5,72.5,113.28,140.16,149.76}; y_12yk=300.0;
float y_13x[]={37.64,59.5,72.96,51.84,65.28};   y_13xk=91.0;
float y_13y[]={11.29,18.2,21.89,15.55,19.59};   y_13yk=28.0;
float y_14x[]={44.55,82.0,134.4,124.8,109.44};  y_14xk=205.0;
float y_14y[]={13.4,22.7,40.32,37.44,32.84};    y_14yk=62.0;
float y_15x[]={27.96,48.0,69.88,52.42,52.41};   y_15xk=2.0;
if((a>=1)&&(a<=3))
      {
      k_2x=polym(x,y_2x,5,a);    k_2y=polym(x,y_2y,5,a);
      k_4y=polym(x,y_4y,5,a);    k_3x=polym(x,y_3x,5,a);
      k_5x=polym(x,y_5x,5,a);    k_5y=polym(x,y_5y,5,a);
      k_7y=polym(x,y_7y,5,a);    k_6x=polym(x,y_6x,5,a);
      k_8x=polym(x,y_8x,5,a);    k_8y=polym(x,y_8y,5,a);
      k_10y=polym(x,y_10y,5,a);  k_9x=polym(x,y_9x,5,a);
      k_11x=polym(x,y_11x,5,a);  k_11y=polym(x,y_11y,5,a);
      k_12x=polym(x,y_12x,5,a);  k_12y=polym(x,y_12y,5,a);
      k_13x=polym(x,y_13x,5,a);  k_13y=polym(x,y_13y,5,a);
      k_14x=polym(x,y_14x,5,a);  k_14y=polym(x,y_14y,5,a);
      k_15x=polym(x,y_15x,5,a);
      }
else if(a>3)
      {
      k_2x=y_2xk; k_2y=y_2yk; k_4y=y_4yk;   k_3x=y_3xk;
      k_5x=y_5xk; k_5y=y_5yk; k_7y=y_7yk;   k_6x=y_6xk;
      k_8x=y_8xk; k_8y=y_8yk; k_10y=y_10yk; k_9x=y_9xk;
      k_11x=y_11xk; k_11y=y_11yk; k_12x=y_12xk;
      k_12y=y_12yk; k_13x=y_13xk; k_13y=y_13yk;
      k_14x=y_14xk; k_14y=y_14yk; k_15x=y_15xk;
      }
if(b==2){
float k_2xAr[]={k_2x,k_2y,k_4y,k_3x}; kR=big(k_2xAr,4);     *p=kR;}
```

```
else if(b==3){
float k_3xAr[]={k_2x,k_2y,k_4y,k_3x}; kR=big(k_3xAr,4); *p=kR;}
else if(b==5){
floatk_5xAr[]={k_5x,k_5y,k_7y,k_6x};kR2sl=big(k_5xAr,4);*p=kR2sl;}
else if(b==8){
float
k_8xAr[]={k_8x,k_8y,k_10y,k_9x};kR2ls=big(k_8xAr,4);*p=kR2ls;}
else if(b==11){
float k_11xAr[]={k_11x,k_11y,k_12x,k_12y,k_13x,k_13y,k_14x,k_14y,
            k_15x};
            kR3fl=big(k_11xAr,9); *p=kR3fl;
      }
}

//Function for analysis of stresses in vertical stiffener.

void Stress_VS(float ca[], float Ma, float Smax, float BS,
             float Fcomp, float Lopt,float *p,float *q,
             float *r, float *s, float *t, float *u,float *v,
             float*x,float*y, float*z,float *a)
{
float webL[]={60,60,60,60,55,50,50};
float webW[]={1.2,1.18,1.12,1.2,1.12,1.02,0.92};
float flgL[]={28,25,25,21,19,18,18};
float flgW[]={2.36,2.36,2.13,2.08,1.93,1.72,1.41};
float wVSa1[]={165.5,145.1,133.7,122.6,103.7,86.9,75.0};
float a_caw,a_web,a_flg,y_caw,y_web,y_flg,ay_caw,ay_web,ay_flg;
float aT,ayT,y1_caw,y1_web,y1_flg,y2_caw,y2_web,y2_flg;
float ay2_caw,ay2_web,ay2_flg,Islf,I;
float f1a,f2a,f3a,wVSa,fxa,fya,Sa,Scomp,Scomba,STspa,STflga;
float fxa1,fya1,Sa1,Scomp1,Scomba1,STspa1,STflga1;
cout.precision(3);
for(int i=0;i<7;i++)
      {
webL[i]=webL[i]/2-webW[i];  a_caw=ca[0]*ca[1];
a_web=webL[i]*webW[i];      a_flg=flgL[i]*flgW[i];y_caw=ca[1]/2;
y_web=webL[i]/2+ca[1];      y_flg=ca[1]+webL[i]+flgW[i]/2;
ay_caw=a_caw*y_caw;  ay_web=a_web*y_web; ay_flg=a_flg*y_flg;
aT=a_caw+a_web+a_flg; ayT=ay_caw+ay_web+ay_flg;
y1_caw=ayT/aT; y1_web=webL[i]+flgW[i]+ca[1]-y1_caw;
y1_flg=webL[i]+flgW[i]-y1_web;
y2_caw=y1_caw-ca[1]/2; y2_web=y_web-y1_caw;
y2_flg=y_flg-y1_caw; ay2_caw=pow(y2_caw,2)*a_caw;
ay2_web=pow(y2_web,2)*a_web; ay2_flg=pow(y2_flg,2)*a_flg;
Islf=pow(webL[i],3)*webW[i]/12; I=ay2_caw+ay2_web+ay2_flg+Islf;
      wVSa=wVSa1[i]/2;
      f1a=(Ma*Lopt/(I/y1_caw))*1000;
      f2a=(Ma*Lopt/(I/y1_web))*1000;
      f3a=(Ma*Lopt/(I/y1_flg))*1000;
      Sa=Smax*10*Lopt/a_web;
      Scomp=(-Fcomp/aT); STspa=f1a+Scomp; STflga=(-f2a+Scomp);
      fxa=(-BS); fya=f3a+Scomp;
      Scomba=sqrt(pow(fxa,2)+pow(fya,2)-(fxa*fya));
if((((f1a>1125)||(f2a>1125))||(abs(f3a)>1125))||(((Sa>875)
      ||((STspa>1125)||(STflga>1125)))||(Scomba>1500))) break;
      *p=f1a;*q=f2a;*r=f3a; *s=Sa;*t=STspa; *u=STflga;
      *v=Scomba;*x=webL[i];*y=flgL[i];*z=flgW[i];*a=wVSa;
      }
float webL1[11]={25,20,12.5,10,10,8,6,5,4,3,2};
float webW1[11]={0.92,0.8,0.88,0.78,1.0,0.8,0.6,0.6,0.6,0.3,0.3};
float flgL1[11]={18,16.5,25,20,10,8,6,5,4,3,2};
```

```
float flgW1[11]={1.41,1.25,0.97,0.9,1.0,0.8,0.6,0.6,0.6,0.3,0.3};
floatwVSa2[11]={37.5,28.4,27.4,20.0,15.0,9.6,5.4,4.5,3.5,1.4,0.9};
float a_caw1,a_web1,a_flg1,y_caw1,y_web1,y_flg1,ay_caw1,
ay_web1,ay_flg1,aT1,ayT1,y1_caw1,y1_web1,y1_flg1,y2_caw1,
y2_web1,y2_flg1,ay2_caw1,ay2_web1,ay2_flg1,Islf1,I1,
f1a1,f2a1,f3a1,wVSa11;
cout.precision(3);
for(int j=0;j<11;j++)
      {
webL1[j]=webL1[j]-webW1[j];
a_caw1=ca[0]*ca[1];  a_web1=webL1[j]*webW1[j];
a_flg1=flgL1[j]*flgW1[j];y_caw1=ca[1]/2;
y_web1=webL1[j]/2+ca[1]; y_flg1=ca[1]+webL1[j]+flgW1[j]/2;
ay_caw1=a_caw1*y_caw1;   ay_web1=a_web1*y_web1;
ay_flg1=a_flg1*y_flg1;
aT1=a_caw1+a_web1+a_flg1; ayT1=ay_caw1+ay_web1+ay_flg1;
y1_caw1=ayT1/aT1; y1_web1=webL1[j]+flgW1[j]+ca[1]-y1_caw1;
y1_flg1=webL1[j]+flgW1[j]-y1_web1;
y2_caw1=y1_caw1-ca[1]/2; y2_web1=y_web1-y1_caw1;
y2_flg1=y_flg1-y1_caw1; ay2_caw1=pow(y2_caw1,2)*a_caw1;
ay2_web1=pow(y2_web1,2)*a_web1; ay2_flg1=pow(y2_flg1,2)*a_flg1;
Islf1=pow(webL1[j],3)*webW1[j]/12;
I1=ay2_caw1+ay2_web1+ay2_flg1+Islf1;
      wVSa11=wVSa2[j];
      f1a1=(Ma*Lopt/(I1/y1_caw1))*1000;
      f2a1=(Ma*Lopt/(I1/y1_web1))*1000;
      f3a1=(Ma*Lopt/(I1/y1_flg1))*1000;
      Sa1=Smax*10*Lopt/a_web1;
      Scomp1=(-Fcomp/aT1); STspa1=f1a1+Scomp1;
      STflga1=(-f2a1+Scomp1); fxa1=(-BS); fya1=f3a1+Scomp1;
      Scomba1=sqrt(pow(fxa1,2)+pow(fya1,2)-(fxa1*fya1));
if((((f1a1>1125)||(f2a1>1125))||(abs(f3a1)>1125))||(((Sa1>875)
      ||((STspa1>1125)||(STflga1>1125)))||(Scomba1>1500))) break;
      *p=f1a1;*q=f2a1;*r=f3a1; *s=Sa1;*t=STspa1; *u=STflga1;
      *v=Scomba1;*x=webL1[j];*y=flgL1[j];*z=flgW1[j];*a=wVSa11;
      }
}

//Function for analysis of stresses in  horizontal girder in
//Vertical Lift Gate.

void Stress_VHG(float ca[], float CS, float Ra, float FFw,
            float *p, float *q, float *r, float *s, float *t,
            float *u, float *v)
{
//Moment and forces for girders
//Condition 1:(water load and sill pressure). UDL=Ra.
//Girder moments:

float dl,E=2.1e+6;
float MGcentre=1*pow(CS,2)/8;       //BM at span CS.
float MG_sp=MGcentre*Ra;      //BM at mid-span.(tm).
float RA1=Ra*CS/2;            //Reaction in tonnes.
float MGmax=MG_sp; float SFmax=RA1;  float dlG,dlmax;
float xG,zG,yG,Zxx,Sarea,fbG,SSmax,wHG; long Ixx;
float webL[]={350,300,280,260,250,250,240,230,240,230,220,225,
            220,230,220,220,200,180,150,140,120,110,105,100,85,
            80,80,70,55,50,45,40,36,34,32};
float webW[]={10,10,10,10,9,8,8,7.5,7,6.5,6,5,5,4.5,4.5,3.2,3.2,
            3.2,3.2,3.2,4,4,3.2,3.2,3.2,3.2,2.5,2.5,2.5,2.5,
            2.5,2.5,2,2,2};
```

```
float       flgL[]={50,50,50,50,50,50,50,50,47,50,46,43,45,32,35,36,
            40,40,36,40,40,42,32,25,30,35,32,30,30,28,26,25,
            25,25,25};
float       flgW[]={6,6,6,5,5,5,5,5,4,4,5,5,4,4,4,4,4,4,5,4,4,4,4,4,
            4,3.2,3.2,3.2,3.2,3.2,3.2,3.2,3.2,3.2,2.5};
float xG3a,yG3a,zG3a,Zxx3a,Sarea3a,fbG3a,SSmax3a; long Ixx3a;
float webL3a[]={60,55,50,50,45,40,35,32.5,30};
float webW3a[]={1.12,1.12,1.02,0.92,0.86,0.8,0.74,0.7,0.67};
float flgL3a[]={25,19,18,18,17,16.5,16.5,16.5,15.0};
float flgW3a[]={2.13,1.93,1.72,1.41,1.34,1.25,1.14,0.98,0.94};
float wHG3a[]={133.7,103.7,86.9,75.0,65.3,56.9,49.5,43.1,37.7};
for(int i=0;i<35;i++)
            {
      xG=webL[i]/2+flgW[i]/2; zG=webL[i]/2+flgW[i]+ca[1]/2;
      Ixx=webW[i]*pow(webL[i],3)/12+2*flgL[i]*flgW[i]*pow(xG,2)
          +ca[0]*ca[1]*pow(zG,2);
      yG=webL[i]/2+flgW[i];
      Zxx=Ixx/yG;  Sarea=webL[i]*webW[i];
      wHG=(webL[i]*webW[i]+2*flgL[i]*flgW[i])*0.7850;
      fbG=MGmax*100*1000/Zxx; SSmax=SFmax*1000/Sarea; dlG=CS/8;
      dlmax=5*Ra*10*pow((FFw*100),4)/384/E/Ixx;
      if(((fabs(fbG)>1080)||(SSmax>840))||(dlmax>dlG)) break;
        *p=webL[i];*q=flgL[i]; *r=flgW[i];; *s=wHG; *u=dlmax;
            }
      for(int j=0;j<9;j++)
            {
      webL3a[j]=webL3a[j]-2*flgW3a[j];
      xG3a=webL3a[j]/2+flgW3a[j]/2;
      zG3a=webL3a[j]/2+flgW3a[j]+ca[1]/2;
      Ixx3a=webW3a[j]*pow(webL3a[j],3)/12
            +2*flgL3a[j]*flgW3a[j]*pow(xG3a,2)
            +ca[0]*ca[1]*pow(zG3a,2);
      yG3a=webL3a[j]/2+flgW3a[j]; Zxx3a=Ixx3a/yG3a;
      Sarea3a=webL3a[j]*webW3a[j]; fbG3a=MGmax*100*1000/Zxx3a;
      SSmax3a=SFmax*1000/Sarea3a;  dlG=CS/8;
      dlmax=5*Ra*10*pow((FFw*100),4)/384/E/Ixx3a;
if(((fabs(fbG3a)>1080)||(SSmax3a>840))||(dlmax>dlG)) break;
      *p=webL3a[j];*q=flgL3a[j]; *r=flgW3a[j];; *s=wHG3a[j];
      *u=dlmax;
      }
      *t=RA1; *v=MG_sp;
}

//Function for analysis of stresses on vertical end girder.

void Stress_VEG(float tsp, float Mmax, float SFmax, float Lopt,
            float *p,float *q,float *r, float *s,
            float *t, float *u)
{
float webLVG[]={350,350,350,350,350,300,280,260,250,250,240,230,
            240,230,220,225,220,230,220,220,200,180,150,140,
            120,110,105,100,85,80,80,70,55,50,45,40,36,34,32};
float webWVG[]={30,25,20,15,10,10,10,10,9,8,8,7.5,7,6.5,6,5,5,4.5,
            4.5,3.2,3.2,3.2,3.2,3.2,4,4,3.2,3.2,3.2,3.2,2.5,
            2.5,2.5,2.5,2.5,2.5,2,2,2};
float a_spl,a_web,a_hol,y_spl,y_web,y_hol,ay_spl,ay_web,ay_hol;
float aT,ayT,y1_spl,y1_web,y1_hol,y2_spl,y2_web,y2_hol;
float ay2_spl,ay2_web,ay2_hol,Islf,I;
float fb_sp,fb_opp,SS,wVEG;
cout.precision(3);
for(int i=0;i<29;i++)
```

```
      {
a_spl=tsp*webWVG[i];
a_web=webLVG[i]*webWVG[i]; a_hol=0.2*webLVG[i]*webWVG[i];
y_spl=tsp/2; y_web=webLVG[i]/2+tsp; y_hol=y_web;
ay_spl=a_spl*y_spl;  ay_web=a_web*y_web; ay_hol=a_hol*y_hol;
aT=a_spl+a_web-a_hol; ayT=ay_spl+ay_web-ay_hol;
y1_spl=ayT/aT; y1_web=webLVG[i]+tsp-y1_spl;
y2_spl=y1_spl-tsp/2; y2_web=y_web-y1_spl;
y2_hol=y_hol-y1_spl; ay2_spl=pow(y2_spl,2)*a_spl;
ay2_web=pow(y2_web,2)*a_web; ay2_hol=pow(y2_hol,2)*a_hol;
Islf=pow(webLVG[i],3)*webWVG[i]/12;I=ay2_spl+ay2_web-ay2_hol+Islf;
      wVEG=(webLVG[i]*webWVG[i]-a_hol)*0.7850;
      fb_sp=(Mmax*Lopt/(I/y1_spl))*1000;
      fb_opp=(Mmax*Lopt/(I/y1_web))*1000;
      SS=SFmax*10*Lopt/(a_web-a_hol);
if(((fb_sp>1080)||(fb_opp>1080))||(SS>840))  break;
  *p=fb_sp;*q=fb_opp;*r=SS;*s=webLVG[i];*t=webWVG[i];*u=wVEG;
      }
}

//Function for computing wheel of vertical lift gate.

void Wheel(float PN, float PE, float HD, float *p,float *q,
         float *r, float *s)
{
float P,BHN,R1,R2,Pois,UTS,SSall,SconallP,SconallL,Scrit,SallN,
      SallE,Apro,AproN,AproE,A,B,Ratio,k,yP,yZ1,y1Z,EP,a,S1Zz,
      SSWmax,Z1,E,aa,bb,SconP,SconL,wWheel,DwheelA; int w;
float Rat[]={1,2,3,4,5,6,7,8};
float yk[]={1,0.65,0.5,0.41,0.36,0.32,0.3,0.28};
float yPa3[]={1.32,0.655,0.42,0.305,0.225,0.175,0.15,0.13};
float yZ1a[]={0.475,0.375,0.33,0.275,0.24,0.235,0.21,0.2};
float y1Zz[]={0.415,0.33,0.275,0.24,0.215,0.185,0.17,0.16};
//float y0Zz[]={0.17,0.16,0.145,0.14,0.13,0.115,0.1,0.095};
      BHN=255; R1=76.8; Pois=0.25; UTS=9000;
      SSall=24.61*BHN;  SconallP=2.4*UTS; SconallL=1.6*UTS;
      Scrit=1.72*BHN-154.68; E=2.1e+6;
      SallN=Scrit/3; SallE=Scrit/2;
      AproN=PN/SallN*1000; AproE=PE/SallE*1000;
if(AproE>AproN){ P=PE*1000; Apro=AproE; }
            else{ P=PN*1000; Apro=AproN; }
            cout.precision(2);
if(HD<6) DwheelA=35;
else if((HD>=6)&&(HD<8)) DwheelA=40;
else if((HD>=8)&&(HD<10)) DwheelA=45;
else if((HD>=10)&&(HD<12)) DwheelA=55;
else if((HD>=12)&&(HD<15)) DwheelA=65;
else if(HD>15) DwheelA=75;
do{
      R2=DwheelA/2; A=1/(2*R1); B=1/(2*R2); Ratio=B/A;
      w=Apro/(2*R2)+1;  k=polym(Rat,yk,8,Ratio);
      yP=polym(Rat,yPa3,8,Ratio); yZ1=polym(Rat,yZ1a,8,Ratio);
      y1Z=polym(Rat,y1Zz,8,Ratio);//y0Z=polym(Rat,y0Zz,8,Ratio);
      EP=2*(1-pow(Pois,2))/(E*(A+B));
      aa=pow((EP*P/yP),1/3); S1Zz=y1Z*aa/EP; SSWmax=S1Zz/2;
      Z1=yZ1*aa; bb=k*aa; SconP=P/((2/3)*3.145927*aa*bb);
      SconL=0.418*pow((P*E/w*R2),1/2);
      wWheel=3.145927*pow(R2,2)*w*7.850/1000;
      }
while(((SSWmax>SSall)||(SconP>SconallP))||(SconL>SconallL));
      *p=Z1;*q=R2;*r=w;*s=wWheel;
```

```
}

//Function for analysis of stresses in  horizontal girders

void Stress_HG(float ca[],float Rad,float CS,float LarmCor,
             float Ra, float Raw, float RTh,float *p,float *q,
             float *r,float *s,float *t,float *u,float *v)
{
float AB,BC,CD,BE,IG,IA,LG,LA,KBC,KBE;
      AB=CS*(0.2071); CD=AB;  BC=CS-(2*AB); LG=CS;
      BE=Rad/cos(atan(AB/Rad));  LA=BE-LarmCor;
      KBC=(4*25/LG)/(4*25/LG+3/LA);     //IG=25*IA;
      KBE=1-KBC;   float ep=0.1e-5;
float MBA=1*pow(AB,2)/2;  float MCB=1*pow(BC,2)/12;
float MBC=-MCB;              float McantG=MBA;   float MbeamG=MBC;
float MRbeamG=(MbeamG+McantG); float CMbeamG,tb; float McanTG=0;
      do
      {
      MbeamG=-MRbeamG*KBC;McanTG+=-MRbeamG*KBE;CMbeamG=-MbeamG/2;
      tb=CMbeamG; CMbeamG=MRbeamG; MRbeamG=tb;
      }
      while(fabs(CMbeamG)<ep);
MbeamG=-(McantG+McanTG); float BMcentre=1*pow(BC,2)/8+MbeamG;

//Cantilever moment from rope tension @ x-x axis of girder  for
//unit load.

float McantR=1*(CD-300/1000);     //tm.

//Moment distribution due to rope tension for unit load.

float MRbeamR=McantR;  float MbeamR,CMbeamR,tr;  float McanTR=0;
      do
      {
      MbeamR=-MRbeamR*KBC;McanTR+=-MRbeamR*KBE;CMbeamR=-MbeamR/2;
      tr=CMbeamR; CMbeamR=MRbeamR; MRbeamR=tr;
      }
      while(fabs(CMbeamR)<ep);
      MbeamR=-(McantR+McanTR);

//Moment and forces for girders
//Condition 1:(water load and sill pressure). UDL=Ra.
//Girder moments:

float MG1=-(MbeamG*Ra);        //BM at 'B' or 'C'.
float MG_BC1=BMcentre*Ra;      //BM at span.(tm).
float RA1=Ra*CS/2;  float SFbot1=AB*Ra; //Reaction in tonnes.
float SFtop1=RA1-SFbot1;             //Max. shear force.

//Condition 2:(Water load and rope tension). UDL=Raw.

float MG2=(-MbeamG*Raw)+(-MbeamR*RTh);//BM at support 'a',tm.
float MG_BC2=BMcentre*Raw+MbeamR*RTh; //BM at mid span 'BC',tm.
float RA2=Raw*CS/2+RTh;  float SFbot2=Raw*AB;//Reaction in tonnes.
float SFtop2=RA2-SFbot2;
float MGmaxArr[]={MG1,MG_BC1,MG2,MG_BC2}; //Check for stresses
float MGmax=big(MGmaxArr,4);
float SFArr[]={SFbot1,SFtop1,SFbot2,SFtop2};
float SFmax=big(SFArr,4); float BMarm=Raw*McanTG+RTh*McanTR;
float xG,zG,yG,Zxx,Sarea,fbG,SSmax,wHG; long Ixx;
float webL[]={350,300,280,260,250,250,240,230,240,230,220,225,
```

```
            220,230,220,220,200,180,150,140,120,110,105,100,85,
            80,80,70,55,50,45,40,36,34,32};
float webW[]={10,10,10,10,9,8,8,7.5,7,6.5,6,5,5,4.5,4.5,3.2,3.2,
            3.2,3.2,3.2,4,4,3.2,3.2,3.2,3.2,2.5,2.5,2.5,2.5,2.5,
            2.5,2,2,2};
float flgL[]={50,50,50,50,50,50,50,50,47,50,46,43,45,32,35,36,40,
            40,36,40,40,42,32,25,30,35,32,30,30,28,26,25,25,
            25,25};
float flgW[]={6,6,6,5,5,5,5,5,4,4,5,5,4,4,4,4,4,4,5,4,4,4,4,4,4,
            3.2,3.2,3.2,3.2,3.2,3.2,3.2,3.2,3.2,2.5};
float xG3a,yG3a,zG3a,Zxx3a,Sarea3a,fbG3a,SSmax3a; long Ixx3a;
float webL3a[8]={55,50,50,45,40,35,32.5,30};
float webW3a[8]={1.12,1.02,0.92,0.86,0.8,0.74,0.7,0.67};
float flgL3a[8]={19,18,18,17,16.5,16.5,16.5,15.0};
float flgW3a[8]={1.93,1.72,1.41,1.34,1.25,1.14,0.98,0.94};
float wHG3a[8]={103.7,86.9,75.0,65.3,56.9,49.5,43.1,37.7};
for(int i=0;i<35;i++)
            {
      xG=webL[i]/2+flgW[i]/2; zG=webL[i]/2+flgW[i]+ca[1]/2;
      Ixx=webW[i]*pow(webL[i],3)/12+2*flgL[i]*flgW[i]*pow(xG,2)
          +ca[0]*ca[1]*pow(zG,2);
      yG=webL[i]/2+flgW[i]; yG=webL[i]/2+flgW[i];
      Zxx=Ixx/yG;  Sarea=webL[i]*webW[i];
      wHG=(webL[i]*webW[i]+2*flgL[i]*flgW[i])*0.7850;
      fbG=MGmax*100*1000/Zxx; SSmax=SFmax*1000/Sarea;
      if((fabs(fbG)>1080)||(SSmax>840)) break;
          *p=webL[i];*q=flgL[i]; *r=flgW[i]; *s=wHG; *t=RA1;
            }
      for(int j=0;j<8;j++)
            {
      webL3a[j]=webL3a[j]-2*flgW3a[j];
      xG3a=webL3a[j]/2+flgW3a[j]/2;
      zG3a=webL[j]/2+flgW[j]+ca[1]/2;
      Ixx3a=webW3a[j]*pow(webL3a[j],3)/12
            +2*flgL3a[j]*flgW3a[j]*pow(xG3a,2)
            +ca[0]*ca[1]*pow(zG3a,2);;
      yG3a=webL3a[j]/2+flgW3a[j];
      Zxx3a=Ixx3a/yG3a;  Sarea3a=webL3a[j]*webW3a[j];
      fbG3a=MGmax*100*1000/Zxx3a; SSmax3a=SFmax*1000/Sarea3a;
      if((fabs(fbG3a)>1080)||(SSmax3a>840)) break;
          *p=webL3a[j];*q=flgL3a[j]; *r=flgW3a[j]; *s=wHG3a[j];
          *t=RA1;
          }
          *u=BMarm; *v=LA;
}

//Function for computing Trunnion Level.

void Rvv(float Rvvx[], float *p,float *q,float *r, float *s)
{
float Rh,Rv,TL,Rvb,Rvt,A;
      {
      Rh=Rvvx[0]*0.805+Rvvx[2];
      Rv=pow(Rh,1.85)*pow((Rvvx[1]-0.3),-0.85)/2.0;
      TL=Rvvx[4]-Rv-Rvvx[3]+Rvvx[1];   //Trunnion level.
      Rvb=TL-Rvvx[4]+1.500; Rvt=Rvvx[1]-Rvb;
      A=asin(Rvb/Rvvx[0]);       //Angles in radians.
      }
      *p=TL; *q=Rvb; *r=Rvt; *s=A;
}
```

```
//Function for computing allowable stress for a slenderness ratio.

void Pbc_all(float a, float *p, char c)
{
float Pc;
float x1[]={0.0,10.0,20.0,30.0,40.0,50.0,60.0,70.0,80.0};
float x2[]={0.0,20.0,40.0,60.0,80.0,100.0,120.0,140.0,160.0};
float x3[]={0.0,30.0,60.0,90.0,120.0,150.0,180.0,210.0,140.0};
float y1[]={1250.0,1246.0,1239.0,1224.0,1203.0,1172.0,1130.0,
          1007.0,928.0};
float y2[]={1250.0,1239.0,1203.0,1130.0,1007.0,840.0,671.0,531.0,
          423.0};
float y3[]={1250.0,1224.0,1130.0,928.0,671.0,474.0,336.0,243.0,
          181.0};
if(c=='l'){Pc=polym(x1,y1,9,a);}
      else if(c=='m'){Pc=polym(x2,y2,9,a);}
      else if(c=='h'){Pc=polym(x3,y3,9,a);} // kg/sq.cm.
if(Pc<1080)Pc=Pc;
      else {Pc=1080;}   *p=Pc;
}

//Function for analysis of stresses in  Arms.

void Stress_Arm(float Faxmax, float BMarmmax, float le,
            float *p, float *q, float *r,float *s)
{
float webL[]={56}; float webW[]={3.2}; float flgL[]={40};
float flgW[]={4};
float fc,fbc,fT;   //lr : SlRatio, Pbc : Allowable stress.
float SA,Ixx,x,y,Zxx,rxx,lr,Pbc,wArm;
for(int i=0;i<1;i++)
      {
      SA=2*flgL[i]*flgW[i]+webL[i]*webW[i];
      x=webL[i]/2+flgW[i]/2;
      Ixx=webW[i]*pow(webL[i],3)/12+2*flgL[i]*flgW[i]*pow(x,2);
      y=(webL[i]+2*flgW[i])/2; Zxx=Ixx/y;
      rxx=pow(Ixx,0.5)/(pow(SA,0.5)); lr=le/rxx*100;
      wArm=(webL[i]*webW[i]+2*flgL[i]*flgW[i])*0.7850;
if(lr<80.0)Pbc_all(lr,&Pbc,'l');
      else if((lr>80.0)&&(lr<160))Pbc_all(lr,&Pbc,'m');
      else if((lr>160)&&(lr<240))Pbc_all(lr,&Pbc,'h'); Pbc=Pbc;
fc=Faxmax/SA*1000; //Direct compressive stress. kg/sq.cm.
fbc=BMarmmax/Zxx*100*1000; //Bending stress, kg/sq.cm.
fT=fc+fbc;
if(fT>Pbc) break;  *p=webL[i]; *q=flgL[i];  *r=flgW[i];  *s=wArm;
      }
float webL1=45; float webW1=1.13; float flgL1=25;
float flgW1=1.37; float plaL1=40;
float plaW1[6]={4,3.2,2.5,2.0,1.6,1.2};
float wArm11[6]={343.7,293.5,249.5,218.1,193.0,167.9};
float fc1,fbc1,fT1;     //lr : SlRatio, Pbc : Allowable stress.
float SA1,Ixx1,x1a,x1b,y1,Zxx1,rxx1,lr1,Pbc1,wArm1;
for(i=0;i<6;i++)
      {
      SA1=2*flgL1*flgW1+webL1*webW1+2*plaL1*plaW1[i];
      x1a=webL1/2+flgW1/2; x1b=webL1/2+flgW1+plaW1[i]/2;
      Ixx1=webW1*pow(webL1,3)/12+2*flgL1*flgW1*pow(x1a,2)
           +2*plaL1*plaW1[i]*pow(x1b,2);
      y1=(webL1+2*flgW1+2*plaW1[i])/2; Zxx1=Ixx1/y1;
      rxx1=pow(Ixx1,0.5)/(pow(SA1,0.5));
      lr=le/rxx1*100; wArm1=wArm11[i];
```

