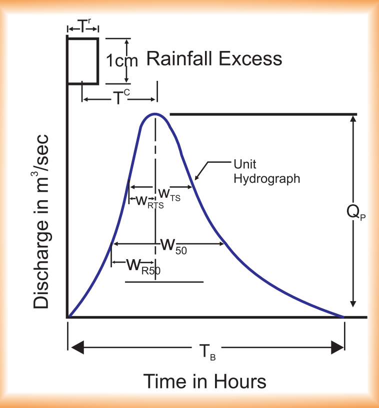
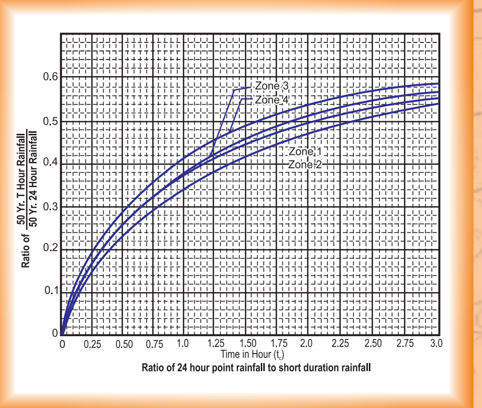
ज्ञान ज्योति से मार्गदर्शन

To Beam As A Beacon of Knowledge

Bridge Planning including Hydrological Investigation





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Pune - 411001.

FOREWORD TO FIRST REVISED EDITION

The book illustrates process of finding optimal and expeditious solution for Railway Bridges. The cost, time of planning & construction required for bridges forms substantial part of the project. Any change in the Bridge configuration in terms of span arrangement and depth of foundation at the later date i.e. after the construction is a very difficult and cumbersome process. Therefore, the concepts related to these technical issues are very important and play a significant role in timely execution of these works.

In this first revised edition, following important changes have been incorporated:

Illustration on working out design discharge Q50 based on flood estimation report, illustration on working out linear waterway/span and foundation depth, the provisions of estimation of seismic loads based on "IRS Seismic Code 2017" and estimation of catchment properties, using Google Earth and Bhuvan.

The book has been revised and updated by Shri Ramesh Pinjani, Dean IRICEN incorporating the latest information, correction slips and illustrations. Sh. Rajesh Shekhawat, Senior Professor IRICEN has contributed for estimation of catchment properties, using Google Earth and Bhuvan.

I believe that the book is useful to the construction engineers involved in Bridge planning & construction, as the theoretical concepts and various guidelines including step by step approach to deal with various issues related to bridge planning are explained in detail.

The suggestions for improvement are welcome, which can be mailed on director@iricen.gov.in

November 2019

Ajay Goyal
Director
IRICEN

FOREWORD

The book illustrates process of finding optimal solution for Railway Bridge to cross a water body, another roadway or Railway.Bridge cost form a major portion of cost of the project. Bridges are also the least feasible infrastructure component in terms of accommodation of future un-predictive functionary charges.

It is hoped that the book will be found useful by the field Engineers, involved in the planning, design & construction of railway bridges.

The suggestions for improvement are welcome.

October 2016

N. C. Sharda
Director / IRICEN
director@iricen.gov.in

PREFACE

The book is a step-by-step approach to do the Bridge Planning, starting with Bridge Design aspects, Calculation of Design Discharge, finalization of span & depth of foundation, aspects related to locating the bridge and deciding type of foundation, substructure and superstructure.

I acknowledge the work of Sh. R. K. Gupta, Ex ED (B&S) RDSO, who published a technical paper on Economics of steel bridges vs concrete bridges, few important concepts of this paper have been incorporated in this book.

I am thankful to Shri Vishwesh Chaubey Ex.Director, IRICEN, who inspired me & provided valuable guideance to write this book.

Various guidelines as available in Bridge Rules, Engineering Code, Sub-Structure code, Bridge Manual, Flood estimation Reports & RDSO Report No. RBF-16 have been followed while presenting the same in this book.

I dedicate this book to the cause of an efficient, smooth and confident Bridge Planning on Indian Railways network.

October 2016

(Ramesh Pinjani)
Senior Professor Bridges/IRICEN

CONTENTS

CHAPTER - 1

Introduction

1.0 Introduction

During construction of any railway project, bridge planning is an important issue. Bridges are expected to have design life of 75 to 100 years. They are also one of the expensive components of railway system. They are least flexible infrastructure component for accommodation of future unpredictive functionary changes.

Bridge planning is the process of finding optimal solution for crossing a water course, another roadway or railway.

1.1 Sequence of Planning

Planning of bridge involves mainly deliberation & decision on the following issues in chronological order-

1.1.1 Site history and constituent

1.1.2 Working out Hydrological parameters for given flood recurrence interval generally 50 years) and finalisation of span arrangement & depth of foundation. The steps involved are:

a) Assessment of catchment properties i.e. catchment size, length of longest stream, stream slope, locating C.G of catchment & its distance up to bridge site

b) Estimation of design discharge (Q_{50}).

c) Estimation of water way requirement, scour depth, fixing vertical clearance, free board

d) Finalization of spans arrangement and foundation depth.

e) Assessment of span arrangement w.r.t various norms such as free board, vertical clearance, velocity of flow, HFL

1.1.3 Geotechnical Investigation

1.1.4 Environmental aspects

1.1.5 Location of bridge

1.1.6 Investigation for Bridge, depending upon whether it is a minor, major or Important bridge

1.1.7 Deciding geometry of bridge including type of material to be used for the construction of bridge components

a) Foundation : Type of foundation i.e. Open or Deep foundation (Pile or Well)

b) Sub Structure: Type of sub structure i.e. Masonry or Mass Concrete or RCC substructure

c) Super structure: Type of super structure i.e. RCC or PSC or steel super structure.

1.1.8 Staging& construction methodology

1.1.9 Land availability.

The recommended bridge planning outcomes must be supported by technical efforts and confirmatory investigation. All the above issues (except Geotechnical investigation and environmental issues) are deliberated & discussed in detail in the chapters.

■ ■ ■

CHAPTER 2

Working out Catchment Properties

2.0 General

For purpose of calculation of design discharge as per RDSO Report RBF -16 or Flood Estimation Report following physical characteristics need to be estimated:

1) Marking catchment boundaries & estimate catchment area
2) Marking length of longest stream & work out length of longest stream (L)
3) Locating C.G of Catchment & working out distance between C.G of catchment & bridge site (Lc)

For getting above data, topo sheets are the basic references. Topo sheets for a particular area may be obtained from Survey of India. There are 2 types of topo sheets, one which is available for public domain and another one is restricted area topo sheet. Restricted area topo sheets are only made available on the specific requests for bonafide uses.

Topo sheets on relevant area are available in the scale of 1:50000, it means 1 cm measurement in topo sheet = actual measurement of 500 meters on ground.

Topo sheets are available for the continuous area and are to be referred as a series. At the bottom part of topo sheet a grid is given, there are 9 topo sheets in which present topo sheet number is shown in the centre. For the right hand side area of topo sheet right hand side number of grid is to be referred and so on. In the topo sheet bearing a particular number adjacent 8 topo sheets numbers are readily available in the grid. In this way we can make a series of topo sheets to cover the required area.

Now-a-days digital topo sheets are also available from Survey of India. The biggest advantage of digital topo sheets is the contour interval is 5 m against 20 m on conventional topo sheet. Moreover, digital topo sheet can be easily zoomed out and zoomed in on the computer screen for referring to more details. In conventional topo sheet available in map-form all details are visible simultaneously which are more clumsy and may not be relevant for a particular requirement, where as in digital topo sheet information is kept in different layers (say 5-11) and these layers can be switched on or switched off as per requirement making them more clear for use. Accordingly relevant details can be seen/ visualise in better way.

On the topo sheet the different ground details such as roads, railway track, jungle, mines habitat area, reserve forests etc. are given in tabular form on bottom right hand corner. These different legends are shown in different colours on conventional topo sheets. Similar legend are also used in digital Topo Sheets.

For the calculation of catchment area either topo sheets can be used or the same can be done with the tools available with Google Earth or similar software. Normally on I.R topo sheets are preferred. Topo sheets are required to be updated by Survey of India but it is seen that conventional topo sheets are as old as 30-40 years. Thus, uses of digital topo sheets is much advantageous as they are 2-3 years old only. Due to latest version they have updated details like dams, railway lines, ridges, new habitat areasetc., hence latest catchment features are available in digital Topo Sheets.

2.1 Catchment Area (A)

Catchment area is the area enveloping the regions, which contributes the flow at a given point. For estimation of catchment step-by-step procedure is given below:

i) Marking boundaries of catchment area - for the purpose of marking boundaries of catchment area, select the appropriate topo sheet and mark the location of bridge based on it coordinates i.e. latitude and longitude, also mark the alignment of the railway track on the topo sheet.

ii) After marking the location of bridge on topo sheet the next task is to mark the boundary of catchment area.

iii) For identifying the ridges and valleys we have to understand the pattern of the contours, i.e. If the elevation outside the loops of the contour is more, then it is a valley and if the level inside the loops are more, then it is a ridge.

In a particular catchment, stream pattern is more or less like routes of a tree. Smaller streams merges to bigger stream and ultimately they form a river or a bigger stream which is leading to a bridge site.

iv) For marking of catchment boundary one has to find out the mid-point in between two streams flowing in opposite direction i.e. ridge point. First trace the streams starting from the bridge location, towards upstream side up to the end of each branch of stream. The point where the stream ends, (contributing to stream of interest), we will find the start of another stream which is flowing towards the opposite side. Mark the centre of these 2 points,this exercise is to be done for all the branches of streams & then join these points .On joining all such points catchment boundary will be plotted.

The Check should be made to ensure the catchment boundary does not cross any rivers/streams except at the catchment outlet i.e. at bridge location. Site inspection may be necessary to fix the boundary of small or flat catchment. For identifying boundary line of the catchment starting at proposed outlet (scheme location / Bridge), moving up hill to the highest point, ridge line and

Fig. 2.1 Topo Sheet

following the highest points or all the starting points of the streams, then again come to the bridge.

Step 2

Calculation of Area of catchment: Easiest method to calculate area of an uneven figure is to use planimeter. We can calculate area of catchment map/figure by moving needle point on the boundary line of the catchment. If planimeter is not available the work can be done manually using graph paper. For this purpose take a graph paper of appropriate size, trace the catchment boundary on it, with carbon paper, including the bridge location from the topo sheet. Count the full squares, half squares, 1/4th, 3/4th squares of centimeter from the figure of catchment on graph sheet. Then calculate the area of total figure in square centimetre. Such calculated area in sqcm is required to be converted to actual scale i.e. Say if scale is 1:50000 then 1 c.m on topo sheet = 500 mtr or 0.5 kms on ground, thus $1cm^2 = 0.5 \times 0.5 = 0.25$ sq. km. This area is to be used for calculation of design discharge.

Fig.2.2 Planimeter

Fig.2.3 Digital Planimeter

2.2 Length of Main Stream (L)

This is the length of main/longest stream along the stream, from the farthest boundary of the catchment to the bridge site i.e. point under consideration. Mark the longest stream on the toposheet from the bridge location to the farthest point. Take a thread, move along the stream flows and then measure the length of thread with the scale. Convert the measured length (in cm) to actual length (in km) of stream using scale of map (say 1: 50,000 i.e. 1cm: 0.5 km).

2.3 Length of Concentration (Lc)

It is the length of longest stream (along the stream) from a point opposite to centroid of the catchment area to the bridge site.

For getting Lc, we have to find Centre of Gravity of the shape of the catchment area. The catchment area is not the regular figure so to find the C.G. a different processes is adopted.

Trace the catchment area figure on the card sheet, thicker sheet, by carbon paper from the already marked topo sheet. Also mark the longest stream on the card sheet. Cut the sheet along the catchment boundary. We will get the sheet into the shape of catchment area. Take a drawing pin, make a slightly bigger hole near the edge of card sheet catchment. Put the pin in it and hang the sheet on the wall, the sheet should be allowed to move freely. Take a plumb bob, put the thread on the pin, when it is settled, mark a point on the card sheet catchment. Mark a line joining from pin point to the mark. Rotate the catchment and do the same exercise again for other point/ location, so that we will get another line at different angle. The point of intersection of these two lines is the C.G. of this non-regular figure of the catchment.

The longest stream may or may not pass through the centre of gravity so the nearest point to the C.G., which is falling on longest stream is taken as CG to find the Lc. Measure the length along the stream from the nearest point of C.G. falling on the longest stream to the bridge location.

2.4. Use of "Google Earth" for estimating Catchment Area Properties :

Google Earth (its' Desktop Version is Google Earth Pro) is a free downloadable software from the website "https://www.google.com / intl/en_in/earth/versions/ #earth-pro".

Open Google Earth Pro. In the top right hand window, type the name of the Place to be explored (Fig. 2.4). Alternatively the Latitude and Longitude of the place to be explored, with a comma in between, can also be entered. When the "terrain" layer is selected, in the bottom left hand corner, this will open the map of the terrain area.

Fig. 2.4

Display the required catchment area on the screen by adjusting the scale of the map, using ZoomIn or ZoomOut slider. The Latitude and Longitude of the cursor point are displayed on the bottom right hand side of the screen. Salient points on the area can be marked using "Add Placemark" tool from the menu bar on top and then selecting the required location. The selected point can be given a name, which will be saved in the "Places" list and it can be given selected "Colour" in the "Add Placemark" menu (Fig.2.5).