```
if(lr<80.0)Pbc_all(lr,&Pbc,'l');
      else if((lr>80.0)&&(lr<160))Pbc_all(lr,&Pbc,'m');
      else if((lr>160)&&(lr<240))Pbc_all(lr,&Pbc,'h'); Pbc=Pbc;
fc1=Faxmax/SA1*1000; //Direct compressive stress. kg/sq.cm.
fbc1=BMarmmax/Zxx1*100*1000; //Bending stress, kg/sq.cm.
fT1=fc1+fbc1;
if(fT1>Pbc) break;  *p=webL1; *q=flgL1;  *r=flgW1;  *s=wArm1;
      }
float webL2=40; float webW2=1.06; float flgL2=25;
float flgW2=1.27; float plaL2=32;
float plaW2[2]={1.6,1.2}; float wArm22[2]={162.5,142.4};
float fc2,fbc2,fT2;   //lr : SlRatio, Pbc : Allowable stress.
float SA2,Ixx2,x2a,x2b,y2,Zxx2,rxx2,lr2,Pbc2,wArm2;
for(i=0;i<2;i++)
      {
      SA2=2*flgL2*flgW2+webL2*webW2+2*plaL2*plaW2[i];
      x2a=webL2/2+flgW2/2; x2b=webL2/2+flgW2+plaW2[i]/2;
      Ixx2=webW2*pow(webL2,3)/12+2*flgL2*flgW2*pow(x2a,2)
           +2*plaL2*plaW2[i]*pow(x2b,2);
      y2=(webL2+2*flgW2+2*plaW2[i])/2; Zxx2=Ixx2/y2;
      rxx2=pow(Ixx2,0.5)/(pow(SA2,0.5));
      lr=le/rxx2*100;  wArm2=wArm22[i];
if(lr<80.0)Pbc_all(lr,&Pbc,'l');
      else if((lr>80.0)&&(lr<160))Pbc_all(lr,&Pbc,'m');
      else if((lr>160)&&(lr<240))Pbc_all(lr,&Pbc,'h'); Pbc=Pbc;
fc2=Faxmax/SA2*1000; //Direct compressive stress. kg/sq.cm.
fbc2=BMarmmax/Zxx2*100*1000; //Bending stress, kg/sq.cm.
fT2=fc2+fbc2;
if(fT2>Pbc) break;  *p=webL2; *q=flgL2;  *r=flgW2;  *s=wArm2;
      }
float webL3=35; float webW3=1.01; float flgL3=25;
float flgW3=1.16; float plaL3=32; float plaW3[1]={1.2};
float wArm33[1]={132.7};
float fc3,fbc3,fT3;     //lr : SlRatio, Pbc : Allowable stress.
float SA3,Ixx3,x3a,x3b,y3,Zxx3,rxx3,lr3,Pbc3,wArm3;
for(i=0;i<1;i++)
      {
      SA3=2*flgL3*flgW3+webL3*webW3+2*plaL3*plaW3[i];
      x3a=webL3/2+flgW3/2; x3b=webL3/2+flgW3+plaW3[i]/2;
      Ixx3=webW3*pow(webL3,3)/12+2*flgL3*flgW3*pow(x3a,2)
           +2*plaL3*plaW3[i]*pow(x3b,2);
      y3=(webL3+2*flgW3+2*plaW3[i])/2;  Zxx3=Ixx3/y3;
      rxx3=pow(Ixx3,0.5)/(pow(SA3,0.5));
      lr=le/rxx3*100;   wArm3=wArm33[i];
if(lr<80.0)Pbc_all(lr,&Pbc,'l');
      else if((lr>80.0)&&(lr<160))Pbc_all(lr,&Pbc,'m');
      else if((lr>160)&&(lr<240))Pbc_all(lr,&Pbc,'h'); Pbc=Pbc;
fc3=Faxmax/SA3*1000; //Direct compressive stress. kg/sq.cm.
fbc3=BMarmmax/Zxx3*100*1000; //Bending stress, kg/sq.cm.
fT3=fc3+fbc3;
if(fT3>Pbc) break;  *p=webL3; *q=flgL3;  *r=flgW3;  *s=wArm3;
      }
webL3=32;  webW3=0.83;  flgL3=25;   flgW3=0.97;  plaL3=32;
float plaW3a[1]={1.2};  float wArm33a[1]={127.7};
fc3,fbc3,fT3;        //lr : SlRatio, Pbc : Allowable stress.
SA3,Ixx3,x3a,x3b,y3,Zxx3,rxx3,lr3,Pbc3,wArm3;
for(i=0;i<1;i++)
      {
      SA3=2*flgL3*flgW3+webL3*webW3+2*plaL3*plaW3a[i];
      x3a=webL3/2+flgW3/2; x3b=webL3/2+flgW3+plaW3a[i]/2;
      Ixx3=webW3*pow(webL3,3)/12+2*flgL3*flgW3*pow(x3a,2)
```

```
           +2*plaL3*plaW3a[i]*pow(x3b,2);
      y3=(webL3+2*flgW3+2*plaW3a[i])/2; Zxx3=Ixx3/y3;
      rxx3=pow(Ixx3,0.5)/(pow(SA3,0.5));
      lr=le/rxx3*100;  wArm3=wArm33a[i];
if(lr<80.0)Pbc_all(lr,&Pbc,'l');
      else if((lr>80.0)&&(lr<160))Pbc_all(lr,&Pbc,'m');
      else if((lr>160)&&(lr<240))Pbc_all(lr,&Pbc,'h'); Pbc=Pbc;
fc3=Faxmax/SA3*1000; //Direct compressive stress. kg/sq.cm.
fbc3=BMarmmax/Zxx3*100*1000; //Bending stress, kg/sq.cm.
fT3=fc3+fbc3;
if(fT3>Pbc) break;  *p=webL3; *q=flgL3;  *r=flgW3;  *s=wArm3;
      }
float webL4=25; float webW4=0.88; float flgL4=25;
float flgW4=0.97; float plaL4=40;
float plaW4[1]={1.2};  float wArm44[1]={126.4};
float fc4,fbc4,fT4;    //lr : SlRatio, Pbc : Allowable stress.
float SA4,Ixx4,x4a,x4b,y4,Zxx4,rxx4,lr4,Pbc4,wArm4;
for(i=0;i<1;i++)
      {
      SA4=2*flgL4*flgW4+webL4*webW4+2*plaL4*plaW4[i];
      x4a=webL4/2+flgW4/2; x4b=webL4/2+flgW4+plaW4[i]/2;
      Ixx4=webW4*pow(webL4,3)/12+2*flgL4*flgW4*pow(x4a,2)
           +2*plaL4*plaW4[i]*pow(x4b,2);
      y4=(webL4+2*flgW4+2*plaW4[i])/2; Zxx4=Ixx4/y4;
      rxx4=pow(Ixx4,0.5)/(pow(SA4,0.5));
      lr=le/rxx4*100;   wArm4=wArm44[i];
if(lr<80.0)Pbc_all(lr,&Pbc,'l');
      else if((lr>80.0)&&(lr<160))Pbc_all(lr,&Pbc,'m');
      else if((lr>160)&&(lr<240))Pbc_all(lr,&Pbc,'h'); Pbc=Pbc;
fc4=Faxmax/SA4*1000; //Direct compressive stress. kg/sq.cm.
fbc4=BMarmmax/Zxx4*100*1000; //Bending stress, kg/sq.cm.
fT4=fc4+fbc4;
if(fT4>Pbc) break;  *p=webL4; *q=flgL4;  *r=flgW4;  *s=wArm4;
      }
float webL5=22.5; float webW5=0.86; float flgL5=22.5;
float flgW5=0.91; float plaL5=32;   float plaW5[1]={1.2};
float wArm55[1]={107.1};
float fc5,fbc5,fT5;    //lr : SlRatio, Pbc : Allowable stress.
float SA5,Ixx5,x5a,x5b,y5,Zxx5,rxx5,lr5,Pbc5,wArm5;
for(i=0;i<1;i++)
      {
      SA5=2*flgL5*flgW5+webL5*webW5+2*plaL5*plaW5[i];
      x5a=webL5/2+flgW5/2; x5b=webL5/2+flgW5+plaW5[i]/2;
      Ixx5=webW5*pow(webL5,3)/12+2*flgL5*flgW5*pow(x5a,2)
           +2*plaL5*plaW5[i]*pow(x5b,2);
      y5=(webL5+2*flgW5+2*plaW5[i])/2; Zxx5=Ixx5/y5;
      rxx5=pow(Ixx5,0.5)/(pow(SA5,0.5));
      lr=le/rxx5*100;  wArm5=wArm55[i];
if(lr<80.0)Pbc_all(lr,&Pbc,'l');
      else if((lr>80.0)&&(lr<160))Pbc_all(lr,&Pbc,'m');
      else if((lr>160)&&(lr<240))Pbc_all(lr,&Pbc,'h'); Pbc=Pbc;
fc5=Faxmax/SA5*1000; //Direct compressive stress. kg/sq.cm.
fbc5=BMarmmax/Zxx5*100*1000; //Bending stress, kg/sq.cm.
fT5=fc5+fbc5;
if(fT5>Pbc) break;  *p=webL5; *q=flgL5;  *r=flgW5;  *s=wArm5;
      }
float webL6=20; float webW6=0.78; float flgL6=20;
float flgW6=0.9; float plaL6=25;  float plaW6[1]={1.6};
float wArm66[1]={102.8};
float fc6,fbc6,fT6;        //lr : SlRatio, Pbc : Allowable stress.
float SA6,Ixx6,x6a,x6b,y6,Zxx6,rxx6,lr6,Pbc6,wArm6;
```

```
for(i=0;i<1;i++)
      {
      SA6=2*flgL6*flgW6+webL6*webW6+2*plaL6*plaW6[i];
      x6a=webL6/2+flgW6/2; x6b=webL6/2+flgW6+plaW6[i]/2;
      Ixx6=webW6*pow(webL6,3)/12+2*flgL6*flgW6*pow(x6a,2)
           +2*plaL6*plaW6[i]*pow(x6b,2);
      y6=(webL6+2*flgW6+2*plaW6[i])/2;  Zxx6=Ixx6/y6;
      rxx6=pow(Ixx6,0.5)/(pow(SA6,0.5));
      lr=le/rxx6*100;  wArm6=wArm66[i];
if(lr<80.0)Pbc_all(lr,&Pbc,'l');
      else if((lr>80.0)&&(lr<160))Pbc_all(lr,&Pbc,'m');
      else if((lr>160)&&(lr<240))Pbc_all(lr,&Pbc,'h'); Pbc=Pbc;
fc6=Faxmax/SA6*1000; //Direct compressive stress. kg/sq.cm.
fbc6=BMarmmax/Zxx6*100*1000; //Bending stress, kg/sq.cm.
fT6=fc6+fbc6;
if(fT6>Pbc) break;  *p=webL6; *q=flgL6;  *r=flgW6;  *s=wArm6;
      }
float webL7=17.5; float webW7=1.18; float flgL7=15;
float flgW7=0.9; float plaL7=25;
float plaW7[1]={1.6};  float wArm77[1]={93.4};
float fc7,fbc7,fT7;        //lr : SlRatio, Pbc : Allowable stress.
float SA7,Ixx7,x7a,x7b,y7,Zxx7,rxx7,lr7,Pbc7,wArm7;
for(i=0;i<1;i++)
      {
      SA7=2*flgL7*flgW7+webL7*webW7+2*plaL7*plaW7[i];
      x7a=webL7/2+flgW7/2; x7b=webL7/2+flgW7+plaW7[i]/2;
      Ixx7=webW7*pow(webL7,3)/12+2*flgL7*flgW7*pow(x7a,2)
           +2*plaL7*plaW7[i]*pow(x7b,2);
      y7=(webL7+2*flgW7+2*plaW7[i])/2;  Zxx7=Ixx7/y7;
      rxx7=pow(Ixx7,0.5)/(pow(SA7,0.5));
      lr=le/rxx7*100;  wArm7=wArm77[i];
if(lr<80.0)Pbc_all(lr,&Pbc,'l');
      else if((lr>80.0)&&(lr<160))Pbc_all(lr,&Pbc,'m');
      else if((lr>160)&&(lr<240))Pbc_all(lr,&Pbc,'h'); Pbc=Pbc;
fc7=Faxmax/SA7*1000; //Direct compressive stress. kg/sq.cm.
fbc7=BMarmmax/Zxx7*100*1000; //Bending stress, kg/sq.cm.
fT7=fc7+fbc7;
if(fT7>Pbc) break;  *p=webL7; *q=flgL7;  *r=flgW7;  *s=wArm7;
      }
float webL8=17.5; float webW8=0.58; float flgL8=12.5;
float flgW8=0.74; float plaL8=20;
float plaW8[1]={2};
float wArm88[1]={84.9};
float fc8,fbc8,fT8;     //lr : SlRatio, Pbc : Allowable stress.
float SA8,Ixx8,x8a,x8b,y8,Zxx8,rxx8,lr8,Pbc8,wArm8;
for(i=0;i<1;i++)
      {
      SA8=2*flgL8*flgW8+webL8*webW8+2*plaL8*plaW8[i];
      x8a=webL8/2+flgW8/2; x8b=webL8/2+flgW8+plaW8[i]/2;
      Ixx8=webW8*pow(webL8,3)/12+2*flgL8*flgW8*pow(x8a,2)
           +2*plaL8*plaW8[i]*pow(x8b,2);
      y8=(webL8+2*flgW8+2*plaW8[i])/2;  Zxx8=Ixx8/y8;
      rxx8=pow(Ixx8,0.5)/(pow(SA8,0.5));
      lr=le/rxx8*100;  wArm8=wArm88[i];
if(lr<80.0)Pbc_all(lr,&Pbc,'l');
      else if((lr>80.0)&&(lr<160))Pbc_all(lr,&Pbc,'m');
      else if((lr>160)&&(lr<240))Pbc_all(lr,&Pbc,'h'); Pbc=Pbc;
fc8=Faxmax/SA8*1000; //Direct compressive stress. kg/sq.cm.
fbc8=BMarmmax/Zxx8*100*1000; //Bending stress, kg/sq.cm.
fT8=fc8+fbc8;
if(fT8>Pbc) break;  *p=webL8; *q=flgL8;  *r=flgW8;  *s=wArm8;
```

```
        }
float webL9=15;  float webW9=0.54; float flgL9=10;
float flgW9=0.7; float plaL9=16;
float plaW9[5]={2.5,2.0,1.6,1.2,1.0};
float wArm99[5]={79.8,67.3,57.2,47.2,42.1};
float fc9,fbc9,fT9;    //lr : SlRatio, Pbc : Allowable stress.
float SA9,Ixx9,x9a,x9b,y9,Zxx9,rxx9,lr9,Pbc9,wArm9;
for(i=0;i<5;i++)
        {
        SA9=2*flgL9*flgW9+webL9*webW9+2*plaL9*plaW9[i];
        x9a=webL9/2+flgW9/2; x9b=webL9/2+flgW9+plaW9[i]/2;
        Ixx9=webW9*pow(webL9,3)/12+2*flgL9*flgW9*pow(x9a,2)
             +2*plaL9*plaW9[i]*pow(x9b,2);
        y9=(webL9+2*flgW9+2*plaW9[i])/2;  Zxx9=Ixx9/y9;
        rxx9=pow(Ixx9,0.5)/(pow(SA9,0.5));
        lr=le/rxx9*100;  wArm9=wArm99[i];
if(lr<80.0)Pbc_all(lr,&Pbc,'l');
        else if((lr>80.0)&&(lr<160))Pbc_all(lr,&Pbc,'m');
        else if((lr>160)&&(lr<240))Pbc_all(lr,&Pbc,'h'); Pbc=Pbc;
fc9=Faxmax/SA9*1000; //Direct compressive stress. kg/sq.cm.9
fbc9=BMarmmax/Zxx9*100*1000; //Bending stress, kg/sq.cm.
fT9=fc9+fbc9;
if(fT9>Pbc) break;  *p=webL9; *q=flgL9;  *r=flgW9;  *s=wArm9;
        }
}

//Function for analysis of stresses on skin plate

void Stress_SP(float Lopt,float t,float P,float L,int x,float*p)
{
//Check for skin plate as plate,  all edges rigidly fixed(=R).
//Here s=t,a=Lopt,b=ab=PM.

if(x==3)
{
float R2PPM=P; float PM=L; float kR2,kR3;
if(Lopt>(PM*100))
        {
float xp3x=Lopt/(PM*100);    k_nondim(xp3x,3,&kR3);
float fb_2x=kR3*R2PPM*pow(Lopt,2)/pow(t,2)/100;    *p=fb_2x;
        }
        else if(Lopt<(PM*100))
        {
float xp2x=(PM*100)/Lopt;    k_nondim(xp2x,2,&kR2);
float fb_2x=kR2*R2PPM*pow(Lopt,2)/pow(t,2)/100;    *p=fb_2x;
        }
}

//Check for skin plate as plate, for two short and one long edge
//fixed and one long edge simply supported.(=R2sl).
//Here b=Lopt, a=Aa.

//Check for skin plate as plate, for two long and one short edge
//fixed and one short edge simply supported.(=R2ls).
//Here b=Aa, a=Lopt.

else if(x==5)
{
float R2PAa=P; float Aa=L;    float kR2sl,kR2ls;
if(Lopt>Aa*100)
        {
```

```
float xp5x=Lopt/(Aa*100);   k_nondim(xp5x,5,&kR2sl);
float fb_5x=kR2sl*R2PAa*pow((Aa*100),2)/pow(t,2)/100;   *p=fb_5x;
      }
else if(Lopt<Aa*100)
      {
float xp8x=(Aa*100)/Lopt;    k_nondim(xp8x,8,&kR21s);
float fb_8x=kR21s*R2PAa*pow(Lopt,2)/pow(t,2)/100;   *p=fb_8x;
      }
}
//Check for skin plate  as plate, for three edges fixed and one
//(longer) edge free(=R3fl1). Here b=Aa, a=Lopt(for Aa>Lopt).

//Check for skin plate  as plate, for three edges fixed and one
//(longer) edge free(=R3fl2). Here b=Lopt, a=Aa(for Aa<Lopt).

else if(x==11)
{
float PM=L; float R2PPM=P;float Lopt1=Lopt;  float kR3fl1,kR3fl2;
if(Lopt1>PM*100)
      {
float xp11x2=Lopt1/(PM*100);  k_nondim(xp11x2,11,&kR3fl2);
float fb_11x=kR3fl2*R2PPM*pow((PM*100),2)/pow(t,2)/100; *p=fb_11x;
      }
      else if(Lopt1<PM*100)
      {
float xp11x1=(PM*100)/Lopt1;  k_nondim(xp11x1,11,&kR3fl1);
float fb_11x=kR3fl1*R2PPM*pow(Lopt1,2)/pow(t,2)/100;  *p=fb_11x;
      }
 } }

//Function for computing use rates of equipments.

void Use_Rat(float P,float N,float Rep_Pro,float Wor_Hor,
           float POL, int lab, int hel, float *p)
{
float Dep_cost,Rep_cost,POL_cost,lab_cost,misc_cost,Use_Rate;
      Dep_cost=5/4*0.9*P/N;
      Rep_cost=0.1*Rep_Pro*P/Wor_Hor; //10 % of Repair provision.
      POL_cost=POL;
      lab_cost=((lab*250+hel*200)/Wor_Hor)*12*30*1.2;
                        //20 % leave reserve.
      misc_cost=0.1*Rep_cost;

Use_Rate=1.1*(Dep_cost+Rep_cost+POL_cost+lab_cost+misc_cost);
                        //10 % overhead cost.
      *p=Use_Rate;
}

//Function for computing cost of gate

void COST(float AB, float CS, float Nvs, float WG1, float HC1,
        float Cgate, char C, float f1, float f2, float *p)
{
//FABRICATION COST /FC/EDGE  PREPARATION

//FC/EP/CUTTING : Pug Cutting Machine(pcm)
float Ppcm=20000; float Npcm=16000; float Rep_Propcm=0.80;
float POLpcm=0.5*2.5+50;          //Rs.50 for O^2 gases etc.
int labpcm=2; int helpcm=2; float Wor_Horpcm=2000;
float Use_Ratepcm;
Use_Rat(Ppcm,Npcm,Rep_Propcm,Wor_Horpcm,POLpcm,labpcm,helpcm,
```

```
          &Use_Ratepcm);

//FC/EP/GRINDING : Grinding Machine(gm)
float Pgm=12000; float Ngm=16000; float Rep_Progm=0.80;
float POLgm=0.25*2.5; int labgm=2; int helgm=0;
float Wor_Horgm=2200; float Use_Rategm;
Use_Rat(Pgm,Ngm,Rep_Progm,Wor_Horgm,POLgm,labgm,helgm,
          &Use_Rategm);
int HDx=AB/2.5;  float Cut_spl=2*AB+CS*(HDx+1);
float Cut_vs=Nvs*AB;  float Cut_tot=(Cut_spl+Cut_vs);
float Tim_cut=Cut_tot/3;    //cutting rate 1 m/20 min (assumed).
float Tim_gri=Cut_tot/1.5;  //grinding rate 1 m/10 min (assumed).
float Cut_cost=Tim_cut*Use_Ratepcm;
float Gri_cost=Tim_gri*Use_Rategm;
float Cep=(Cut_cost+Gri_cost)/100000;

//FC/WELDING  :  Welding Machine/(wm)(25 KVA)
float Pwm=45000; float Nwm=16000; float Rep_Prowm=0.80;
float POLwm=20*2.5;   //20 units consumed/hr.
int labwm=2; int helwm=2; float Wor_Horwm=2200; float Use_Ratewm;
Use_Rat(Pwm,Nwm,Rep_Prowm,Wor_Horwm,POLwm,labwm,helwm,
          &Use_Ratewm);

//FC/WEL/skin plate :
float Wel_spl=2*(HDx-1);
float C_elect_spl=(9.9*3+2.6*4+2.1*5+4.8*6)*Wel_spl;
float Arc_Tim_spl=Wel_spl*2*35.26;
float Dslg_tim_spl=Wel_spl*2*3.88;
float Seal_Tim_spl=Wel_spl*11.88;
float Wel_Tim_tot_spl=(Arc_Tim_spl+Dslg_tim_spl+Seal_Tim_spl);
//FC/WEL/vertical stiffener :

float Wel_fil_vs=2*AB*Nvs; float N_electvs=7.7*Wel_fil_vs;
float C_elect_vs=N_electvs*3;  //rate of electrode (assumed).
float Arc_Tim_vs=AB*14.36;
float Dslg_tim_vs=AB*3.35;
float Seal_Tim_vs=0; //ancillary : 0.34.//per elect. change 6.56.
float Wel_Tim_tot_vs=(Arc_Tim_vs+Dslg_tim_vs+Seal_Tim_vs+0.34
                    +6.56)*Nvs*4;
//FC/WEL/vertical end girder :
float Wel_Tim_tot_veg=0; float C_elect_veg=0;
if(C=='V')
          {
float Wel_fil_veg=8*AB; float N_electveg=7.7*Wel_fil_veg;
          C_elect_veg=N_electveg*3;//rate of electrode (assumed).
float Arc_Tim_veg=AB*14.36;
float Dslg_tim_veg=AB*3.35;
float Seal_Tim_veg=0; //ancillary : 0.34.//per elect. change 6.56.
          Wel_Tim_tot_veg=(Arc_Tim_veg+Dslg_tim_veg+Seal_Tim_veg
                    +0.34+6.56)*4;
          }
          else Wel_Tim_tot_veg=0; C_elect_veg=0;
//FC/WEL/MS welding on top of gate
float Wel_fil_ms=AB+CS; float N_electms=7.7*Wel_fil_ms;
float C_elect_ms=N_electms*3;//rate of electrode (assumed).
float Arc_Tim_ms=(AB+CS)*14.36;
float Dslg_tim_ms=(AB+CS)*3.35;
float Seal_Tim_ms=0; //ancillary : 0.34.//per elect. change 6.56.
float Wel_Tim_tot_ms=(Arc_Tim_ms+Dslg_tim_ms+Seal_Tim_ms+0.34
                    +6.56)*2;
//FC/WEL/SS welding seal of gate
```

```
float Wel_fil_ss=2*CS+2*AB; float N_electss=7.7*Wel_fil_ss;
float C_elect_ss=N_electss*3;//rate of electrode (assumed).
float Arc_Tim_ss=2*(AB+CS)*14.36;
float Dslg_tim_ss=2*(AB+CS)*3.35;
float Seal_Tim_ss=0;//ancillary : 0.34.//per elect. change 6.56.
float Wel_Tim_tot_ss=(Arc_Tim_ss+Dslg_tim_ss+Seal_Tim_ss+0.34
                  +6.56)*2;
float Celect=(C_elect_spl+C_elect_vs+C_elect_veg+C_elect_ms
            +C_elect_ss);
float Wel_Tim_tot=(Wel_Tim_tot_spl+Wel_Tim_tot_vs+Wel_Tim_tot_veg
               +Wel_Tim_tot_ms+Wel_Tim_tot_ss);
int Wel_Tim=Wel_Tim_tot/60+1;
float Cwel=f1*(Wel_Tim*Use_Ratewm+Celect)/100000;

//FC/DRILLING : Drilling Machine(dm)      //to fix seal of gate.
float Pdm=12000; float Ndm=16000; float Rep_Prodm=0.80;
float POLdm=0.25*2.5;   //0.25 units consumed/hr.
int labdm=0; int heldm=2; float Wor_Hordm=1200;
float Use_Ratedm;
Use_Rat(Pdm,Ndm,Rep_Prodm,Wor_Hordm,POLdm,labdm,heldm,
      &Use_Ratedm);
float Cdril=f1*(0.2*Wel_Tim*Use_Ratedm)/100000;

//PAINTING COST /PC

//PC : Air Compressor(diesel)/(ac)
float Pac=100000; float Nac=12000; float Rep_Proac=1.00;
float POLac=0.15*130*0.75*10*1.3;
      //130 hp m/c @ Rs.10/hp @ 0.75 l.f. & 30 % for lubricants.
int labac=1; int helac=1; float Wor_Horac=1200; float Use_Rateac;
Use_Rat(Pac,Nac,Rep_Proac,Wor_Horac,POLac,labac,helac,&Use_Rateac);
float Tim_paint=1.5*2*11*(CS*AB)/300;
      //hrs /A : CS*AB and 3 coating for 100 sqm in 11 hr.
float C_painting=Tim_paint*Use_Rateac;
float C_paints=1.3*(1/300*CS*AB*2)*(6*75+15*100);
float Cpaints=f1*WG1/9.2*(C_painting+C_paints)/100000*f2;

//TRANSPORTATION COST /TC

//TC : Truck (diesel)/(tr)
float Ptr=600000; float Ntr=20000/40; float Rep_Protr=1.40;
float POLtr=0.15*98*0.75*10*1.3;//98 hp m/c @ Rs.10/hp @ 0.75 l.f.
                        //& 30 % for lubricants.
int labtr=1; int heltr=1; float Wor_Hortr=600000*2/10/40;
float Use_Ratetr;
Use_Rat(Ptr,Ntr,Rep_Protr,Wor_Hortr,POLtr,labtr,heltr,&Use_Ratetr);
float Dep_cost_tyre=36000/3000;
float Rep_cost_tyre=0.15*Dep_cost_tyre;
float Use_Ratetyre=(Dep_cost_tyre+Rep_cost_tyre);
      Use_Ratetr=Use_Ratetr/100000;
      Use_Ratetr+=Use_Ratetyre/100000;
float Use_Ratekm=Use_Ratetr/40;

//TC : Trailer (diesel)/(trl)
float Ptrl=1000000; float Ntrl=20000; float Rep_Protrl=1.40;
float POLtrl=0.15*220*0.75*10*1.3;
      //220 hp m/c @ Rs.10/hp @ 0.75 l.f. & 30 % for lubricants.
int labtrl=1; int heltrl=1; float Wor_Hortrl=1200;
float Use_Ratetrl;
Use_Rat(Ptrl,Ntrl,Rep_Protrl,Wor_Hortrl,POLtrl,labtrl,heltrl,
      &Use_Ratetrl);
```

```
float Ctrans=f1*WG1/9.2*(8*Use_Ratetr+50*Use_Ratekm
           +16*Use_Ratetrl/100000)*f2;

//ERECTION COST /EC

//EC : Crane (diesel, 10 T)/(crn)
float Pcrn=800000; float Ncrn=15000; float Rep_Procrn=1.20;
float POLcrn=0.15*280*0.6*10*1.3;//280 hp m/c @ Rs.10/hp @ 0.6 l.f.
                         //& 30 % for lubricants.
int labcrn=1; int helcrn=1; float Wor_Horcrn=1200;
float Use_Ratecrn;
Use_Rat(Pcrn,Ncrn,Rep_Procrn,Wor_Horcrn,POLcrn,labcrn,helcrn,
      &Use_Ratecrn);

//EC : Winch  (diesel, 10 T)/(win)
float Pwin=150000; float Nwin=15000; float Rep_Prowin=0.80;
float POLwin=0.5;            //cost for grease.
int labwin=0; int helwin=6; float Wor_Horwin=2000;
float Use_Ratewin;
Use_Rat(Pwin,Nwin,Rep_Prowin,Wor_Horwin,POLwin,labwin,helwin,
      &Use_Ratewin);

//EC : Generator Set (diesel)/(gen)
float Pgen=600000; float Ngen=20000; float Rep_Progen=1.00;
float POLgen=0.15*200*0.6*10*1.3;//200 hp m/c @ Rs.10/hp @ 0.6 l.f.
                         //& 30 % for lubricants.
int labgen=2; int helgen=0; float Wor_Horgen=2000;
float Use_Rategen;
Use_Rat(Pgen,Ngen,Rep_Progen,Wor_Horgen,POLgen,labgen,helgen,
      &Use_Rategen);
float Cerec=f1*WG1/9.2*(16*Use_Ratecrn+24*Use_Ratewin
        +30*Use_Rategen)/100000*f2;
float Choist=1+HC1/9.2/10;
float Cinsp=0.1*(Cep+Cwel+Cdril+Cpaints+Ctrans+Cerec+Choist);
float Ctotal=(Cgate+Cep+Cwel+Cdril+Cpaints+Ctrans+Cerec+Choist
          +Cinsp);
      *p=Ctotal*1.35;    //35 % for embedded parts.
}     //Function definitions end.
```

```
//--------------------------------------------------------------
//                   :: OPTGATR3.CPP ::
//PROGRAM FOR 'OPTIMISATION OF DESIGN OF SPILLWAY GATES'
//--------------------------------------------------------------

#include<iostream.h>
#include<conio.h>
#include<math.h>
#include<process.h>
#include<iomanip.h>

void main()       //Main program starts.
{
clrscr();

//-------------------------------------------------------------
//   FUNCTION DECLARATIONS
//-------------------------------------------------------------

void Rvv(float [], float*, float*, float*, float*);
float xcube(float [], float [], float, float, int);
void nchar(int, char);  long fact(int);
float xsqrt(float [], float);
float polym(float[], float [], int, float);
float caw2(float, float, float);
float cawl(float, float, float);
void k_nondim(float, int, float*);
void Stress_VS(float [], float, float, float, float, float,
             float*, float*, float*, float*, float*, float*,
             float*, float*, float*, float*, float*);
float big(float [], int);     float small(float [], int);
void Stress_HG(float [], float ,float, float ,float, float,
             float, float*, float*, float*, float*, float*,
             float*, float*);
void Pbc_all(float, float*, char);
void Stress_Arm(float, float, float, float*, float*, float*,
            float*);
void Use_Rat(float, float, float, float, float, int, int,
           float*);
void Stress_SP(float, float, float, float, int, float*);
void COST(float, float, float, float, float, float, char, float,
        float, float*);

cout.precision(3);

//--------------------------------------------------------------
//   SKIN PLATE AND VERTICAL STIFFENER
//--------------------------------------------------------------

float FRL,CL,HD,SL,Sh,Sv,TL;
float CS; FRL=100; CL=90;
float CSArr[]={20,18,16,14,12,10,8,6};
cout<<"\nCost analysis of Radial Gate w.r.t. Span (3 HG) :"<<endl;
nchar(70,'-');
cout<<"\n"<<setw(8)<<"Head"<<setw(8)<<"Span"<<setw(13)<<"WG"
    <<setw(10)<<"CG"<<setw(17)<<"Hoist capacity"<<setw(13)
    <<"Cost";
cout<<"\n"<<setw(8)<<"(m)"<<setw(8)<<"(m)"<<setw(13)<<"(tonnes)"
    <<setw(10)<<"(m)"<<setw(17)<<"(tonnes)"<<setw(13)
```

```
    <<"(lakh Rs.)"<<endl;
nchar(70,'-');    cout<<endl;
for(int k=0;k<8;k++)
{
CS=CSArr[k];  SL=CL;
for(int i=0;i<5;i++)
      {
      HD=FRL-SL; Sh=0.15*HD;
      Sv=pow(Sh,1.85)*pow(HD,-0.85)/2.0;  SL=CL-Sv;
      }
      HD=FRL-SL+0.300;
float Rf=1.22; float R=Rf*HD; float Rvb,Rvt,A;
float Rvvx[]={R,HD,Sh,Sv,SL};
Rvv(Rvvx,&TL,&Rvb,&Rvt,&A);
float B=asin(Rvt/R); float C=A+B; float D=sin(A);
float E=sin(B);      float F=D+E;       F=2*asin(F/2);
float Tss=12;           //Side seal thickness.
float FFl=CS-2*Tss/1000;            //Face to face length.
float TA=FFl*R;               //Total area of water load.
float P=TA*F*Rvt+R*cos(B)*TA*(1-cos(C))
      -R*TA*sin(B)*sin(C);    //Total pr. in tonnes.
float Arc_AB=R*F;             //Arc length of skin plate.
float t,MLopt;   int Lopt;
float Hb=HD/10;  float Zsp;  float fbsp;
float tArr[]={2.0,1.8,1.4,1.2,1.0};;
int LoptArr[8]={40,41,42,43,44,45,46,47};;
for(i=0;i<5;i++){
            t=tArr[i]-0.15; Zsp=1*pow(t,2)/6;
            for(int j=0;j<8;j++)
                  {
                  Lopt=LoptArr[j];
                  MLopt=Hb*pow(Lopt,2)/12;
                  fbsp=MLopt/Zsp;
                  }
                  if(fbsp>1125) break;Lopt=Lopt; t=t;
             }

//Arrangement of Horizontal Girders.

Lopt+=1;

LoptFinal : Lopt-=1;

float Aa=0.0905*Arc_AB;   float PX=0.2615*Arc_AB;
float XM=0.349*Arc_AB;  float cB=0.299*Arc_AB;
float AD=D*R; float DB=E*R;
float DM=DB-cB; float PD=AD-Aa;
float A1=PD/R; float B1=A-A1; float C1=DM/R;
float PQ=R*sin(A1); float MN=R*sin(C1); float XY=R*sin(B1);

//Water load at girder locations.

float wa=(Rvt+PQ); float wb=(Rvt+XY); float wc=(Rvt-MN);
float wA=HD;      //in t/sq.m.

//Bending moment at support points  (1 m width of load).

float Maw=pow(Aa,2)*1/2*wa+pow(Aa,2)*(wA-wa)/2*2/3;  //in t.m/m
float Mabw=pow(PX,2)*wb/12+pow(PX,2)*(wa-wb)/2/10;
float Mbaw=pow(PX,2)*wb/12+pow(PX,2)*(wa-wb)/2/15;
float Mbcw=pow(XM,2)*wc/12+pow(XM,2)*(wb-wc)/2/10;
```

```
float Mcbw=pow(XM,2)*wc/12+pow(XM,2)*(wb-wc)/2/15;
float McBw=pow(cB,2)*1/2*1/3*wc; float Mcw=McBw;
float kba3=(3/PX)/(3/PX+3/XM); float kbc3=1-kba3;
float MRbw,CMbaw,CMbcw,MRaw,MRcw;
      Mabw=-Mabw; Mbcw=-Mbcw; McBw=-McBw;
      MRaw=-(Mabw+Maw); MRcw=-(McBw+Mcbw); MRbw=-(Mbaw+Mbcw);
      CMbaw=MRbw*kba3; CMbcw=MRbw*kbc3; Mabw+=MRaw;
      Mbaw+=CMbaw; Mbcw+=CMbcw;  Mcbw+=MRcw;
float Mbw=Mbaw;

//Reactions at support points due to water load. (load wtdth 1 m)

float Raw=(wA+wa)*Aa/2+wb*PX/2+(wa-wb)*PX/2*2/3-(Mbaw+Mabw)/PX;
float Rbw=wb*PX/2+(wa-wb)*PX/2/3+(Mbaw+Mabw)/PX+wc*XM/2
            +(wb-wc)*XM/2*2/3-(Mcbw+Mbcw)/XM;  //tonnes/m.
float Rcw=wc*XM/2+(wb-wc)*XM/2/3+(Mcbw+Mbcw)/XM+wc*cB/2;//tonnes/m.

//The effect of sill pressure.

float hg;  float ep=0.1e-5;  float CG1=R*0.7; float WG1=50;

CGTEST:

float Lst=WG1*CG1/(R*cos(A1));
            //Lst: length from SL to centre line of Trunnion.
float Wrad=Lst*sin(A1)/CS;//Radial load/m width of gate, t/m
float Wthr=Lst*cos(A1)/CS;//Direct thrust/m width of gate, t/m
float Mas=Wrad*Aa;       //t.m.
float MRas,CMbas,Mabs,Mbas,CMbcs,Mbcs,Mbs; float Mcs=0;
      MRas=-Mas/2; CMbas=MRas*kba3; Mabs=MRas; Mbas=CMbas;
      CMbas=-(CMbas*kba3); CMbcs=-(CMbas*kbc3);
      Mbas+=CMbas; Mbcs=CMbcs; Mbs=Mbas;
float Ras=Wrad-(Mabs+Mbas)/PX; float Rbs=(Mabs+Mbas)/PX-Mbcs/XM;
float Rcs=Mbcs/XM;
float Ra=Raw+Ras; float Rb=Rbw+Rbs; float Rc=Rcw+Rcs;
float Ma=Maw+Mas; float Mb=Mbw+Mbs; float Mc=Mcw+Mcs;

//Maximum bending moment along span ab occurs when shear force
//is zero or shear force equals to Rb. (from 'c')

float R3Qu_bc_a=-(wb-wc)/XM;float R3Qu_bc_b=-(2*wc);
float R3Qu_bc_c=(2*Rc-wc*cB);
float R3Q_bc_Arrc[]={R3Qu_bc_a,R3Qu_bc_b,R3Qu_bc_c};

//Max span BM due to combined load of water and sill pres. at
//dist. x from 'c' in t.m.

//float Mspbc_c=-pow(xcl,3)*(wb-wc)/6/XM-wc/2*pow(xcl,2)
//            +(Rc-wc*cB/2)*xcl-(wc*pow(cB,2))/6;
float R3Cu_bc_a=-(wb-wc)/6/XM; float R3Cu_bc_b=-wc/2;
float R3Cu_bc_c=Rc-wc*cB/2; float R3Cu_bc_d=-wc/6*pow(cB,2);
float R3C_bc_Arrc[]={R3Cu_bc_a,R3Cu_bc_b,R3Cu_bc_c,R3Cu_bc_d};
float spbcr=0.2*XM; float spbcl=0.8*XM;
float conflxbcr=xcube(R3C_bc_Arrc,R3Q_bc_Arrc,spbcr,XM,1);
float conflxbcl=xcube(R3C_bc_Arrc,R3Q_bc_Arrc,spbcl,XM,2);

//Calculation of co-acting width at support points/span.

float lcon_spbc=conflxbcl+conflxbcr;
float CAWspbc=caw1(XM,lcon_spbc,Lopt);//CAW at span bc.
float CAWxc=caw2(cB,conflxbcr,Lopt);  //CAW at support 'c'.
```

```
float cawArrc[]={CAWxc,CAWspbc};
float CAWxclow=small(cawArrc,2);

//Maximum bending moment along span ab occurs when shear force
//is zero or shear force equals to Rb. (from 'a')

float R3Qu_ab_aa=(wa-wb)/PX; float R3Qu_ab_ab=-(2*wa);
float R3Qu_ab_ac=(2*(Ra-Wrad)-(wA+wa)*Aa);
float R3Q_ab_Arra[]={R3Qu_ab_aa,R3Qu_ab_ab,R3Qu_ab_ac};

//Max BM due to combined load of water and sill pres. at dist. x
//from 'a'( in t.m.).

//float Mspab_a=pow(xar,3)*(wa-wb)/6/PX-wa/2*pow(xar,2)
//             +(Ra-Wrad-(wA+wa)*Aa/2)*xar-(wa+2*wA)*pow(Aa,2)/6;
float R3Cu_ab_aa=(wa-wb)/6/PX; float R3Cu_ab_ab=-wa/2;
float R3Cu_ab_ac=Ra-Wrad-(wA+wa)*Aa/2;
float R3Cu_ab_ad=-(wa+2*wA)*pow(Aa,2)/6;
float R3C_ab_Arra[]={R3Cu_ab_aa,R3Cu_ab_ab,R3Cu_ab_ac,R3Cu_ab_ad};
float spabl=0.2*PX; float spabr=0.8*PX;
float conflxabl_a=xcube(R3C_ab_Arra,R3Q_ab_Arra,spabl,PX,1);
float conflxabr_a=xcube(R3C_ab_Arra,R3Q_ab_Arra,spabr,PX,2);

//Calculation of co-acting width at support points.

float lcon_spab=conflxabl_a+conflxabr_a;
float lcon_b=conflxbcl+conflxabr_a;
float CAWspab=caw1(PX,lcon_spab,Lopt);  //CAW) at span ab
float CAWxa_a=caw2(Aa,conflxabl_a,Lopt);//CAW at support 'a'.
float CAWxb_a=caw2(XM,lcon_b,Lopt);     //CAW at support 'b'.
float cawArra[]={CAWxa_a,CAWspab};
float cawArrb[]={CAWxb_a,CAWspab,CAWspbc};
float CAWxalow=small(cawArra,2);
float CAWxblow=small(cawArrb,3);

//Check for skin plate as plate,  all edges rigidly fixed(=R).
//Here s=t,a=Lopt,b=ab=PX.

float R3PPX=(Rvt+(PQ-XY)/2)/10; float fb_2_3xPX,tPX;
float t1=0.85;  t=1.05;
if(R3PPX*10<=10){tPX=t1;}     else tPX=t;
Stress_SP(Lopt,tPX,R3PPX,PX,3,&fb_2_3xPX);
if(fb_2_3xPX>1125) goto LoptFinal;

//Check for skin plate as plate,  all edges rigidly fixed(=R).
//Here s=t,a=Lopt,b=ab=XM.

float R3PXM=(Rvt-(MN+XY)/2)/10;  float fb_2_3xXM;
if(R3PPX*10<=10){tPX=t1;}     else tPX=t;
Stress_SP(Lopt,tPX,R3PXM,XM,3,&fb_2_3xXM);
if(fb_2_3xXM>1125) goto LoptFinal;

//Check for skin plate as plate, for two short and one long edges
//fixed and one long edge simply supported.(=R2sl). b=Lopt, a=Aa.

//Check for skin plate as plate, for two long and one short edges
//fixed and one short edge simply supported.(=R2ls). b=Aa, a=Lopt.

float R3PAa=(HD+Rvt+PQ)/2/10;    float fb_5_8xAa,tAa;
if(R3PAa*10<=10){tAa=t1;}     else tAa=t;
Stress_SP(Lopt,tAa,R3PAa,Aa/2,5,&fb_5_8xAa);
```

```
if(fb_5_8xAa>1125)goto LoptFinal;

//Check for skin plate  as plate, for three edges fixed and one
//(longer) edge free(=R3fl1). Here b=PX, a=Lopt (for PX>Lopt).

//Check for skin plate  as plate, for three edges fixed and one
//(longer) edge free(=R3fl2). Here b=Lopt, a=PX (for PX<Lopt).

float LoptPX;  int CSPX=CS*100;  int RemPX=(CSPX) % Lopt;
if(RemPX==0) LoptPX=Lopt/5;
      else if(RemPX>(Lopt*0.4)) LoptPX=RemPX/4;
      else if(RemPX<(Lopt*0.4)) LoptPX=(Lopt+RemPX)/5;
float fb_11xPX;
Stress_SP(LoptPX,tPX,R3PPX,PX,11,&fb_11xPX);
if(fb_11xPX>1125)goto LoptFinal;

//Check for skin plate  as plate, for three edges fixed and one
//(longer) edge free(=R3fl1). Here b=XM, a=Lopt (for XM>Lopt).

//Check for skin plate  as plate, for three edges fixed and one
//(longer) edge free(=R3fl2). Here b=Lopt, a=XM (for XM<Lopt).

float LoptXM;  int CSXM=CS*100;  int RemXM=(CSXM) % Lopt;
if(RemXM==0) LoptXM=Lopt/5;
      else if(RemXM>(Lopt*0.4)) LoptXM=RemXM/4;
      else if(RemXM<(Lopt*0.4)) LoptXM=(Lopt+RemXM)/5;
float fb_11xXM,tXM;
if(R3PXM*10<=10){tXM=t1;}     else tXM=t;
Stress_SP(LoptXM,tXM,R3PXM,XM,11,&fb_11xXM);
if(fb_11xXM>1125)goto LoptFinal;

//Check for stresses in skin plate at  girder points co-acting
//with vertical stiffeners  and span.

//At support 'a': sh. force:
float Hax,Hbx,Hcx,tax,tbx,tcx;
      Hax=Rvt+PQ; Hbx=Rvt+XY; Hcx=Rvt-MN;
if(Hax<=10){tax=t1;} else tax=t;
float SFbot_a=Aa*(wA+wa)/2+Wrad; float SFtop_a=Ra-SFbot_a;
float SFArr_a[]={SFbot_a,SFtop_a};
float SFmax_a=big(SFArr_a,2);        //in tonnes./m
//dir. comp. force:
float Fcomp_a=(Wthr*Lopt/100/1000);        //in kgf.
float Mpo=wA/10*pow(LoptPX,2)/2; float Mpq=wA/10*pow(Lopt,2)/12;
float MGArrA[]={Mpo,Mpq};
float MmaxGA=big(MGArrA,2);
float BSa=MmaxGA*wa/wA/(pow(tax,2)/6);  //in kgf/sqcm.
float cawa[2]={CAWxalow*100,tax};
float f1a,f2a,f3a,Sa,STspa,STflga,Scomba,webLVSa,flgLVSa,flgWVSa,
      wVSa;
Stress_VS(cawa,Ma,SFmax_a,BSa,Fcomp_a,Lopt,&f1a,&f2a,&f3a,&Sa,
      &STspa,&STflga,&Scomba,&webLVSa,&flgLVSa,&flgWVSa,&wVSa);

//At support 'b': sh. force:
if(Hbx<=10){tbx=t1;} else tbx=t;
float SFbot_b=Aa*(wA+wa)/2+Wrad+(wa+wb)/2*PX-Ra;
float SFtop_b=Rb-SFbot_b; float SFArr_b[]={SFbot_b,SFtop_b};
float SFmax_b=big(SFArr_b,2);        //in tonnes./m
//dir. comp. force:
float Fcomp_b=(Wthr*Lopt/100/1000);        //in kgf.
float BSb=MmaxGA*wb/wA/(pow(tbx,2)/6);  //in kgf/sqcm.
```

```
float cawb[2]={CAWxblow*100,tbx};
float f1b,f2b,f3b,Sb,STspb,STflgb,Scombb,webLVSb,flgLVSb,
      flgWVSb,wVSb;
Stress_VS(cawb,Mb,SFmax_b,BSb,Fcomp_b,Lopt,&f1b,&f2b,&f3b,&Sb,
      &STspb,&STflgb,&Scombb,&webLVSb,&flgLVSb,&flgWVSb,&wVSb);

//At support 'c': sh. force:
if(Hcx<=10){tcx=t1;} else tcx=t;
float SFbot_c=Aa*(wA+wa)/2+Wrad+(wa+wb)/2*PX
           +(wb+wc)/2*XM-(Ra+Rb);
float SFtop_c=Rc-SFbot_c; float SFArr_c[]={SFbot_c,SFtop_c};
float SFmax_c=big(SFArr_c,2);       //in tonnes./m
//dir. comp. force:
float Fcomp_c=(Wthr*Lopt/100/1000);       //in kgf.
float BSc=MmaxGA*wc/wA/(pow(tcx,2)/6);  //in kgf/sqcm.
float cawc[2]={CAWxclow*100,tcx};
float f1c,f2c,f3c,Sc,STspc,STflgc,Scombc,webLVSc,flgLVSc,
      flgWVSc,wVSc;
Stress_VS(cawc,Mc,SFmax_c,BSc,Fcomp_c,Lopt,&f1c,&f2c,&f3c,&Sc,
      &STspc,&STflgc,&Scombc,&webLVSc,&flgLVSc,&flgWVSc,&wVSc);

//-----------------------------------------------------------------
//     HORIZONTAL GIRDERS
//-----------------------------------------------------------------

//Analysis for water load and sill pressure on Horizontal Girders.

float Lconn=HD/12.5 ;   //in metre.
float LarmCor=(webLVSa+flgWVSa)/100+Lconn;

//Effect of Rope Tension .

float RA1=3.14/3;      //RA1 is inclination of rope to horizontal.
float HC1=50*cos(RA1);//HC1 is hoist capacity.

HCTEST:

float RT=HC1/2;           //RT is rope tension in tonnes.
float RTh=RT*cos(RA1);    //RT in x-x direction.
float webLGa,flgLGa,flgWGa,wHGa,Taxmaxa,BMarma,LAa;
float RTha=RTh;

//Stresses at H/girder 'a'.

Stress_HG(cawa,R,CS,LarmCor,Ra,Raw,RTha,&webLGa,&flgLGa,&flgWGa,
       &wHGa,&Taxmaxa,&BMarma,&LAa);

//Stresses at H/girder 'b'.

float webLGb,flgLGb,flgWGb,wHGb,Taxmaxb,BMarmb,LAb; float RThb=0;
Stress_HG(cawb,R,CS,LarmCor,Rb,Rbw,RThb,&webLGb,&flgLGb,&flgWGb,
        &wHGb,&Taxmaxb,&BMarmb,&LAb);

//Stresses at H/girder 'c'.

float webLGc,flgLGc,flgWGc,wHGc,Taxmaxc,BMarmc,LAc; float RThc=0;
Stress_HG(cawc,R,CS,LarmCor,Rc,Rcw,RThc,&webLGc,&flgLGc,&flgWGc,
        &wHGc,&Taxmaxc,&BMarmc,&LAc);
```

```
//------------------------------------------------------------------
//    ARMS
//------------------------------------------------------------------

float Faxa=1*Taxmaxa; float Faxb=Taxmaxb; //Axial load.
float Faxc=Taxmaxc;

//Effect of frictional forces in trunnion.
//Max. BM at 'a'.

float MFrmaxa=Faxa*0.2*0.200; //tm.
float larma=R-(webLVSa+flgWVSa)/100;
float Marma=MFrmaxa*(larma-0.1*larma)/larma;

//Effect of frictional forces in trunnion.
//Max. BM at 'b'.

float MFrmaxb=Faxb*0.2*0.200; //tm.
float Marmb=MFrmaxb*(larma-0.095*larma)/larma;
float MFrmaxc=Faxc*0.2*0.200; //tm.
float Marmc=MFrmaxc*(larma-0.085*larma)/larma;
//Condition for biggest of axial forces.
//Total axial load.
float Lev_arma=2*0.1*larma*sin(C/2);
float Lev_armb=2*0.095*larma*sin(C/2);
float Lev_armc=2*0.085*larma*sin(C/2);
float Faxmaxa=Faxa+Marma/Lev_arma;
float Faxmaxb=Faxb+Marmb/Lev_armb;
float Faxmaxc=Faxc+Marmc/Lev_armc; float BMarmaa=1*BMarma;
float BMarmbb=BMarmb;   float BMarmcc=BMarmc;
float lea=R-(webLVSa+flgWVSa+(webLGa+2*flgWGa)/2)/100;
float leb=R-(webLVSa+flgWVSa+(webLGb+2*flgWGb)/2)/100;
float lec=R-(webLVSa+flgWVSa+(webLGb+2*flgWGb)/2)/100;
float webLArma,webWArma,flgLArma,flgWArma,wArma;
Stress_Arm(Faxmaxa,BMarmaa,lea,&webLArma,&flgLArma,&flgWArma,
            &wArma);
float webLArmb,webWArmb,flgLArmb,flgWArmb,wArmb;
Stress_Arm(Faxmaxb,BMarmbb,leb,&webLArmb,&flgLArmb,&flgWArmb,
            &wArmb);
float webLArmc,webWArmc,flgLArmc,flgWArmc,wArmc;
Stress_Arm(Faxmaxc,BMarmcc,lec,&webLArmc,&flgLArmc,&flgWArmc,
            &wArmc);

//------------------------------------------------------------------
//    CALCULATION OF WEIGHT OF GATE
//------------------------------------------------------------------

//Skin plate weight in tonnes.
float WG=0;float DG=0; float MG=0; float Arc_DB,tb,Lxt,Lxa,Arc_x;
float Ltb=0;float Lt=Arc_AB; t=0.85;
if(HD>=10){
        Arc_DB=E*R; Lxt=10-Rvt; Lxa=sin(Lxt/R); Arc_x=asin(Lxa);
        Ltb=Arc_AB-(Arc_DB+Arc_x);  tb=t; Lt=Arc_AB-Ltb;
        }
float wsp=(Ltb*(tb+0.15)+(t+0.15)*Lt)/100*CS*7.850;
float dsp=(R+2*R*cos(C/2))/3; //cg. of skin plate.
float Msp=wsp*dsp;  WG+=wsp;DG+=dsp;MG+=Msp;
//V/stiffener weight in tonnes.
float d_VSa=(webLVSa+flgWVSa)/100;  int Nvs;int CS1=CS*100;
if(RemPX==0)Nvs=CS1/Lopt+4;
      else if(RemPX<0.4*Lopt)Nvs=(CS1-CS1 % Lopt)/Lopt+3;
```

```
      else if(RemPX>0.4*Lopt)Nvs=(CS1-CS1 % Lopt)/Lopt+4;
float wvs=Nvs*wVSa*Arc_AB/1000;
float dvs=((R-(d_VSa)*2/3+2*(R-(d_VSa)*2/3)*cos(C/2)))/3;
float Mvs=wvs*dvs;   WG+=wvs;DG+=dvs;MG+=Mvs;
//H/Girder weight in tonnes.
float whga=wHGa*CS/1000; float whgb=wHGb*CS/1000;
float whgc=wHGc*CS/1000; float whg=whga+whgb+whgc;
float d_VSHGa=(webLVSa+flgWVSa+(webLGa+2*flgWGa)/2)/100;
float d_VSHGb=(webLVSa+flgWVSa+(webLGb+2*flgWGb)/2)/100;
float d_VSHGc=(webLVSa+flgWVSa+(webLGc+2*flgWGc)/2)/100;
float dhga=(R-d_VSHGa)*cos(A); float dhgb=(R-d_VSHGb)*cos(B);
float dhgc=(R-d_VSHGc)*cos(C); float dhg=dhga+dhgb+dhgc;
float mhga=whga*dhga; float mhgb=whgb*dhgb;float mhgc=whgc*dhgc;
float mhg=mhga+mhgb+mhgc;   WG+=whg;DG+=dhg;MG+=mhg;
//Arm weight in tonnes.
float warma=wArma*LAa/1000; float warmb=wArmb*LAb/1000;
float warmc=wArmc*LAc/1000; float warm=warma+warmb+warmc;
float darma=(R-d_VSHGa)*cos(A)/2;
float darmb=(R-d_VSHGb)*cos(B)/2;
float darmc=(R-d_VSHGc)*cos(C)/2;
float darm=darma+darmb+darmc; float marma=warma*darma;
float marmb=warmb*darmb;      float marmc=warmc*darmc;
float marm=marma+marmb+marmc; WG+=warm;DG+=darm;MG+=marm;
float wTrAssm=2.5/100*WG;//weight of Trunnion assembly with bush.
float wbrc=5/100*WG;     //weight of bracing assumed in %
float dbrc=darm*2/3;    float mbrc=wbrc*dbrc;
      WG+=wTrAssm+wbrc;DG+=dbrc;MG+=mbrc;
float CG=MG/WG;  hg=WG1-WG;
float wg=WG; WG=WG1; WG1=wg; float hg1=CG; CG=CG1; CG1=hg1;
if(fabs(hg)<ep) goto CGTEST;

//-----------------------------------------------------------------
//    CALCULATION OF HOISTING CAPACITY OF THE GATE.
//-----------------------------------------------------------------


float TS=R-d_VSHGa;
float TT1=TS*sin(A1);//vertical distance from TL to 'a'.
float ST1=TS*cos(A1);//horizontal dist.from 'a' to c/line of TL.
float Rx=(HD/2+TT1)/R;
float R1=2*asin(Rx); //angle of rotation of lifted gate.
float R2=R1-A1;      float Ry=(HD+TT1)/(ST1-0.45*R);
float Lx=atan(Ry);   float L2=Lx-A1;
float Rz=(HD+TT1+6/100*R)/(ST1-TS*cos(R2)); float Ly=atan(Rz);
float L3=Ly-A1;     float Rl=(5+sin(L3-L2))/(1+5*cos(L3-L2));
float RA=atan(Rl);     //rope inclination in radians.
float Pd=TS*sin(RA+L2);//perpend'lar dist. of resultant from Trnn.
//Loads & forces.
float FF=2*0.025*FFl*HD/2*1.5;//seal friction.
float TF=P*0.2;                //Trunnion friction, tonnes.
float HC=(FF*R+(RT*cos(L2)+WG1)*CG1+TF*0.2)/Pd;     //HC1/2=RT.
      HC+=5/100*WG1;      //addition for ropes.
      HC+=20/100*HC;         //addition for reserve.
float hc=HC-HC1;
float hh=HC; HC=HC1; HC1=hh; float rr=RA; RA=RA1; RA1=rr;
if(fabs(hc)<ep) goto HCTEST;

//-----------------------------------------------------------------
//    COST EVALUATION
//-----------------------------------------------------------------

//MATERIAL COST OF GATE (Mat_cost)
```

```
float Cspl=1.05*wsp; float Cvs=1.05*wvs; float Chg=1.05*whg;
float Carm=1.05*warm; float Cbrc=1.05*wbrc;
float Css=1.05*2*(Arc_AB+CS)*8*80/1000/1000*7.85;
float Mat_cost=1*(Cspl+Cvs+Chg+Carm+Cbrc+Css)*25000/100000;
float Ctotal;
cout.precision(1);
COST(Arc_AB,CS,Nvs,WG1,HC1,Mat_cost,'R',1,1,&Ctotal);
cout<<setw(8)<<HD<<setw(8)<<CS<<setw(13)<<WG1*1.35<<setw(10)<<CG1
    <<setw(17)<<HC1<<setw(13)<<Ctotal<<endl;
}
nchar(70,'-');
getch();
}      //Main program ends.
```

```
//------------------------------------------------------------
//                   :: OPTGATR4.CPP ::
//PROGRAM FOR 'OPTIMISATION OF DESIGN OF SPILLWAY GATES'
//------------------------------------------------------------

#include<iostream.h>
#include<conio.h>
#include<math.h>
#include<process.h>
#include<iomanip.h>

void main() //Main program starts.
{
clrscr();

//-----------------------------------------------------------
//     FUNCTION DECLARATIONS
//-----------------------------------------------------------

void Rvv(float [], float*, float*, float*, float*);
float xcube(float [], float [], float, float, int);
void nchar(int, char); long fact(int);
float xsqrt(float [], float);
float polym(float [], float [], int, float);
float caw2(float, float, float);
float caw1(float, float, float);
void k_nondim(float, int, float*);
void Stress_VS(float [], float, float, float, float, float,
             float*, float*, float*, float*, float*, float*,
             float*, float*, float*, float*, float*);
float big(float [], int);     float small(float [], int);
void Stress_HG(float [], float, float, float, float, float,
             float, float*, float*, float*, float*, float*,
             float*, float*);
void Pbc_all(float, float*, char);
void Stress_Arm(float, float, float, float*, float*, float*,
            float*);
void Use_Rat(float, float, float, float, float, int, int,
           float*);
void Stress_SP(float, float, float, float, int, float*);
void COST(float, float, float, float, float, float, char, float,
        float, float*);

cout.precision(2);

//------------------------------------------------------------
//    SKIN PLATE AND VERTICAL STIFFENER
//------------------------------------------------------------

float FRL,CL,HD,SL,Sh,Sv,TL;
float CS;   FRL=100;   CL=90;
float CSArr[]={20,18,16,14,12,10,8,6};
cout<<"\n\tCost analysis of Radial Gate (4 HG) : "<<endl;
nchar(70,'-');
cout<<"\n"<<setw(8)<<"Head"<<setw(8)<<"Span"<<setw(13)<<"WG"
    <<setw(10)<<"CG"<<setw(17)<<"Hoist capacity"<<setw(13)
    <<"Cost";
cout<<"\n"<<setw(8)<<"(m)"<<setw(8)<<"(m)"<<setw(13)<<"(tonnes)"
    <<setw(10)<<"(m)"<<setw(17)<<"(tonnes)"<<setw(13)
    <<"(lakh Rs.)"<<endl;
```

```
nchar(70,'-');    cout<<endl;
for(int k=0;k<8;k++)
{
CS=CSArr[k]; SL=CL;
for(int i=0;i<5;i++)
      {
      HD=FRL-SL;  Sh=0.15*HD;
      Sv=pow(Sh,1.85)*pow(HD,-0.85)/2.0;  SL=CL-Sv;
      }
      HD=FRL-SL+0.300;
float Rf=1.22;  float R=Rf*HD;   float Rvb,Rvt,A;
float Rvvx[]={R,HD,Sh,Sv,SL};
Rvv(Rvvx,&TL,&Rvb,&Rvt,&A);
float B=asin(Rvt/R);  float C=A+B; float D=sin(A);
float E=sin(B);       float F=D+E;        F=2*asin(F/2);
float Tss=12;           //Side seal thickness.
float FFl=CS-2*Tss/1000;            //Face to face length.
float TA=FFl*R;               //Total area of water load.
float P=TA*F*Rvt+R*cos(B)*TA*(1-cos(C))
      -R*TA*sin(B)*sin(C);    //Total pr. in tonnes.
float Arc_AB=R*F;             //Arc length of skin plate.
float t,MLopt;  int Lopt;
float Hb=HD/10;  float Zsp;  float fbsp;
float tArr[5]={2.0,1.8,1.4,1.2,1.0};;
int LoptArr[8]={40,41,42,43,44,45,46,47};;
for(i=0;i<5;i++)
            {
            t=tArr[i]-0.15; Zsp=1*pow(t,2)/6;
            for(int j=0;j<8;j++)
                  {
                  Lopt=LoptArr[j];
                  MLopt=Hb*pow(Lopt,2)/12;
                  fbsp=MLopt/Zsp;
                  }
            if(fbsp>1125) break; Lopt=Lopt; t=t;
            }

//Arrangement of Horizontal Girders.

Lopt+=1;

LoptFinal :  Lopt-=1;

float Aa=0.065*Arc_AB;  float PR=0.185*Arc_AB;
float RX=0.23*Arc_AB;   float XM=0.27*Arc_AB;
float dB=0.25*Arc_AB;
float AD=D*R; float DB=E*R;
float DM=DB-dB; float PD=AD-Aa; float DX=DB-(dB+XM);
float RD=AD-(Aa+PR);
float A1=PD/R; float B1=RD/R; float C1=DX/R; float D1=DM/R;
float PQ=R*sin(A1); float RS=R*sin(B1);
float XY=R*sin(C1); float MN=R*sin(D1);

//Water load at girder locations.

float wa=(Rvt+PQ); float wb=(Rvt+RS); float wc=(Rvt-XY);
float wd=(Rvt-MN); float wA=HD;      //in t/sq.m.

//Bending moment at support points (1 m width of load).

float Maw=pow(Aa,2)*wa*1/2+pow(Aa,2)*(wA-wa)/2*2/3;  //in t.m/m
```

```
float Mabw=pow(PR,2)*wb/12+pow(PR,2)*(wa-wb)/2/10;
float Mbaw=pow(PR,2)*wb/12+pow(PR,2)*(wa-wb)/2/15;
float Mbcw=pow(RX,2)*wc/12+pow(RX,2)*(wb-wc)/2/10;
float Mcbw=pow(RX,2)*wc/12+pow(RX,2)*(wb-wc)/2/15;
float Mcdw=pow(XM,2)*wd/12+pow(XM,2)*(wc-wd)/2/10;
float Mdcw=pow(XM,2)*wd/12+pow(XM,2)*(wc-wd)/2/15;
float MdBw=pow(dB,2)*wd*1/2*1/3;  float Mdw=MdBw;
float kba4=(3/PR)/(3/PR+3/RX); float kbc4=1-kba4;
float kcb4=(3/RX)/(3/RX+3/XM); float kcd4=1-kcb4;
float MRbw,MRcw,CMbaw,CMbcw,CMcbw,CMcdw,MRaw,MRdw;
      Mabw=-Mabw; Mbcw=-Mbcw; Mcdw=-Mcdw; MdBw=-MdBw;
      MRaw=-(Mabw+Maw); MRdw=-(Mdcw+MdBw);
      MRbw=-(Mbaw+Mbcw); MRcw=-(Mcbw+Mcdw);
      CMbaw=MRbw*kba4; CMbcw=MRbw*kbc4; CMcbw=MRcw*kcb4;
      CMcdw=MRcw*kcd4; Mabw+=MRaw; Mbaw+=CMbaw; Mbcw+=CMbcw;
      Mcbw+=CMcbw; Mcdw+=CMcdw; Mdcw+=MRdw;
 Maw=Maw; float Mbw=Mbaw;  float Mcw=Mcbw;  Mdw=Mdw;

//Reactions at support points due to water load. (load wtdth 1 m)

float Raw=(wA+wa)*Aa/2+wb*PR/2+(wa-wb)*PR/2*2/3-(Mbaw+Mabw)/PR;
float Rbw=wb*PR/2+(wa-wb)*PR/2/3+(Mbaw+Mabw)/PR+wc*RX/2
            +(wb-wc)*RX/2*2/3-(Mcbw+Mbcw)/RX;  //tonnes/m.
float Rcw=wc*RX/2+(wb-wc)*RX/2/3+(Mcbw+Mbcw)/RX
            +wd*XM/2+(wc-wd)*XM/2*2/3-(Mdcw+Mcdw)/XM; //t/m.
float Rdw=wd*XM/2+(wc-wd)*XM/2/3+(Mdcw+Mcdw)/XM+wd*dB/2;  //t/m.