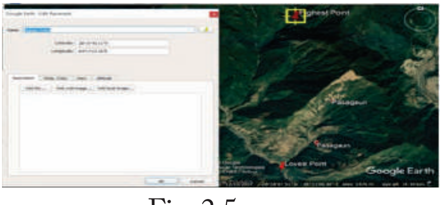

Fig. 2.5

Using the "Show Ruler" tool from the menu bar on the top and then selecting the "Polygon" tab, the catchment area boundary can be marked by expanding the polygon shape in small steps. Take care to continuously move in either clockwise or anti-clockwise direction only, while expanding the polygon shape. The boundary line can be marked in any selected colour and thickness. The catchment area can also be marked in any selected colour (Fig.2.6).

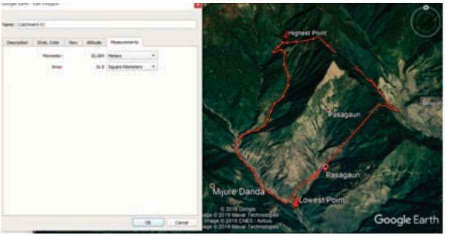

Fig. 2.6

The Perimeter and the Area of the marked area displayed and can be read directly from the "Polygon" tab.

For calculation of stream slope parameters, first mark the stream path using "Add Path" tool from the menu bar on top. Then select the marked stream path, right click the mouse and select "Show Elevation Profile". This will display the elevation profile of the stream path (Fig. 2.7). From this profile, the length of stream up to any given point, elevation of this point and slope at this point is directly displayed. Any other calculation required for the stream slope can be easily calculated using this profile.

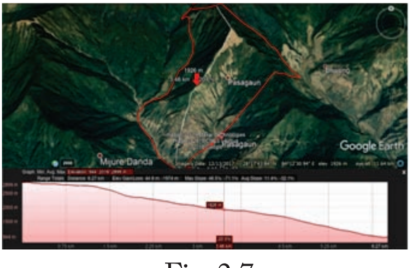

Fig. 2.7

Estimation of other parameters like Centroid of the area etc. canbe done using tools like "Earth Point" by registering as a user, which is free for limited/educational use.

2.5 Use of "Bhuvan" for estimating Catchment Area Properties:

"Bhuvan" is an Indian Geo-platform of Indian Space Research Organisation (ISRO). This is GIS platform with various features, including topographical and hydrological information, incorporated in it, which are regularly updated based on satellite imagery. This website address of this platform is "bhuvan.nrsc.gov.in/bhuvan_links.php" (Fig. 2.8).

Fig. 2.8

On this platform, some of the facilities are free and do not require any login (e.g. Bhuvan-2D, Bhuvan-3D etc.) whereas for some other facilities (e.g. Open Data Archive) require a login username and password is required, which can be obtained free by any Government Organisation.

This platform has many Special Applications also, which are listed on bottom left hand corner of the careen, and one of these applications is "Hydrological Products". Using this application, many hydrological parameters like Rainfall, Runoff etc. for any given area and given period can be obtained which are used for

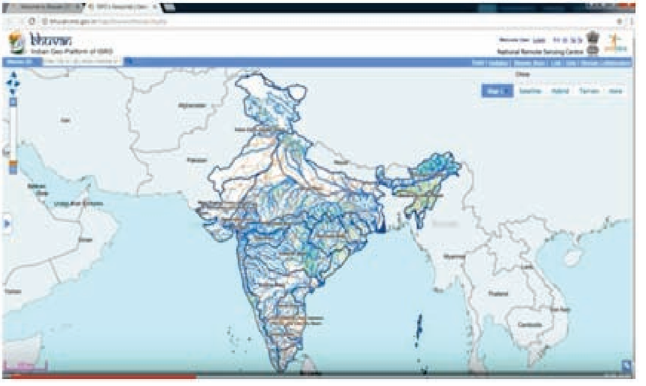

Fig. 2.9

design discharge calculations for bridges.

One of the easiest way to calculate catchment are properties is to use "Bhuvan-2D" menu. Open this menu, then Open "Map" menu near top right hand corner of the screen and select "Base Hydrology" option. This will open the hydrology map of the India (Fig. 2.9). For exploring any specific point, either give location of that point or its' Longitude & Latitude, with a coma in between them, in the search window near top left hand corner of the screen. This will open the selected catchment area with the selected point of exploration marked on it (Fig. 2.10).

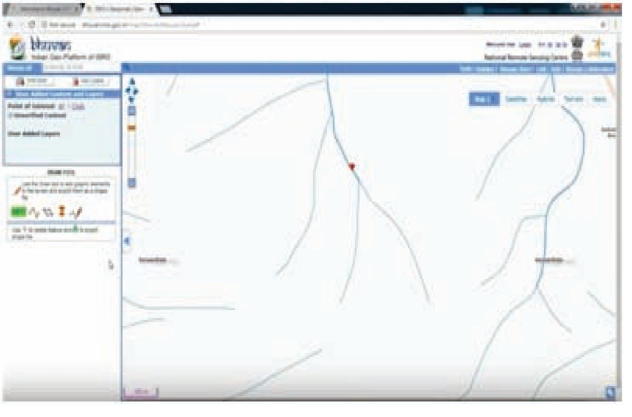

Fig. 2.10

Select "Tools" menu and then select "Draw Tool". This will open "Draw Tool" window. First tool in this window is used for "colour selection" of the boundary line, the second tool is for "drawing a line", the third tool is for "drawing polygon", fourth tool is for marking any "specific location" and fifth tool is for "correction of polygon drawn".

The catchment area boundary can be drawn using "draw polygon" tool, in the same way as in Google Earth and area of this polygonal will be displayed automatically when this area is selected. Any stream can be drawn using "draw line" tool and length of this line will be displayed automatically when this line is selected.

Estimation of other parameters like Centroid of the area etc. can be done using tools like "Earth Point" by registering as a user, which is free for limited/educational use.

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CHAPTER - 3

Working out Hydrological Parameters

3.0 Estimation of Design Discharge

Design discharge (Q) is the estimated discharge for the design of the bridge and its appurtenances (accessories). This shall normally be the computed flood with a probable recurrence interval of 50 years (Q_{50}).

3.1 Estimation of design discharge for various types of projects

1) Bridges constructed on New Railway Lines

Following methods are available for estimation of design discharge (Q_{50}) as per Sub structure code Para 4.3

i. From actual data (SSC - Para 4.3.1)

Where stream flow records (yearly peak discharges) are available for the desired recurrence interval or more, design discharge shall be; the computed flood for the desired recurrence interval

ii. Statistical methods (SSC - Para 4.3.2)

Where such Stream flow records exist for less than the desired recurrence interval but sufficient for the statistical analysis, design discharge may be; computed statistically for the desired recurrence interval

iii. Unit hydrograph (SSC - Para 4.3.3)

Where records of floods are not available for sufficient length to permit reliable statistical analysis but where rainfall pattern & intensity records are available for sufficient length of time & where it is feasible to carry out at least limited observations of rainfall & discharge, Unit hydrograph based on such observations may be developed and design discharge of the desired recurrence interval computed by applying appropriate design storm.

iv. Synthetic hydrograph concept & RDSO report RBF-16 (SSC - Para 4.3.4)

Where such observations, as mentioned in Cl. 4.3.3 of S.S.C., are not possible,

A synthetic unit hydrograph may be developed for medium size catchment (i.e. Area 25 sq. Km or more but less than 2500 sq. Km) by utilising established relationships as mentioned in Flood Estimation Report for respective hydro-meteorological sub zone.

For small size catchment (less than 25 sq. Km), design discharge may be estimated using the techniques described in RDSO report no. RBF-16, titled as "Flood Estimation Methods for Catchments less than 25 km^2 area."

v. Other methods (stage-discharge relationship (SSC - Para 4.3.5)

Where feasible, gauging of the stream may be done to establish the stage– discharge relationships, & discharge at known HFL determined. Otherwise, the discharge may be estimated by slope area method after obtaining flood slope by field observations

For Indian Rly bridges, the design discharge Q_{50} is generally estimated on the basis of sub structure code para 4.3.4 above i.e. for catchment up to 25 sqkm using RBF-16 and for catchment area 25 sqkm & above and up to 2500 sqkm using flood estimation report for respective sub zone.

2. Bridges constructed in c/w Doubling Works (SSC - Para 4.5.7)

i) Where there is no history of past incidents of over flow/washout/excessive scour etc. during last 50 years: The water way of existing bridge may be retained after taking measures for safety as considered necessary by Chief Engineer In charge.

ii) For locations where there is history of past incidents of over flow/washout/excessive scour: The waterway has to be re-assessed based on the freshly estimated design discharge using clause 4.3.1 to 4.3.4.

iii) For locations, where existing bridges are less than 50 years old and there is no past history of incidents of over flow/washout/excessive scour etc.: The water way may be judiciously decided after calculation of the design discharge and keeping in view the water way of existing bridges on adjacent loccations on the same river (Para 4.5.7 of SSC)

3) Gauge Conversion Projects (SSC - Para 4.5.9)

For strengthening existing bridges by jacketing etc., a reduction in waterway area may be allowed by the Chief Bridge Engineer provided that there has been no history of past incidents of overflow/washout/excessive scour etc. and that measures for safety as considered necessary by the Field Engineer and approved by CBE are taken.

Detailed calculation of waterway to be done by Zonal Railway in every case and minimum clearance should b e maintained from safety point of view where allowing the reduction in the waterway. Where the clearances are not available, the bridge should be rebuilt.

4) Rebuilding of Bridges on existing lines (SSC - Para 4.5.8)

For rebuilding of bridge: The waterway shall be determined keeping in view the design discharge as worked out from clause 4.3 of S.S.C.

3.2 Requirement of Linear Water Way

1) Linear water way for River / stream flowing bank to bank width (SSC - Para 4.5.1)

In the case of a river which flows between stable high banks and which has the whole of the bank-to-bank width functioning actively in a flood of magnitude Q ; the waterway provided shall be practically equal to the width of water spread between the stable banks for such discharge. if, however, a river spills over its banks and the depth of spill is appreciable, The waterway shall be suitably increased beyond the bank-to-bank width in order to carry the spill discharge as well

(2) Linear water way for River / stream active channel flowing only to a portion of bank to bank width (SSC - Para 4.5.2)

In the case of a river having a comparatively wide and shallow section, with the active channel in flood confined only to a portion of the full width from bank to bank; the Constriction of the natural waterway would normally be desirable from both hydraulic and cost considerations. A thorough study of both these factors shall be made before determining the waterway for such a bridge.

(3) Linear water way for River flowing in alluvial beds (SSC - Para 4.5.3)

For river with alluvial beds and sustained floods the waterway shall normally be equal to width given by Lacey's formula: $Pw = 1.811\, C(Q)^{0.5}$, considering $C = 2.67$

$Pw = 4.83\, (Q)^{0.5}$

Where Pw = Wetted perimeter in metres which can be taken as the effective width of waterway in case of large streams, Q = design discharge in cum/sec, C = a coefficient normally equal to 2.67, but which may vary from 2.5 to 3.5 according to local conditions depending upon bed slope and bed material.

(4) Linear water way for River of flashy nature & non alluvial bed (SSC - Para 4.5.4)

If the river is of a flashy nature i.e. the rise and fall of flood is sudden or the bed material is not alluvial and does not submit readily to the scouring effect of the flood, Lacey's regime width formula as given in clause 4.5.3 will not apply

(5) Linear water way for Rivers in sub- montane stage (SSC - Para 4.5.5)

In case of rivers in sub-montane stage, where the bed slopes are steep and the bed material may range from heavy boulders to gravel, it is not possible to lay down rigid rules regarding constriction of water way. Any constriction in such cases shall be governed largely by :

- The configuration of active channels
- The Cost involved in diversion & training of these channels
- The cost of guide bunds which will need much heavier protection than the guide bunds of alluvial rivers.

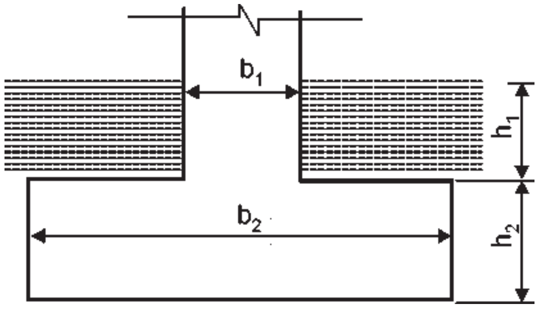
Each case shall be examined on merits from both hydraulic & economic consideration and best possible solution chosen.

(6) Effect of pier width on waterway provided (SSC - Para 4.5.6.1)

In case of a bridge having one or more piers, the width of waterway obtained from procedure outlined in clause 4.5.3 to 4.5.5 of S.S.C above shall be increased by twice the sum of the weighted mean submerged width of all the piers including footings for wells to arrive at the total width of waterway to be provided between the ends of the bridge; where such increase is not made, the same shall be applied as a deduction from the total width of waterway actually provided to arrive at the effective width.