//The effect of sill pressure.

float hg;  float ep=0.1e-5;  float CG1=R*0.7; float WG1=50;

CGTEST:

float Lst=WG1*CG1/(R*cos(A1));
      //Lst: length from SL to centre line of Trunnion.
float Wrad=Lst*sin(A1)/CS;//Radial load/m width of gate, t/m
float Wthr=Lst*cos(A1)/CS;//Direct thrust/m width of gate, t/m
float Mas=Wrad*Aa;        //t.m.
float MRas,CMbas,Mabs,Mbas,CMbcs,Mbcs,MRcbs,CMcbs,CMcds,Mcbs,Mcds;
float Mds=0;
      MRas=-Mas/2; CMbas=MRas*kba4; Mabs=MRas; Mbas=CMbas;
      CMbas=-(CMbas*kba4); CMbcs=-(CMbcs*kbc4);
      Mbas+=CMbas; Mbcs=CMbcs; MRcbs=Mbcs/2;
      CMcbs=-(MRcbs*kcb4); CMcds=-(MRcbs*kcd4);
      Mcbs=MRcbs+CMcbs; Mcds=CMcds;
float Mbs=Mbas; float Mcs=Mcds; float Ras=Wrad-(Mabs+Mbas)/PR;
float Rbs=(Mabs+Mbas)/PR-(Mbcs+Mcbs)/RX;
float Rcs=(Mbcs+Mcbs)/RX-Mcds/XM; float Rds=Mcds/XM;
float Ra=Raw+Ras;float Rb=Rbw+Rbs;float Rc=Rcw+Rcs;
float Rd=Rdw+Rds;float Ma=Maw+Mas;float Mb=Mbw+Mbs;
float Mc=Mcw+Mcs;float Md=Mdw+Mds;

//Maximum bending moment along span ab occurs when shear force
//is zero or shear force equals to Rb. (from 'd')
//ie. -(wc-wd)/XM*xd1^2-(2*wd)*xd1+(2*Rd-wd*dB)=0

float R4Qu_cd_a=-(wc-wd)/XM;float R4Qu_cd_b=-(2*wd);
float R4Qu_cd_c=(2*Rd-wd*dB);
float R4Q_cd_Arrd[]={R4Qu_cd_a,R4Qu_cd_b,R4Qu_cd_c};

//Max span BM due to combined load of water and sill pres. at
```

```
//dist. x from 'd' in t.m.

//float Mspcd_d=-pow(xdl,3)*(wc-wd)/6/XM-wd/2*pow(xdl,2)
//          +(Rd-wd*dB/2)*xdl-(wd*pow(dB,2))/6;
float R4Cu_cd_a=-(wc-wd)/6/XM; float R4Cu_cd_b=-wd/2;
float R4Cu_cd_c=Rd-wd*dB/2; float R4Cu_cd_d=-wd/6*pow(dB,2);
float R4C_cd_Arrd[]={R4Cu_cd_a,R4Cu_cd_b,R4Cu_cd_c,R4Cu_cd_d};
float spcdr=0.2*XM; float spcdl=0.8*XM;
float conflxcdr=xcube(R4C_cd_Arrd,R4Q_cd_Arrd,spcdr,XM,1);
float conflxcdl=xcube(R4C_cd_Arrd,R4Q_cd_Arrd,spcdl,XM,2);

//Calculation of co-acting width at support points/span.

float lcon_spcd=conflxcdl+conflxcdr;
float CAWspcd=caw1(XM,lcon_spcd,Lopt);//CAW at span cd
float CAWxd=caw2(dB,conflxcdr,Lopt); //CAW at support 'b'.
float cawArrd[]={CAWxd,CAWspcd};float CAWxdlow=small(cawArrd,2);

//Maximum bending moment along span ab occurs when shear force
//is zero or shear force equals to (Rc+Rd). (from 'c')

float R4Qu_bc_a=-(wb-wc)/RX;float R4Qu_bc_b=-(2*wc);
float R4Qu_bc_c=2*(Rc+Rd)-(wc+wd)*XM-wd*dB;
float R4Q_bc_Arrc[]={R4Qu_bc_a,R4Qu_bc_b,R4Qu_bc_c};

//Max span BM due to combined load of water and sill pres. at
//dist. x from 'c' in t.m.

//float Mspbc_c=-pow(xcl,3)*(wb-wc)/RX/6-wc/2*pow(xcl,2)
//          +(Rc+Rd-(wc+wd)/2*XM-wd/2*dB)*xcl
//          +Rd*XM-(wc+2*wd)/6*pow(XM,2)-wd/2*dB*(XM+dB/3);
float R4Cu_bc_a=-(wb-wc)/6/RX; float R4Cu_bc_b=-wc/2;
float R4Cu_bc_c=Rc+Rd-(wc+wd)/2*XM-wd/2*dB;
float R4Cu_bc_d=Rd*XM-(wc+2*wd)/6*pow(XM,2)-wd/2*(XM+dB/3)*dB;
float R4C_bc_Arrc[]={R4Cu_bc_a,R4Cu_bc_b,R4Cu_bc_c,R4Cu_bc_d};
float spbcr=0.2*RX; float spbcl=0.8*RX;
float conflxbcr=xcube(R4C_bc_Arrc,R4Q_bc_Arrc,spbcr,RX,1);
float conflxbcl=xcube(R4C_bc_Arrc,R4Q_bc_Arrc,spbcl,RX,2);

//Calculation of co-acting width at support points/span.

float lcon_spbc=conflxbcl+conflxbcr;
float lcon_c=conflxcdl+conflxbcr;
float CAWspbc=caw1(RX,lcon_spbc,Lopt);//CAW at span bc
float CAWxc=caw2(RX,lcon_c,Lopt);      //CAW at support 'c'.
float cawArrc[]={CAWxc,CAWspbc,CAWspcd};
float CAWxclow=small(cawArrc,3);

//Maximum bending moment along span ab occurs when shear force
//is zero or shear force equals to Rb. (from 'a')

float R4Qu_ab_aa=(wa-wb)/PR; float R4Qu_ab_ab=-(2*wa);
float R4Qu_ab_ac=(2*(Ra-Wrad)-(wA+wa)*Aa);
float R4Q_ab_Arra[]={R4Qu_ab_aa,R4Qu_ab_ab,R4Qu_ab_ac};

//Max BM due to combined load of water and sill pres. at dist. x
//from 'a'( in t.m.).

//float Mspab_a=pow(xar,3)*(wa-wb)/6/PR-wa/2*pow(xar,2)
//            +(Ra-Wrad-(wA+wa)*Aa/2)*xar-(wa+2*wA)*pow(Aa,2)/6
//          +Wrad*Aa;
```

```
float R4Cu_ab_aa=(wa-wb)/6/PR; float R4Cu_ab_ab=-wa/2;
float R4Cu_ab_ac=Ra-Wrad-(wA+wa)*Aa/2;
float R4Cu_ab_ad=-(wa+2*wA)*pow(Aa,2)/6+Wrad*Aa;
float R4C_ab_Arra[]={R4Cu_ab_aa,R4Cu_ab_ab,R4Cu_ab_ac,R4Cu_ab_ad};
float spabl=0.2*PR; float spabr=0.8*PR;
float conflxabl_a=xcube(R4C_ab_Arra,R4Q_ab_Arra,spabl,PR,1);
float conflxabr_a=xcube(R4C_ab_Arra,R4Q_ab_Arra,spabr,PR,2);

//Calculation of co-acting width at support points.

float lcon_spab=conflxabl_a+conflxabr_a;
float lcon_b=conflxbcl+conflxabr_a;
float CAWspab=caw1(PR,lcon_spab,Lopt);  //CAW) at span ab
float CAWxa_a=caw2(Aa,conflxabl_a,Lopt);//CAW at support 'a'.
float CAWxb_a=caw2(RX,lcon_b,Lopt);     //CAW at support 'b'.
float cawArra[]={CAWxa_a,CAWspab};
float cawArrb[]={CAWxb_a,CAWspab,CAWspbc};
float CAWxalow=small(cawArra,2);
float CAWxblow=small(cawArrb,3);

//Check for skin plate as plate,  all edges rigidly fixed(=R).
//Here s=t,a=Lopt,b=ab=PR.

float t1=0.85;  t=1.05;
float R4PPR=(Rvt+(PQ+RS)/2)/10; float fb_2_3xPR,tPR;
if(R4PPR*10<=10){tPR=t1;}      else tPR=t;
Stress_SP(Lopt,tPR,R4PPR,PR,3,&fb_2_3xPR);
if(fb_2_3xPR>1125) goto LoptFinal;

//Check for skin plate as plate,  all edges rigidly fixed(=R).
//Here s=t,a=Lopt,b=ab=RX.

float R4PRX=(Rvt+(RS-XY)/2)/10; float fb_2_3xRX,tRX;
if(R4PRX*10<=10){tRX=t1;}      else tRX=t;
Stress_SP(Lopt,tRX,R4PRX,RX,3,&fb_2_3xRX);
if(fb_2_3xRX>1125) goto LoptFinal;

//Check for skin plate as plate,  all edges rigidly fixed(=R).
//Here s=t,a=Lopt,b=ab=XM.

float R4PXM=(Rvt+(MN-XY)/2)/10; float fb_2_3xXM,tXM;
if(R4PXM*10<=10){tXM=t1;}      else tXM=t;
Stress_SP(Lopt,tXM,R4PXM,XM,3,&fb_2_3xXM);
if(fb_2_3xXM>1125) goto LoptFinal;

//Check for skin plate as plate, for two short and one long edge
//fixed and one long edge simply supported.(=R2sl). b=Lopt, a=Aa.

//Check for skin plate  as plate, for two long and one short edge
//fixed and one short edge simply supported.(=R2ls). b=Aa, a=Lopt.

float R4PAa=(HD+Rvt+PQ)/2/10;    float fb_5_8xAa,tAa;
if(R4PAa*10<=10){tAa=t1;}      else tAa=t;
Stress_SP(Lopt,tAa,R4PAa,Aa,5,&fb_5_8xAa);
if(fb_5_8xAa>1125)goto LoptFinal;

//Check for skin plate  as plate, for three edges fixed and one
//(longer) edge free(=R3fl1). Here b=PR, a=Lopt (for PR>Lopt).

//Check for skin plate  as plate, for three edges fixed and one
//(longer) edge free(=R3fl2). Here b=Lopt, a=PR (for PR<Lopt).
```

```
float LoptPR;  int CSPR=CS*100;  int RemPR=CSPR % Lopt;
if(RemPR==0) LoptPR=Lopt/5;
      else if(RemPR>(Lopt*0.4)) LoptPR=RemPR/4;
      else if(RemPR<(Lopt*0.4)) LoptPR=(Lopt+RemPR)/5;
float fb_11xPR;
Stress_SP(LoptPR,tPR,R4PPR,PR,11,&fb_11xPR);
if(fb_11xPR>1125)goto LoptFinal;

//Check for skin plate  as plate, for three edges fixed and one
//(longer) edge free(=R3fl1). Here b=RX, a=Lopt (for RX>Lopt).

//Check for skin plate  as plate, for three edges fixed and one
//(longer) edge free(=R3fl2). Here b=Lopt, a=RX (for RX<Lopt).

float LoptRX;  int CSRX=CS*100;  int RemRX=CSRX % Lopt;
if(RemRX==0) LoptRX=Lopt/5;
      else if(RemRX>(Lopt*0.4)) LoptRX=RemRX/4;
      else if(RemRX<(Lopt*0.4)) LoptRX=(Lopt+RemRX)/5;
float fb_11xRX;
Stress_SP(LoptRX,tRX,R4PRX,RX,11,&fb_11xRX);
if(fb_11xRX>1125)goto LoptFinal;

//Check for skin plate  as plate, for three edges fixed and one
//(longer) edge free(=R3fl1). Here b=XM, a=Lopt (for XM>Lopt).

//Check for skin plate  as plate, for three edges fixed and one
//(longer) edge free(=R3fl2). Here b=Lopt, a=XM (for XM<Lopt).

float LoptXM;  int CSXM=CS*100;  int RemXM=CSXM % Lopt;
if(RemXM==0) LoptXM=Lopt/5;
      else if(RemXM>(Lopt*0.4)) LoptXM=RemXM/4;
      else if(RemXM<(Lopt*0.4)) LoptXM=(Lopt+RemXM)/5;
float fb_11xXM;
Stress_SP(LoptXM,tXM,R4PXM,XM,11,&fb_11xXM);
if(fb_11xXM>1125)goto LoptFinal;

//Check for stresses in skin plate at  girder points co-acting
//with vertical stiffeners  and span.

//At support 'a': sh. force:
float Hax,Hbx,Hcx,Hdx,tax,tbx,tcx,tdx;
      Hax=Rvt+PQ; Hbx=Rvt+RS; Hcx=Rvt+XY; Hdx=Rvt-MN;
if(Hax<=10){tax=t1;} else tax=t;
float SFbot_a=Aa*(wA+wa)/2+Wrad; float SFtop_a=Ra-SFbot_a;
float SFArr_a[]={SFbot_a,SFtop_a};
float SFmax_a=big(SFArr_a,2);       //in tonnes./m
//dir. comp. force:
float Fcomp_a=(Wthr*Lopt/100/1000);       //in kgf.
float Mpo=wA/10*pow(LoptPR,2)/2; float Mpq=wA/10*pow(Lopt,2)/12;
float MGArrA[]={Mpo,Mpq};   float MmaxGA=big(MGArrA,2);
float BSa=MmaxGA*wa/wA/(pow(tax,2)/6);  //in kgf/sqcm.
float cawa[2]={CAWxalow*100,tax};
float f1a,f2a,f3a,Sa,STspa,STflga,Scomba,webLVSa,flgLVSa,flgWVSa,
      wVSa;
Stress_VS(cawa,Ma,SFmax_a,BSa,Fcomp_a,Lopt,&f1a,&f2a,&f3a,&Sa,
      &STspa,&STflga,&Scomba,&webLVSa,&flgLVSa,&flgWVSa,&wVSa);

//At support 'b': sh. force:
if(Hbx<=10){tbx=t1;} else tbx=t;
float SFbot_b=Aa*(wA+wa)/2+Wrad+(wa+wb)/2*PR-Ra;
```

```
float SFtop_b=Rb-SFbot_b; float SFArr_b[]={SFbot_b,SFtop_b};
float SFmax_b=big(SFArr_b,2);        //in tonnes./m
//dir. comp. force:
float Fcomp_b=(Wthr*Lopt/100/1000);        //in kgf.
float BSb=MmaxGA*wb/wA/(pow(tbx,2)/6);  //in kgf/sqcm.
float cawb[2]={CAWxblow*100,tbx};
float f1b,f2b,f3b,Sb,STspb,STflgb,Scombb,webLVSb,flgLVSb,flgWVSb,
      wVSb;
Stress_VS(cawb,Mb,SFmax_b,BSb,Fcomp_b,Lopt,&f1b,&f2b,&f3b,&Sb,
      &STspb,&STflgb,&Scombb,&webLVSb,&flgLVSb,&flgWVSb,&wVSb);

//At support 'c': sh. force:
if(Hcx<=10){tcx=t1;} else tcx=t;
float SFbot_c=Aa*(wA+wa)/2+Wrad+(wa+wb)/2*PR+(wb+wc)/2*RX-(Ra+Rb);
float SFtop_c=Rc-SFbot_c;  float SFArr_c[]={SFbot_c,SFtop_c};
float SFmax_c=big(SFArr_c,2);        //in tonnes./m
//dir. comp. force:
float Fcomp_c=(Wthr*Lopt/100/1000);        //in kgf.
float BSc=MmaxGA*wc/wA/(pow(tcx,2)/6);  //in kgf/sqcm.
float cawc[2]={CAWxclow*100,tcx};
float f1c,f2c,f3c,Sc,STspc,STflgc,Scombc,webLVSc,flgLVSc,
      flgWVSc,wVSc;
Stress_VS(cawc,Mc,SFmax_c,BSc,Fcomp_c,Lopt,&f1c,&f2c,&f3c,&Sc,
      &STspc,&STflgc,&Scombc,&webLVSc,&flgLVSc,&flgWVSc,&wVSc);

//At support 'd': sh. force:
if(Hdx<=10){tdx=t1;} else tdx=t;
float SFbot_d=Aa*(wA+wa)/2+Wrad+(wa+wb)/2*PR+(wb+wc)/2*RX
            +(wc+wd)/2*XM-(Ra+Rb+Rc);
float SFtop_d=Rc-SFbot_d; float SFArr_d[]={SFbot_d,SFtop_d};
float SFmax_d=big(SFArr_d,2);        //in tonnes./m
//dir. comp. force:
float Fcomp_d=(Wthr*Lopt/100/1000);        //in kgf.
float BSd=MmaxGA*wd/wA/(pow(tdx,2)/6);  //in kgf/sqcm.
float cawd[2]={CAWxdlow*100,tdx};
float f1d,f2d,f3d,Sd,STspd,STflgd,Scombd,webLVSd,flgLVSd,
      flgWVSd,wVSd;
Stress_VS(cawd,Md,SFmax_d,BSd,Fcomp_d,Lopt,&f1d,&f2d,&f3d,&Sd,
      &STspd,&STflgd,&Scombd,&webLVSd,&flgLVSd,&flgWVSd,&wVSd);

//-----------------------------------------------------------------
//      HORIZONTAL GIRDERS
//-----------------------------------------------------------------

//Analysis for water load and sill pressure on Horizontal Girders.

float Lconn=HD/12.5 ;   //in metre.
float LarmCor=(webLVSa+flgWVSa)/100+Lconn;

//Effect of Rope Tension .

float RA1=3.14/3;     //RA1 is inclination of rope to horizontal.
float HC1=50*cos(RA1);//HC1 is hoist capacity.

HCTEST:

float RT=HC1/2;           //RT is rope tension in tonnes.
float RTh=RT*cos(RA1);    //RT in x-x direction.
float webLGa,flgLGa,flgWGa,wHGa,Taxmaxa,BMarma,LAa;
float RTha=RTh;
```

```
//Stresses at H/girder 'a'.

Stress_HG(cawa,R,CS,LarmCor,Ra,Raw,RTha,&webLGa,&flgLGa,&flgWGa,
        &wHGa,&Taxmaxa,&BMarma,&LAa);

//Stresses at H/girder 'b'.

float webLGb,flgLGb,flgWGb,wHGb,Taxmaxb,BMarmb,LAb;float RThb=0;
Stress_HG(cawb,R,CS,LarmCor,Rb,Rbw,RThb,&webLGb,&flgLGb,&flgWGb,
        &wHGb,&Taxmaxb,&BMarmb,&LAb);

//Stresses at H/girder 'c'.

float webLGc,flgLGc,flgWGc,wHGc,Taxmaxc,BMarmc,LAc;float RThc=0;
Stress_HG(cawc,R,CS,LarmCor,Rc,Rcw,RThc,&webLGc,&flgLGc,&flgWGc,
        &wHGc,&Taxmaxc,&BMarmc,&LAc);

//Stresses at H/girder 'd'.

float webLGd,flgLGd,flgWGd,wHGd,Taxmaxd,BMarmd,LAd;float RThd=0;
Stress_HG(cawd,R,CS,LarmCor,Rd,Rdw,RThd,&webLGd,&flgLGd,&flgWGd,
        &wHGd,&Taxmaxd,&BMarmd,&LAd);

//------------------------------------------------------------------
//    ARMS
//------------------------------------------------------------------

float Faxa=1*Taxmaxa; float Faxb=Taxmaxb; //Axial load.
float Faxc=Taxmaxc;   float Faxd=Taxmaxd;

//Effect of frictional forces in trunnion.
//Max. BM at 'a'.

float MFrmaxa=Faxa*0.2*0.200; //tm.
float larma=R-(webLVSa+flgWVSa)/100;
float Marma=MFrmaxa*(larma-0.1*larma)/larma;

//Effect of frictional forces in trunnion.
//Max. BM at 'b'.

float MFrmaxb=Faxb*0.2*0.200; //tm.
float Marmb=MFrmaxb*(larma-0.095*larma)/larma;
float MFrmaxc=Faxc*0.2*0.200; //tm.
float Marmc=MFrmaxc*(larma-0.085*larma)/larma;
float MFrmaxd=Faxd*0.2*0.200; //tm.
float Marmd=MFrmaxd*(larma-0.08*larma)/larma;
//Condition for biggest of axial forces.
//Total axial load.
float Lev_arma=2*0.1*larma*sin(C/2);
float Lev_armb=2*0.095*larma*sin(C/2);
float Lev_armc=2*0.085*larma*sin(C/2);
float Lev_armd=2*0.08*larma*sin(C/2);
float Faxmaxa=Faxa+Marma/Lev_arma;
float Faxmaxb=Faxb+Marmb/Lev_armb;
float Faxmaxc=Faxc+Marmc/Lev_armc;
float Faxmaxd=Faxd+Marmd/Lev_armd; float BMarmaa=1*BMarma;
float BMarmbb=BMarmb;float BMarmcc=BMarmc;float BMarmdd=BMarmd;
float lea=R-(webLVSa+flgWVSa+(webLGa+2*flgWGa)/2)/100;
float leb=R-(webLVSa+flgWVSa+(webLGb+2*flgWGb)/2)/100;
float lec=R-(webLVSa+flgWVSa+(webLGb+2*flgWGb)/2)/100;
float led=R-(webLVSa+flgWVSa+(webLGb+2*flgWGb)/2)/100;
```

```
float webLArma,webWArma,flgLArma,flgWArma,wArma;
Stress_Arm(Faxmaxa,BMarmaa,lea,&webLArma,&flgLArma,&flgWArma,
         &wArma);
float webLArmb,webWArmb,flgLArmb,flgWArmb,wArmb;
Stress_Arm(Faxmaxb,BMarmbb,leb,&webLArmb,&flgLArmb,&flgWArmb,
         &wArmb);
float webLArmc,webWArmc,flgLArmc,flgWArmc,wArmc;
Stress_Arm(Faxmaxc,BMarmcc,lec,&webLArmc,&flgLArmc,&flgWArmc,
         &wArmc);
float webLArmd,webWArmd,flgLArmd,flgWArmd,wArmd;
Stress_Arm(Faxmaxd,BMarmdd,led,&webLArmd,&flgLArmd,&flgWArmd,
         &wArmd);

//-------------------------------------------------------------
//    CALCULATION OF WEIGHT OF GATE
//-------------------------------------------------------------

//Skin plate weight in tonnes.
float WG=0;float DG=0; float MG=0; float Arc_DB,tb,Lxt,Lxa,Arc_x;
float Ltb=0;float Lt=Arc_AB;  t=0.85;
if(HD>=10){
        Arc_DB=E*R; Lxt=10-Rvt; Lxa=sin(Lxt/R); Arc_x=asin(Lxa);
        Ltb=Arc_AB-(Arc_DB+Arc_x);  tb=t; Lt=Arc_AB-Ltb;
        }
float wsp=(Ltb*(tb+0.15)+(t+0.15)*Lt)/100*CS*7.850;
float dsp=(R+2*R*cos(C/2))/3; //cg. of skin plate.
float Msp=wsp*dsp;  WG+=wsp;DG+=dsp;MG+=Msp;
//V/stiffener weight in tonnes.
float d_VSa=(webLVSa+flgWVSa)/100; int Nvs;int CS1=CS*100;
if(RemPR==0)Nvs=CS1/Lopt+4;
      else if(RemPR<0.4*Lopt)Nvs=(CS1-CS1 % Lopt)/Lopt+3;
      else if(RemPR>0.4*Lopt)Nvs=(CS1-CS1 % Lopt)/Lopt+4;
float wvs=Nvs*wVSa*Arc_AB/1000;
float dvs=((R-(d_VSa)*2/3+2*(R-(d_VSa)*2/3)*cos(C/2)))/3;
float Mvs=wvs*dvs;  WG+=wvs;DG+=dvs;MG+=Mvs;
//H/Girder weight in tonnes.
float whga=wHGa*CS/1000; float whgb=wHGb*CS/1000;
float whgc=wHGc*CS/1000; float whgd=wHGd*CS/1000;
float whg=whga+whgb+whgc+whgd;
float d_VSHGa=(webLVSa+flgWVSa+(webLGa+2*flgWGa)/2)/100;
float d_VSHGb=(webLVSa+flgWVSa+(webLGb+2*flgWGb)/2)/100;
float d_VSHGc=(webLVSa+flgWVSa+(webLGc+2*flgWGc)/2)/100;
float d_VSHGd=(webLVSa+flgWVSa+(webLGd+2*flgWGd)/2)/100;
float dhga=(R-d_VSHGa)*cos(A); float dhgb=(R-d_VSHGb)*cos(B);
float dhgc=(R-d_VSHGa)*cos(C); float dhgd=(R-d_VSHGd)*cos(D);
float dhg=dhga+dhgb+dhgc+dhgd;
float mhga=whga*dhga; float mhgb=whgb*dhgb;
float mhgc=whgc*dhgc; float mhgd=whgd*dhgd;
float mhg=mhga+mhgb+mhgc+mhgd; WG+=whg;DG+=dhg;MG+=mhg;
//Arm weight in tonnes.
float warma=wArma*LAa/1000;float warmb=wArmb*LAb/1000;
float warmc=wArmc*LAc/1000;float warmd=wArmd*LAd/1000;
float warm=warma+warmb+warmc+warmd;
float darma=(R-d_VSHGa)*cos(A)/2;float darmb=(R-d_VSHGb)*cos(B)/2;
float darmc=(R-d_VSHGc)*cos(C)/2;float darmd=(R-d_VSHGd)*cos(D)/2;
float darm=darma+darmb+darmc+darmd;
float marma=warma*darma; float marmb=warmb*darmb;
float marmc=warmc*darmc; float marmd=warmd*darmd;
float marm=marma+marmb+marmc+marmd; WG+=warm;DG+=darm;MG+=marm;
float wTrAssm=2.5/100*WG;//weight of Trunnion assembly with bush.
float wbrc=5/100*WG;     //weight of bracing assumed.(in pc)
```

```
float dbrc=darm*2/3; float mbrc=wbrc*dbrc;
      WG+=wTrAssm+wbrc;DG+=dbrc;MG+=mbrc;
float CG=MG/WG;   hg=WG1-WG;
float wg=WG; WG=WG1; WG1=wg; float hg1=CG; CG=CG1; CG1=hg1;
if(fabs(hg)<ep) goto CGTEST;

//------------------------------------------------------------------
//    CALCULATION OF HOISTING CAPACITY OF THE GATE.
//------------------------------------------------------------------

float TS=R-d_VSHGa;
float TT1=TS*sin(A1); //vertical distance from TL to 'a'.
float ST1=TS*cos(A1); //horizontal dist. from 'a' to c/line of TL.
float Rx=(HD/2+TT1)/R;
float R1=2*asin(Rx);  //angle of rotation of lifted gate.
float R2=R1-A1;float Ry=(HD+TT1)/(ST1-0.45*R);float Lx=atan(Ry);
float L2=Lx-A1;  float Rz=(HD+TT1+6/100*R)/(ST1-TS*cos(R2));
float Ly=atan(Rz); float L3=Ly-A1;
float Rl=(5+sin(L3-L2))/(1+5*cos(L3-L2));
float RA=atan(Rl);      //rope inclination in radians.
float Pd=TS*sin(RA+L2);//perpend'lar dist. of resultant from Trnn.
//Loads & forces.
float FF=2*0.025*FFl*HD/2*1.5;//seal friction.
float TF=P*0.2;                 //Trunnion friction, tonnes.
float HC=(FF*R+(RT*cos(L2)+WG1)*CG1+TF*0.2)/Pd;       //HC1/2=RT
      HC+=5/100*WG1;      //addition for ropes.
      HC+=20/100*HC;        //addition for reserve.
float hc=HC-HC1;
float hh=HC; HC=HC1; HC1=hh; float rr=RA; RA=RA1; RA1=rr;
if(fabs(hc)<ep) goto HCTEST;

//------------------------------------------------------------------
//    COST EVALUATION
//------------------------------------------------------------------

//MATERIAL COST OF GATE (Mat_cost)

float Cspl=1.05*wsp; float Cvs=1.05*wvs; float Chg=1.05*whg;
float Carm=1.05*warm; float Cbrc=1.05*wbrc;
float Css=1.05*2*(Arc_AB+CS)*8*80/1000/1000*7.85;
float Mat_cost=1*(Cspl+Cvs+Chg+Carm+Cbrc+Css)*25000/100000;
float Ctotal;
cout.precision(1);
COST(Arc_AB,CS,Nvs,WG1,HC1,Mat_cost,'R',1,1,&Ctotal);
cout<<setw(8)<<HD<<setw(8)<<CS<<setw(13)<<WG1*1.35<<setw(10)<<CG1
    <<setw(17)<<HC1<<setw(13)<<Ctotal<<endl;
}
nchar(70,'-');
getch();
}      //Main program ends.
```

```
//---------------------------------------------------------------------
//                    :: OPTGATV2.CPP ::
//PROGRAM FOR 'OPTIMISATION OF DESIGN OF SPILLWAY GATES'
//---------------------------------------------------------------------

#include<iostream.h>
#include<conio.h>
#include<math.h>
#include<process.h>
#include<iomanip.h>

void main()        //Main program starts.
{
clrscr();

//-------------------------------------------------------------------
//    FUNCTION DECLARATIONS
//-------------------------------------------------------------------

void Rvv(float [], float*, float*, float*, float*);
float xcube(float [], float [], float, float, int);
void nchar(int, char);  long fact(int);
float xsqrt(float [], float);
float polym(float[], float [], int, float);
float caw2(float, float, float);
float caw1(float, float, float);
void k_nondim(float, int, float*);
void Stress_VS(float [], float, float, float, float, float,
             float*, float*, float*, float*, float*, float*,
             float*, float*, float*, float*, float*);
float big(float [],int);      float small(float [], int);
void Stress_VHG(float [], float, float, float, float*, float*,
            float*, float*, float*, float*, float*);
void Stress_VEG(float, float, float, float, float*, float*,
            float*, float*, float*, float*);
void Wheel(float, float, float, float*, float*, float*, float*);
void Use_Rat(float, float, float, float, float, int, int,
           float*);
void Stress_SP(float, float, float, float,int, float*);
void COST(float, float, float, float, float, float, char, float,
        float, float*);

cout.precision(3);

//-------------------------------------------------------------------
//    SKIN PLATE AND VERTICAL STIFFENER
//-------------------------------------------------------------------

float FRL,CL,HD,SL,Sh,Sv,TL;
float CS;  FRL=100;  CL=90;
float CSArr[]={16,14,12,10,8,6};
cout<<"\nCost Analysis of Vertical Lift Gate w.r.t. Span (2 HG): "
    <<endl;
nchar(70,'-');
cout<<"\n"<<setw(8)<<"Head"<<setw(8)<<"Span"<<setw(13)<<"WG"
    <<setw(10)<<"CG"<<setw(17)<<"Hoist capacity"<<setw(13)
    <<"Cost";
cout<<"\n"<<setw(8)<<"(m)"<<setw(8)<<"(m)"<<setw(13)<<"(tonnes)"
    <<setw(10)<<"(m)"<<setw(17)<<"(tonnes)"<<setw(13)
    <<"(Lakh Rs.)"<<endl;
```

```
nchar(70,'-'); cout<<endl;
for(int k=0;k<6;k++)
{
CS=CSArr[k];  SL=CL;
for(int i=0;i<5;i++)
      {
      HD=FRL-SL;   Sh=0.15*HD;
      Sv=pow(Sh,1.85)*pow(HD,-0.85)/2.0;  SL=CL-Sv;
      }
      HD=FRL-SL+0.300;
float ha=HD*(pow(2,1.5)-pow(1,1.5))*2/3/sqrt(2);
float hb=HD*(pow(1,1.5)-pow(0,1.5))*2/3/sqrt(2);
float Aa=HD-ha; float ab=ha-hb; float bB=hb;
float Tsl=150;                //Side seal length.
float FFw=CS+2*Tsl/1000;            //Face to face length to wheels.