If the width of the pier is b_1, for a height h_1, and b_2 for height h_2 in the submerged portion of the pier having a total height $h_1 + h_2$, the weighted mean submerged width is given by the expression.

$$\mathbf{b}_{mean} = \frac{h_1 b_1 + h_2 b_2}{h_1 + h_2}$$



3.3 Estimation of Scour Depth

(1) Scour depth based on local conditions (SSC - Para 4.6.1)

The probable max depth of scour for design of foundations and training & protection works shall be estimated considering local conditions

(2) Scour depth based on soundings, duly augmented for design discharge (SSC - Para 4.6.2)

Wherever feasible & especially for flashy rivers and with beds having boulders or gravels, sounding for purpose of determining the depth of scour shall be taken in the vicinity of site proposed for the bridge. Such sounding are best taken during or immediately after flood. In calculating design depth of scour allowance shall be made in the observed depth for increased scour due to:

i) The Design discharge being greater than observed discharge

ii) Increase velocity due to constriction

iii) Increase in scour in the proximity of pier/abutments

(3) Scour depth for natural channels/ Rivers in alluvial beds, where water way provided is not less than Lacey's regime width (SSC - Para 4.6.3)

In the case of natural channels flowing in alluvial beds where the width of waterway provided is not less than Lacey's regime width; The normal depth of Scour (D) below the foundation design discharge (Q_f) level may be estimated from Lacey's formulas as indicated below:

$$D = 0.473 \left(\frac{Q_f}{f} \right)^{\frac{1}{3}}$$

Where D is depth in metres Q_f is in cumecs and f is Lacey's silt factor.

Note : The silt factor 'f' shall be determined for representative samples of bed material collected from scour zone using the formula :

$$f = 1.76 \sqrt{m}$$

Where m is weighted mean diameter of the bed material particles (in mm)

(4) Scour depth for Rivers in alluvial beds, where water way provided is less than Lacey's regime width (SSC - Para 4.6.4)

Where due to constriction of waterway, the width is less than Lacey's regime width for Q_{50} or where it is narrow and deep as in the case of incised rivers and has sandy bed, the normal depth of scour may be estimated by the following formula:

$$D = 1.338(q_f^2/f)^{\frac{1}{3}}$$

Where q_f is the discharge intensity in cubic metre per second per metre width and 'f' is silt factor as defined in clause 4.6.3 of S.S.C i.e. sub para 3 above.

(5) Assess- ment of max scour depth near hydraulic structure (SSC - Para 4.6.6)

The depth calculated (vide clause 4.6.3 and 4.6.4 of S.S.C i.e. is sub para 3 & 4 above) shall be increased as indicated below, to obtain maximum depth of scour for design of foundations, protection works and training woks:

Nature of the river	**Depth of scour**
In a straight reach	1.25 D
At the moderate bend conditions e.g. Along apron of guide bund	1.5 D
At a severe bend	1.75 D
At a right angle bend or at nose of piers	2.0 D
In severe swirls e.g. Against mole head of a guide bund	2.5 to 2.75 D

(6) Scour depth for clayey beds

In case of clayey beds, wherever possible, maximum depth of scour shall be assessed from actual observations.

3.4 Free Board

The free board is vertical distance between the water level corresponding to design discharge (Q_{50}) including afflux (h) and the formation level of its approach bank / top level of guide bank:–

Minimum free Board shall be one meter, suitably increased if heavy wave action is expected.

CE/CBE can relax Free Board in special Circumstances as indicated below:-

Discharge (cumecs)	Min free board (mm)
Less than 3	600 mm
3 to 30	750 mm
More than 30	No relaxation

3.5 Vertical Clearance

The vertical distance between the water level corresponding to design discharge (Q_{50}) including afflux and the point on the bridge super structure where the clearance is required to be measured.

3.5.1 The Minimum clearance for bridges excluding arch bridges, pipe culvert and Box culverts (SSC - Para 4.8.1)

Discharge (cumecs)	Vertical clearance
0 - 30	600 mm
31-300	600 mm – 1200 mm
301 – 3000	1500 mm
Above 3000	1800 mm

3.5.2 The Siphons, pipe and box culverts are designed as pressure conduits, therefore no clearances are considered necessary for these structures (Ref: Para 312(3) Bridge manual).

3.5.3 In the case of arch Bridge, Minimum clearance measured to crown shall be as under. (Para 4.8.2 SSC)

Span of Arch	Clearance
Less than 4 m	Rise or 1200 mm
4.0 to 7.0 m	2/3 rise or 1500mm
7.1 to 20.0 m	2/3 rise or 1800 mm
Above 20.0 m	2/3 rise

3.5.4 The Clearance can be relaxed by CE/CBE provided: Adoption of prescribed clearance results in heavy expenditure and /or serious difficulties---The clearance can be safely reduced to (SSC - Para 4.8.3)

Discharge (cum)	Clearance (mm)
Less than 3	300
3 to 30	300 - 400 (Pro-rata)
31 to 300	400 - 1200 (Pro-rata)

The relaxation shall be personally exercised by PCE/CBE, due consideration being given to past history of bridge.

3.5.5 While executing works other than rebuilding, retain existing clearance (SSC - Para 4.8.4)

3.5.6 Where a tendency has been observed for the bed level of stream to rise, clearance shall be provided taking this factor into account. (SSC - Para 4.8.5)

3.6 Method Statement for Estimation of Design Discharge (SSC - Para 4.3)

Para 4.3.4 of SSC specifies that where observations, as mentioned in Cl. 4.3.3 are not possible, a synthetic unit hydrograph may be developed for medium size catchment i.e. Area 25 sq. Km or more but less than 2500 sq. Km, by utilising established relationships as mentioned in Flood Estimation Report for respective hydro-meteorological sub zone.

For small size catchment less than 25 sq. Km, the design discharge may be estimated using the techniques described in RDSO report no. RBF-16.

3.6.1 Flood estimation for small catchments: area < 25 sq km – RDSO report RBF-16

$$Q_{50} = 0.278\ C\ I_{50}\ A$$

Where C= run off coefficient, A : catchment area in sq km,

I_{50} : 50 year rainfall intensity in mm/hr =

Method statement for working out design discharge Q_{50}

Step-1: Calculate time of concentration (in hrs.)

$$t_c = \left[\frac{L^3}{H}\right]^{0.345}$$

Where t_c is time of concentration (in hrs), It is the time taken by water to travel from most distant point on the periphery of catchment to the point of interest. L is Length of longest stream (in kms) from source to bridge site, H= height of farthest point from bed level at bridge site (in meter).

Step-2: Working out areal reduction factor (F) for given catchment area (in sqkm) & value of t_c

Table : 1 Values of F (Areal reduction factor)

Catchment area	Duration of Rainfall (t_c)		
(km^2)	< 30 min	30 to 60 min	60 to 100 min
< 2.5	0.72	0.81	0.88
> 2.5 < 5.0	0.71	0.80	0.87
> 5.0 < 13.0	0.70	0.79	0.86
> 13.0 < 25.0	0.68	0.78	0.85

Step-3: Working out Runoff coeff (C)

$$C = X(R.F)^{0.2}$$

It depends upon nature of soil, soil cover and location of catchment:

R = 50 year 24 hrs. Point rainfall (in cm) from figure given in the report for the country zone

F: Areal reduction factor

X: 0.249 to 0.498 depends on soil type and location

Table : 2

S. No.	Description of the Catchment	Value of X
1	Sandy Soil/Sandy loam/Arid areas	0.249
2	Alluvium/silt loam/coastal areas	0.332
3	Red soil/clayey loam/cultivated plains /tall crops/wooded areas	0.415
4	Black cotton clayey soil/lightly covered/plain & barren	0.456
5	Hilly soil/plateau and barren	0.498

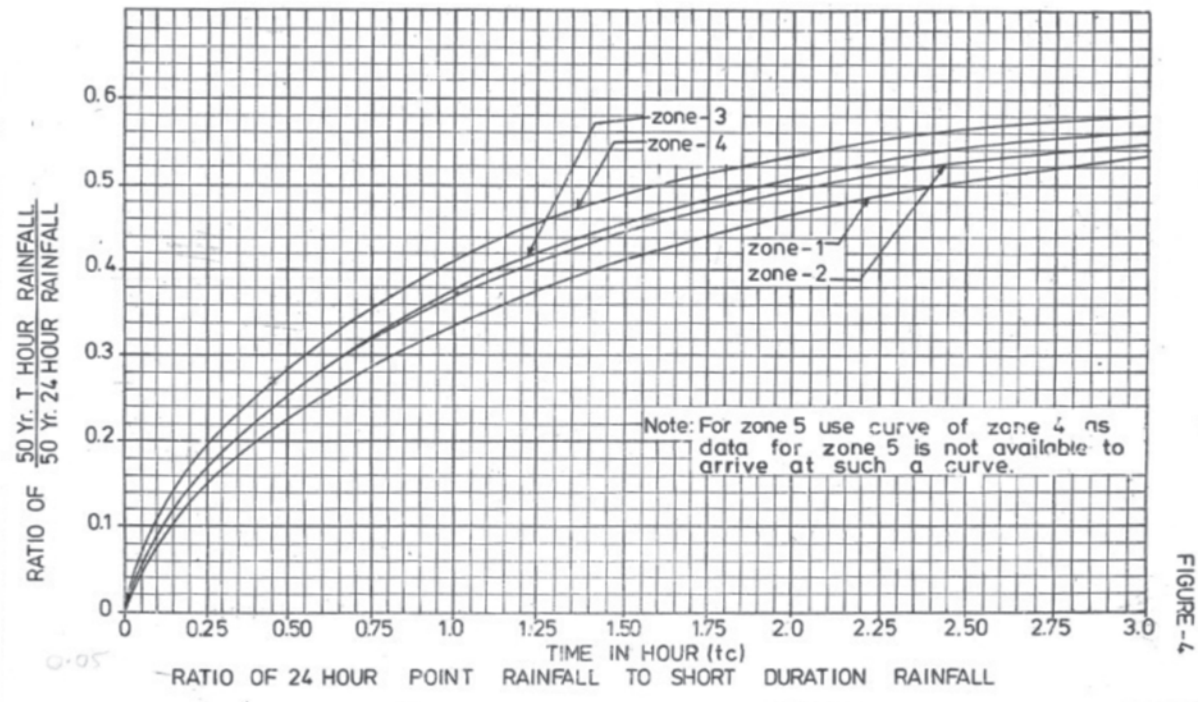


Fig. 3.1 : (Fig 4 of RDSO report RBF-16)

Step-4 Calculation of 50 year rainfall intensity in mm/hr. lasting for tc hrs duration

$$I_{50} = \frac{R_{50(tc)}}{tc}$$

Where $R_{50(tc)}$ is worked out referring fig-4 of report

For tc hrs duration read from the report "ratio of 50 year tc hrs rainfall/50 year 24 hrs rainfall"

$R_{50(tc)} = R_{50\ (24\ hrs)}$ rainfall x above ratio,

$$I = \frac{R_{50(tc)}}{tc} \text{ in hrs}$$

<u>Important Note:</u> RBF-16 report contains 50 yr 1 hr rainfall data for certain subzones, in that case these data are to be used for working out $R_{50(tc)}$ rainfall. These are given here under.

(a) Obtain 50 year 1 hr rainfall value using the appropriate rainfall map, if the catchment lies in any one of the subzones given below.
Subzones 1(g), 2(b), 3(b), 3(c), 3(d), 3(f), 3(h)⇒ {These maps are available as Fig 3.1 to fig 3.7 of RDSO report RBF-16}

(b) If the catchment lies in any one of the subzones given below for which 50 year 1 hour maps are not available. Obtain 50 year 24 hour rainfall using the appropriate rainfall maps and estimate the 50 year 1 hour rainfall value using the ratio of 1 hour to 24 hour rainfall given on the same maps.
Subzones 1(b), 1(d), 1(e), 1(f), 3(a), 3(e), 3(i), 4(a, b & c), 5(a &b)⇒ {These maps are available as Fig 3.8 to fig 3.16 of RDSO report RBF-16}

(c) If the catchment lies in any one of the following zone/sub zones for which 50 year 1 hour or 50 year 24 hour rainfall maps are not available, obtain 50 year 24 hour rainfall value using all India map and estimate 50 year 1 hour value as equal to 0.37 of 24 hour rainfall value

Subzones 2(a), 1(a), 1(c), 2(c), 3(g), 7 $\Rightarrow$ {The map is available as Fig 1 of RDSO report RBF 16}

Method of computing of $R_{50(tc)}$ using R_{50} (1 hr) rainfall

a) Read the ratio for tc hrs from figure-4 of the report

b) Read the ratio for 1 hour from figure-4 of the report

c) Obtain coefficient k = tc hrs ratio / 1 hr ratio i.e. $R_{50\ tc}$ hrs rainfall / R_{50} 1st hr rainfall

d) $R_{50(tc)} = k \times R_{50}(1\ hr)$

e) Rainfall intensity

Step-5 Now $Q_{50} = 0.278\ C\ I_{50}\ A$

Q_{50} is the 50 year return flood (m^3/s), C is the runoff coefficient, I_{50}= 50 year rainfall lasting for tc duration,
A = Catchment area in sq km

Sample calculations for design discharge of small catchment (Area<=25 km^2)

Illustration -1

Input Parameters:

1)	Catchment area A (in km^2)	2.54
2)	Length of longest stream course from source to bridge site L (in kms)	2.5

Table contd...

3)	Height of farthest point from bed level H (in meters)	67.25
4)	50 year 24 hrs rainfall R (in cms)	16.00
5)	Catchment Description	Red soil
6)	Sub zone	3i Kaveri
7)	R_{50}-1^{st} hr rainfall (in cms), if available (Optional)	Not specified

Calculations

Step-1 Time of Concentration(t_c)

$t_c=(L^3/H)^{0.345}$

$$= \left(\frac{2.5^3}{67.25}\right)^{0.345} = 0.604 \text{ hrs}$$

Step-2 Working out areal reduction factor (F) = 0.8 from Table-1

Step-3 Working out Runoff Coefficient

$C=X(R.F)^{0.2}$

X-depends on soil type & for Red soil the value of X is 0.415 (Ref. table2)

$C = 0.415(16 \times 0.8)^{0.2} = 0.69$

Step-4 Calculation of I_{50} (50 yr rainfall intensity in mm/hr lasting for tc hrs duration

Refer Fig-4 of the Report (page 26 of book)

Ratio = 50 yr tc hrs rainfall / 50 yrs 24 hrs rainfall = 0.28 for tc = 0.6 hr

Therefore 50 year t_C duration rainfall =

0.28 x 16 = 4.48 cms

$$I_{50} = \frac{R_{50}(t_c)}{t_c} = \frac{4.48}{0.6} = 7.46 \text{ cm} = 74.6 \text{ mm}$$

Step-5 Design Discharge Q_{50}

$= 0.278 \times C \times I_{50} \times A = 0.278 \times 0.69 \times 74.6 \times 2.54$

$= 36.3\ m^3/sec$

Illustration -2

1.	Catchment area A (in km^2)	2.54
2.	Length of longest stream course from source to bridge site L (in kms)	2.5
3.	Height of farthest point from bed level H (in meters)	67.25
4.	50 year 24 hrs rainfall R (in cms)	16.00
5.	Catchment Description	Red soil
6.	Sub zone	3i Kaveri
7.	R_{50}-1 hr rainfall (in cms), if available (Optional)	7.5

Calculations:

Step-1

Time of Concentration (t_c)

$$t_c = \left(\frac{L^3}{H}\right)^{0.345}$$

$$= \left(\frac{2.5^3}{67.25} \right)^{0.345}$$

Step-2

Working out areal reduction factor (F) = 0.8
from Table-1

Step-3

Working out Runoff coefficient
$C = X\,(R.F)^{0.2}$
X-depends on soil type & for Red soil the value of X is 0.415
$C = 0.415\,(16 \times 0.8)^{0.2} = 0.69$

Step-4

Calculation of I_{50} (50 yr rainfall intensity mm/hr lasting for tc hrs duration)

From Fig-4 of the Report

Ratio of 50 yr tc hrs rainfall / 50 yrs 24 hrs duration rainfall = 0.28

Ratio of 50 yr 1 hrs rainfall / 50 yrs 24 hrs rainfall = 0.42

Ratio of 50 yrs tc duration / 50 yrs 1 hr duration (k) =0.667
Therefore 50 yrs Rainfall intensity for tc duration

$R_{50(tc)} = k\,(R_{50(1hr)}) = 0.667 \times 7.5 = 5.00$

Therefore $I = \dfrac{R_{50(tc)}}{tc} = 5.00 / 0.6 = 8.33$ cm = 83.3mm

Step-5

Design Discharge Q_{50}
$= 0.278 \times C \times I \times A$
$= 0.278 \times 0.69 \times 83.3 \times 2.54 = 40.58\ m^3/sec$

3.6.2 Method statement for Estimation of Design discharge (Q_{50}) for catchments (25 to 2500 sqkm)

Step-1: Work out effective stream slope (s)

$S = \Sigma Li (D_{i-1} + D_i)/L^2$ in m/km, where Li is length of i^{th} segment, Di-1 elevation of point i-1 from datum, Di elevation of point i from datum, L is length of longest stream

Sr no	Distance from bridge	RL of stream bed	Length of segment Li	Height above datum at i^{th} location (D_i)	$D_{i-1} + D_i$	$Li (D_{i-1} + D_i)$

Step-2: Determination of Synthetic unit hydrograph parameters: 7 parameters are to be worked out based on catchment physiographic properties. These 7 Parameters are tp, qp, TB, W_{50} W_{75}, W_{R50}, W_{R75}

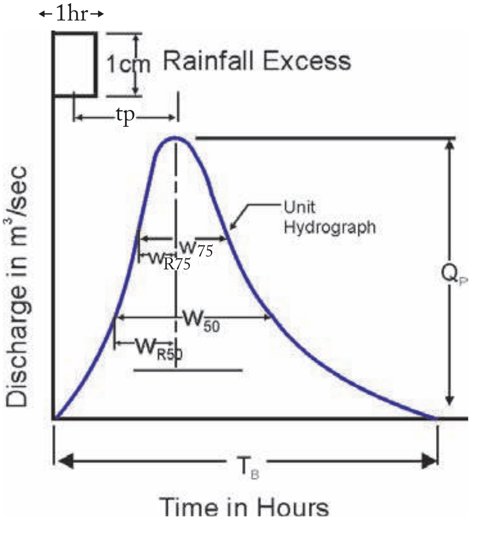


Fig. 3.2 Synthetic Unit Hydrograph

(Example: For Kaveri sub zone -3(i)) these 7 parameters are as under)

SUH para meter	Parameter description	Formulae
t_p	Time taken from centre of rainfall excess(1 cm) in 1 hr unit duration to the UG peak (in hrs)	$0.553(L\ L_C)^{0.405}$
q_p	Peak discharge of UG per unit area m^3/sec per sqkm	$2.043/(t_p)^{0.872}$
W_{50}	Width of UG measured at 50% of peak discharge ordinate (in hrs)	$2.197(q_p)^{1.067}$
W_{75}	Width of UG measured at 75% of peak discharge ordinate (in hrs)	$1.325/(q_p)^{1.088}$
W_{R50}	Width of UG on rising side at 50% of peak discharge ordinate (in hrs)	$0.799/(q_p)^{1.138}$
W_{R75}	Width of UG on rising side at 75% of peak discharge ordinate (in hrs)	$0.536/(q_p)^{1.109}$
T_B	Base width of UG (hrs)	$5.083(t_p)^{0.733}$
T_m	Time taken from start of rainfall excess to UG peak	$Tm = t_p + tr/2$
Q_p	Peak discharge of UG m^3/sec	$Qp = q_p \times A$

Step-3: Plotting of UH based on above calculated parameters as worked out in step-2 above and then working out discharge for each hr interval

Using the above parametrs 7 points are fixed on the hydrograph and then it is drawn in such manner that $\sum Q_i = A/0.36$

Step-4: Estimation of design storm duration

$T_D = 1.1 \times t_p$

Step-5: a) Estimation of point rainfall

50 year – 24 hrs rainfall to be taken based on bridge site location, using flood estimation report say plate-10 for Kaveri basin zone 3(i) specify the 50 yr - 24 hrs rain fall data.

Then from fig-10 of report for a given storm duration, ratio is to be read, Say for 7 hrs duration the ratio is 0.74

So 50 year point rainfall for T_D duration = 50 year – 24 hr rainfall x ratio

b) Areal reduction factor

The areal reduction factor depends upon catchment area and design storm duration (Ref table-3 page -14 of flood estimation report of sub zone 3 (i))

50 year T_D areal rainfall = 50 year T_D point rainfall x (point to areal rainfall ratio)

Step-6 : Time distribution of areal rainfall

The areal rainfall estimated for 50 years Td duration areal rainfall is further distributed to obtain 1 hr gross rainfall units by using the distribution coeff for duration equal to design storm duration (Ref Table A-2 page-13 of flood estimation report of sub zone 3 (i)).

Example : 7 hrs. design storm duration is distributed as under.

hourly	1	2	3	4	5	6	7
Distribution coeffcient	0.62	0.75	0.83	0.89	0.94	0.97	1.00

Using above distribution coefficients, each hr rain falls is worked out.

Say 3rd hr rainfall will be = (0.83 - 0.75) x 50 year T_D duration rainfall

Step-7: Estimation of rainfall excess units

The design loss rate can be a numeric value or based on a formula i.e. it can be say 0.5 cm/hr, or may be a formula ex. For Kaveri sub basin it is calculated from following formula

Now Loss rate is $=1.12 \times R^{0.61} / (T_D)^{0.355}$ Where R is T_D duration areal rainfall in cm & T_D is design storm duration in hrs, & loss rate is in cm/hrs.

The loss rate calculated above, is to be subtracted from hourly gross rainfall units, to get 1 hr rainfall excess units.

Step-8: Estimation of base flow

The design base flow rate can be numeric value or based on a formula i.e. it can be say 0.05 m^3/sec per sqkm therefore total base flow = 0.05 x A or it maybe a formula ex. For Kaveri sub basin it is calculated using formula $qb = 0.032 / (A)^{0.1004}$, where A is catchment area in sqkm and qb is base flow rate in m^3/sec/sq.km

Step-9: Working out flood hydrograph

Unit Hydrograph		Excess rainfall units at time lag of one hr				Base flow (Q_b)	Design flood
	Discharge	Ist hr excess rainfall (R_1)	2nd hr excess rainfall (R_2)	3rd hr excess rainfall (R_3)	4th hr excess rainfall (R_4)		
0	0	0	-	-	-		
1	Q_1	$Q_1 R_1$	0	-	-		
2	Q_2	$Q_2 R_1$	$Q_1 R_2$	0	-		
3	Q_3	$Q_3 R_1$	$Q_2 R_2$	$Q_1 R_3$	0		$Q_3 R_1 + Q_2 R_2 + Q_1 R_3 + 0 + Q_b$
4	Q_4	$Q_4 R_1$	$Q_3 R_2$	$Q_2 R_3$	$Q_1 R_4$		
5	Q_5	$Q_5 R_1$	$Q_4 R_2$	$Q_3 R_3$	$Q_2 R_4$		
			$Q_5 R_2$	$Q_4 R_3$	$Q_3 R_4$		

Based on above table, the maximum discharge (which is Design discharge Q_{50}) is calculated.

■ ■ ■

Illustration on working out Design Discharge (Q_{50}) based on Flood estimation report (SUH concept)

i	ii	iii	iv	v		vi
Name of site	Name of rly section	Name of tributary	shape of catchment	Location		Topography
Rly Br. No. 37	JOLLERAPETTAI -SALEM	Pambar	Oblong	latitude 12-24-00	longitude 78-30-18	Moderately steep slope

vii	viii	ix	x	xi
Name & no of subzone	Catchment area (A) (in Km^2)	Length of longest stream (L) (In Km)	Length of longest stream up to CG (Lc) (In km)	50 Year 24-Hrs Rain fall (in Cms) (ref. plate 9)
subzone 3(i)	294	43.47	22.72	17.50

Stream data

Point	1	2	3	4	5	6	7	8
Distance from bridge (km)	0.00	3.220	6.44	9.66	13.68	17.71	20.12	22.72
RL of stream bed (m)	365.70	381.10	396.34	411.59	426.83	442.07	457.32	469.51

Point	9	10	11	12	13	14	15	16
Distance from bridge (km)	24.15	26.56	28.98	33.00	35.42	40.25	42.66	43.47
RL of stream bed (m)	472.56	487.80	503.05	518.29	533.54	609.76	685.98	762.20

Step-1: Estimation of effective slope (S)

Sr No	Distance from bridge(km)	RL of stream bed(m)	Li	Height above datum (Di)	Di-1 + Di	Li(Di-1 +Di)
1	0	365.7				
2	3.22	381.1	3.22	15.4	15.4	49.58
3	6.44	396.34	3.22	30.64	46.04	148.24
4	9.66	411.59	3.22	45.89	76.53	246.42
5	13.68	426.83	4.02	61.13	107.02	430.22
6	17.71	442.07	4.03	76.37	137.5	554.12
7	20.12	457.32	2.41	91.62	167.99	404.85
8	22.72	469.51	2.6	103.81	195.43	508.11
9	24.15	472.56	1.43	106.86	210.67	301.25
10	26.56	487.8	2.41	122.1	228.96	551.79
11	28.98	503.05	2.42	137.35	259.45	627.86
12	33	518.29	4.02	152.59	289.94	1165.5
13	35.42	533.54	2.42	167.84	320.43	775.44
14	40.25	609.76	4.83	244.06	411.9	1989.47
15	42.66	685.98	2.41	320.28	564.34	1360.05
16	43.47	762.2	0.81	396.5	716.78	580.59