//FEM (1 m width of gate)

float Ma=ha*pow(Aa,2)/2+(HD-ha)*pow(Aa,2)/2*2/3;
float Mb=pow(bB,3)/2/3;
float Ra=(HD+ha)/2*Aa+hb*ab/2+(ha-hb)/2*ab*2/3;
float Rb=pow(bB,2)/2+hb*ab/2+(ha-hb)/2*ab/3;
float t,MLopt;   int Lopt;
float Hb=HD/10;  float Zsp;  float fbsp;
float tArr[5]={2.0,1.8,1.4,1.2,1.0};
int LoptArr[8]={40,41,42,43,44,45,46,47};
for(i=0;i<5;i++)
            {
            t=tArr[i]-0.15; Zsp=1*pow(t,2)/6;
            for(int j=0;j<8;j++)
                  {
                  Lopt=LoptArr[j];
                  MLopt=Hb*pow(Lopt,2)/12; fbsp=MLopt/Zsp;
                  }
            if(fbsp>1125) break; Lopt=Lopt; t=t;
            }

Lopt+=Lopt;

LoptFinal :       Lopt-=1;

//Maximum bending moment along span ab occurs when shear force
//is zero or shear force equals to Rb. (from 'a')
//ie. (wa-wb)/ab*x^2-(2*ha)*x+(2*Ra-(HD+ha)*Aa)=0

float V2Qu_ab_aa=(ha-hb)/ab; float V2Qu_ab_ab=-2*ha;
float V2Qu_ab_ac=2*Ra-(HD+ha)*Aa;
float V2Q_ab_Arra[]={V2Qu_ab_aa,V2Qu_ab_ab,V2Qu_ab_ac};

//Max BM due to combined load of water and sill pres. at dist. x
//from 'a'( in t.m.).

//float Mspab_a=pow(xar,3)*(ha-hb)/6/ab-ha/2*pow(xar,2)
//            +(Ra-(HD+ha)*Aa/2)*xar-(ha+2*HD)*pow(Aa,2)/6;
float V2Cu_ab_aa=(ha-hb)/6/ab; float V2Cu_ab_ab=-ha/2;
float V2Cu_ab_ac=Ra-(HD+ha)*Aa/2;
float V2Cu_ab_ad=-(ha+2*HD)*pow(Aa,2)/6;
float V2C_ab_Arra[]={V2Cu_ab_aa,V2Cu_ab_ab,V2Cu_ab_ac,V2Cu_ab_ad};
float spabl=0.2*ab; float spabr=0.8*ab;
float conflxabl_a=xcube(V2C_ab_Arra,V2Q_ab_Arra,spabl,ab,1);
float conflxabr_a=xcube(V2C_ab_Arra,V2Q_ab_Arra,spabr,ab,2);
```

```
//Calculation of co-acting width at support points.

float conflxabspW=conflxabl_a+conflxabr_a;
float CAWxa_a=caw2(Aa,conflxabl_a,Lopt);  //CAW at support 'a'.
float CAWxb_a=caw2(bB,conflxabr_a,Lopt);  //CAW at support 'b'.
float CAWspab=caw1(ab,conflxabspW,Lopt);  //CAW at span ab
float cawArraa[]={CAWxa_a,CAWspab};
float cawArrbb[]={CAWxb_a,CAWspab};
float CAWxaalow=small(cawArraa,2);
float CAWxbblow=small(cawArrbb,2);

//Check for skin plate as plate,  all edges rigidly fixed(=R).
//Here s=t,a=Lopt,b=ab.

float t1=0.85;  t=1.05;
float V2Pab=(ha+hb)/2/10;  float fb_2_3x,tab;
if(V2Pab*10<=10){tab=t1;}     else tab=t;
Stress_SP(Lopt,tab,V2Pab,ab/2,3,&fb_2_3x);
if(fb_2_3x>1125) goto LoptFinal;

//Check for skin plate as plate, for two short and one long edge
//fixed and one long edge simply supported.(=R2sl). b=Lopt, a=Aa.

//Check for skin plate  as plate, for two long and one short edge
//fixed and one short edge simply supported.(=R2ls). b=Aa, a=Lopt.

float V2PAa=(HD+ha)/2/10;    float fb_5_8x,tAa;
if(V2PAa*10<=10){tAa=t1;}     else tAa=t;
Stress_SP(Lopt,tAa,V2PAa,Aa,3,&fb_5_8x);
if(fb_5_8x>1125)goto LoptFinal;

//Check for stresses in skin plate at  girder points co-acting
//with vertical stiffeners  and span.
//v/stiffener selected (1/2 cut ISMB 400 and T-sections).

//At support 'a': sh. force:
float Hax,Hbx,tax,tbx; Hax=ha; Hbx=hb;
if(Hax<=10){tax=t1;} else tax=t;
float SFbot_a=Aa*(HD+ha)/2; float SFtop_a=Ra-SFbot_a;
float SFArr_a[]={SFbot_a,SFtop_a};
float SFmax_a=big(SFArr_a,2);        //in tonnes./m
//dir. comp. force:
float Fcomp_a=0; float Mpo=0; float Mpq=HD/10*pow(Lopt,2)/12;
float MGArrA[]={Mpo,Mpq};      float MmaxGA=big(MGArrA,2);
float BSa=MmaxGA*ha/HD/(pow(tax,2)/6);  //in kgf/sqcm.
float cawa[2]={CAWxaalow*100,tax};
float f1a,f2a,f3a,Sa,STspa,STflga,Scomba,wVSa,webLVSa,flgLVSa,
      flgWVSa;
Stress_VS(cawa,Ma,SFmax_a,BSa,Fcomp_a,Lopt,&f1a,&f2a,&f3a,&Sa,
      &STspa,&STflga,&Scomba,&webLVSa,&flgLVSa,&flgWVSa,&wVSa);

//At support 'b': sh. force:
if(Hbx<=10){tbx=t1;} else tbx=t;
float SFbot_b=Aa*(HD+ha)/2+(ha+hb)/2*ab-Ra;
float SFtop_b=Rb-SFbot_a; float SFArr_b[]={SFbot_b,SFtop_b};
float SFmax_b=big(SFArr_b,2);        //in tonnes./m
//dir. comp. force:
float Fcomp_b=0;
float BSb=MmaxGA*hb/HD/(pow(tbx,2)/6);  //in kgf/sqcm.
float cawb[2]={CAWxbblow*100,tbx};
```

```
float f1b,f2b,f3b,Sb,STspb,STflgb,Scombb,wVSb,webLVSb,flgLVSb,
      flgWVSb;
Stress_VS(cawb,Mb,SFmax_b,BSb,Fcomp_b,Lopt,&f1b,&f2b,&f3b,&Sb,
      &STspb,&STflgb,&Scombb,&webLVSb,&flgLVSb,&flgWVSb,&wVSb);

//----------------------------------------------------------------
//    HORIZONTAL GIRDERS
//----------------------------------------------------------------

//Stresses at H/girder 'a'.

float webLGa,flgLGa,flgWGa,wHGa,RAmaxa,MG_spa,dlmaxa;
Stress_VHG(cawa,CS,Ra,FFw,&webLGa,&flgLGa,&flgWGa,&wHGa,&RAmaxa,
         &dlmaxa,&MG_spa);

//Stresses at H/girder 'a'.

float webLGb,flgLGb,flgWGb,wHGb,RAmaxb,MG_spb,dlmaxb;
Stress_VHG(cawb,CS,Rb,FFw,&webLGb,&flgLGb,&flgWGb,&wHGb,&RAmaxb,
         &dlmaxb,&MG_spb);

//----------------------------------------------------------------
//    VERTICAL END GIRDERS
//----------------------------------------------------------------

float Lab,Lcd,Lbc,Lac,Lad,Lbd;
      Lab=HD*5/100; Lcd=HD*5/100;//Wheels are equi-flanked to HG.
      Lbc=ab-Lab;   Lac=Lab+Lbc;   Lad=Lac+Lcd; Lbd=Lbc+Lcd;
//Reaction on h/girders
float RAa=RAmaxa/2; float RAb=RAmaxb/2;
float MFLbc,MFLcb,MFa,MFb,MFc,MFd;
float MFLab=-(RAa*Lab/8);      float MFLba=-MFLab;
float MFLcd=-(RAb*Lcd/8);      //float MFLdc=-MFLcd;
float kba=(3/Lab)/(3/Lab+4/Lbc);//float kbc=1-kba;
float kcb=(4/Lbc)/(4/Lbc+3/Lcd);//float kcd=1-kcb;
      MFLba+=-MFLba*kba; MFLcb=-MFLcd*kcb;
      MFd=0; MFb=MFLba; MFc=MFLcb;

//Reactions:

float RWa=(RAa/2-MFb/Lab);
float RWb=(RAa*(Lab/2+Lbc)-MFc-RWa*Lac)/Lbc;
float RWc=(RAa*(Lab/2+Lbd)-MFd-RWa*Lad-RWb*Lbd+RAb*Lcd/2)/Lcd;
float RWd=RAa+RAb-(RWa+RWb+RWc);
//BM at HG positions:
float MGW_spa=RWa*Lab/2; float MGW_spb=RWd*Lcd/2;

//Analysis of stresses on the VEG.

float BMArra[]={MGW_spa,MGW_spb,MFb,MFc};
float SFArra[]={RWa,RWb,RWc,RWd};
float SFmax=big(SFArra,4); float Mmax=big(BMArra,4);
float fb_spa,fb_oppa,SSa,webLVGa,webWVGa,wVEGa;
Stress_VEG(t, Mmax, SFmax, Lopt,&fb_spa,&fb_oppa,&SSa,&webLVGa,
         &webWVGa,&wVEGa);

//----------------------------------------------------------------
//    WHEEL OF VERTICAL LIFT GATE
//----------------------------------------------------------------
```

```
float wWheel,Z1,R2,w; float PE=0; float PN=SFmax;
Wheel(PN,PE,HD,&Z1,&R2,&w,&wWheel);

//-----------------------------------------------------------------
//    COST EVALUATION
//-----------------------------------------------------------------

//WEIGHT OF GATE  AND CG OF GATE

float webLVS,flgWVS;
if(wVSa>wVSb){webLVS=webLVSa;flgWVS=flgWVSa;}
      else {webLVS=webLVSb;flgWVS=flgWVSb;}
int Nvs;int CS1=CS*100;int CSab=CS*100;int Remab=(CSab) % Lopt;
if(Remab==0)Nvs=CS1/Lopt+4;
      else if(Remab<0.4*Lopt)Nvs=(CS1-CS1 % Lopt)/Lopt+3;
      else if(Remab>0.4*Lopt)Nvs=(CS1-CS1 % Lopt)/Lopt+4;
float Ltb=0; float tb,Lt=HD;   t=0.85;
if(HD>=10){
        Ltb=HD-10;  tb=t; Lt=10;
        }
float Wspl=(Ltb*(tb+0.15)+(t+0.15)*Lt)/100*CS*7.850;
float Dspl=(t+0.15)/100/2;  float Mspl=Wspl*Dspl;
float Wvs=wVSb*HD*Nvs/1000;
float Dvs=((t+0.15)+(webLVS+flgWVS)*2/3)/100; float Mvs=Wvs*Dvs;
float Whga=wHGa*FFw/1000; float Whgb=wHGb*FFw/1000;
float Dhga=(t+0.15+flgWVS+webLVS+(2*flgWGa+webLGa)/2)/100;
float Dhgb=(t+0.15+flgWVS+webLVS+(2*flgWGb+webLGb)/2)/100;
float Mhga=Whga*Dhga; float Mhgb=Whgb*Dhgb;
float Whg=Whga+Whgb; float Mhg=Mhga+Mhgb;
float Wveg=2*wVEGa*HD/1000; float Dveg=((t+0.15)+webLVGa/2)/100;
float Mveg=Wveg*Dveg;  float Wwheel=wWheel*8/1000;
float Dwheel=(t+0.15+webLVGa-R2)/100;float Mwheel=Wwheel*Dwheel;
float WVG=(Wspl+Wvs+Whg+Wveg+Wwheel);
float MVG=(Mspl+Mvs+Mhg+Mveg+Mwheel); float CVG=MVG/WVG;

//HOISTING CAPACITY OF GATE

float FFl=CS-2*12/1000;
float P=1*FFl*pow(HD,2)/2;    //total hydrostatic load
float F=P*(0.015*1+1.5)/(R2*10);//fa=0.015, fr=1.5
float fg=(5/100*WVG)*4*0.5;   //guide friction @ 5 % of gate wt.
float fs=HD*0.25*2/10;        //seal friction for seal length.
float Wrope=1.5/100*WVG;      //rope wt. @ 1.5 % of gate wt.
float Ft=F+fg+fs+Wrope;  float WVGt=1.2*(WVG+Ft);

//MATERIAL COST OF GATE (Mat_cost)

float Cspl=1.05*Wspl; float Cvs=1.05*Wvs; float Chg=1.05*Whg;
float Cveg=1.05*Wveg; float Cwheel=1.05*Wwheel;
float Css=1.05*2*(HD+CS)*8*80/1000/1000*7.850;
float Mat_cost=1*(Cspl+Cvs+Chg+Cveg+Cwheel+Css)/100000*25000;
float Ctotal;
cout.precision(1);
COST(HD,CS,Nvs,WVG,WVGt,Mat_cost,'V',1,1,&Ctotal);
cout<<setw(8)<<HD<<setw(8)<<CS<<setw(13)<<WVG*1.25<<setw(10)<<CVG
    <<setw(17)<<WVGt<<setw(13)<<Ctotal<<endl;
}
nchar(70,'-');
getch();
}     //Main program ends.
```

```
//--------------------------------------------------------------------
//                    :: OPTGATV3.CPP ::
//PROGRAM FOR 'OPTIMISATION OF DESIGN OF SPILLWAY GATES'
//--------------------------------------------------------------------

#include<iostream.h>
#include<conio.h>
#include<math.h>
#include<process.h>
#include<iomanip.h>

void main()       //Main program starts.
{
clrscr();

//--------------------------------------------------------------------
//    FUNCTION DECLARATIONS
//--------------------------------------------------------------------

void Rvv(float [], float*, float*, float*, float*);
float xcube(float [], float [], float, float, int);
void nchar(int, char);  long fact(int);
float xsqrt(float [], float);
float polym(float[], float [], int, float);
float caw2(float, float, float);
float caw1(float, float, float);
void k_nondim(float, int, float*);
void Stress_VS(float [], float, float, float, float, float,
              float*, float*, float*, float*, float*, float*,
              float*, float*, float*, float*, float*);
float big(float [],int);      float small(float [], int);
void Stress_VHG(float [], float, float, float, float*, float*,
             float*, float*, float*, float*, float*);
void Stress_VEG(float, float, float, float, float*, float*,
             float*, float*, float*, float*);
void Wheel(float, float, float, float*, float*, float*, float*);
void Use_Rat(float, float, float, float, float,int,int,float*);
void Stress_SP(float, float, float, float, int, float*);
void COST(float, float, float, float, float, float, char, float,
         float, float*);

cout.precision(3);

//--------------------------------------------------------------------
//    SKIN PLATE AND VERTICAL STIFFENER
//--------------------------------------------------------------------

float FRL,CL,HD,SL,Sh,Sv,TL;
float CS;  FRL=100;   CL=90;
float CSArr[]={20,18,16,14,12,10,8,6};
cout<<"\nCost Analysis of Vertical Lift Gate w.r.t. Span (3 HG):"
    <<endl;
nchar(70,'-');
cout<<"\n"<<setw(8)<<"Head"<<setw(8)<<"Span"<<setw(13)<<"WG"
    <<setw(10)<<"CG"<<setw(17)<<"Hoist capacity"<<setw(13)
    <<"Cost";
cout<<"\n"<<setw(8)<<"(m)"<<setw(8)<<"(m)"<<setw(13)<<"(tonnes)"
    <<setw(10)<<"(m)"<<setw(17)<<"(tonnes)"<<setw(13)
    <<"(lakh Rs.)"<<endl;
nchar(70,'-');    cout<<endl;
```

```
for(int k=0;k<8;k++)
{
CS=CSArr[k]; SL=CL;
for(int i=0;i<5;i++)
       {
       HD=FRL-SL;  Sh=0.15*HD;
       Sv=pow(Sh,1.85)*pow(HD,-0.85)/2.0;  SL=CL-Sv;
       }
       HD=FRL-SL+0.300;
float ha=HD*(pow(3,1.5)-pow(2,1.5))*2/3/sqrt(3);
float hb=HD*(pow(2,1.5)-pow(1,1.5))*2/3/sqrt(3);
float hc=HD*(pow(1,1.5)-pow(0,1.5))*2/3/sqrt(3);
float Aa=HD-ha; float ab=ha-hb; float bc=hb-hc; float cB=hc;
float Tsl=150;                    //Side seal length.
float FFw=CS+2*Tsl/1000;                 //Face to face length to wheels.

//Bending moment at  support points  (1 m width of load).

float Ma=ha*pow(Aa,2)/2+(HD-ha)*pow(Aa,2)/2*2/3;   //in t.m/m
float Mab=hb*pow(ab,2)/12+(ha-hb)*pow(ab,2)/2/10;
float Mba=hb*pow(ab,2)/12+(ha-hb)*pow(ab,2)/2/15;
float Mbc=hc*pow(bc,2)/12+(hb-hc)*pow(bc,2)/2/10;
float Mcb=hc*pow(bc,2)/12+(hb-hc)*pow(bc,2)/2/15;
float McB=hc*pow(cB,2)/2/3;  float Mc=McB;
float kba3=(3/ab)/(3/ab+3/bc); float kbc3=1-kba3;
float MRb,CMba,CMbc,MRa,MRc;
       Mab=-Mab; Mbc=-Mbc; McB=-McB;
       MRa=-(Mab+Ma); MRc=-(McB+Mcb);  MRb=-(Mba+Mbc);
       CMba=MRb*kba3; CMbc=MRb*kbc3; Mab+=MRa;
       Mba+=CMba; Mbc+=CMbc;  Mcb+=MRc;
 float Mb=Mba;

//Reactions at support points due to water load. (load wtdth 1 m)

float Ra=(HD+ha)*Aa/2+hb*ab/2+(ha-hb)*ab/2*2/3-(Mba+Mab)/ab;
float Rb=hb*ab/2+(ha-hb)*ab/2/3+(Mba+Mab)/ab+hc*bc/2
              +(hb-hc)*bc/2*2/3-(Mcb+Mbc)/bc;         //tonnes/m.
float Rc=hc*bc/2+(hb-hc)*bc/2/3+(Mcb+Mbc)/bc+hc*cB/2;  //tonnes/m.
float t, MLopt;  int Lopt;
float Hb=HD/10;  float Zsp;  float fbsp;
float tArr[5]={2.0,1.8,1.4,1.2,1.0};;
int LoptArr[6]={45,46,47,48,49,50};;
for(i=0;i<5;i++)
              {
              t=tArr[i]-0.15; Zsp=1*pow(t,2)/6;
              for(int j=0;j<6;j++)
                     {
                     Lopt=LoptArr[j];
                     MLopt=Hb*pow(Lopt,2)/12; fbsp=MLopt/Zsp;
                     }
              if(fbsp>1125) break; Lopt=Lopt; t=t;
              }

Lopt+=1;

LoptFinal :          Lopt-=1;

//Maximum bending moment along span ab occurs when shear force
//is zero or shear force equals to Rb. (from 'c')

float V3Qu_bc_a=-(hb-hc)/bc;float V3Qu_bc_b=-2*hc;
```

```
float V3Qu_bc_c=(2*Rc-hc*cB);
float V3Q_bc_Arrc[]={V3Qu_bc_a,V3Qu_bc_b,V3Qu_bc_c};

//Max span BM due to combined load of water and sill pres. at
//dist. x from 'c' in t.m.

//float Mspbc_c=-pow(xcl,3)*(hb-hc)/6/bc-hc/2*pow(xcl,2)
//            +(Rc-hc*cB/2)*xcl-hc/6*pow(cB,2);
float V3Cu_bc_a=-(hb-hc)/6/bc; float V3Cu_bc_b=-hc/2;
float V3Cu_bc_c=(Rc-hc*cB/2); float V3Cu_bc_d=-hc/6*pow(cB,2);
float V3C_bc_Arrc[]={V3Cu_bc_a,V3Cu_bc_b,V3Cu_bc_c,V3Cu_bc_d};
float spbcr=0.2*bc; float spbcl=0.8*bc;
float conflxbcr=xcube(V3C_bc_Arrc,V3Q_bc_Arrc,spbcr,bc,1);
float conflxbcl=xcube(V3C_bc_Arrc,V3Q_bc_Arrc,spbcl,bc,2);

//Calculation of co-acting width at support points/span.

float lcon_spbc=conflxbcl+conflxbcr;
float CAWspbc=caw1(bc,lcon_spbc,Lopt);//CAW at span bc
float CAWxc=caw2(cB,conflxbcr,Lopt);  //CAW at support 'c'.
float cawArrc[]={CAWxc,CAWspbc};
float CAWxclow=small(cawArrc,2);

//Maximum bending moment along span ab occurs when shear force
//is zero or shear force equals to Rb. (from 'a')

float V3Qu_ab_aa=(ha-hb)/ab; float V3Qu_ab_ab=-2*ha;
float V3Qu_ab_ac=2*Ra-(HD+ha)*Aa;
float V3Q_ab_Arra[]={V3Qu_ab_aa,V3Qu_ab_ab,V3Qu_ab_ac};

//Max BM due to combined load of water and sill pres. at dist. x
//from 'a'( in t.m.).

//float Mspab_a=pow(xar,3)*(ha-hb)/6/ab-ha/2*pow(xar,2)
//           +(Ra-(HD+ha)*Aa/2)*xar-(ha+2*HD)*pow(Aa,2)/6;
float V3Cu_ab_aa=(ha-hb)/6/ab; float V3Cu_ab_ab=-ha/2;
float V3Cu_ab_ac=Ra-(HD+ha)*Aa/2;
float V3Cu_ab_ad=-(ha+2*HD)*pow(Aa,2)/6;
float V3C_ab_Arra[]={V3Cu_ab_aa,V3Cu_ab_ab,V3Cu_ab_ac,V3Cu_ab_ad};
float spabl=0.2*ab; float spabr=0.8*ab;
float conflxabl_a=xcube(V3C_ab_Arra,V3Q_ab_Arra,spabl,ab,1);
float conflxabr_a=xcube(V3C_ab_Arra,V3Q_ab_Arra,spabr,ab,2);

//Calculation of co-acting width at support points.

float lcon_spab=conflxabl_a+conflxabr_a;
float lcon_b=conflxbcl+conflxabr_a;
float CAWxa_a=caw2(Aa,conflxabl_a,Lopt);//CAW at support 'a'.
float CAWspab=caw1(ab,lcon_spab,Lopt);  //CAW at span ab
float CAWxb=caw2(cB,lcon_b,Lopt);
float cawArraa[]={CAWxa_a,CAWspab};
float cawArrbb[]={CAWxb,CAWspab,CAWspbc};
float CAWxaalow=small(cawArraa,2);
float CAWxbblow=small(cawArrbb,3);

//Check for skin plate as plate,  all edges rigidly fixed(=R).
//Here s=t,a=Lopt,b=ab.

float t1=0.85;  t=1.05;
float V3Pab=(ha+hb)/2/10;  float fb_2_3xab,tab;
if(V3Pab*10<=10){tab=t1;}  else tab=t;
```

```
Stress_SP(Lopt,tab,V3Pab,ab,3,&fb_2_3xab);
if(fb_2_3xab>1125) goto LoptFinal;

//Check for skin plate as plate,  all edges rigidly fixed(=R).
//Here s=t,a=Lopt,b=bc.

float V3Pbc=(hb+hc)/2/10;   float fb_2_3xbc,tbc;
if(V3Pbc*10<=10){tbc=t1;}  else tbc=t;
Stress_SP(Lopt,tbc,V3Pbc,bc,3,&fb_2_3xbc);
if(fb_2_3xbc>1125) goto LoptFinal;

//Check for skin plate as plate, for two short and one long edge
//fixed and one long edge simply supported.(=R2s1). b=Lopt, a=Aa.

//Check for skin plate  as plate, for two long and one short edge
//fixed and one short edge simply supported.(=R21s). b=Aa, a=Lopt.

float V3PAa=(HD+ha)/2/10;  float fb_5_8xAa,tAa;
if(V3PAa*10<=10){tAa=t1;}  else tAa=t;
Stress_SP(Lopt,tAa,V3PAa,Aa/2,5,&fb_5_8xAa);
if(fb_5_8xAa>1125)goto LoptFinal;

//Check for stresses in skin plate at  girder points co-acting
//with vertical stiffeners  and span.
//v/stiffener selected (1/2 cut ISMB and T-sections).

//At support 'a': sh. force:
float Hax,Hbx,Hcx,tax,tbx,tcx;  Hax=ha; Hbx=hb; Hcx=hc;
if(Hax<=10){tax=t1;} else tax=t;
float SFbot_a=Aa*(HD+ha)/2; float SFtop_a=Ra-SFbot_a;
float SFArr_a[]={SFbot_a,SFtop_a};
float SFmax_a=big(SFArr_a,2);       //in tonnes/m
//dir. comp. force:
float Fcomp_a=0;  float Mpo=0; float Mpq=HD/10*pow(Lopt,2)/12;
float MGArrA[]={Mpo,Mpq};  float MmaxGA=big(MGArrA,2);
float BSa=MmaxGA*ha/HD/(pow(tax,2)/6); //in kgf/sqcm.
float cawa[2]={CAWxaalow*100,tax};
float f1a,f2a,f3a,Sa,STspa,STflga,Scomba,webLVSa,flgLVSa,flgWVSa,
      wVSa;
Stress_VS(cawa,Ma,SFmax_a,BSa,Fcomp_a,Lopt,&f1a,&f2a,&f3a,&Sa,
      &STspa,&STflga,&Scomba,&webLVSa,&flgLVSa,&flgWVSa,&wVSa);

//At support 'b': sh. force:
if(Hbx<=10){tbx=t1;} else tbx=t;
float SFbot_b=Aa*(HD+ha)/2+(ha+hb)/2*ab-Ra;
float SFtop_b=Rb-SFbot_b; float SFArr_b[]={SFbot_b,SFtop_b};
float SFmax_b=big(SFArr_b,2);       //in tonnes./m
//dir. comp. force:
float Fcomp_b=0;
float BSb=MmaxGA*hb/HD/(pow(tbx,2)/6);  //in kgf/sqcm.
float cawb[2]={CAWxbblow*100,tbx};
float f1b,f2b,f3b,Sb,STspb,STflgb,Scombb,webLVSb,flgLVSb,flgWVSb,
      wVSb;
Stress_VS(cawb,Mb,SFmax_b,BSb,Fcomp_b,Lopt,&f1b,&f2b,&f3b,&Sb,
      &STspb,&STflgb,&Scombb,&webLVSb,&flgLVSb,&flgWVSb,&wVSb);

//At support 'c': sh. force:
if(Hcx<=10){tcx=t1;} else tcx=t;
float SFbot_c=Aa*(HD+ha)/2+(ha+hb)/2*ab+(hb+hc)/2*bc-(Ra+Rb);
float SFtop_c=Rc-SFbot_c; float SFArr_c[]={SFbot_c,SFtop_c};
float SFmax_c=big(SFArr_c,2);       //in tonnes./m
```

```
//dir. comp. force:
float Fcomp_c=0;
float BSc=MmaxGA*hc/HD/(pow(tcx,2)/6);  //in kgf/sqcm.
float cawc[2]={CAWxclow*100,tcx};
float f1c,f2c,f3c,Sc,STspc,STflgc,Scombc,webLVSc,flgLVSc,flgWVSc,
      wVSc;
Stress_VS(cawc,Mc,SFmax_c,BSc,Fcomp_c,Lopt,&f1c,&f2c,&f3c,&Sc,
      &STspc,&STflgc,&Scombc,&webLVSc,&flgLVSc,&flgWVSc,&wVSc);

//-----------------------------------------------------------------
//    HORIZONTAL GIRDERS
//-----------------------------------------------------------------

//Stresses at H/girder 'a'.

float webLGa,flgLGa,flgWGa,wHGa,RAmaxa,MG_spa,dlmaxa;
Stress_VHG(cawa,CS,Ra,FFw,&webLGa,&flgLGa,&flgWGa,&wHGa,&RAmaxa,
         &dlmaxa,&MG_spa);

//Stresses at H/girder 'b'.

float webLGb,flgLGb,flgWGb,wHGb,RAmaxb,MG_spb,dlmaxb;
Stress_VHG(cawb,CS,Rb,FFw,&webLGb,&flgLGb,&flgWGb,&wHGb,&RAmaxb,
         &dlmaxb,&MG_spb);

//Stresses at H/girder 'c'.

float webLGc,flgLGc,flgWGc,wHGc,RAmaxc,MG_spc,dlmaxc;
Stress_VHG(cawc,CS,Rc,FFw,&webLGc,&flgLGc,&flgWGc,&wHGc,&RAmaxc,
         &dlmaxc,&MG_spc);

//-----------------------------------------------------------------
//    VERTICAL END GIRDERS
//-----------------------------------------------------------------

float Lab,Lbc,Lcd,Lac,Lad,Lae,Lbd,Ldf,Lcf,Lbf,Laf,Lef,Lde,Lbe;
      Lab=HD*5/100; Lcd=HD*5/100;//Wheels are equi-flanked to HG.
      Lef=HD*5/100; Lde=bc-Lcd; Lbc=ab-Lab; Lac=Lab+Lbc;
      Lbd=Lbc+Lcd; Lad=Lac+Lcd; Lbe=Lbd+Lde; Lae=Lad+Lde;
      Lbe=Lbd+Lde; Ldf=Lde+Lef;
//Reaction on h/girders
float RAa=RAmaxa/2; float RAb=RAmaxb/2; float RAc=RAmaxc/2;
float MFLbc,MFLcb,MFa,MFb,MFc,MFd;
float MFLde,MFLed,MFe,MFf;
float MFLab=-(RAa*Lab/8);     float MFLba=-MFLab;
float MFLcd=-(RAb*Lcd/8);     float MFLdc=-MFLcd;
float MFLef=-(RAc*Lef/8);       //float MFLfe=-MFLef;
float kba=(3/Lab)/(3/Lab+4/Lbc);//float kbc=1-kba;
float kcb=(4/Lbc)/(4/Lbc+4/Lcd);//float kcd=1-kcb;
float kdc=(4/Lcd)/(4/Lcd+4/Lde);//float kde=1-kdc;
float ked=(4/Lde)/(4/Lde+3/Lef);//float kef=1-ked;
      MFLba+=-MFLba*kba; MFLcb=-MFLcd*kcb;
      MFLdc+=-MFLdc*kdc; MFLed=-MFLef*ked;
      MFb=MFLba; MFc=MFLcb; MFd=MFLdc; MFe=MFLed;
//Reactions:
float RWa=(RAa/2-MFb/Lab);
float RWb=(RAa*(Lab/2+Lbc)-MFc-RWa*Lac)/Lbc;
float RWc=(RAa*(Lab/2+Lbd)-MFd-RWa*Lad-RWb*Lbd+RAb*Lcd/2)/Lcd;
float RWd=(RAa*(Lab/2+Lbe)-MFe-RWa*Lae-RWb*Lbe+RAb*(Lcd/2+Lde)
         -RWc*(Lcd+Lde))/Lde;
float RWf=(RAc/2-MFe/Lef);
```

```
float RWe=(RAc*(Lcd/2+Lde)-MFd-RWf*Ldf)/Lde;
//BM at HG positions:
float MGW_spa=RWa*Lab/2; float MGW_spc=RWc*Lef/2;
float MGW_spb=RWa*(Lac+Lcd/2)-RAa*(Lab/2+Lbc+Lcd/2)
            +RWb*(Lbc+Lcd/2)+RWc*Lcd/2;

//Analysis of stresses on the VEG.

float BMArra[]={MGW_spa,MGW_spb,MGW_spc,MFb,MFc,MFd,MFe};
float SFArra[]={RWa,RWb,RWc,RWd,RWe,RWf};
float SFmax=big(SFArra,6);
float Mmax=big(BMArra,7);
float fb_spa,fb_oppa,SSa,webLVGa,webWVGa,wVEGa;
Stress_VEG(t, Mmax, SFmax, Lopt,&fb_spa,&fb_oppa,&SSa,&webLVGa,
         &webWVGa,&wVEGa);

//---------------------------------------------------------------
//    WHEEL OF VERTICAL LIFT GATE
//---------------------------------------------------------------

float wWheel,Z1,R2,w; float PE=0; float PN=SFmax;
Wheel(PN,PE,HD,&Z1,&R2,&w,&wWheel);

//---------------------------------------------------------------
//    COST EVALUATION
//---------------------------------------------------------------

//WEIGHT OF GATE  AND CG OF GATE

float webLVS,flgWVS;
if(wVSa>wVSb){webLVS=webLVSa;flgWVS=flgWVSa;}
      else {webLVS=webLVSb;flgWVS=flgWVSb;}
if(wVSb>wVSc){webLVS=webLVSb;flgWVS=flgWVSb;}
      else {webLVS=webLVSc;flgWVS=flgWVSc;}
int Nvs;int CS1=CS*100;int CSab=CS*100;int Remab=(CSab) % Lopt;
if(Remab==0)Nvs=CS1/Lopt+4;
      else if(Remab<0.4*Lopt)Nvs=(CS1-CS1 % Lopt)/Lopt+3;
      else if(Remab>0.4*Lopt)Nvs=(CS1-CS1 % Lopt)/Lopt+4;
float Ltb=0; float tb,Lt=HD;   t=0.85;
if(HD>=10){
        Ltb=HD-10;  tb=t; Lt=10;
        }
float Wspl=(Ltb*(tb+0.15)+(t+0.15)*Lt)/100*CS*7.850;
float Dspl=(t+0.15)/100/2; float Mspl=Wspl*Dspl;
float Wvs=wVSc*HD*Nvs/1000;
float Dvs=((t+0.15)+(webLVS+flgWVS)*2/3)/100; float Mvs=Wvs*Dvs;
float Whga=wHGa*FFw/1000; float Whgb=wHGb*FFw/1000;
float Whgc=wHGc*FFw/1000;
float Dhga=(t+0.15+flgWVS+webLVS+(2*flgWGa+webLGa)/2)/100;
float Dhgb=(t+0.15+flgWVS+webLVS+(2*flgWGb+webLGb)/2)/100;
float Dhgc=(t+0.15+flgWVS+webLVS+(2*flgWGc+webLGc)/2)/100;
float Mhga=Whga*Dhga; float Mhgb=Whgb*Dhgb; float Mhgc=Whgc*Dhgc;
float Whg=Whga+Whgb+Whgc; float Mhg=Mhga+Mhgb+Mhgc;
float Wveg=2*wVEGa*HD/1000; float Dveg=((t+0.15)+webLVGa/2)/100;
float Mveg=Wveg*Dveg;  float Wwheel=wWheel*12/1000;
float Dwheel=(t+0.15+webLVGa-R2)/100;float Mwheel=Wwheel*Dwheel;
float WVG=(Wspl+Wvs+Whg+Wveg+Wwheel);
float MVG=(Mspl+Mvs+Mhg+Mveg+Mwheel); float CVG=MVG/WVG;
```

```
//HOISTING CAPACITY OF GATE

float FFl=CS-2*12/1000;
float P=1*FFl*pow(HD,2)/2;    //total hydrostatic load
float F=P*(0.015*1+1.5)/(R2*10);//fa=0.015, fr=1.5
float fg=(5/100*WVG)*4*0.5;   //guide friction @ 5 % of gate wt.
float fs=HD*0.25*2/10;        //seal friction for seal length.
float Wrope=1.5/100*WVG;      //rope wt. @ 1.5 % of gate wt.
float Ft=F+fg+fs+Wrope;  float WVGt=1.2*(WVG+Ft);

//MATERIAL COST OF GATE (Mat_cost)

float Cspl=1.05*Wspl; float Cvs=1.05*Wvs; float Chg=1.05*Whg;
float Cveg=1.05*Wveg; float Cwheel=1.05*Wwheel;
float Css=1.05*2*(HD+CS)*8*80/1000/1000*7.850;
float Mat_cost=1*(Cspl+Cvs+Chg+Cveg+Cwheel+Css)/100000*25000;
float Ctotal;
cout.precision(1);
COST(HD,FFw,Nvs,WVG,WVGt,Mat_cost,'V',1,1,&Ctotal);
cout<<setw(8)<<HD<<setw(8)<<CS<<setw(13)<<WVG*1.25<<setw(10)<<CVG
    <<setw(17)<<WVGt<<setw(13)<<Ctotal<<endl;
}
nchar(70,'-');
getch();
}     //Main program ends.
```

```
//-----------------------------------------------------------------
//                   :: OPTGATV4.CPP ::
//PROGRAM FOR 'OPTIMISATION OF DESIGN OF SPILLWAY GATES'
//-----------------------------------------------------------------

#include<iostream.h>
#include<conio.h>
#include<math.h>
#include<process.h>
#include<iomanip.h>

void main()       //Main program starts.
{
clrscr();

//----------------------------------------------------------------
//    FUNCTION DECLARATIONS
//----------------------------------------------------------------

void Rvv(float [], float*, float*, float*, float*);
float xcube(float [], float [], float, float, int);
void nchar(int, char);  long fact(int);
float xsqrt(float [], float);
float polym(float[], float [], int, float);
float caw2(float, float, float);
float caw1(float, float, float);
void k_nondim(float, int, float*);
void Stress_VS(float [], float, float, float, float, float,
             float*, float*, float*, float*, float*, float*,
             float*, float*, float*, float*, float*);
float big(float [],int);      float small(float [], int);
void Stress_VHG(float [], float, float, float, float*, float*,
            float*, float*, float*, float*, float*);
void Stress_VEG(float, float, float, float, float*, float*,
            float*, float*, float*, float*);
void Wheel(float, float, float, float*, float*, float*, float*);
void Use_Rat(float, float, float, float, float, int, int,float*);
void Stress_SP(float, float, float, float,int,float*);
void COST(float, float, float, float, float, float, char, float,
        float, float*);

cout.precision(3);

//-----------------------------------------------------------------
//    SKIN PLATE AND VERTICAL STIFFENER
//-----------------------------------------------------------------

float FRL,CL,HD,SL,Sh,Sv,TL;
float CS;    FRL=100;   CL=90;
float CSArr[]={20,18,16,14,12,10,8,6};
cout<<"\nCost analysis of Vertical Lift Gate w.r.t. Span (4 HG):"
    <<endl;
nchar(70,'-');
cout<<"\n"<<setw(8)<<"Head"<<setw(8)<<"Span"<<setw(13)<<"WG"
    <<setw(10)<<"CG"<<setw(17)<<"Hoist capacity"<<setw(13)<<"Cost";
cout<<"\n"<<setw(8)<<"(m)"<<setw(8)<<"(m)"<<setw(13)<<"(tonnes)"
    <<setw(10)<<"(m)"<<setw(17)<<"(tonnes)"<<setw(13)
    <<"(lakh Rs.)"<<endl;
nchar(70,'-');    cout<<endl;
for(int k=0;k<8;k++)
```

```
{
CS=CSArr[k];  SL=CL;
for(int i=0;i<5;i++)
      {
      HD=FRL-SL;  Sh=0.15*HD;
      Sv=pow(Sh,1.85)*pow(HD,-0.85)/2.0;  SL=CL-Sv;
      }
      HD=FRL-SL+0.300;
float ha=HD*(pow(4,1.5)-pow(3,1.5))*2/3/sqrt(4);
float hb=HD*(pow(3,1.5)-pow(2,1.5))*2/3/sqrt(4);
float hc=HD*(pow(2,1.5)-pow(1,1.5))*2/3/sqrt(4);
float hd=HD*(pow(1,1.5)-pow(0,1.5))*2/3/sqrt(4);
float Aa=HD-ha; float ab=ha-hb; float bc=hb-hc;
float cd=hc-hd; float dB=hd;
float Tsl=150;                //Side seal length.
float FFw=CS+2*Tsl/1000;            //Face to face length to wheels.

//Bending moment at support points  (1 m width of load).

float Ma=pow(Aa,2)*ha*1/2+pow(Aa,2)*(HD-ha)/2*2/3;  //in t.m/m
float Mab=pow(ab,2)*hb/12+pow(ab,2)*(ha-hb)/2/10;
float Mba=pow(ab,2)*hb/12+pow(ab,2)*(ha-hb)/2/15;
float Mbc=pow(bc,2)*hc/12+pow(bc,2)*(hb-hc)/2/10;
float Mcb=pow(bc,2)*hc/12+pow(bc,2)*(hb-hc)/2/15;
float Mcd=pow(cd,2)*hd/12+pow(cd,2)*(hc-hd)/2/10;
float Mdc=pow(cd,2)*hd/12+pow(cd,2)*(hc-hd)/2/15;
float MdB=pow(dB,2)*hd*1/2*1/3;  float Md=MdB;
float kba4=(3/ab)/(3/ab+3/bc); float kbc4=1-kba4;
float kcb4=(3/bc)/(3/bc+3/cd); float kcd4=1-kcb4;
float MRb,MRc,CMba,CMbc,CMcb,CMcd,MRa,MRd;
      Mab=-Mab; Mbc=-Mbc; Mcd=-Mcd; MdB=-MdB;
      MRa=-(Mab+Ma); MRd=-(Mdc+MdB);
      MRb=-(Mba+Mbc); MRc=-(Mcb+Mcd);
      CMba=MRb*kba4; CMbc=MRb*kbc4; CMcb=MRc*kcb4;
      CMcd=MRc*kcd4; Mab+=MRa; Mba+=CMba; Mbc+=CMbc;
      Mcb+=CMcb; Mcd+=CMcd; Mdc+=MRd;
Ma=Ma; float Mb=Mba;  float Mc=Mcb;  Md=Mdc;

//Reactions at support points due to water load. (load wtdth 1 m)

float Ra=(HD+ha)*Aa/2+hb*ab/2+(ha-hb)*ab/2*2/3-(Mba+Mab)/ab;
float Rb=hb*ab/2+(ha-hb)*ab/2/3+(Mba+Mab)/ab+hc*bc/2
            +(hb-hc)*bc/2*2/3-(Mcb+Mbc)/bc;     //tonnes/m.
float Rc=hc*bc/2+(hb-hc)*bc/2/3+(Mcb+Mbc)/bc
            +hd*cd/2+(hc-hd)*cd/2*2/3-(Mdc+Mcd)/cd; //tonnes/m.
float Rd=hd*cd/2+(hc-hd)*cd/2/3+(Mdc+Mcd)/cd+hd*dB/2;   //tonnes/m.
float t,MLopt;   int Lopt;
float Hb=HD/10;  float Zsp;  float fbsp;
float tArr[5]={2.0,1.8,1.4,1.2,1.0};;
int LoptArr[6]={45,46,47,48,49,50};;
for(i=0;i<5;i++)
            {
            t=tArr[i]-0.15; Zsp=1*pow(t,2)/6;
            for(int j=0;j<6;j++)
                  {
                  Lopt=LoptArr[j];
                  MLopt=Hb*pow(Lopt,2)/12; fbsp=MLopt/Zsp;
                  }
            if(fbsp>1125) break; Lopt=Lopt; t=t;
            }
```

```
Lopt+=1;

LoptFinal :      Lopt-=1;

//Maximum bending moment along span ab occurs when shear force
//is zero or shear force equals to Rb. (from 'd')
//ie. -(hc-hd)/cd*xdl^2-(2*hd)*xdl+(2*Rd-hd*dB)=0

float V4Qu_cd_a=-(hc-hd)/cd;float V4Qu_cd_b=-(2*hd);
float V4Qu_cd_c=(2*Rd-hd*dB);
float V4Q_cd_Arrd[]={V4Qu_cd_a,V4Qu_cd_b,V4Qu_cd_c};

//Max span BM due to combined load of water and sill pres. at
//dist. x from 'd' in t.m.

//float Mspcd_d=-pow(xdl,3)*(hc-hd)/6/cd-hd/2*pow(xdl,2)
//          +(Rd-hd*dB/2)*xdl-(hd*pow(dB,2))/6;
float V4Cu_cd_a=-(hc-hd)/6/cd; float V4Cu_cd_b=-hd/2;
float V4Cu_cd_c=Rd-hd*dB/2; float V4Cu_cd_d=-hd/6*pow(dB,2);
float V4C_cd_Arrd[]={V4Cu_cd_a,V4Cu_cd_b,V4Cu_cd_c,V4Cu_cd_d};
float spcdr=0.2*cd; float spcdl=0.8*cd;
float conflxcdr=xcube(V4C_cd_Arrd,V4Q_cd_Arrd,spcdr,cd,1);
float conflxcdl=xcube(V4C_cd_Arrd,V4Q_cd_Arrd,spcdl,cd,2);

//Calculation of co-acting width at support points/span.

float lcon_spcd=conflxcdl+conflxcdr;
float CAWspcd=caw1(cd,lcon_spcd,Lopt);//CAW at span cd
float CAWxd=caw2(dB,conflxcdr,Lopt);  //CAW at support 'b'.
float cawArrd[]={CAWxd,CAWspcd};
float CAWxdlow=small(cawArrd,2);

//Maximum bending moment along span ab occurs when shear force
//is zero or shear force equals to (Rc+Rd). (from 'c')

float V4Qu_bc_a=-(hb-hc)/bc;float V4Qu_bc_b=-(2*hc);
float V4Qu_bc_c=2*(Rc+Rd)-(hc+hd)*cd-hd*dB;
float V4Q_bc_Arrc[]={V4Qu_bc_a,V4Qu_bc_b,V4Qu_bc_c};

//Max span BM due to combined load of water and sill pres. at
//dist. x from 'c' in t.m.

//float Mspbc_c=-pow(xcl,3)*(hb-hc)/bc/6-hc/2*pow(xcl,2)
//          +(Rc+Rd-(hc+hd)/2*cd-hd/2*dB)*xcl
//          +Rd*cd-(hc+2*hd)/6*pow(cd,2)-hd/2*dB*(cd+dB/3);
float V4Cu_bc_a=-(hb-hc)/6/bc; float V4Cu_bc_b=-hc/2;
float V4Cu_bc_c=Rc+Rd-(hc+hd)/2*cd-hd/2*dB;
float V4Cu_bc_d=Rd*cd-(hc+2*hd)/6*pow(cd,2)-hd/2*(cd+dB/3)*dB;
float V4C_bc_Arrc[]={V4Cu_bc_a,V4Cu_bc_b,V4Cu_bc_c,V4Cu_bc_d};
float spbcr=0.2*bc; float spbcl=0.8*bc;
float conflxbcr=xcube(V4C_bc_Arrc,V4Q_bc_Arrc,spbcr,bc,1);
float conflxbcl=xcube(V4C_bc_Arrc,V4Q_bc_Arrc,spbcl,bc,2);

//Calculation of co-acting width at support points/span.

float lcon_spbc=conflxbcl+conflxbcr;
float lcon_c=conflxcdl+conflxbcr;
float CAWspbc=caw1(bc,lcon_spbc,Lopt);//CAW at span bc
float CAWxc=caw2(bc,lcon_c,Lopt);     //CAW at support 'c'.
float cawArrc[]={CAWxc,CAWspbc,CAWspcd};
float CAWxclow=small(cawArrc,3);
```

```
//Maximum bending moment along span ab occurs when shear force
//is zero or shear force equals to Rb. (from 'a')
//ie. (ha-hb)/ab*x^2-(2*ha)*x+2*Ra-(wA+wa)*Aa)=0

float V4Qu_ab_aa=(ha-hb)/ab; float V4Qu_ab_ab=-(2*ha);
float V4Qu_ab_ac=2*Ra-(HD+ha)*Aa;
float V4Q_ab_Arra[]={V4Qu_ab_aa,V4Qu_ab_ab,V4Qu_ab_ac};

//Max BM due to combined load of water and sill pres. at dist. x
//from 'a'( in t.m.).

//float Mspab_a=pow(xar,3)*(ha-hb)/6/ab-ha/2*pow(xar,2)
//          +(Ra-(HD+ha)*Aa/2)*xar-(ha+2*HD)*pow(Aa,2)/6;
float V4Cu_ab_aa=(ha-hb)/6/ab; float V4Cu_ab_ab=-ha/2;
float V4Cu_ab_ac=Ra-(HD+ha)*Aa/2;
float V4Cu_ab_ad=-(ha+2*HD)*pow(Aa,2)/6;
float V4C_ab_Arra[]={V4Cu_ab_aa,V4Cu_ab_ab,V4Cu_ab_ac,V4Cu_ab_ad};
float spabl=0.2*ab; float spabr=0.8*ab;
float conflxabl_a=xcube(V4C_ab_Arra,V4Q_ab_Arra,spabl,ab,1);
float conflxabr_a=xcube(V4C_ab_Arra,V4Q_ab_Arra,spabr,ab,2);

//Calculation of co-acting width at support points.

float lcon_spab=conflxabl_a+conflxabr_a;
float lcon_b=conflxbcl+conflxabr_a;
float CAWspab=caw1(ab,lcon_spab,Lopt);  //CAW) at span ab
float CAWxa_a=caw2(Aa,conflxabl_a,Lopt);//CAW at support 'a'.
float CAWxb_a=caw2(bc,lcon_b,Lopt);     //CAW at support 'b'.
float cawArra[]={CAWxa_a,CAWspab};
float cawArrb[]={CAWxb_a,CAWspab,CAWspbc};
float CAWxalow=small(cawArra,2);
float CAWxblow=small(cawArrb,3);

//Check for skin plate as plate,  all edges rigidly fixed(=R).
//Here s=t,a=Lopt,b=ab.

float t1=0.85;  t=1.05;
float V4Pab=(ha+hb)/2/10;  float fb_2_3xab,tab;
if(V4Pab*10<=10){tab=t1;}  else tab=t;
Stress_SP(Lopt,tab,V4Pab,ab,3,&fb_2_3xab);
if(fb_2_3xab>1125) goto LoptFinal;

//Check for skin plate as plate,  all edges rigidly fixed(=R).
//Here s=t,a=Lopt,b=bc.

float V4Pbc=(hb+hc)/2/10;   float fb_2_3xbc,tbc;
if(V4Pbc*10<=10){tbc=t1;}  else tbc=t;
Stress_SP(Lopt,tbc,V4Pbc,bc,3,&fb_2_3xbc);
if(fb_2_3xbc>1125) goto LoptFinal;

//Check for skin plate as plate,  all edges rigidly fixed(=R).
//Here s=t,a=Lopt,b=cd.

float V4Pcd=(hc+hd)/2/10;  float fb_2_3xcd,tcd;
if(V4Pcd*10<=10){tcd=t1;}  else tcd=t;
Stress_SP(Lopt,tcd,V4Pcd,cd,3,&fb_2_3xcd);
if(fb_2_3xcd>1125) goto LoptFinal;

//Check for skin plate as plate, for two short and one long edge
//fixed and one long edge simply supported.(=R2sl). b=Lopt, a=Aa.
```

```
//Check for skin plate  as plate, for two long and one short edge
//fixed and one short edge simply supported.(=R21s). b=Aa, a=Lopt.

float V4PAa=(HD+ha)/2/10;  float fb_5_8xAa,tAa;
if(V4PAa*10<=10){tAa=t1;}  else tAa=t;
Stress_SP(Lopt,tAa,V4PAa,Aa,5,&fb_5_8xAa);
if(fb_5_8xAa>1125)goto LoptFinal;

//Check for stresses in skin plate at  girder points co-acting
//with vertical stiffeners  and span.
//v/stiffener selected (1/2 cut ISMB and T-sections).

//At support 'a': sh. force:
float Hax,Hbx,Hcx,Hdx,tax,tbx,tcx,tdx;
      Hax=ha; Hbx=hb; Hcx=hc; Hdx=hd;
if(Hax<=10){tax=t1;} else tax=t;
float SFbot_a=Aa*(HD+ha)/2; float SFtop_a=Ra-SFbot_a;
float SFArr_a[]={SFbot_a,SFtop_a};
float SFmax_a=big(SFArr_a,2);        //in tonnes./m
float Fcomp_a=0;
//dir. comp. force:
float Mpo=0; float Mpq=HD/10*pow(Lopt,2)/12;
float MGArrA[]={Mpo,Mpq}; float MmaxGA=big(MGArrA,2);
float BSa=MmaxGA*ha/HD/(pow(tax,2)/6);  //in kgf/sqcm.
float cawa[2]={CAWxalow*100,tax};
float f1a,f2a,f3a,Sa,STspa,STflga,Scomba,webLVSa,flgLVSa,flgWVSa,
      wVSa;
Stress_VS(cawa,Ma,SFmax_a,BSa,Fcomp_a,Lopt,&f1a,&f2a,&f3a,&Sa,
      &STspa,&STflga,&Scomba,&webLVSa,&flgLVSa,&flgWVSa,&wVSa);

//At support 'b': sh. force:
if(Hbx<=10){tbx=t1;} else tbx=t;
float SFbot_b=Aa*(HD+ha)/2+(ha+hb)/2*ab-Ra;
float SFtop_b=Rb-SFbot_b; float SFArr_b[]={SFbot_b,SFtop_b};
float SFmax_b=big(SFArr_b,2);        //in tonnes./m
//dir. comp. force:
float Fcomp_b=0;
float BSb=MmaxGA*hb/HD/(pow(tbx,2)/6);  //in kgf/sqcm.
float cawb[2]={CAWxblow*100,tbx};
float f1b,f2b,f3b,Sb,STspb,STflgb,Scombb,webLVSb,flgLVSb,flgWVSb,
      wVSb;
Stress_VS(cawb,Mb,SFmax_b,BSb,Fcomp_b,Lopt,&f1b,&f2b,&f3b,&Sb,
      &STspb,&STflgb,&Scombb,&webLVSb,&flgLVSb,&flgWVSb,&wVSb);

//At support 'c': sh. force:
if(Hcx<=10){tcx=t1;} else tcx=t;
float SFbot_c=Aa*(HD+ha)/2+(ha+hb)/2*ab+(hb+hc)/2*bc-(Ra+Rb);
float SFtop_c=Rc-SFbot_c; float SFArr_c[]={SFbot_c,SFtop_c};
float SFmax_c=big(SFArr_c,2);        //in tonnes./m
//dir. comp. force:
float Fcomp_c=0;
float BSc=MmaxGA*hc/HD/(pow(tcx,2)/6);  //in kgf/sqcm.
float cawc[2]={CAWxclow*100,tcx};
float f1c,f2c,f3c,Sc,STspc,STflgc,Scombc,webLVSc,flgLVSc,flgWVSc,
      wVSc;
Stress_VS(cawc,Mc,SFmax_c,BSc,Fcomp_c,Lopt,&f1c,&f2c,&f3c,&Sc,
      &STspc,&STflgc,&Scombc,&webLVSc,&flgLVSc,&flgWVSc,&wVSc);

//At support 'd':
//sh. force:
```

```
if(Hdx<=10){tdx=t1;} else tdx=t;
float SFbot_d=Aa*(HD+ha)/2+(ha+hb)/2*ab+(hb+hc)/2*bc
           +(hc+hd)/2*cd-(Ra+Rb+Rc);
float SFtop_d=Rc-SFbot_d; float SFArr_d[]={SFbot_d,SFtop_d};
float SFmax_d=big(SFArr_d,2);       //in tonnes./m
//dir. comp. force:
float Fcomp_d=0;
float BSd=MmaxGA*hd/HD/(pow(tdx,2)/6);  //in kgf/sqcm.
float cawd[2]={CAWxdlow*100,tdx};
float f1d,f2d,f3d,Sd,STspd,STflgd,Scombd,webLVSd,flgLVSd,flgWVSd,
      wVSd;
Stress_VS(cawd,Md,SFmax_d,BSd,Fcomp_d,Lopt,&f1d,&f2d,&f3d,&Sd,
      &STspd,&STflgd,&Scombd,&webLVSd,&flgLVSd,&flgWVSd,&wVSd);

//---------------------------------------------------------------
//    HORIZONTAL GIRDERS
//---------------------------------------------------------------

//Stresses at H/girder 'a'.

float webLGa,flgLGa,flgWGa,wHGa,RAmaxa,MG_spa,dlmaxa;
Stress_VHG(cawa,CS,Ra,FFw,&webLGa,&flgLGa,&flgWGa,&wHGa,&RAmaxa,
         &dlmaxa,&MG_spa);

//Stresses at H/girder 'b'.

float webLGb,flgLGb,flgWGb,wHGb,RAmaxb,MG_spb,dlmaxb;
Stress_VHG(cawb,CS,Rb,FFw,&webLGb,&flgLGb,&flgWGb,&wHGb,&RAmaxb,
         &dlmaxb,&MG_spb);

//Stresses at H/girder 'c'.

float webLGc,flgLGc,flgWGc,wHGc,RAmaxc,MG_spc,dlmaxc;
Stress_VHG(cawc,CS,Rc,FFw,&webLGc,&flgLGc,&flgWGc,&wHGc,&RAmaxc,
         &dlmaxc,&MG_spc);

//Stresses at H/girder 'd'.

float webLGd,flgLGd,flgWGd,wHGd,RAmaxd,MG_spd,dlmaxd;
Stress_VHG(cawd,CS,Rd,FFw,&webLGd,&flgLGd,&flgWGd,&wHGd,&RAmaxd,
         &dlmaxd,&MG_spd);

//------------------------------------------------------------------
//    VERTICAL END GIRDERS
//------------------------------------------------------------------

float Lab,Lcd,Lef,Lgh;
      Lab=HD*5/100;     //Wheels are equi-flanked to HG.
      Lcd=Lef=Lgh=Lab;
float Lde=bc-Lcd; float Lbc=ab-Lab; float Lfg=cd-Lgh;
//Reaction on h/girders
float RAa=RAmaxa/2; float RAb=RAmaxb/2; float RAc=RAmaxc/2;
float RAd=RAmaxd/2;
float MFLbc,MFLcb,MFLde,MFLed,MFLgf;
float MFa,MFb,MFc,MFd,MFe,MFf,MFg;
float MFLab=-(RAa*Lab/8);     float MFLba=-MFLab;
float MFLcd=-(RAb*Lcd/8);     float MFLdc=-MFLcd;
float MFLef=-(RAc*Lef/8);     float MFLfe=-MFLef;
float MFLgh=-(RAd*Lgh/8);     //float MFLhg=-MFLgh;
float kba=(3/Lab)/(3/Lab+4/Lbc);//float kbc=1-kba;
float kcb=(4/Lbc)/(4/Lbc+4/Lcd);//float kcd=1-kcb;
```

```
float kdc=(4/Lcd)/(4/Lcd+4/Lde);//float kde=1-kdc;
float ked=(4/Lde)/(4/Lde+4/Lef);//float kef=1-ked;
float kfe=(4/Lef)/(4/Lef+4/Lfg);//float kfg=1-kfe;
float kgf=(4/Lfg)/(4/Lfg+3/Lgh);//float kgh=1-kgf;
      MFLba+=-MFLba*kba;       //MFLbc=-MFLba*kbc;
      MFLcb=-MFLcd*kcb;
      MFLdc+=-MFLdc*kdc;       //MFLde=-MFLdc*kde;
      MFLed=-MFLef*ked;
      MFLfe+=-MFLfe*kfe;       //MFLfg=-MFLfe*kfg;
      MFLgf=-MFLgh*kgf;
      MFb=MFLba; MFc=MFLcb; MFd=MFLdc; MFe=MFLed;
      MFf=MFLfe; MFg=MFLgf;

//Reactions:

float Lac=Lab+Lbc; float Lad=Lac+Lcd; float Lae=Lad+Lde;
float Lbd=Lbc+Lcd; float Lbe=Lbd+Lde; float Lfh=Lfg+Lgh;
float Leh=Lfh+Lef; float Ldh=Lcd+Leh; float Leg=Lfg+Lef;
float Ldg=Ldh-Lgh; float RWa=(RAa/2-MFb/Lab);
float RWb=(RAa*(Lab/2+Lbc)-MFc-RWa*Lac)/Lbc;
float RWc=(RAa*(Lab/2+Lbd)-MFd-RWa*Lad-RWb*Lbd+RAb*Lcd/2)/Lcd;
float RWd=(RAa*(Lab/2+Lbe)-MFe-RWa*Lae-RWb*Lbe+RAb*(Lcd/2+Lde)
         -RWc*(Lcd+Lde))/Lde;
float RWh=(RAd/2-MFg/Lgh);
float RWg=(RAd*(Lgh/2+Lfg)-MFf-RWh*Lfh)/Lfg;
float RWf=(RAd*(Lgh/2+Leg)-MFe-RWh*Leh-RWg*Leg+RAc*Lef/2)/Lef;
float RWe=(RAd*(Lgh/2+Ldg)-MFd-RWh*Ldh-RWg*Ldg+RAc*(Lef/2+Lde)
         -RWf*(Lde+Lef))/Lde;
//BM at HG positions:
float MGW_spa=RWa*Lab/2; float MGW_spd=RWd*Lgh/2;
float MGW_spb=RWa*(Lac+Lcd/2)-RAa*(Lab/2+Lbc+Lcd/2)+RWb*(Lbc
           +Lcd/2)+RWc*Lcd/2;
float MGW_spc=RWh*(Lfh+Lef/2)-RAd*(Lgh/2+Lfg+Lef/2)
           +RWg*(Lef/2+Lfg)+RWf*Lef/2;

//Analysis of stresses on the VEG.

float BMArra1[]={MFb,MFc,MFd,MFe,MFf,MFg};
float BMArra2[]={MGW_spa,MGW_spb,MGW_spc,MGW_spd};
float SFArra[]={RWa,RWb,RWc,RWd,RWe,RWf,RWg,RWh};
float SFmax=big(SFArra,8);
float Mmax1=big(BMArra1,6); float Mmax2=big(BMArra2,4);
float MmaxA[]={Mmax1,Mmax2}; float Mmax=big(MmaxA,2);
float fb_spa,fb_oppa,SSa,webLVGa,webWVGa,wVEGa;
Stress_VEG(t, Mmax, SFmax, Lopt,&fb_spa,&fb_oppa,&SSa,&webLVGa,
           &webWVGa,&wVEGa);

//-----------------------------------------------------------------
//    WHEEL OF VERTICAL LIFT GATE
//-----------------------------------------------------------------

float wWheel,Z1,R2,w; float PE=0; float PN=SFmax;
Wheel(PN,PE,HD,&Z1,&R2,&w,&wWheel);

//-----------------------------------------------------------------
//    COST EVALUATION
//-----------------------------------------------------------------