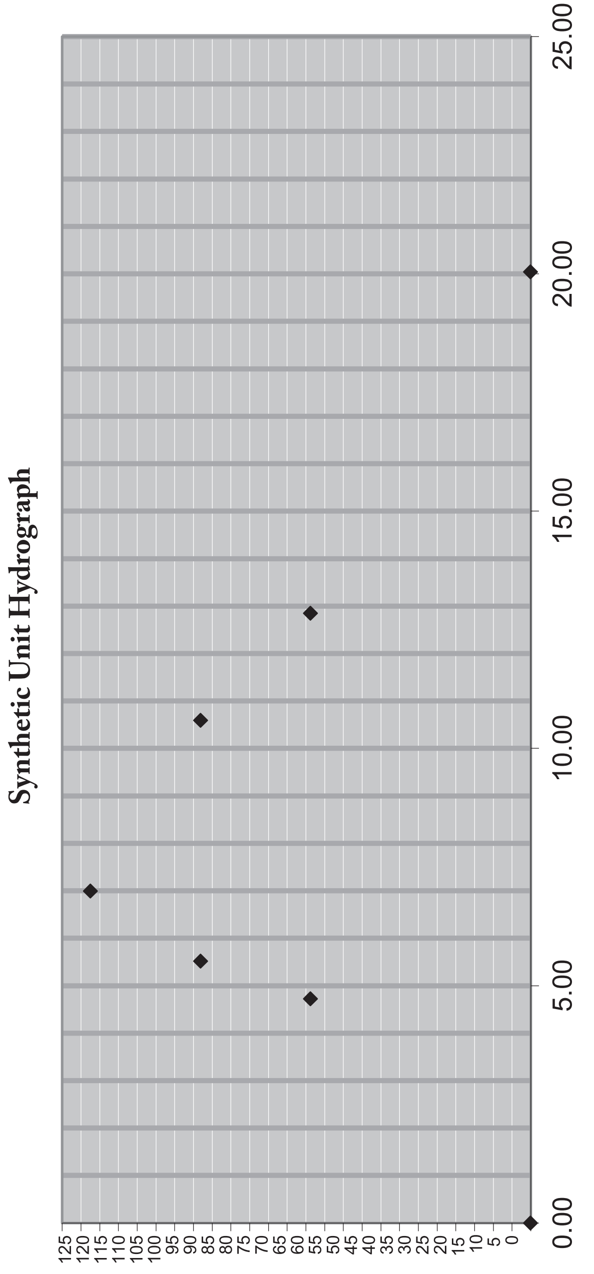
₤ Li(Di-1 +Di) =	**9693.631**
Slope (S) = ₤ Li(Di-1 +Di) / L^2 (in m / KM)	**5.12988 m/km**

Step-2: Estimation of SUH parameters

Parameter	Formulae	Value of parameter	Values
t_p	0.553*(L*Lc/S^0.5)^0.405	6.5	6.5
q_p	2.043/(t_p)^0.872	0.399	0.4
W_{50}	2.197/(q_p)^1.067	5.849	5.85
W_{75}	1.325/(q_p)^1.088	3.596	3.6
W_{R50}	0.799/(q_p)^1.138	2.270	2.27
W_{R75}	0.536/(q_p)^1.109	1.483	1.48
T_B	5.083*(t_p)^0.733	20.044	20
Q_p	q_p A	117.423	117.42
T_m	t_p + tr/2	7	7
£ Q_i	A/(0.36 x tr)	816.666	816.67
T_D	1.1 t_p	7.15	7.15
t_r	Unit duration of rainfall (in hrs.)	1	

X- Y Coordinates of SUH

X	0	4.72	5.51	7	10.59	12.84	20.04
Y	0	58.71	88.06	117.42	88.06	58.71	0



Synthetic Unit Hydrograph
0.00
5.00
10.00
15.00
20.00
25.00
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125

Step-3 : Synthetic Unit Hydrograph - The above SUH graph is plotted and hourly discharge is worked out/read from the plotted graph. The values of hourly discharge Qi based on plotted graph are placed here under:

HRS	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Qi	0	1	2	4	7	69	104	117	106	98	86
HRS	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	
Qi	74	59	44	23	10	6	4	2	1	0	

$\sum Q_i$ **= 817**

Step-4 : Design storm period (TD)

T_D= 1.1 tp = 1.1 x 6.5 = 7.15 hrs say 7 hrs.

Step-5 : 50 year TD duration point rainfall

R_{50} 24 hrs rainfall = 17.5 cms

50 year TD duration rain fall = Ratio x 50 year 24 hrs rainfall
Ratio of TD duration rainfall to 24 hrs rainfall = 0.74 (for sub zone 3 i)
Therefore 50 year TD duration point rainfall =17.5 x 0.74
= 12.95 cms

Step-6 : 50 year TD duration areal rainfall

Reduction factor for 250 Sq. kms. area = 0.81 (sub zone 3 i)
Reduction factor for 300 Sq. kms. area = 0.79 (sub zone 3 i)
Therefore, Reduction factor for 294 sq. kms catchment area

Therefore Areal reduction factor = 0.7924

50 year TD duration areal rainfall = areal reduction factor x 50 year TD duration point rainfall

Therefore Areal reduction factor = 12.95 x 0.7924

50 year TD duration areal rainfall = 10.26 cms.

Step-7 : Rainfall loss rate

Rainfall loss rate equation = $1.12*(R)^{0.611}/(T_D)^{0.355}$

Rainfall loss rate per hr = 2.32

Rainfall loss rate for unit duration = 2.32

Step-8 : Estimation of excess rainfall units

Design storm duration = 7 hrs

50 year T_D duration, total areal rainfall = 10.26 c.m

Hrs.	1Hrs	2Hrs	3Hrs	4hrs	5Hrs	6Hrs	7Hrs
Distribution Coefficients	0.62	0.75	0.83	0.89	0.94	0.97	1
Coeff. for each hr	0.62	0.13	0.08	0.06	0.05	0.03	0.03
Rainfall each hr	6.36	1.33	0.82	0.61	0.51	0.30	0.30
loss rate	2.32	2.32	2.32	2.32	2.32	2.32	2.32
Excess rainfall	4.03	0	0	0	0	0	0

Step-9 : Estimation of base flow

Base flow equation for sub zone 3 i = $(0.032/A^{0.1004}) \times A$

Base flow = 5.31 m^3/sec

Step-10 : Estimation of flood hydrograph

Hrs	Hourly Discharge Q_i of S.U.H.	Discharge Due to R_1=4.03	Flood Discharge Hydrograph in m^3/sec
0	0	0	0
1	1	4.03	4.03
2	2	8.06	8.06
3	4	16.13	16.13
4	7	28.23	28.23
5	69	278.32	278.32
6	104	419.51	419.51
7	117	471.95	471.95
8	106	427.57	427.57
9	98	395.30	395.30
10	86	346.90	346.90
11	74	298.49	298.49
12	59	237.99	237.99
13	44	177.48	177.48
14	23	92.77	92.77
15	10	40.33	40.33
16	6	24.20	24.20
17	4	16.13	16.13
18	2	8.06	8.06
19	1	4.03	4.03
20	0	0	0

Maximum peak direct run off. = 471.95 m^3/sec
Base flow = 5.31 m^3/sec
Therefore, Design discharge Q_{50} = 477 m^3/sec.

■ ■ ■

CHAPTER- 4

Fixing Location of Bridge

4.0 Introduction

For deciding the location of a bridge, we have to understand the river phases during its flow journey from its origin point to its merger in other water body. The river phases & characteristics of river are discussed here under

4.1 River Phases

Various River Phases (Para 801)

- ❖ Upper Reaches (Mountainous)
- ❖ Sub-montane Reaches (Foot Hills)
- ❖ Quasi-Alluvial Reaches (Trough)
- ❖ Alluvial Reaches
- ❖ Tidal Reaches

4.1.1 Upper reaches (Mountainous Rivers)

Fig 4.1 Upper Reaches (Mountainous Rivers)

4.1.1.1 Characteristics of river phase

Narrow, Deep Cross Section, Steep Slope
Bed Material – Rock, Boulders, Gravel
Rise – Sudden and Flashy
Water with high concentration of sediment load

4.1.1.2 Suggested protective measures

- ❖ Protection to piers by RSJ, fenders or rails
- ❖ Soil erosion control, arresting bed load
- ❖ Chutes with paved apron at the entrance

4.1.2 Sub-montane reaches (Foot Hills)

4.1.2.1 Characteristics of river phase

Fig 4.2

Bed slopes 1 in 50 to 1 in 500

Bed Material –Boulders, Gravel and Sand

Floods – Sudden and Flashy :All these channels normally overflow during high floods and the river acquires very wide and shallow cross section. The rivers in this reach are prone to progressively raise their beds by sediment deposition. Such rivers are known as "Aggrading" type.

4.1.2.2 Suggested protective measures

It is not desirable to locate bridge in such reaches. However, if a bridge is to be provided, training measures in the form of marginal bunds, extending right up to the high ground in the hills are required to shift the point of aggradation downstream

To reduce the erosive action on the marginal bund.

a) Suitable slope protection with boulders or concrete slabs,
b) adequate toe protection in the form of two rows of in-situ concrete blocks or boulders in wire crates and
c) boulders in wire crates forming flexible type apron may be provided.

4.1.3 Quasi alluvial reaches

4.1.3.1 Characteristics of river phase

Bed slopes 1 in 500 to 1 in 2500
Bed Material –Small size gravel and Medium Sand
Channel–Generally well defined course

4.1.3.2 Suggested protective measures

Bridging such rivers normally involves constriction of River – Guide Bunds
Hydraulic Model studies desirable

4.1.4 Alluvial reaches

4.1.4.1 Characteristics of river phase

Bed slopes 1 in 2500 to 1 in 25000
River flows on flat Bed of Material Alluvium (sediment deposited by flowing water)

River Meanders in its Khadir(a strip of low land with in which river meanders)
River Bed is normally stable

4.1.4.2 Suggested protective measures

- Guide Bunds – main objective being to guide the river near the bridge to its course

4.1.5 Tidal reaches

At the confluence of river with sea, the tidal effects predominate, Constriction of waterway to be avoided

4.2 Types of Rivers

- Hilly, sub-mountain, alluvial, coastal
- Meandering, straight, braided
- Aggrading, degrading, stable
- Flashy, virgin

Fig. 4.3 Meandering River

Fig. 4.3 Braided River

4.2.1 Braided river

When flow in river channel is insufficient to transport the eroded material & gets deposited , thereby blocking the channel, another channel then may be formed and in course of time river bed become a network of such channels with island in between. Such streams are called braided stream

4.2.2 Aggrading: Rivers in this reach are prone to raise their beds by sediment deposition, due to reduction in velocity.

4.2.3 Degrading: lowering of bed by erosion due to higher velocity

4.2.4 Stable: No perceptible rise or lowering of river bed occurring over long periods

4.2.5 Virgin: They have no outfall in the sea nor do they join any other stream. Such rivers after traversing some distance loose all their water by percolation & evaporation

Fig 4.5 Degrading River

Fig 4.6 Virgin River

4.3 Meandering Rivers

Concept of meandering is explained through the photographs/ sketches given here under:

4.3.1 When river flow over flatter land, they develop large bends i.e. A stream may assume a meandering course

Fig 4.7

4.3.2 A meander is formed when the moving water of river erodes the outer banks and widen its valley by depositing of sediment on inner bank

Fig. 4.8

4.3.3 The velocity of water current is non uniform along the cross section of water. The line of fastest flow called thalweg, initiates the meandering action. On the inside of the bend there is much less water, making the river shallow & slow flowing. The river is eroding sideways into the bank rather than downwards into its bed, a process called lateral erosion

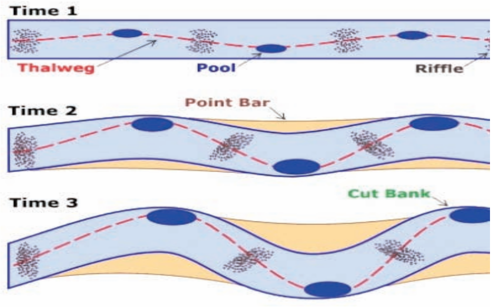


Fig. 4.9

4.3.4 The water has to flow on larger path on the outside of bend , compare to inner path, therefore the velocity on outer path is more than on inner path, resulting erosion of bank on outer path & deposition on inner path.