//WEIGHT OF GATE  AND CG OF GATE

float webLVS,flgWVS;
```

```
if(wVSa>wVSb){webLVS=webLVSa;flgWVS=flgWVSa;}
      else {webLVS=webLVSb;flgWVS=flgWVSb;}
if(wVSb>wVSc){webLVS=webLVSb;flgWVS=flgWVSb;}
      else {webLVS=webLVSc;flgWVS=flgWVSc;}
if(wVSc>wVSd){webLVS=webLVSc;flgWVS=flgWVSc;}
      else {webLVS=webLVSd;flgWVS=flgWVSd;}
int Nvs; int CS1=CS*100; int CSab=CS*100; int Remab=CSab % Lopt;
if(Remab==0)Nvs=CS1/Lopt+4;
      else if(Remab<0.4*Lopt)Nvs=(CS1-CS1 % Lopt)/Lopt+3;
      else if(Remab>0.4*Lopt)Nvs=(CS1-CS1 % Lopt)/Lopt+4;
float Ltb=0;float tb,Lt=HD;   t=0.85;
if(HD>=10){
        Ltb=HD-10;  tb=t; Lt=10;
        }
float Wspl=(Ltb*(tb+0.15)+(t+0.15)*Lt)/100*CS*7.850;
float Dspl=(t+0.15)/100/2; float Mspl=Wspl*Dspl;
float Wvs=wVSd*HD*Nvs/1000;
float Dvs=((t+0.15)+(webLVS+flgWVS)*2/3)/100; float Mvs=Wvs*Dvs;
float Whga=wHGa*FFw/1000; float Whgb=wHGb*FFw/1000;
float Whgc=wHGc*FFw/1000; float Whgd=wHGd*FFw/1000;
float Dhga=(t+0.15+flgWVS+webLVS+(2*flgWGa+webLGa)/2)/100;
float Dhgb=(t+0.15+flgWVS+webLVS+(2*flgWGb+webLGb)/2)/100;
float Dhgc=(t+0.15+flgWVS+webLVS+(2*flgWGc+webLGc)/2)/100;
float Dhgd=(t+0.15+flgWVS+webLVS+(2*flgWGd+webLGd)/2)/100;
float Mhga=Whga*Dhga; float Mhgb=Whgb*Dhgb;
float Mhgc=Whgc*Dhgc; float Mhgd=Whgd*Dhgd;
float Whg=Whga+Whgb+Whgc+Whgd; float Mhg=Mhga+Mhgb+Mhgc+Mhgd;
float Wveg=2*wVEGa*HD/1000; float Dveg=((t+0.15)+webLVGa/2)/100;
float Mveg=Wveg*Dveg; float Wwheel=wWheel*16/1000;
float Dwheel=(t+0.15+webLVGa-R2)/100;  float Mwheel=Wwheel*Dwheel;
float WVG=(Wspl+Wvs+Whg+Wveg+Wwheel);
float MVG=(Mspl+Mvs+Mhg+Mveg+Mwheel);  float CVG=MVG/WVG;

//HOISTING CAPACITY OF GATE

float FFl=CS-2*12/1000;
float P=1*FFl*pow(HD,2)/2;    //total hydrostatic load
float F=P*(0.015*1+1.5)/(R2*10);//fa=0.015, fr=1.5
float fg=(5/100*WVG)*4*0.5;   //guide friction @ 5 % of gate wt.
float fs=HD*0.25*2/10;        //seal friction for seal length.
float Wrope=1.5/100*WVG;      //rope wt. @ 1.5 % of gate wt.
float Ft=F+fg+fs+Wrope;  float WVGt=1.2*(WVG+Ft);

//MATERIAL COST OF GATE (Mat_cost)