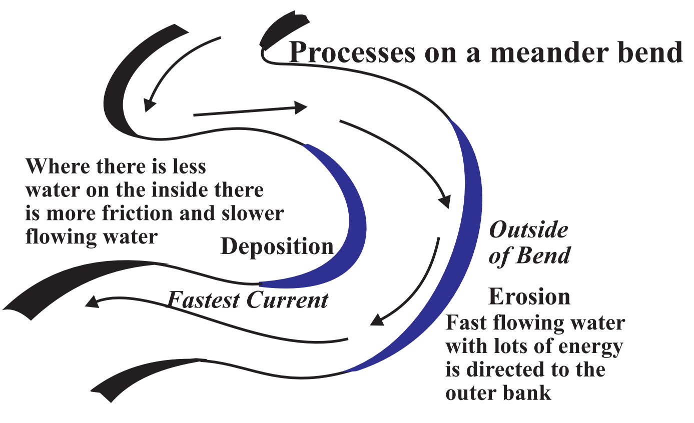


Fig. 4.10 Meander Formation

4.3.5 The position of maximum velocity current Thalweg is shown in the cross section

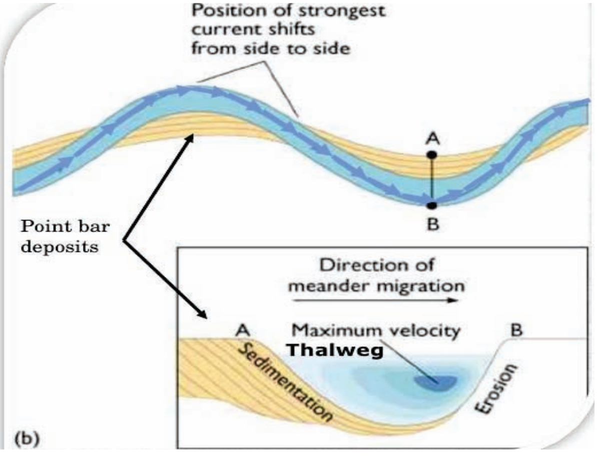


Fig. 4.11

4.3.6 The maximum erosion & deposition lines are indicated in the figure

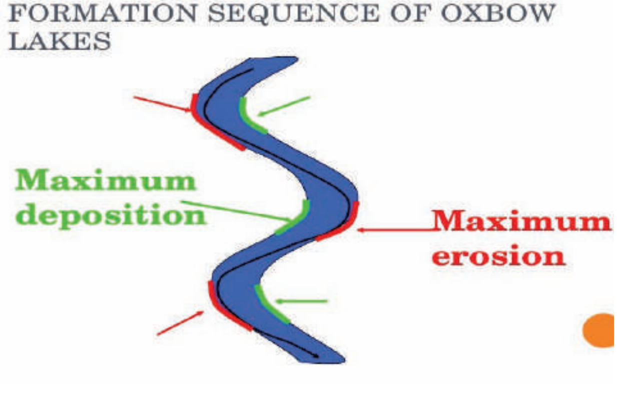


Fig. 4.12

4.3.7 When actual channel length is more than 1.5 times the straight line distance, the we can say that meandering channel is formed.

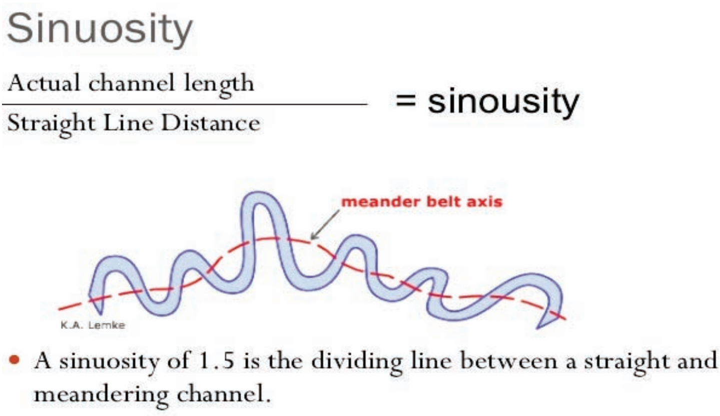


Fig. 4.13 Sinuosity

4.4.5 The terms meander length & meander belt has been explained in the figure below

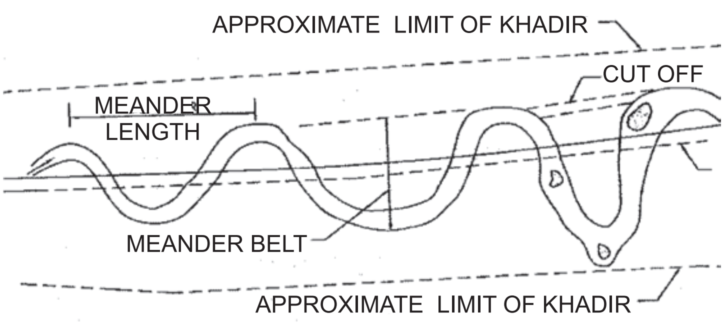


Fig. 4.14

4.3.9 The final stage of meandering where the ox bow lake is formed. The various stages of formation of meander are explained here under

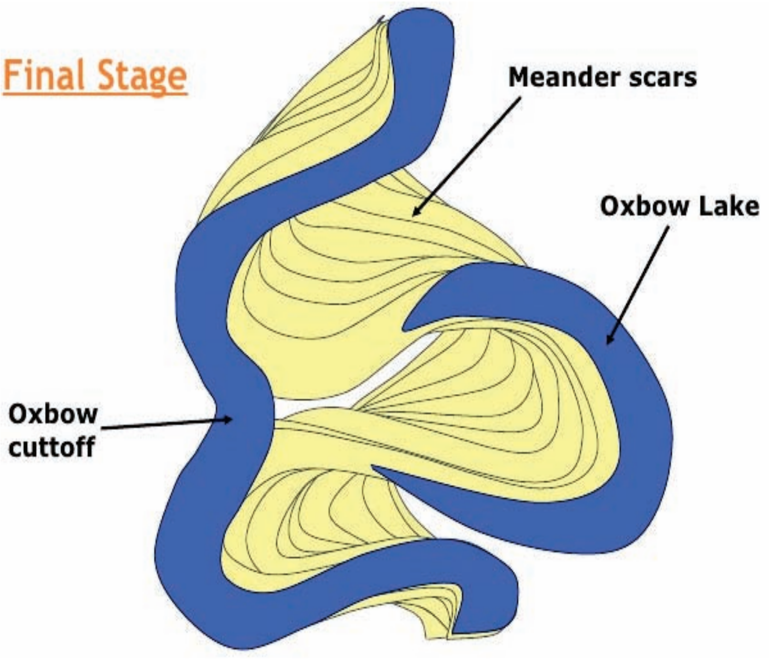


Fig. 4.15 Final Stage

4.4 Various Stages of Meandering Formation

The various stages of formation of meandering has been explained through the sketch fig 4.16. Due to erosion on the outside of the bend and deposition on the inside, the shape of meander will change over a period of time. Erosion narrows the neck of land within the meander.

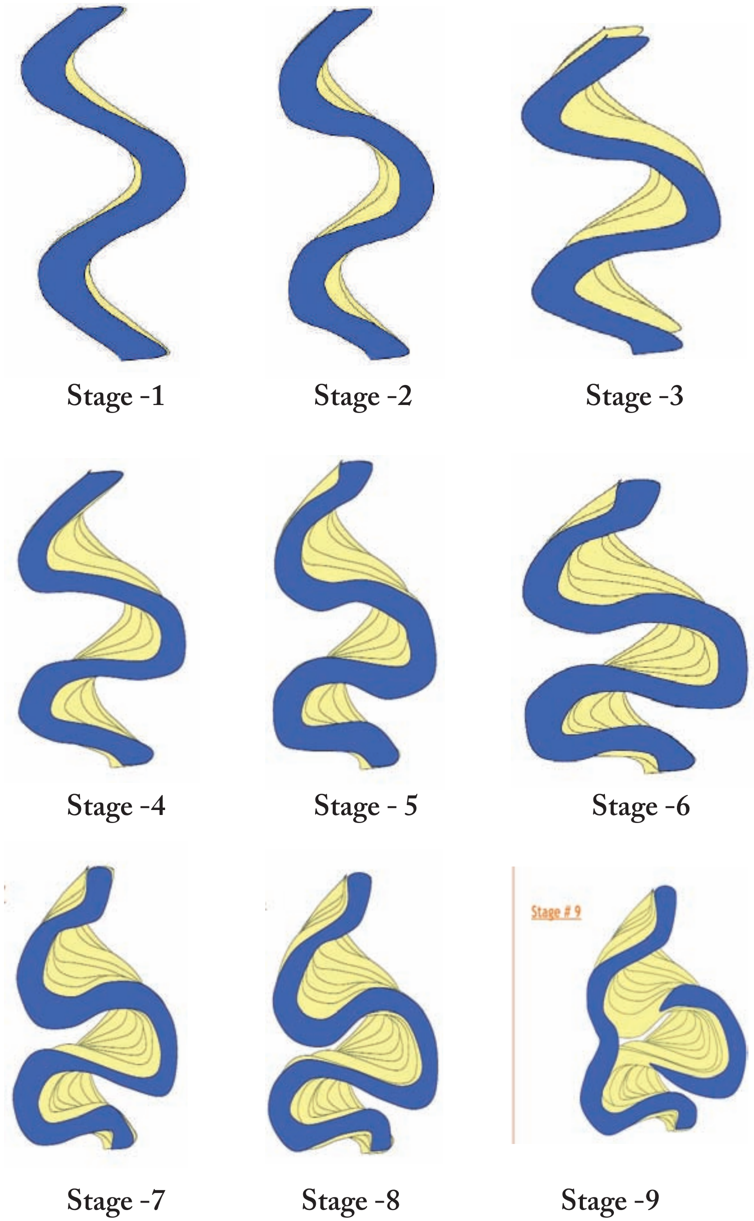


Fig. 4.16 Various Stages of Meandening formation

4.5 Guide Lines for Fixing Location of Bridge (Para 308 of Bridge Manual)

The following factors should be considered in the choice of a site.

1. The reach of the river, especially the upstream should be straight.
2. The river in the reach should have a regime flow, free of whirls, eddies and excess currents.
3. The site should have firm high banks that are fairly in erodible.
4. In the case of a meandering river, the site should be located near a nodal point. A nodal point is defined as the location where the river regime does not normally shift and the location serves as a fulcrum about which the river channels swing laterally (both upstream and downstream.)
5. The site should have suitable strata at a reasonable and workable depth for founding piers and abutments.
6. The bridge is normally located where the river section has minimum width and the bridge should be aligned normal to the river as far as possible.
7. Wide Khadir for bridge location should be avoided. Location of bridge with respect to Khadir width should be carefully decided. If the bridge is located near one end of the Khadir width and the Khadir bank is non-erodible clay, one guide bound can be saved. However, longer length of approach at other end gets exposed and becomes vulnerable to river attack in this case. On the other hand, the central location of the bridge reduces length of approach open to river attack, minimizes obliquity of approach, but requires provision of two guide bunds.

8. The bridge should not normally be located where frequent changes occur in the river course, tendency for aggradation or degradation is manifest and there is problem of bank erosion.
9. The approach bank should be secure and not be liable to flash floods or major spills during floods. If the approach bank passes over braided channels which have connections with the main river upstream, there is always the danger of these channels getting activated some time or the other. If the spill is wide, the bank formed across will cause development of a parallel flow, which at times can become so large and swift as to cause erosion, bank slips or even breaches through the bank.
10. The approach bank should not pass through a heavy hilly terrain or marshy land nor cut across a major drainage so as to avoid expensive construction works.
11. Approach banks in the case of constricted bridges should avoid curvature.
12. In addition following factors needs to be considered

Project	**Consideration**
New line projects	Geological & Geotechnical condition in the context of suitability of foundations for abutment, pier & protection works
Doubling/ construction of multiple lines	Land availability Speed potential consideration, in case curves on approaches are to be provided. Scour consideration (effect of scour on existing bridges)
Gauge conversion projects	Speed potential consideration , in case curves on approaches are to be provided

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CHAPTER - 5

Survey of Rivers & Investigation for Bridges

5.1 Survey of Rivers in Connection with the Location of an Important Bridge (Para 305 Bridge Manual)

1. **Survey of river:** The River should be surveyed for a distance of 8 kms Upstream and 2 kms downstream of the location of the bridge, all spill-channels up-stream being shown on the plan. These distances of 8 and 2 kms are to be taken as measured at right angles to the center line of the Railway and not along the course of the river.

2. Cross section of the river bed should be taken at suitable points and positions marked on the survey plan. The level of the highest known flood and ordinary low water should be noted on each cross section. The average slope of the river bed is to be determined from a point about 2 kms upstream of the Railway crossing to a point 2 kms downstream of the same. In case there are sharp changes in the bed slopes, the local bed slope should be determined over a shorter length.

3. **High flood levels:** Reliable information of high flood levels should be obtained and noted. This information is required for deciding the formation level.

4. **Diversion of rivers:** Should it be considered desirable to divert the course of any river or stream, the best method of doing so should be examined, the necessary surveys and sections made and the diversion shown on the survey plan.

5. **Protection works:** Protection works required to prevent encroachment by rivers or to mitigate the effect of bursting

of tanks or scour in the vicinity of the railway line should be carefully considered and the position and the extent of such works surveyed and determined. High flood marks of the spill water should be carefully located and recorded on the plans and sections.

5.2 Minor/Major / Important Bridge

Major Bridge means, those having total water way >= 18 m Or Clear opening of 12 m or more in any one span.

Important bridge means, those having Linear water way >= 300m Or Total water way >= 1000 sqm Or Classified as important by CE/CBE depending upon consideration such as depth of water way, extent of river training works & maintenance problems

5.3 Investigation for Bridge

The extent of investigation will depend upon whether the bridge is minor/ major/important.

5.3.1 Investigation for minor bridges: The investigation is mostly confined to one particular site and should cover the following aspects:

The investigation should cover the particulars of catchment area, the soil characteristics, the anticipated flood level and other relevant hydraulic particulars.

Further, the minor bridges are generally provided on local drainage crossings, field channels and at canal crossings. The Pipes are normally proposed where sufficient cushion below the sleeper is available; otherwise RCC box is the choice. Where a skew crossing is unavoidable, it is advisable to restrict the skew to 30^0.

5.3.2 Investigation for major bridges (Para 302 of Bridge manual)

The investigation is mostly confined to one particular site and should cover the following aspects:

a) Topographical details.

b) Catchment area with its characteristics from the Survey of India maps.

c) Hydrological particulars such as low water level, high flood level, discharge data, flood velocity and surface slope from local gauging stations of irrigation and flood control departments and local enquiries.

d) Geo-technical investigations to get the soil particulars as necessary, for the design of foundations.

e) Important details of close by bridges across the same river or stream.