float Cspl=1.05*Wspl; float Cvs=1.05*Wvs; float Chg=1.05*Whg;
float Cveg=1.05*Wveg; float Cwheel=1.05*Wwheel;
float Css=1.05*2*(HD+CS)*8*80/1000/1000*7.85;
float Mat_cost=1*(Cspl+Cvs+Chg+Cveg+Cwheel+Css)/100000*25000;
float Ctotal;
cout.precision(1);
COST(HD,CS,Nvs,WVG,WVGt,Mat_cost,'V',1,1,&Ctotal);
cout<<setw(8)<<HD<<setw(8)<<CS<<setw(13)<<WVG*1.25<<setw(10)<<CVG
    <<setw(17)<<WVGt<<setw(13)<<Ctotal<<endl;
}
nchar(70,'-');
getch();
}     //Main program ends.
```

SAMPLE RESULTS

TABLE-1.RF.R2.1:

Cost of Radial Gate (2 HG) w.r.t. Radius Factor for 6.4m Head and 6m Span:

Rf (-)	AG (m^2)	Abay (m^2)	Arc_AB (m)	R (m)	WG (tonne)	WE (tonne)	Cost (lakh Rs)
1.05	39.97	38.35	6.66	6.71	9.17	9.91	5.89
1.1	39.81	38.35	6.63	7.03	9.15	9.88	5.87
1.15	39.67	38.35	6.61	7.35	8.2	9.86	5.55
1.2	39.55	38.35	6.59	7.67	8.22	9.84	5.55
1.25	39.45	38.35	6.58	7.99	8.24	9.82	5.55
1.3	39.36	38.35	6.56	8.31	8.26	9.81	5.55
1.35	39.28	38.35	6.55	8.63	8.29	9.79	5.56
1.4	39.21	38.35	6.54	8.95	8.31	9.78	5.56
1.45	39.15	38.35	6.53	9.27	8.34	9.77	5.57
1.5	39.09	38.35	6.52	9.59	8.32	9.76	5.56
1.55	39.04	38.35	6.51	9.91	8.35	9.75	5.57
1.6	39	38.35	6.5	10.23	8.38	9.75	5.58
1.65	38.96	38.35	6.49	10.55	8.41	9.74	5.59
1.7	38.92	38.35	6.49	10.86	8.51	9.73	5.62
1.75	38.89	38.35	6.48	11.18	8.55	9.73	5.63

TABLE-1.RF.R2.2:

Cost of Radial Gate (2 HG) w.r.t. Radius Factor for 6.4m Head and 10m Span:

Rf (-)	AG (m^2)	Abay (m^2)	Arc_AB (m)	R (m)	WG (tonne)	WE (tonne)	Cost (lakh Rs)
1.05	66.61	63.91	6.66	6.71	13.97	19.71	8.07
1.1	66.35	63.91	6.63	7.03	14.1	19.65	8.1
1.15	66.12	63.91	6.61	7.35	14.23	19.61	8.14
1.2	65.92	63.91	6.59	7.67	13.61	19.57	7.93
1.25	65.75	63.91	6.58	7.99	13.63	19.53	7.93
1.3	65.6	63.91	6.56	8.31	13.65	19.5	7.93
1.35	65.47	63.91	6.55	8.63	13.79	19.48	7.98
1.4	65.35	63.91	6.54	8.95	13.82	19.45	7.98
1.45	65.25	63.91	6.53	9.27	13.85	19.43	7.99
1.5	65.16	63.91	6.52	9.59	14.01	19.41	8.04
1.55	65.07	63.91	6.51	9.91	14.05	19.4	8.05
1.6	65	63.91	6.5	10.23	14.1	19.38	8.06
1.65	64.93	63.91	6.49	10.55	14.28	19.37	8.12
1.7	64.87	63.91	6.49	10.86	14.33	19.36	8.14
1.75	64.81	63.91	6.48	11.18	14.38	19.35	8.16

TABLE-1.RF.R3.1:

Cost of Radial Gate (3 HG) w.r.t. Radius Factor for 9m Head and 5m Span:

Rf (-)	AG (m^2)	Abay (m^2)	Arc_AB (m)	R (m)	WG (tonne)	WE (tonne)	Cost (lakh Rs)
1.05	47.06	45.15	9.41	9.48	14.68	12.35	8
1.1	46.87	45.15	9.37	9.93	14.72	12.31	8
1.15	46.71	45.15	9.34	10.39	14.88	12.28	8.05
1.2	46.57	45.15	9.31	10.84	13.59	12.26	7.6
1.25	46.45	45.15	9.29	11.29	13.66	12.24	7.62
1.3	46.35	45.15	9.27	11.74	13.74	12.22	7.65
1.35	46.25	45.15	9.25	12.19	14.04	12.2	7.74
1.4	46.17	45.15	9.23	12.64	14.22	12.19	7.8
1.45	46.1	45.15	9.22	13.09	14.53	12.17	7.9
1.5	46.03	45.15	9.21	13.55	15.03	12.16	8.06
1.55	45.97	45.15	9.19	14	15.46	12.15	8.2
1.6	45.92	45.15	9.18	14.45	15.75	12.14	8.29
1.65	45.87	45.15	9.17	14.9	14.95	12.13	8.01
1.7	45.83	45.15	9.17	15.35	15.29	12.13	8.12
1.75	45.79	45.15	9.16	15.8	14.72	12.12	7.93

TABLE-1.RF.R3.1:

Cost of Radial Gate (3 HG) w.r.t. Radius Factor for 9m Head and 9m Span:

Rf (-)	AG (m^2)	Abay (m^2)	Arc_AB (m)	R (m)	WG (tonne)	WE (tonne)	Cost (lakh Rs)
1.05	84.71	81.27	9.41	9.48	23.79	27.23	11.86
1.1	84.37	81.27	9.37	9.93	23.13	27.16	11.63
1.15	84.08	81.27	9.34	10.39	23.35	27.1	11.69
1.2	83.83	81.27	9.31	10.84	23.44	27.04	11.71
1.25	83.62	81.27	9.29	11.29	23.96	27	11.88
1.3	83.43	81.27	9.27	11.74	25.17	26.95	12.28
1.35	83.26	81.27	9.25	12.19	25.43	26.92	12.37
1.4	83.11	81.27	9.23	12.64	25.91	26.89	12.52
1.45	82.98	81.27	9.22	13.09	27.15	26.86	12.94
1.5	82.86	81.27	9.21	13.55	27.38	26.83	13.01
1.55	82.75	81.27	9.19	14	27.98	26.81	13.21
1.6	82.66	81.27	9.18	14.45	28.3	26.79	13.39
1.65	82.57	81.27	9.17	14.9	26.58	26.77	12.87
1.7	82.49	81.27	9.17	15.35	27.3	26.75	13.11
1.75	82.42	81.27	9.16	15.8	26.31	26.74	12.77

TABLE-1.RF.R4.1:

Cost of Radial Gate (4 HG) w.r.t. Radius Factor for 12m head and 12m span :

Rf (-)	CS (m)	HD (m)	Arc_AB (m)	R (m)	WG (tonne)	WE (tonne)	Cost (lakh Rs)
1.05	12	12.08	12.59	12.68	55.29	59.31	24.77
1.1	12	12.08	12.54	13.28	51.23	59.15	23.36
1.15	12	12.08	12.49	13.89	53.99	59.01	23.84
1.2	12	12.08	12.46	14.49	54.39	58.9	23.96
1.25	12	12.08	12.42	15.1	51.03	58.79	22.8
1.3	12	12.08	12.4	15.7	52.16	58.7	23.38
1.35	12	12.08	12.37	16.3	52.52	58.63	23.49
1.4	12	12.08	12.35	16.91	53.67	58.55	24.08
1.45	12	12.08	12.33	17.51	53.03	58.49	23.44
1.5	12	12.08	12.31	18.11	52.94	58.44	23.4
1.55	12	12.08	12.3	18.72	53.35	58.39	23.53
1.6	12	12.08	12.28	19.32	54.25	58.34	23.84
1.65	12	12.08	12.27	19.93	55.26	58.3	24.28
1.7	12	12.08	12.26	20.53	56.03	58.26	24.64
1.75	12	12.08	12.25	21.13	57.29	58.23	25.06

TABLE-1.RF.R4.2:

Cost of Radial Gate (4 HG) w.r.t. Radius Factor for 12m head and 15m span :

Rf (-)	CS (m)	HD (m)	Arc_AB (m)	R (m)	WG (tonne)	WE (tonne)	Cost (lakh Rs)
1.05	15	12.08	12.59	12.68	68.11	80.09	30.14
1.1	15	12.08	12.54	13.28	68.77	79.87	30.34
1.15	15	12.08	12.49	13.89	72.44	79.69	31.02
1.2	15	12.08	12.46	14.49	67.74	79.53	29.39
1.25	15	12.08	12.42	15.1	68.9	79.39	29.87
1.3	15	12.08	12.4	15.7	71.04	79.27	30.8
1.35	15	12.08	12.37	16.3	72.38	79.16	31.35
1.4	15	12.08	12.35	16.91	71.06	79.07	31
1.45	15	12.08	12.33	17.51	69.36	78.98	29.89
1.5	15	12.08	12.31	18.11	70.2	78.91	30.17
1.55	15	12.08	12.3	18.72	70.66	78.84	30.32
1.6	15	12.08	12.28	19.32	71.95	78.78	30.86
1.65	15	12.08	12.27	19.93	72.89	78.72	31.27
1.7	15	12.08	12.26	20.53	74.38	78.67	31.88
1.75	15	12.08	12.25	21.13	75.21	78.63	32.26

TABLE-2.HD.V2.1:

Cost of Fixed Wheel Vertical Lift Gate (2 HG) w.r.t. Head for 8m Span :

HD (m)	CS (m)	AG (m^2)	(AE) (m^4)	WG (tonne)	CG (m)	WE (tonne)	Cost (lakh Rs)
14.51	8	116.1	13.48	69.32	0.38	55.96	31.34
12.48	8	99.86	9.97	56.9	0.38	45.32	25.77
10.45	8	83.61	6.99	38.55	0.38	35.35	18.65
8.42	8	67.37	4.54	24.58	0.32	26.12	12.66
6.39	8	51.13	2.61	18.06	0.27	17.75	9.58
4.36	8	34.89	1.22	10.53	0.24	10.4	6.25

TABLE-2.HD.V2.2:

Cost of Fixed Wheel Vertical Lift Gate (2 HG) w.r.t. Head for 12m Span :

HD (m)	CS (m)	AG (m^2)	(AE) (m^4)	WG (tonne)	CG (m)	WE (tonne)	Cost (lakh Rs)
14.51	12	174.15	30.33	117.34	0.63	98.73	51.28
12.48	12	149.79	22.44	89.19	0.6	79.95	39.29
10.45	12	125.42	15.73	60.15	0.58	62.35	27.93
8.42	12	101.06	10.21	42.12	0.47	46.08	20.08
6.39	12	76.69	5.88	29.86	0.38	31.32	14.58
4.36	12	52.33	2.74	18.63	0.34	18.34	9.56

TABLE-2.HD.V2.3:

Cost of Fixed Wheel Vertical Lift Gate (2 HG) w.r.t. Head for 15m Span :

HD (m)	CS (m)	AG (m^2)	(AE) (m^4)	WG (tonne)	CG (m)	WE (tonne)	Cost (lakh Rs)
14.51	15	217.69	47.39	165	0.79	134.93	70.87
12.48	15	187.23	35.06	129.34	0.76	109.26	55.69
10.45	15	156.78	24.58	86.35	0.76	85.22	38.74
8.42	15	126.32	15.96	55.74	0.67	62.98	25.81
6.39	15	95.87	9.19	43.06	0.5	42.8	19.93
4.36	15	65.41	4.28	27.32	0.45	25.06	13.08

TABLE-2.HD.V3.1:

Cost of Fixed Wheel Vertical Lift Gate (3 HG) w.r.t. Head for 8m Span :

HD (m)	CS (m)	AG (m^2)	AE (m^4)	WG (tonne)	CG (m)	WE (tonne)	Cost (lakh Rs)
16.54	8	132.34	17.51	76.16	0.42	67.22	34.52
14.51	8	116.1	13.48	62.64	0.42	55.96	28.46
12.48	8	99.86	9.97	45.11	0.4	45.32	21.22
10.45	8	83.61	6.99	34.2	0.35	35.35	16.85
8.42	8	67.37	4.54	25.69	0.28	26.12	13.01
6.39	8	51.13	2.61	18.49	0.27	17.75	9.86
4.36	8	34.89	1.22	10.72	0.25	10.4	6.51

TABLE-2.HD.V3.2:

Cost of Fixed Wheel Vertical Lift Gate (3 HG) w.r.t. Head for 12m Span :

HD (m)	CS (m)	AG (m^2)	AE (m^4)	WG (tonne)	CG (m)	WE (tonne)	Cost (lakh Rs)
16.54	12	198.51	39.41	132.14	0.71	118.59	57.84
14.51	12	174.15	30.33	96.09	0.65	98.73	42.7
12.48	12	149.79	22.44	75.26	0.62	79.95	33.9
10.45	12	125.42	15.73	58.15	0.53	62.35	26.93
8.42	12	101.06	10.21	44.25	0.41	46.08	20.83
6.39	12	76.69	5.88	32.59	0.38	31.32	15.72
4.36	12	52.33	2.74	21.98	0.33	18.34	11.12

TABLE-2.HD.V3.3:

Cost of Fixed Wheel Vertical Lift Gate (3 HG) w.r.t. Head for 15m Span :

HD (m)	CS (m)	AG (m^2)	AE (m^4)	WG (tonne)	CG (m)	WE (tonne)	Cost (lakh Rs)
16.54	15	248.14	61.58	193.06	0.87	162.08	82.86
14.51	15	217.69	47.39	145.7	0.84	134.93	62.88
12.48	15	187.23	35.06	107.47	0.83	109.26	47.03
10.45	15	156.78	24.58	77.5	0.7	85.22	35.12
8.42	15	126.32	15.96	61.51	0.55	62.98	27.88
6.39	15	95.87	9.19	51.75	0.51	42.8	23.4
4.36	15	65.41	4.28	32.87	0.41	25.06	15.51

TABLE-2.HD.V4.1:

Cost of Fixed Wheel Vertical Lift Gate (4 HG)w.r.t. Head for 8m Span :

HD (m)	CS (m)	AG (m^2)	AE (m^4)	WG (tonne)	CG (m)	WE (tonne)	Cost (lakh Rs)
16.54	8	132.34	17.51	75.23	0.43	67.22	34.13
14.51	8	116.1	13.48	55.13	0.42	55.96	25.84
12.48	8	99.86	9.97	46.77	0.38	45.32	22.04
10.45	8	83.61	6.99	35.22	0.31	35.35	17.22
8.42	8	67.37	4.54	27.12	0.31	26.12	13.55
6.39	8	51.13	2.61	20.45	0.27	17.75	10.59
4.36	8	34.89	1.22	10.64	0.24	10.4	6.47

TABLE-2.HD.V4.3:

Cost of Fixed Wheel Vertical Lift Gate (4 HG)w.r.t. Head for 12m Span :

HD (m)	CS (m)	AG (m^2)	AE (m^4)	WG (tonne)	CG (m)	WE (tonne)	Cost (lakh Rs)
16.54	12	198.51	39.41	116.37	0.68	118.59	51.74
14.51	12	174.15	30.33	92.48	0.66	98.73	41.53
12.48	12	149.79	22.44	78.37	0.57	79.95	35.27
10.45	12	125.42	15.73	67.56	0.46	62.35	30.57
8.42	12	101.06	10.21	46.59	0.43	46.08	21.7
6.39	12	76.69	5.88	34.65	0.37	31.32	16.49
4.36	12	52.33	2.74	25.84	0.35	18.34	12.57

TABLE-2.HD.V4.4:

Cost of Fixed Wheel Vertical Lift Gate (4 HG)w.r.t. Head for 15m Span :

HD (m)	CS (m)	AG (m^2)	AE (m^4)	WG (tonne)	CG (m)	WE (tonne)	Cost (lakh Rs)
16.54	15	248.14	61.58	179.77	0.87	162.08	77.66
14.51	15	217.69	47.39	139.11	0.87	134.93	60.78
12.48	15	187.23	35.06	107.24	0.78	109.26	47.32
10.45	15	156.78	24.58	85.41	0.59	85.22	38.2
8.42	15	126.32	15.96	71.57	0.51	62.98	31.75
6.39	15	95.87	9.19	52.35	0.5	42.8	23.61
4.36	15	65.41	4.28	33.89	0.39	25.06	15.9

TABLE-2.CS.V2.1:

Cost of Fixed Wheel Vertical Lift Gate (2 HG) w.r.t. Span for 6.4m Head :

CS (m)	HD (m)	AG (m^2)	AE (m^4)	WG (tonne)	CG (m)	WE (tonne)	Cost (lakh Rs)
18	6.39	115.04	13.23	53.98	0.63	55.25	24.51
16	6.39	102.26	10.46	45.25	0.53	46.85	20.91
14	6.39	89.48	8.01	40.78	0.46	38.86	18.98
12	6.39	76.69	5.88	29.86	0.38	31.32	14.58
10	6.39	63.91	4.08	23.48	0.31	24.26	11.89
8	6.39	51.13	2.61	18.06	0.27	17.75	9.58

TABLE-2.CS.V2.2:

Cost of Fixed Wheel Vertical Lift Gate (2 HG) w.r.t. Span for 8.4m Head :

CS (m)	HD (m)	AG (m^2)	AE (m^4)	WG (tonne)	CG (m)	WE (tonne)	Cost (lakh Rs)
18	8.42	151.59	22.98	82.02	0.86	81.29	36.56
16	8.42	134.74	18.16	59.93	0.7	68.94	27.67
14	8.42	117.9	13.9	50.81	0.6	57.18	23.75
12	8.42	101.06	10.21	42.12	0.47	46.08	20.08
10	8.42	84.21	7.09	33.91	0.42	35.7	16.54
8	8.42	67.37	4.54	24.58	0.32	26.12	12.66

TABLE-2.CS.V2.3:

Cost of Fixed Wheel Vertical Lift Gate (2 HG) w.r.t. Span for 10.5m Head :

CS (m)	HD (m)	AG (m^2)	AE (m^4)	WG (tonne)	CG (m)	WE (tonne)	Cost (lakh Rs)
18	10.45	188.13	35.39	122.24	0.9	110	53.43
16	10.45	167.23	27.97	96.31	0.8	93.28	42.88
14	10.45	146.33	21.41	74.75	0.69	77.37	34.06
12	10.45	125.42	15.73	60.15	0.58	62.35	27.93
10	10.45	104.52	10.92	48.52	0.43	48.31	22.96
8	10.45	83.61	6.99	38.55	0.38	35.35	18.65

TABLE-2.CS.V2.4:

Cost of Fixed Wheel Vertical Lift Gate (2 HG) w.r.t. Span for 12m Head :

CS (m)	HD (m)	AG (m^2)	AE (m^4)	WG (tonne)	CG (m)	WE (tonne)	Cost (lakh Rs)
18	12.08	217.37	47.25	164.4	0.94	134.65	70.06
16	12.08	193.22	37.33	131.18	0.83	114.18	56.53
14	12.08	169.07	28.58	102.5	0.72	94.71	44.93
12	12.08	144.91	21	79.43	0.61	76.33	35.44
10	12.08	120.76	14.58	63.14	0.48	59.13	28.68
8	12.08	96.61	9.33	50.49	0.39	43.27	23.25

TABLE-2.CS.V3.1:

Cost of Fixed Wheel Vertical Lift Gate (3 HG) w.r.t. Span for 6.4m Head :

CS (m)	HD (m)	AG (m^2)	AE (m^4)	WG (tonne)	CG (m)	WE (tonne)	Cost (lakh Rs)
18	6.39	115.04	13.23	60.92	0.61	55.25	27.32
16	6.39	102.26	10.46	54.9	0.51	46.85	24.73
14	6.39	89.48	8.01	40.86	0.46	38.86	19.13
12	6.39	76.69	5.88	32.59	0.38	31.32	15.72
10	6.39	63.91	4.08	24.21	0.33	24.26	12.29
8	6.39	51.13	2.61	18.49	0.27	17.75	9.86

TABLE-2.CS.V3.2:

Cost of Fixed Wheel Vertical Lift Gate (3 HG) w.r.t. Span for 8.4m Head :

CS (m)	HD (m)	AG (m^2)	AE (m^4)	WG (tonne)	CG (m)	WE (tonne)	Cost (lakh Rs)
18	8.42	151.59	22.98	79.88	0.7	81.29	35.54
16	8.42	134.74	18.16	67.67	0.58	68.94	30.42
14	8.42	117.9	13.9	59.2	0.5	57.18	26.81
12	8.42	101.06	10.21	44.25	0.41	46.08	20.83
10	8.42	84.21	7.09	35.06	0.34	35.7	16.91
8	8.42	67.37	4.54	25.69	0.28	26.12	13.01

TABLE-2.CS.V3.3:

Cost of Fixed Wheel Vertical Lift Gate (3 HG) w.r.t. Span for 10.5m Head :

CS (m)	HD (m)	AG (m^2)	AE (m^4)	WG (tonne)	CG (m)	WE (tonne)	Cost (lakh Rs)
18	10.45	188.13	35.39	110.93	0.9	110	48.78
16	10.45	167.23	27.97	84.53	0.78	93.28	38.06
14	10.45	146.33	21.41	71.07	0.65	77.37	32.42
12	10.45	125.42	15.73	58.15	0.53	62.35	26.93
10	10.45	104.52	10.92	47.44	0.45	48.31	22.31
8	10.45	83.61	6.99	34.2	0.35	35.35	16.85

TABLE-2.CS.V3.4:

Cost of Fixed Wheel Vertical Lift Gate (3 HG) w.r.t. Span for 12m Head :

CS (m)	HD (m)	AG (m^2)	AE (m^4)	WG (tonne)	CG (m)	WE (tonne)	Cost (lakh Rs)
18	12.08	217.37	47.25	145.95	0.93	134.65	63.5
16	12.08	193.22	37.33	119.56	0.86	114.18	52.61
14	12.08	169.07	28.58	88.26	0.73	94.71	39.91
12	12.08	144.91	21	73.13	0.6	76.33	33.46
10	12.08	120.76	14.58	59.78	0.47	59.13	27.73
8	12.08	96.61	9.33	44.64	0.4	43.27	21.36

TABLE-2.CS.V4.1:

Cost of Fixed Wheel Vertical Lift Gate (4 HG)w.r.t. Span for 6.4m Head :

CS (m)	HD (m)	AG (m^2)	AE (m^4)	WG (tonne)	CG (m)	WE (tonne)	Cost (lakh Rs)
18	6.39	115.04	13.23	75.77	0.56	55.25	32.93
16	6.39	102.26	10.46	58.69	0.51	46.85	26.16
14	6.39	89.48	8.01	45.12	0.46	38.86	20.73
12	6.39	76.69	5.88	34.65	0.37	31.32	16.49
10	6.39	63.91	4.08	27.11	0.33	24.26	13.37
8	6.39	51.13	2.61	20.45	0.27	17.75	10.59

TABLE-2.CS.V4.2:

Cost of Fixed Wheel Vertical Lift Gate (4 HG)w.r.t. Span for 8.4m Head :

CS (m)	HD (m)	AG (m^2)	AE (m^4)	WG (tonne)	CG (m)	WE (tonne)	Cost (lakh Rs)
18	8.42	151.59	22.98	88.94	0.65	81.29	38.98
16	8.42	134.74	18.16	75.5	0.58	68.94	33.45
14	8.42	117.9	13.9	66.92	0.5	57.18	29.79
12	8.42	101.06	10.21	46.59	0.43	46.08	21.7
10	8.42	84.21	7.09	35.04	0.34	35.7	16.89
8	8.42	67.37	4.54	27.12	0.31	26.12	13.55

TABLE-2.CS.V4.3:

Cost of Fixed Wheel Vertical Lift Gate (4 HG)w.r.t. Span for 10.5m Head :

CS (m)	HD (m)	AG (m^2)	AE (m^4)	WG (tonne)	CG (m)	WE (tonne)	Cost (lakh Rs)
18	10.45	188.13	35.39	110.96	0.78	110	48.85
16	10.45	167.23	27.97	93.7	0.65	93.28	41.62
14	10.45	146.33	21.41	77.06	0.55	77.37	34.68
12	10.45	125.42	15.73	67.56	0.46	62.35	30.57
10	10.45	104.52	10.92	47.63	0.39	48.31	22.45
8	10.45	83.61	6.99	35.22	0.31	35.35	17.22

TABLE-2.CS.V4.4:

Cost of Fixed Wheel Vertical Lift Gate (4 HG)w.r.t. Span for 12m Head :

CS (m)	HD (m)	AG (m^2)	AE (m^4)	WG (tonne)	CG (m)	WE (tonne)	Cost (lakh Rs)
18	12.08	217.37	47.25	141.55	0.94	134.65	61.37
16	12.08	193.22	37.33	106.85	0.81	114.18	47.3
14	12.08	169.07	28.58	90.34	0.69	94.71	40.38
12	12.08	144.91	21	73.65	0.54	76.33	33.34
10	12.08	120.76	14.58	60.27	0.48	59.13	27.59
8	12.08	96.61	9.33	42.31	0.37	43.27	20.26

TABLE-2.HDA.V2.1:

Cost of Fixed Wheel Vertical Lift Gate (2 HG) w.r.t. Head for area of Spillway of 75m^2 :

HD (m)	CS (m)	AG (m^2)	AE (m^4)	WG (tonne)	CG (m)	WE (tonne)	Cost (lakh Rs)
14.51	5.17	75	5.62	44.77	0.3	30.35	20.86
12.48	6.01	75	5.63	43.04	0.32	30.35	19.98
10.45	7.18	75	5.63	32.96	0.34	30.35	16.24
8.42	8.91	75	5.63	28.55	0.36	30.35	14.33
6.39	11.74	75	5.62	29.19	0.38	30.35	14.26
4.36	17.2	75	5.62	38.46	0.52	30.35	17.45

TABLE-2.HDA.V2.2:

Cost of Fixed Wheel Vertical Lift Gate (2 HG) w.r.t. Head for area of Spillway of 100m^2 :

HD (m)	CS (m)	AG (m^2)	AE (m^4)	WG (tonne)	CG (m)	WE (tonne)	Cost (lakh Rs)
14.51	6.89	100	10	59.5	0.35	45.41	27.04
12.48	8.01	100	10	56.94	0.38	45.41	25.78
10.45	9.57	100	10	46.05	0.43	45.41	21.83
8.42	11.87	100	10	41.4	0.47	45.41	19.73
6.39	15.65	100	10	44.89	0.5	45.41	20.76
4.36	22.93	100	10	54.57	0.74	45.41	24

TABLE-2.HDA.V2.3:

Cost of Fixed Wheel Vertical Lift Gate (2 HG) w.r.t. Head for area of Spillway of 150m^2 :

HD (m)	CS (m)	AG (m^2)	AE (m^4)	WG (tonne)	CG (m)	WE (tonne)	Cost (lakh Rs)
14.51	10.34	150	22.5	91.45	0.53	80.11	40.59
12.48	12.02	150	22.5	89.24	0.6	80.11	39.31
10.45	14.35	150	22.5	76.2	0.71	80.11	34.64
8.42	17.81	150	22.5	73.12	0.83	80.11	33.08
6.39	23.47	150	22.5	81.87	0.88	80.11	35.91
4.36	34.4	150	22.5	131.68	1.06	80.11	54.35

TABLE-2.HDA.V2.4:

Cost of Fixed Wheel Vertical Lift Gate (2 HG) w.r.t. Head for area of Spillway of 175m^2 :

HD (m)	CS (m)	AG (m^2)	AE (m^4)	WG (tonne)	CG (m)	WE (tonne)	Cost (lakh Rs)
14.51	12.06	175	30.63	116.11	0.63	99.4	50.69
12.48	14.02	175	30.63	116.61	0.69	99.4	50.49
10.45	16.74	175	30.63	103.79	0.82	99.4	45.9
8.42	20.78	175	30.63	104.06	0.92	99.4	45.52
6.39	27.38	175	30.63	126.74	1	99.4	53.71
4.36	40.13	175	30.62	208.9	1.19	99.4	84.48

TABLE-2.HDA.V3.1:

Cost of Fixed Wheel Vertical Lift Gate (3 HG) w.r.t. Head for area of Spillway of 75m^2 :

HD (m)	CS (m)	AG (m^2)	AE (m^4)	WG (tonne)	CG (m)	WE (tonne)	Cost (lakh Rs)
16.54	4.53	75	5.62	42.14	0.31	30.35	19.94
14.51	5.17	75	5.62	38.71	0.32	30.35	18.47
12.48	6.01	75	5.63	32.62	0.32	30.35	15.97
10.45	7.18	75	5.63	29.27	0.32	30.35	14.78
8.42	8.91	75	5.63	29.02	0.31	30.35	14.44
6.39	11.74	75	5.62	31.91	0.38	30.35	15.4
4.36	17.2	75	5.62	39.52	0.48	30.35	18.19

TABLE-2.HDA.V3.2:

Cost of Fixed Wheel Vertical Lift Gate (3 HG) w.r.t. Head for area of Spillway of 100m^2 :

HD (m)	CS (m)	AG (m^2)	AE (m^4)	WG (tonne)	CG (m)	WE (tonne)	Cost (lakh Rs)
16.54	6.04	100	10	55.94	0.35	45.41	25.82
14.51	6.89	100	10	50.91	0.38	45.41	23.57
12.48	8.01	100	10	45.14	0.4	45.41	21.23
10.45	9.57	100	10	42.15	0.42	45.41	20.2
8.42	11.87	100	10	43.64	0.41	45.41	20.52
6.39	15.65	100	10	53.64	0.51	45.41	24.13
4.36	22.93	100	10	67.22	0.67	45.41	29.28

TABLE-2.HDA.V3.3:

Cost of Fixed Wheel Vertical Lift Gate (3 HG) w.r.t. Head for area of Spillway of 150m^2 :

HD (m)	CS (m)	AG (m^2)	AE (m^4)	WG (tonne)	CG (m)	WE (tonne)	Cost (lakh Rs)
16.54	9.07	150	22.5	87.12	0.51	80.11	39.09
14.51	10.34	150	22.5	80.82	0.55	80.11	36.21
12.48	12.02	150	22.5	74.65	0.63	80.11	33.57
10.45	14.35	150	22.5	73.15	0.68	80.11	33.23
8.42	17.81	150	22.5	78.94	0.7	80.11	35.1
6.39	23.47	150	22.5	90.01	0.84	80.11	39.19
4.36	34.4	150	22.5	131.71	1.05	80.11	55.13

TABLE-2.HDA.V3.4:

Cost of Fixed Wheel Vertical Lift Gate (3 HG) w.r.t. Head for area of Spillway of 175m^2 :

HD (m)	CS (m)	AG (m^2)	AE (m^4)	WG (tonne)	CG (m)	WE (tonne)	Cost (lakh Rs)
16.54	10.58	175	30.63	105.31	0.61	99.4	46.78
14.51	12.06	175	30.63	96.34	0.65	99.4	42.81
12.48	14.02	175	30.63	93.44	0.78	99.4	41.34
10.45	16.74	175	30.63	94.16	0.84	99.4	41.97
8.42	20.78	175	30.63	102.85	0.87	99.4	44.87
6.39	27.38	175	30.63	131.38	1	99.4	55.67
4.36	40.13	175	30.62	218.06	1.12	99.4	88.87

TABLE-2.HDA.V4.1:

Cost of Fixed Wheel Vertical Lift Gate (4 HG) w.r.t. Head for Spillway bay of 75m^2 :

HD (m)	CS (m)	AG (m^2)	AE (m^4)	WG (tonne)	CG (m)	WE (tonne)	Cost (lakh Rs)
16.54	4.53	75	5.62	39.18	0.31	30.35	18.8
14.51	5.17	75	5.62	34.4	0.32	30.35	16.96
12.48	6.01	75	5.63	33.29	0.33	30.35	16.31
10.45	7.18	75	5.63	30.87	0.29	30.35	15.36
8.42	8.91	75	5.63	29.94	0.31	30.35	14.78
6.39	11.74	75	5.62	33.04	0.37	30.35	15.82
4.36	17.2	75	5.62	45.92	0.45	30.35	20.59

TABLE-2.HDA.V4.2:

Cost of Fixed Wheel Vertical Lift Gate (4 HG) w.r.t. Head for Spillway bay of 100m^2 :

HD (m)	CS (m)	AG (m^2)	AE (m^4)	WG (tonne)	CG (m)	WE (tonne)	Cost (lakh Rs)
16.54	6.04	100	10	52.2	0.35	45.41	24.39
14.51	6.89	100	10	46.45	0.36	45.41	22.1
12.48	8.01	100	10	46.8	0.38	45.41	22.05
10.45	9.57	100	10	44.98	0.36	45.41	21.34
8.42	11.87	100	10	45.15	0.42	45.41	21.08
6.39	15.65	100	10	54.46	0.5	45.41	24.43
4.36	22.93	100	10	84.33	0.57	45.41	35.74

TABLE-2.HDA.V4.3:

Cost of Fixed Wheel Vertical Lift Gate (4 HG) w.r.t. Head for Spillway bay of 150m^2 :

HD (m)	CS (m)	AG (m^2)	AE (m^4)	WG (tonne)	CG (m)	WE (tonne)	Cost (lakh Rs)
16.54	9.07	150	22.5	82.76	0.49	80.11	37.4
14.51	10.34	150	22.5	75.68	0.53	80.11	34.46
12.48	12.02	150	22.5	78.45	0.57	80.11	35.3
10.45	14.35	150	22.5	78.83	0.55	80.11	35.47
8.42	17.81	150	22.5	88.16	0.65	80.11	38.67
6.39	23.47	150	22.5	108.02	0.83	80.11	46.04
4.36	34.4	150	22.5	150.05	0.98	80.11	62.1

TABLE-2.HDA.V4.4:

Cost of Fixed Wheel Vertical Lift Gate (4 HG) w.r.t. Head for Spillway bay of 175m^2 :

HD (m)	CS (m)	AG (m^2)	AE (m^4)	WG (tonne)	CG (m)	WE (tonne)	Cost (lakh Rs)
16.54	10.58	175	30.63	100.22	0.59	99.4	44.8
14.51	12.06	175	30.63	92.77	0.66	99.4	41.65
12.48	14.02	175	30.63	97.58	0.71	99.4	43.31
10.45	16.74	175	30.63	99.58	0.7	99.4	44.11
8.42	20.78	175	30.63	106.55	0.76	99.4	46.33
6.39	27.38	175	30.63	133.21	0.95	99.4	56.35
4.36	40.13	175	30.62	226.27	1.13	99.4	91.99

TABLE-2.WG.V2.1:

Cost of Fixed Wheel Vertical Lift Gate (2 HG)w.r.t. Head for 10m Span :

HD (m)	wsp (tonne)	wvs (tonne)	whg (tonne)	wveg (tonne)	CG (m)	WG (tonne)	Cost (lakh Rs)
16.5	13	**	22.1	5.7	0.7	**	**
14.5	11.4	34.8	18	5	0.5	89.9	40
12.5	9.8	26.9	14	4.3	0.4	71	31.8
10.5	8.2	13.2	12.7	3.6	0.4	48.5	23
8.4	6.6	6	11.1	2.9	0.4	33.9	16.5
6.4	5	3.9	7.4	2.2	0.3	23.5	11.9
4.4	3.4	1.1	5.9	1.5	0.3	15.2	8.1

TABLE-2.WF.V3.1:

Cost of Fixed Wheel Vertical Lift Gate (3 HG) w.r.t. Head for 10m Span :

HD (m)	wsp (tonne)	wvs (tonne)	whg (tonne)	wveg (tonne)	CG (m)	WG (tonne)	Cost (lakh Rs)
16.5	13	32.1	23.3	5.7	0.6	97.2	43.5
14.5	11.4	22.2	20.8	5	0.5	77.4	34.7
12.5	9.8	13	19.1	4.3	0.5	60.1	27.5
10.5	8.2	7.7	17.3	3.6	0.5	47.4	22.3
8.4	6.6	5.5	12.4	2.9	0.3	35.1	16.9
6.4	5	2.3	9.5	2.2	0.3	24.2	12.3
4.4	3.4	1	8	1.5	0.3	17.6	9.3

TABLE-2.WG.V4.1:

Cost of Fixed Wheel Vertical Lift Gate (4 HG) w.r.t. Head for 10m Span :

HD (m)	wsp (tonne)	wvs (tonne)	whg (tonne)	wveg (tonne)	CG (m)	WG (tonne)	Cost (lakh Rs)
16.5	13	24.9	27.6	5.7	0.5	93.8	42.1
14.5	11.4	14.7	25.4	5	0.5	74.2	33.7
12.5	9.8	12.2	25.1	4.3	0.5	66.8	30.2
10.5	8.2	7.7	17.4	3.6	0.4	47.6	22.5
8.4	6.6	4	13.7	2.9	0.3	35	16.9
6.4	5	2.3	11.9	2.2	0.3	27.1	13.4
4.4	3.4	0.6	9.8	1.5	0.3	19.4	10

TABLE-2.HC.V2.1:

Cost of Fixed Wheel Vertical Lift Gate (2 HG) w.r.t. Head for 10m Span :

HD (m)	CS (m)	WG (tonne)	CG (m)	H'cap (tonne)	Mat'Cost (lakh Rs)	O'Cost (lakh Rs)
16.5	10	**	**	**	**	**
14.5	10	89.9	0.5	94.4	23.7	14.4
12.5	10	71	0.4	74.3	18.7	11.6
10.5	10	48.5	0.4	51.5	12.8	9.1
8.4	10	33.9	0.4	36.4	9	6.9
6.4	10	23.5	0.3	25.1	6.2	5.2
4.4	10	15.2	0.3	16	4	3.7

TABLE-2.HC.V3.1:

Cost of Fixed Wheel Vertical Lift Gate (3 HG) w.r.t. Span for 10m Head :

HD (m)	CS (m)	WG (tonne)	CG (m)	H'cap (tonne)	Mat'Cost (lakh Rs)	O'Cost (lakh Rs)
16.5	10	97.2	0.6	102.3	25.6	15.8
14.5	10	77.4	0.5	82.2	20.4	12.7
12.5	10	60.1	0.5	63.7	15.9	10.3
10.5	10	47.4	0.5	50.5	12.5	8.8
8.4	10	35.1	0.3	37.5	9.3	6.9
6.4	10	24.2	0.3	25.8	6.4	5.4
4.4	10	17.6	0.3	18.4	4.7	4.2

TABLE-2.HC.V4.1:

Cost of Fixed Wheel Vertical Lift Gate (4 HG) w.r.t. Head for 10m Span :

HD (m)	CS (m)	WG (tonne)	CG (m)	H'cap (tonne)	Mat'Cost (lakh Rs)	O'Cost (lakh Rs)
16.5	10	93.8	0.5	99	24.7	15.4
14.5	10	74.2	0.5	79	19.5	12.6
12.5	10	66.8	0.5	70.2	17.6	11.2
10.5	10	47.6	0.4	50.6	12.6	8.9
8.4	10	35	0.3	37.5	9.3	6.9
6.4	10	27.1	0.3	28.7	7.2	5.6
4.4	10	19.4	0.3	20.2	5.2	4.4

TABLE-2.HD.R2.1:

Cost of Radial Gate (2 HG) w.r.t. Head for 8m Span :

HD (m)	AG (m^2)	Abay (m^2)	AE (m^4)	WG (tonne)	Arc_AB (m)	WE (tonne)	Cost (lakh Rs)
16.54	136.36	132.34	18.05	99.25	17.04	52.09	39.55
14.51	119.62	116.1	13.89	52.96	14.95	43.67	22.97
12.48	102.89	99.86	10.27	36.16	12.86	35.65	16.7
10.45	86.15	83.61	7.2	27.74	10.77	28.07	13.65
8.42	69.42	67.37	4.68	19.58	8.68	20.99	10.16
6.39	52.68	51.13	2.69	10.77	6.59	14.48	6.69
4.36	35.94	34.89	1.25	6.66	4.49	8.66	4.87

TABLE-2.HD.R2.2:

Cost of Radial Gate (2 HG) w.r.t. Head for 10m Span :

HD (m)	AG (m^2)	Abay (m^2)	AE (m^4)	WG (tonne)	Arc_AB (m)	WE (tonne)	Cost (lakh Rs)
16.54	170.45	165.43	28.2	121.74	17.04	70.34	48.25
14.51	149.53	145.13	21.7	68.85	14.95	58.97	29.19
12.48	128.61	124.82	16.05	44.99	12.86	48.14	20.27
10.45	107.69	104.52	11.26	34.79	10.77	37.91	16.6
8.42	86.77	84.21	7.31	24.5	8.68	28.35	12.21
6.39	65.85	63.91	4.21	13.62	6.59	19.55	7.93
4.36	44.93	43.61	1.96	8.24	4.49	11.69	5.61

TABLE-2.HD.R3.1:

Cost of Radial Gate (3 HG) w.r.t. Head for 8m Span :

HD (m)	AG (m^2)	Abay (m^2)	AE (m^4)	WG (tonne)	Arc_AB (m)	WE (tonne)	Cost (lakh Rs)
16.54	136.36	132.34	18.05	71.76	17.04	52.09	30.16
14.51	119.62	116.1	13.89	49.41	14.95	43.67	21.99
12.48	102.89	99.86	10.27	34.7	12.86	35.65	16.19
10.45	86.15	83.61	7.2	26.98	10.77	28.07	13.02
8.42	69.42	67.37	4.68	19.04	8.68	20.99	9.91
6.39	52.68	51.13	2.69	11.27	6.59	14.48	6.85
4.36	35.94	34.89	1.25	7.25	4.49	8.66	5.06

TABLE-2.HD.R3.2:

Cost of Radial Gate (3 HG) w.r.t. Head for 10m Span :

HD (m)	AG (m^2)	Abay (m^2)	AE (m^4)	WG (tonne)	Arc_AB (m)	WE (tonne)	Cost (lakh Rs)
16.54	170.45	165.43	28.2	96.97	17.04	70.34	39.69
14.51	149.53	145.13	21.7	66.09	14.95	58.97	28.45
12.48	128.61	124.82	16.05	44.15	12.86	48.14	20.07
10.45	107.69	104.52	11.26	34.88	10.77	37.91	16.16
8.42	86.77	84.21	7.31	23.72	8.68	28.35	11.86
6.39	65.85	63.91	4.21	13.95	6.59	19.55	8.04
4.36	44.93	43.61	1.96	8.88	4.49	11.69	5.81

TABLE-2.HD.R4.1:

Cost of Radial Gate (4 HG) w.r.t. Head for 8m Span :

HD (m)	AG (m^2)	Abay (m^2)	AE (m^4)	WG (tonne)	Arc_AB (m)	WE (tonne)	Cost (lakh Rs)
16.54	136.36	132.34	18.05	60.91	17.04	52.09	26.43
14.51	119.62	116.1	13.89	46.55	14.95	43.67	21
12.48	102.89	99.86	10.27	36.55	12.86	35.65	16.8
10.45	86.15	83.61	7.2	27.8	10.77	28.07	13.48
8.42	69.42	67.37	4.68	16.48	8.68	20.99	9.04
6.39	52.68	51.13	2.69	11.97	6.59	14.48	7.08

TABLE-2.HD.R4.2:

Cost of Radial Gate (4 HG) w.r.t. Head for 10m Span :

HD (m)	AG (m^2)	Abay (m^2)	AE (m^4)	WG (tonne)	Arc_AB (m)	WE (tonne)	Cost (lakh Rs)
16.54	170.45	165.43	28.2	76.32	17.04	70.34	32.62
14.51	149.53	145.13	21.7	58.75	14.95	58.97	25.95
12.48	128.61	124.82	16.05	46.56	12.86	48.14	20.88
10.45	107.69	104.52	11.26	36.22	10.77	37.91	16.79
8.42	86.77	84.21	7.31	20.6	8.68	28.35	10.79
6.39	65.85	63.91	4.21	13.58	6.59	19.55	7.91

TABLE-2.CS.R2.1:

Cost of Radial Gate (2 HG) w.r.t. Span for 6.4m Head :

CS (m)	AG (m^2)	Abay (m^2)	AE (m^4)	WG (tonne)	Arc_AB (m)	WE (tonne)	Cost (lakh Rs)
18	118.53	115.04	13.64	30.52	6.59	43.13	14.88
16	105.36	102.26	10.77	26.91	6.59	36.81	13.36
14	92.19	89.48	8.25	22.27	6.59	30.76	11.49
12	79.02	76.69	6.06	16.82	6.59	24.99	9.36
10	65.85	63.91	4.21	13.62	6.59	19.55	7.93
8	52.68	51.13	2.69	10.77	6.59	14.48	6.69

TABLE-2.CS.R2.3:

Cost of Radial Gate (2 HG) w.r.t. Span for 10.5m Head :

CS (m)	AG (m^2)	Abay (m^2)	AE (m^4)	WG (tonne)	Arc_AB (m)	WE (tonne)	Cost (lakh Rs)
18	193.84	188.13	36.47	73.94	10.77	83.63	32.34
16	172.3	167.23	28.81	60.72	10.77	71.37	27.2
14	150.77	146.33	22.06	51.27	10.77	59.63	23.36
12	129.23	125.42	16.21	42.71	10.77	48.45	19.86
10	107.69	104.52	11.26	34.79	10.77	37.91	16.6
8	86.15	83.61	7.2	27.74	10.77	28.07	13.65

TABLE-2.CS.R3.1:

Cost of Radial Gate (3 HG) w.r.t. Span for 6.4m Head :

CS (m)	AG (m^2)	Abay (m^2)	AE (m^4)	WG (tonne)	Arc_AB (m)	WE (tonne)	Cost (lakh Rs)
18	118.53	115.04	13.64	26.98	6.59	43.13	13.67
16	105.36	102.26	10.77	23.53	6.59	36.81	12.2
14	92.19	89.48	8.25	20.1	6.59	30.76	10.75
12	79.02	76.69	6.06	16.83	6.59	24.99	9.36
10	65.85	63.91	4.21	13.95	6.59	19.55	8.04
8	52.68	51.13	2.69	11.27	6.59	14.48	6.85

TABLE-2.CS.R3.3:

Cost of Radial Gate (3 HG) w.r.t. Span for 10.5m Head :

CS (m)	AG (m^2)	Abay (m^2)	AE (m^4)	WG (tonne)	Arc_AB (m)	WE (tonne)	Cost (lakh Rs)
18	193.84	188.13	36.47	72.31	10.77	83.63	31.02
16	172.3	167.23	28.81	62.56	10.77	71.37	27.16
14	150.77	146.33	22.06	52.4	10.77	59.63	23.19
12	129.23	125.42	16.21	42.27	10.77	48.45	19.25
10	107.69	104.52	11.26	34.56	10.77	37.91	16.05
8	86.15	83.61	7.2	26.71	10.77	28.07	12.93

TABLE-2.CS.R4.1:

Cost of Radial Gate (4 HG) w.r.t. Span for 6.4m Head :

CS (m)	AG (m^2)	Abay (m^2)	AE (m^4)	WG (tonne)	Arc_AB (m)	WE (tonne)	Cost (lakh Rs)
18	118.53	115.04	13.64	25.69	6.59	43.13	13.22
16	105.36	102.26	10.77	22.18	6.59	36.81	11.74
14	92.19	89.48	8.25	19.12	6.59	30.76	10.41
12	79.02	76.69	6.06	16.37	6.59	24.99	9.19
10	65.85	63.91	4.21	13.58	6.59	19.55	7.91
8	52.68	51.13	2.69	11.97	6.59	14.48	7.08

TABLE-2.CS.R4.3:

Cost of Radial Gate (4 HG) w.r.t. Span for 10.5m Head :

CS (m)	AG (m^2)	Abay (m^2)	AE (m^4)	WG (tonne)	Arc_AB (m)	WE (tonne)	Cost (lakh Rs)
18	193.84	188.13	36.47	75.25	10.77	83.63	32.39
16	172.3	167.23	28.81	65.55	10.77	71.37	28.45
14	150.77	146.33	22.06	55.76	10.77	59.63	24.6
12	129.23	125.42	16.21	45.94	10.77	48.45	20.67
10	107.69	104.52	11.26	36.22	10.77	37.91	16.79
8	86.15	83.61	7.2	27.8	10.77	28.07	13.48

TABLE-2.HDA.R2.1:

Cost of Radial Gate (2 HG) w.r.t. Head for area of Spillway bay of 75m^2 :

HD (m)	CS (m)	AG (m^2)	AE (m^4)	WG (tonne)	Arc_AB (m)	WE (tonne)	Cost (lakh Rs)
16.54	4.53	77.28	5.8	39.37	17.04	24.25	17.44
14.51	5.17	77.28	5.8	33.71	14.95	24.25	15.37
12.48	6.01	77.28	5.8	27.4	12.86	24.25	13.08
10.45	7.18	77.28	5.8	24.52	10.77	24.25	12.25
8.42	8.91	77.28	5.8	21.95	8.68	24.25	11.15
6.39	11.74	77.28	5.8	16.32	6.59	24.25	9.12
4.36	17.2	77.28	5.8	14.62	4.49	24.25	8.56

TABLE-2.HDA.R2.2:

Cost of Radial Gate (2 HG) w.r.t. Head for area of Spillway bay of 100m^2 :

HD (m)	CS (m)	AG (m^2)	AE (m^4)	WG (tonne)	Arc_AB (m)	WE (tonne)	Cost (lakh Rs)
16.54	6.04	103.03	10.3	51.07	17.04	35.72	22.1
14.51	6.89	103.03	10.3	46.52	14.95	35.72	20.45
12.48	8.01	103.03	10.3	36.19	12.86	35.72	16.71
10.45	9.57	103.03	10.3	33.16	10.77	35.72	15.84
8.42	11.87	103.03	10.3	31.17	8.68	35.72	14.84
6.39	15.65	103.03	10.3	26.33	6.59	35.72	13.09
4.36	22.93	103.03	10.3	20.58	4.49	35.72	11.19

TABLE-2.HDA.R2.3:

Cost of Radial Gate (2 HG) w.r.t. Head for area of Spillway bay of 125m^2 :

HD (m)	CS (m)	AG (m^2)	AE (m^4)	WG (tonne)	Arc_AB (m)	WE (tonne)	Cost (lakh Rs)
16.54	7.56	128.79	16.1	102.33	17.04	48.24	40.21
14.51	8.61	128.79	16.1	60.24	14.95	48.24	25.74
12.48	10.01	128.79	16.1	45.02	12.86	48.24	20.29
10.45	11.96	128.79	16.1	42.21	10.77	48.24	19.6
8.42	14.84	128.79	16.1	40.97	8.68	48.24	18.83
6.39	19.56	128.79	16.1	38.16	6.59	48.24	17.77
4.36	28.66	128.79	16.1	37.16	4.49	48.24	17.46

TABLE-2.HDA.R3.1:

Cost of Radial Gate (3 HG) w.r.t. Head for area of Spillway bay of 75m^2 :

HD (m)	CS (m)	AG (m^2)	AE (m^4)	WG (tonne)	Arc_AB (m)	WE (tonne)	Cost (lakh Rs)
16.54	4.53	77.28	5.8	43.86	17.04	24.25	19.07
14.51	5.17	77.28	5.8	32.54	14.95	24.25	15.07
12.48	6.01	77.28	5.8	27.36	12.86	24.25	13.15
10.45	7.18	77.28	5.8	23.97	10.77	24.25	11.78
8.42	8.91	77.28	5.8	21.26	8.68	24.25	10.84
6.39	11.74	77.28	5.8	16.44	6.59	24.25	9.16
4.36	17.2	77.28	5.8	14.97	4.49	24.25	8.67

TABLE-2.HDA.R3.2:

Cost of Radial Gate (3 HG) w.r.t. Head for area of Spillway bay of 100m^2 :

HD (m)	CS (m)	AG (m^2)	AE (m^4)	WG (tonne)	Arc_AB (m)	WE (tonne)	Cost (lakh Rs)
16.54	6.04	103.03	10.3	55.95	17.04	35.72	23.88
14.51	6.89	103.03	10.3	41.6	14.95	35.72	18.76
12.48	8.01	103.03	10.3	34.73	12.86	35.72	16.19
10.45	9.57	103.03	10.3	32.61	10.77	35.72	15.28
8.42	11.87	103.03	10.3	27.94	8.68	35.72	13.66
6.39	15.65	103.03	10.3	22.91	6.59	35.72	11.93
4.36	22.93	103.03	10.3	20.31	4.49	35.72	11.09

TABLE-2.HDA.R3.3:

Cost of Radial Gate (3 HG) w.r.t. Head for area of Spillway bay of 125m^2 :

HD (m)	CS (m)	AG (m^2)	AE (m^4)	WG (tonne)	Arc_AB (m)	WE (tonne)	Cost (lakh Rs)
16.54	7.56	128.79	16.1	67.56	17.04	48.24	28.4
14.51	8.61	128.79	16.1	52.25	14.95	48.24	23.14
12.48	10.01	128.79	16.1	44.18	12.86	48.24	20.08
10.45	11.96	128.79	16.1	42.58	10.77	48.24	19.35
8.42	14.84	128.79	16.1	38.93	8.68	48.24	18.04
6.39	19.56	128.79	16.1	34.96	6.59	48.24	16.67
4.36	28.66	128.79	16.1	25.34	4.49	48.24	13.42

TABLE-2.HDA.R4.1:

Cost of Radial Gate (4 HG) w.r.t. Head for area of
Spillway bay of 75m^2 :

HD (m)	CS (m)	AG (m^2)	AE (m^4)	WG (tonne)	Arc_AB (m)	WE (tonne)	Cost (lakh Rs)
16.54	4.53	77.28	5.8	37.53	17.04	24.25	16.76
14.51	5.17	77.28	5.8	32.14	14.95	24.25	14.91
12.48	6.01	77.28	5.8	27.31	12.86	24.25	13.12
10.45	7.18	77.28	5.8	24.73	10.77	24.25	12.22
8.42	8.91	77.28	5.8	18.38	8.68	24.25	9.86
6.39	11.74	77.28	5.8	16.01	6.59	24.25	9.01

TABLE-2.HDA.R4.2:

Cost of Radial Gate (4 HG) w.r.t. Head for area of
Spillway bay of 100m^2 :

HD (m)	CS (m)	AG (m^2)	AE (m^4)	WG (tonne)	Arc_AB (m)	WE (tonne)	Cost (lakh Rs)
16.54	6.04	103.03	10.3	47.13	17.04	35.72	20.71
14.51	6.89	103.03	10.3	40.25	14.95	35.72	18.29
12.48	8.01	103.03	10.3	36.57	12.86	35.72	16.81
10.45	9.57	103.03	10.3	34.76	10.77	35.72	16.19
8.42	11.87	103.03	10.3	25.3	8.68	35.72	12.75
6.39	15.65	103.03	10.3	21.53	6.59	35.72	11.45

TABLE-2.HDA.R4.3:

Cost of Radial Gate (4 HG) w.r.t. Head for area of
Spillway bay of 125m^2 :

HD (m)	CS (m)	AG (m^2)	AE (m^4)	WG (tonne)	Arc_AB (m)	WE (tonne)	Cost (lakh Rs)
16.54	7.56	128.79	16.1	57.5	17.04	48.24	24.94
14.51	8.61	128.79	16.1	49.49	14.95	48.24	22.18
12.48	10.01	128.79	16.1	46.6	12.86	48.24	20.89
10.45	11.96	128.79	16.1	45.85	10.77	48.24	20.63
8.42	14.84	128.79	16.1	38.12	8.68	48.24	17.76
6.39	19.56	128.79	16.1	28.65	6.59	48.24	14.51

TABLE-2.HC.R2.1:

Cost of Radial Gate (2 HG) w.r.t. Head 10m Span :

HD (m)	CS (m)	WG (tonne)	Arc_AB (m)	H'cap (tonne)	Mat'Cost (lakh Rs)	O'Cost (lakh Rs)
16.5	10	121.7	17	92.2	31.3	17
14.5	10	68.9	15	57.5	17.7	11.5
12.5	10	45	12.9	42.7	11.6	8.7
10.5	10	34.8	10.8	35.6	9	7.6
8.4	10	24.5	8.7	28.2	6.3	5.9
6.4	10	13.6	6.6	20.4	3.5	4.4
4.4	10	8.2	4.5	16	2.2	3.4

TABLE-2.HC.R3.1:

Cost of Radial Gate (3 HG) w.r.t. Head 10m Span :

HD (m)	CS (m)	WG (tonne)	Arc_AB (m)	H'cap (tonne)	Mat'Cost (lakh Rs)	O'Cost (lakh Rs)
16.5	10	97	17	73.1	24.9	14.8
14.5	10	66.1	15	53.6	17	11.4
12.5	10	44.2	12.9	40.8	11.4	8.7
10.5	10	34.9	10.8	34.5	9	7.2
8.4	10	23.7	8.7	27.2	6.1	5.7
6.4	10	13.9	6.6	20.3	3.6	4.4
4.4	10	8.9	4.5	16	2.3	3.5

TABLE-2.HC.R4.1:

Cost of Radial Gate (4 HG) w.r.t. Head 10m Span :

HD (m)	CS (m)	WG (tonne)	Arc_AB (m)	H'cap (tonne)	Mat'Cost (lakh Rs)	O'Cost (lakh Rs)
16.5	10	76.3	17	61	19.6	13
14.5	10	58.8	15	49.4	15.1	10.8
12.5	10	46.6	12.9	41.5	12	8.9
10.5	10	36.2	10.8	35.1	9.3	7.4
8.4	10	20.6	8.7	24.7	5.3	5.5
6.4	10	13.6	6.6	19.7	3.5	4.4
4.4	10	9.6	4.5	16.3	2.5	3.5

TABLE-2.WG.R2.1:

Cost of Radial Gate (2 HG) w.r.t. Head for 10m Span :

HD (m)	wsp (tonne)	wvs (tonne)	whg (tonne)	wArm (tonne)	CG (m)	WG (tonne)	Cost (lakh Rs)
16.54	13.38	30.3	36.2	8.1	16.4	121.74	48.25
14.51	11.74	20.93	6.65	10.44	14.22	68.85	29.19
12.48	10.1	12.06	5.27	5.09	12.6	44.99	20.27
10.45	8.45	8.87	4.63	3.19	10.73	34.79	16.6
8.42	6.81	5.94	3.23	1.73	8.8	24.5	12.21
6.39	5.17	2.37	1.52	0.78	6.75	13.62	7.93
4.36	3.53	1.04	0.95	0.44	4.59	8.24	5.61

TABLE-2.WG.R3.1:

Cost of Radial Gate (3 HG) w.r.t. Head for 10m Span :

HD (m)	wsp (tonne)	wvs (tonne)	whg (tonne)	wArm (tonne)	CG (m)	WG (tonne)	Cost (lakh Rs)
16.5	13.4	30.3	8.7	17.7	15.5	97	39.7
14.5	11.7	16.3	8	11.8	13.6	66.1	28.5
12.5	10.1	9.5	6.8	5.5	12.2	44.2	20.1
10.5	8.5	7.3	5.3	4.1	10.3	34.9	16.2
8.4	6.8	5.7	2.5	2.1	8.6	23.7	11.9
6.4	5.2	2.4	1.6	0.9	6.6	13.9	8
4.4	3.5	1	1.2	0.7	4.4	8.9	5.8

TABLE-2.WG.R4.1:

Cost of Radial Gate (4 HG) w.r.t. Head for 10m Span :

HD (m)	wsp (tonne)	wvs (tonne)	whg (tonne)	wArm (tonne)	CG (m)	WG (tonne)	Cost (lakh Rs)
16.5	13.4	18.5	10.4	12.8	15.6	76.3	32.6
14.5	11.7	11.9	9.4	9.5	13.8	58.8	25.9
12.5	10.1	9.2	7.5	6.9	12	46.6	20.9
10.5	8.5	7.7	5.5	4.5	10.3	36.2	16.8
8.4	6.8	3.1	2.6	2.4	8.4	20.6	10.8
6.4	5.2	1.5	1.9	1.3	6.5	13.6	7.9

REFERENCES

1. ANONYMOUS, - IS: 4622-1992, Fixed Wheel Gates Structural Design, Recommendation, Bureau of Indian Standards, Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi-2.
2. ANONYMOUS, - IS: 4623-1984, Radial Gates Structural Design, Recommendation, Bureau of Indian Standards, Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi-2.
3. ANONYMOUS, - IS: 226-1975, 808-1964, 2062-1984, Structural Steel, Bureau of Indian Standards, Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi-2.
4. ANONYMOUS, - IS: 1030-1982, Cast Steel, Bureau of Indian Standards, Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi-2.
5. ANONYMOUS, - IS: 814-1991, Covered Electrodes for Manual Metal Arc Welding of Carbon and Carbon Manganese Steel – Specification, Bureau of Indian Standards, Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi-2.
6. DAVIS, CALVIN VICTOR AND SORENSENS KENNETH, E., (1969), - Handbook of Applied Hydraulics
7. DARNIEF, (1984), - Practices for Design of Gates, Report on Special Problem, ME (WRD), submitted at WRDTC, University of Roorkee, Roorkee.
8. DAS, AMULYA, K., (1987), –Cost Analysis of Vertical Lift Gates; Report on Special Problem, ME (WRD), submitted at WRDTC, University of Roorkee, Roorkee.
9. NIGAM, P. S., (1985), - Handbook of Hydroelectric Engineering, Nemchand and Bros., Roorkee.
10. NOVAK, P., MOFFAT A.I.B., and NALLURY, C. and NARAYANAN, R., (1996), - Hydraulic Structures, E & FN SPON, London, Glasgow, Weinheim, New York, Tokyo, Melbourne, Madras.
11. PUNMIA, B. C., Jain, A. K. and Jain, A. K., (1992), Strength of Material and Theory of Structures, Laxmi Publications, 7/21, Ansari Road, Daryaganj, New Dlhi-2.
12. VARSHNEY, R. S., (1986), - Hydropower Structures, Nemchand and Bros., Roorkee.