5.3.3 Investigation for Important Bridges (Para 303 of Bridge manual)

1. Investigation for important bridges may be carried out in three stages viz.

a) Technical feasibility study (reconnaissance survey)

b) Techno-economic feasibility study (preliminary engineering survey) and

c) Detailed survey and project report stage (final location survey)

2) The reconnaissance stage generally covers the study of maps and a few visits to the possible sites and aerial reconnaissance, as necessary. The remaining two stages of investigations should cover the aspects mentioned in the

Para 302 of bridge manual, ie. aspects involved in investigation of major bridges.

3) In case of the meandering course in alluvial and quasi alluvial rivers and rivers having tortuous flows in sub montane and mountainous regions, number of alternative sites may be available for locating a bridge. Investigations as detailed in Para 302 of bridge manual may be carried out for each one of the alternative sites.

4) Under techno economic feasibility study, only a few preliminary drawings and estimates need accompany the techno-economic feasibility report which however should bring out in full detail the comparative merits and demerits of the various alternative sites. The report should bring out the salient features of the bridge, its estimated cost and cost benefit ratio. For this purpose, the approximate waterway may be based on discharge calculated using "Regional flood frequency approach" developed by R.D.S.O. for various subzones or any other similar approach.

5.3.4 Hydrological Investigations

1. Hydrological investigations to the extent necessary depending on the type and importance of the bridge shall be carried out. The following data should be collected:

a) Area of the catchment.

b) Shape of catchment.(Oblong, fan etc.)

c) Details of the course of the main stream and its tributaries.

d) Longitudinal slope of the main stream and average land slope of the catchment from the contours.

e) Nature of soil in the catchment (rocky, sandy, loamy or clay etc.)

f) Extent of vegetation (forest, pasture,cultivated, barren, etc.). The details can be obtained from the following records:

i) Survey of India Topo sheets to a scale of 1:50,000. ii) Aerial photographs/Satellite imagery.

In some cases aerial survey of the catchment may be necessary.

g) Probable changes that may occur in the catchment characteristics, assessed by enquiries from the right sources.

h) Information from the rainfall records of local or nearby rain gauges.

i) Other climatic conditions (like temperature, humidity, snow accumulation etc.) assessed either from map issued by or from the India Meteorological Department.

j) Changes in the course of the channel.

k) The nature of the material through which the channel flows (whether it consists of boulder, gravel, sand, clay or alluvium.). The description should be based also on actual bore hole particulars.

l) Bank erosion and bed scour observed at the bridge site in the case of alluvial rivers and the nature of the material transported.

m) The maximum observed scour depth in the vicinity of the proposed bridge crossing.

n) Full description of bridges (as given below) existing both upstream and downstream from proposed crossing including relief and overflow structures.

i) Type of bridge including span lengths and pier orientation.

ii) Cross section near the structure, including vertical clearance from water level to soffit of super structures and direction of the current during floods.

iii) All available flood history : high water marks with dates of occurrence, nature of flooding, afflux observed, damages caused with sources of information.

iv) Photographs of existing bridges, past floods, main channels, and flood plains and information as to the nature of drift, stream bed and stability of banks.

p) Factors affecting water stage at the proposed bridge site such as:

i) High flood levels of other streams joining.

ii) Particulars of reservoirs and tanks existing or proposed to be constructed and approximate date of construction.

iii) Flood control projects on the stream or other structures which affect the flow in the stream such as weirs, barrages, training works, spurs etc.

iv) Tides, or back flow due to a confluence downstream.

v) Character of floods:- Whether steady, flashy or eddy forming, etc.

2. A detailed map showing flood flowing patterns, location of proposed bridge, spill openings, if any and alignment of piers, should be prepared to a suitable scale. The map should indicate:

i) Contours at 1m intervals, stream meander, vegetation and man made changes, if any. ii) Three cross sections together with HFL, one on the center line of the proposed bridge, one upstream and one downstream at 100 to 300m intervals.

3. In the case of minor bridges, the scope of data collection may be reduced to Sub paras 1 a to h, p(i), (ii), (iii) and 2 above.

■ ■ ■

CHAPTER 6

Finalisation of Span Arrangement & Foundation Depth

6.1 Method Statement for Finalisation of Span Arrangement

Following steps are involved to finalise the linear water way & span arrangement for given design discharge.

Step-1: Estimation of linear water way based on various guidelines

i) Based on Flood Estimation Report

The Flood estimation report suggests/ recommends the linear water way width, required to be provided, to cater given design discharge (Q_{50}).

For Example : sub zone 3(i) Kaveri basin, Linear water way recommended is = $4.98\,(Q_{50})^{1/3}$

ii) **Based on Lacey's Regime width(Para 4.5.3 SSC)**

Wetted perimeter Pw = $1.811\,C\sqrt{Q}$

Where C = a coefficient normally equal to 2.67, but which may vary from 2.5 to 3.5 according to local conditions depending upon bed slope and bed material,

Considering C= 2.67

$\Rightarrow P_w = 4.83\,(Q_{50})^{0.5}$

Accordingly Wetted perimeter

$\mathbf{P_w = 4.83\,(Q_{50})^{1/2}}$

iii) Based on width of active channel in stream/River (Para 4.5.1 of S.S.C)

a) Bank to Bank width of River regime
= -------------

b) Extent of spilling of water beyond bank to bank width
= -------------

c) Width of Active channel of water in the River regime
= -------------

Waterway based on width of active channel including spilling of water if any = ------

Illustration -1)Suppose bank to bank width of river is 18 mtrs and active channel width is 9m then waterway to be provided can be taken as 9m provided it satisfies all the norms in terms of velocity of flow, free board, clearance, HFL.

Illustration 2) Suppose bank to bank width is 21m, the river is flowing full bank to bank and there is a water spilling beyond banks by say 4m width. In this case the waterway to be provided shall be 25m.

Step-2: Possible maximum & minimum linear water way width

Based on various criteria for fixing linear water way (Step 1 above), Min. & Max. linear water way requirement is worked out.

a) Min. linear Water way Width required = ---------------

b) Max. linear Water way Width required = ----------------

Step-3: Selecting type of bridge (pipe culvert / Box culvert / Arch / Slab / Girder Bridge)

The type of bridge shall be selected on the basis of various factors such as design discharge (Q_{50}), linear water way requirement, velocity of flow, scour depth requirement, approach bank height, soil strata conditions.

Step-4: Fixing norms for Free board, vertical clearance based on type of bridge selected)

i) **Norms for Free Board :** The Minimum free Board from water level of design discharge to formation level of Railway embankment or top of guide bund shall be one meter; however CE/CBE can relax Free Board in special Circumstances as indicated below:-

Discharge (cumecs)	Less than 3	3 to 30	More than 30
Min free board (mm)	600 mm	750 mm	No Relaxation

ii) **Norms for vertical clearance**

Bridges excluding arch bridges, pipe culvert and Box culverts		Siphons, Pipe & Box culverts	Arch Bridge	
Discharge (cumecs)	Vertical clearance (in mm)	No clearances are considered necessary	Span of Arch	Clearance (in mm)
0 - 30	600		Less than 4 m	Rise or 1200
31-300	600–1200		4.0 to 7.0 m	2/3 rise or 1500
301 - 3000	1500		7.1 to 20.0 m	2/3 rise or 1800
Above 3000	1800		Above 20.0 m	2/3 rise

The vertical Clearance can be relaxed by CE/CBE provided: Adoption of prescribed clearance results in heavy expenditure and /or serious difficulties. The clearance can be safely reduced to:-

Discharge (cumecs)	Less than 3	3 to 30	31 to 300
clearance (mm)	300	300-400 (Pro-rata)	100-1200 (Pro-rata)

It shall be personally exercised by PCE/CBE, due consideration being given to past history of bridge.

iii) Norms for velocity of flow

The norms for velocity of flow can be taken as 3 m/sec based on sub structure code Para 5.9.2.1.2. However, velocity during annual peak flow if available, can be also used for guidance.

iv) Norms for HFL

The computed HFL based on depth of flow calculated for assumed water way width should be close to observed HFL. River flow conditions during annual peak flow can also be used for guidance.

Step-5: Value of n & bed slope of stream

Slope (S) : While calculating velocity of flow ($V = 1/n \times R^{2/3} \times S^{1/2}$), the average slope (S) of the river bed is to be determined from a point about 2 kms upstream of the Railway crossing to a point 2 kms downstream of the same. In case there are sharp changes in the bed slopes, the local bed slope should be determined over a shorter length. (Para 305(2) Bridge manual).

Value of n : It depends upon channel condition

Channel / stream condition	**Value of n**
i) Natural channel in fairly good condition	0.030
ii) Natural channel in fairly bad condition	0.040
iii) Natural channel with variable section & some vegetation growing on banks	0.050
iv) Vegetation growing on banks in very bad condition	0.060 - 0.10

Step-6: Working out depth of flow (d) for assumed width of water way (B)

Total width of waterway assumed = B

No of piers assumed = N

Effective width of pier assumed = b

Effective width of waterway shall be (B') = B - n x 2b

$Q_{50} = A \times (1/n \times R^{2/3} \times S^{1/2})$

$\mathbf{Q_{50} = (B' \times d) \times (1/n) ((B' \times d)/(B' + 2d))^{2/3} (S^{1/2})}$

Using above equation, work out depth of flow (d) for assumed value of width of water way (B)/ effective width of waterway B'.

Step-7: Estimating various parameters for the set of assumed value of B (width of water way) & calculated value of d (depth of flow)

1. Actual Velocity of flow

$V = 1/n \times R^{2/3} \times S^{1/2} = (1/n) ((B' \times d)/(B' + 2d))^{2/3} (S^{1/2})$

2. Calculated HFL = Bed level + d
3. Vertical clearance = bottom of slab / girder or underside of box top/pipe – (HFL + afflux)

4. Free board = Approach bank height – (HFL + afflux)

Note: For various widths of waterway as assumed @ suitable interval , between the minimum & maximum possible width of waterway estimated in the step-2, workout depth of flow d for 5 to 7 values of assumed width of waterway & the calculate the above 4 parameters i.e. velocity of flow , calculated HFL, vertical clearance, free board. Compare the values of calculated parameters with laid down norms as discussed in step 4 above.

Step-8: Finalisation of span & working out various parameters for chosen span

Based on the exercise done under step-7, the minimum linear water way which satisfy all laid down norms in terms of velocity of flow, HFL, vertical clearance, free board and which can utilise as far as possible the available standard spans of RDSO is finalised.

Now for this proposed span arrangement, the depth of flow is calculated similar to step 6. Further various parameters i.e. actual velocity of flow, HFL, vertical clearance & Free board are computed for proposed span & computed depth of flow. which are compared / checked again with norms laid down (similar to step 7).

6.2 Method Statement for Estimation of Depth of Foundation for given Span Arrangement Based on Scour Depth Criteria

Step 1 - Design discharge for foundation: The design discharge for foundation (Q_f) shall be estimated based on Q_{50} & size of Catchment (Ref : Design discharge for foundation Para 4.4 S.S.C)

Catchment area	Up to 500 km^2	> 500 & up to 5000 km^2	> 5000 & up to 25000 km^2	> 25000 km^2
Increase over Q_{50}	30%	30% - 20%	20% - 10%	Less than 10%

Step 2 – Normal Scour depth

Now for the given Q_f, the scour depth is estimated using following formula.

a) The normal depth of Scour (D) below the foundation design discharge (Q_f) level may be estimated from Lacey's formulas as indicated below

$D = 0.473 (Q_f/f)^{1/3}$ --------- Eq-1 (Para 4.6.3 SSC)

b) Where due to constriction of waterway, the actual provided width is less than Lacey's regime width or where it is narrow and deep as in the case of incised rivers and has sandy bed, the normal depth of scour may be estimated by the following formula

$D = 1.338 (q_f^2/f)^{1/3}$ ----------Eq-2 (Para 4.6.4 SSC)

Step 3 - Maximum anticipated scour level from water level corresponding to Q_f

The depth calculated based on Eq- 1 or Eq-2 above (as the case may be), shall be increased as indicated below, to obtain maximum depth of scour for design of foundations,

For Abutment: 1.25 x D

For Pier: - 2 x D

Step 4 - Maximum anticipated scour level from bed level

The scour depth calculated in step 3 above, refers to maximum anticipated scour level from the water level corresponding to Q_f, therefore the depth of maximum scour level from the bed level can be ascertained if depth of flow corresponding to Q_f is known.

The depth of flow corresponding to design discharge for foundation (Q_f) for given span arrangement shall be worked out using equation discussed under para 6.1 step-6 above. The maximum anticipated scour depth from bed level shall be accordingly worked out after deducting the depth of flow corresponding to Q_f.

Step 5 - Grip length

The foundation should rest below the maximum anticipated scour depth for certain length called as grip length, the value of grip length in case of open foundation is 1.75 m in case of ordinary soil. However if the rock strata (soft or rock) is available at higher level which is considered as non-erodible bed then the foundation should keyed in rock for 0.3 m (in case of hard rock) & 1.5 m (in case of soft rock).

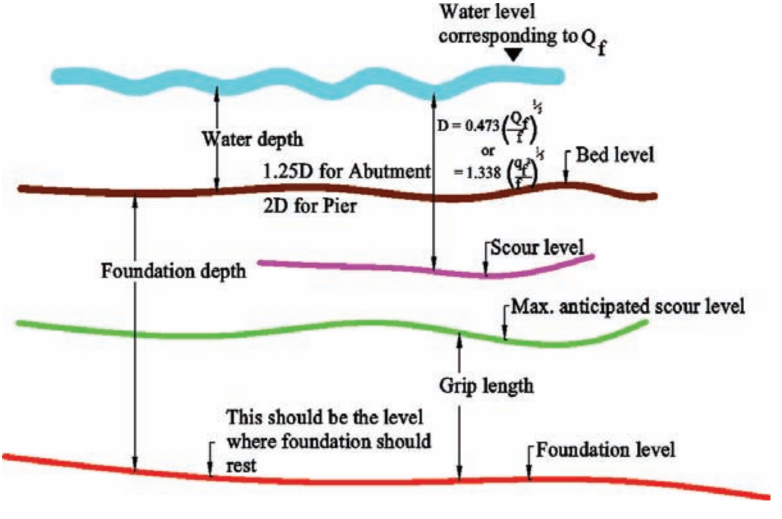

Fig.6.1

Step 6 : Depth of foundation

The depth of foundation shall be accordingly = Maximum scour depth from bed level (as worked out in Step 4) + Grip length (as discussed in Step 5).

Note : In case non scourable strata (rock strata) is available at shallow depths, then the foundation shall rest at that level suitably keyed into the rock strata (as discussed in Step 5 above), irrespective of scour depth calculated in the Step 2 and 3 above.

Illustration on working out linear waterway/span & Foundation depth : Input data

Q_{50}	Active channel width	Span selected	Channel condition	Bed level @300m upstream	Bed level @300m downstream	Soil bore log details
126.145m^3/ sec	21 mts.	12.2m slab	Fairly good condition	605.5m	603.5m	Bed level to 3.5m – soil (1.5mm particle size) Beyond 3.5m there is hard rock

A. Working out linear waterway/Span arrangement :

Step-1: Estimation of linear water way based on various guidelines

i) <u>Based on Flood Estimation Report</u>

The Flood estimation report suggests/ recommends the linear water way width, required to be provided, to cater given design discharge (Q_{50}).

For sub zone 3(i) kaveri basin, Linear water way recommended is = 4.98 (Q_{50})$^{1/3}$

Q_{50}= 126.145 m^3/sec, Therefore linear waterway

= 4.98 (126.145)$^{1/3}$ = 24.93 meters

ii) Based on Lacey's Regime width (Para 4.5.3 SSC)

Wetted perimeter $P_w = 1.811\ C\ \sqrt{Q}$

Considering $C = 2.67$ *the* $P_w = 4.83\ (Q_{50})^{0.5}$

Therefore $P_w = 4.83\ (126.145)^{0.5} = 54.24$ *meters*

iii) Based on width of active channel in stream/River (Para 4.5.1 of S.S.C)

a) Bank to Bank width of River regime = 48 meters

b) Extent of spilling of water beyond bank to bank width = Nil

c) Width of Active channel of water in the River regime =

21 meters

Waterway based on width of active channel including spilling of water if any = 21 meters

Step-2: Possible maximum & minimum linear water way width

a) Min. Possible linear Water way Width = 21 meters (based on active channel width)

b) Max. Possible linear Water way Width= 54.24 meters. (based on lacey regime width).

Step-3: Selecting type of bridge (pipe culvert / Box culvert / Arch / Slab / Girder Bridge)

The type of bridge shall be selected on the basis of various factors such as design discharge (Q_{50})*, linear water way requirement, velocity of flow, scour depth requirement, approach bank height, soil strata conditions.*

In this case type of span selected is 12.2 meter slab.

Step-4: Fixing norms for Free board, vertical clearance based on type of bridge selected)

i) **Norms for Free Board** : The minimum free Board from water level of design discharge to formation level of railway embankment or top of guide bund is kept one meter;

ii) **Norms for vertical clearance : (For Slab Bridges)**

Discharge (cumecs)	V.clearance (in mm)
0 - 30	600 mm
31-300	600 – 1200 mm
301 - 3000	1500 mm
Above 3000	1800 mm

Therefore for Q_{50}= 126.145 m^3/sec, vertical clearance required = 600 + (1200-600) x (126.145-30)/(300-30) = 813mm say 820mm.

iii) **Norms for velocity of flow:** The norms for velocity of flow can be taken as 3 m/sec based on sub structure code Para 5.9.2.1.2. However, velocity during annual peak flow if available can be used for guidance.

In this case velocity of flow should be less than 3m/sec based on above and as per the site topography.

iv) **Norms for HFL** The computed value of HFL based on depth of flow calculated for assumed water way width should be close to observed HFL. River flow conditions during annual peak flow can also be used for guidance.

In this case observed HFL level = 609.97 meters

Step-5: Value of n & bed slope of stream: The Value of n & slope to be considered as under:

Slope (S) : The average slope (S) of the river bed is to be determined from a point about 2 kms upstream of the Railway crossing to a point 2 kms downstream of the same. In case there are sharp changes in the bed slopes, the local bed slope should be determined over a shorter length. (Para 305(2) Bridge manual).

In this case bed level at 300meters upstream is 605.5 meters and bed level at 300 meters downstream is 603.5 meters Therefore, average stream bed slope works out :
$(605.5 - 603.5)/600 = 2/600 = 0.0033$

Value of n:

Channel / stream condition	**Value of n**
i) Natural channel in fairly good condition	0.030
ii) Natural channel in fairly bad condition	0.040
iii) Natural channel with variable section & some vegetation growing on banks	0.050
iv) Vegetation growing on banks in very bad condition	0.060 - 0.10

In this case the channel is in fairly good condition therefore the value of n is taken as 0.03.

Step-6: Working out depth of flow (d) for assumed width of water way (B)

Total width of waterway assumed = B, No of piers assumed = N, Effective width of pier = b

Effective width of waterway shall be (B') = B – n x 2 b

$Q_{50} = A \times (1/n \times R^{2/3} \times S^{1/2})$

$Q_{50} = (B' \times d) \times (1/n) ((B' \times d)/(B'+2d))^{2/3} (S^{1/2})$

Using above equation, work out depth of flow (d) for assumed value of effective width of waterway B'.

In this case, assuming linear waterway 20 meters to 55 meters at the interval of 5 meters the depth of flow (d) is computed using excel sheet. The results are placed here under :

Input data

Q	n	S	BED LEVEL	APP. BANK HT	SLAB BOT.	OBS HFL
126.145	0.03	0.0033	604.525	613.074	611.894	609.969

Calculations output (Using formulae discussed above)

B' assumed	20	25	30	35	40	45	50	55
d (worked out)	2.21	1.89	1.67	1.51	1.38	1.28	1.20	1.13
$Q_{computed}$	126.15	126.14	126.15	126.14	126.14	126.14	126.14	126.14

Step-7: Estimating various parameters for the set of assumed value of B (linear water way) & calculated value of d (depth of flow)

i) *Actual Velocity of flow*

$V = 1/n \times R^{2/3} \times S^{1/2} = (1/n) ((B' \times d)/(B'+2d))^{2/3} (S^{1/2})$

ii) *Calculated HFL = Bed level + d*

iii) *Vertical clearance = bottom of slab / girder or underside of box top/pipe – (HFL + afflux)*

iv) *Free board = Approach bank height – (HFL + afflux)*

For a set of linear water way (B') and computed depth of flow, various flow parameters i.e. velocity of flow, free board, vertical clearance and computed HFL are worked out using above equations in excel sheet, the results are tabulated hereunder :

Effective linear water way (B')	20 m	25 m	30 m	35 m	40 m	45 m	50 m	55 m
Computed d	2.21	1.89	1.67	1.51	1.38	1.28	1.20	1.13
Comp. Velocity	2.85	2.67	2.52	2.39	2.28	2.18	2.1	2.03
Computed HFL	606.74	606.42	606.2	606.03	605.91	605.81	605.73	605.66
Free board	6.34	6.66	6.88	7.04	7.16	7.26	7.35	7.42
V. Clearance	5.16	5.48	5.7	5.86	5.98	6.08	6.17	6.24

It is seen that with minimum effective linear water width of 20 m itself, all the norms are satisfied.

Step-8: Finalisation of span & working out various parameters for chosen span

It is seen that with 20 meters effective linear water width all the norms are satisfied. However, active channel width is 21 meters, therefore, we can provide 2 x 12.2 meters span. The flow data for above span arrangement have been worked out following the step 6 & 7 using excel sheet. The results are as under –

Depth of flow(d)	Velocity computed	Computed HFL	Free board	Vertical Clearance
1.92 m	**2.69 m/s**	**606.45 m**	**6.63 m**	**5.45m**

B. Estimation of depth of foundation for given span arrangement based on scour depth criteria

Step 1 - Design discharge for foundation: The design discharge for foundation (Q_f) shall be estimated based on Q_{50} & size of Catchment (Design discharge for foundation (Para 4.4 S.S.C)

Catchment area	*Up to 500 km2*	*> 500 & up to 5000 km2*	*> 5000 & up to 25000 km2*	*> 25000 km2*
Increase over Q_{50}	*30%*	*30% - 20%*	*20% - 10%*	*Less than 10%*

In this case Q_f = 1.3 x Q_{50} = 1.3 x 126.145 = 163.988 say 164 m^3/sec

Step 2 – Normal Scour depth: Now for the given of, the scour depth is estimated using following formula.

a) The normal depth of Scour (D) below the foundation design discharge (Qf) level may be estimated from Lacey's formulas as indicated below

$D = 0.473 (Q_f / f)^{1/3}$ --------- Eq-1 (Para 4.6.3 SSC)

b) Where due to constriction of waterway, the width is less than Lacey's regime width for Q or where it is narrow and deep as in the case of incised rivers and has sandy bed, the normal depth of scour may be estimated by the following formula

$\mathbf{D = 1.338 (q_f^{\,2}/f)^{1/3}}$ ------------- *Eq-2 (Para 4.6.4 SSC)*

In this case Lacey's width as calculated in Step 1 (ii) is 54.24 meters, whereas provided waterway width is 2 x 12.2 = 24.4 meter.

Therefore, normal scour depth D shall be $\mathbf{1.338 (q_f^{\,2}/f)^{1/3}}$

$qf = 164/24.4 = 6.72\ m^3$/sec/meter width.

Let us assume depth of scour 3 meters.

At the 3 meter depth the mean soil particle size is say 1.5 mm.

Accordingly, $f = 1.76\sqrt{m} = 1.76\sqrt{1.5} = 2.15$.

$D = \mathbf{1.338 (6.72^2/2.15)}^{1/3} = 3.65$ meter.

Therefore D = 3.65 meter

Step 3 - Maximum anticipated scour level from water level corresponding to Q_f:

The depth calculated based on Eq- 1 OR Eq-2 above (as the case may be), shall be increased as indicated below, to obtain maximum depth of scour for design of foundations,

For Abutment: 1.25 x D   For Pier: - 2 x D

In this case depth of foundation from water level corresponding to design discharge for foundation shall be: for abutment = 1.25 x 3.65 = 4.56 meters and for pier = 2 x 3.65 = 7.3 meters.

***S*tep 4 - Maximum anticipated scour level from bed level:**

The scour depth calculated in step 3 above, refers to maximum anticipated scour level from the water level corresponding to Q_f, therefore the depth of maximum scour level from the bed level can be ascertained if depth of flow corresponding to Q_f is known.

The depth of flow corresponding to design discharge for foundation (Q_f) for given span arrangement shall be worked out using equation discussed under para A step-6 above.

Q	n	S	B assumed	d (worked out)
164	0.03	0.0033	24.4	2.27

The maximum anticipated scour depth from bed level shall be accordingly worked out after deducting the depth of flow corresponding to Q_f.

Max. Anticipated scour depth from bed level = 4.56 – 2.27 = 2.29 meter (for abutment)

= 7.3 – 2.27 = 5.03 meters (for pier)

Step 5 - Grip length: The foundation should rest below the maximum anticipated scour length for certain length called as grip length, the value of grip length in case of open foundation is 1.75 m in case of ordinary soil. However if the rock strata (soft or rock) is available at higher level which is considered as non-erodible bed then the foundation should keyed in rock for 0.3 m (in case of hard rock) & 1.5 m (in case of soft rock) .

In this case there is a hard rock strata at 3.5 meters, both at pier & abutments locations, which is considered as non scourable strata.

Step 6 - Depth of foundation: The depth of foundation shall be accordingly = Maximum scour depth from bed level (as worked out in Step 4) plus Grip length (as discussed in Step 5).

Note : In case non scourable strata (rock strata) is available at shallow depths, then the foundation shall rest at that level suitably keyed into the rock strata (as discussed in Step 5 above), irrespective of scour depth calculated in the Step 2 and 3 above.

In this case at pier location depth of foundation = 5.03 meter + 1.75 meter = 6.78 meter, however, there is a hard rock strata at 3.5 meters. Therefore depth of foundation will be 3.5 meters plus 0.3 meters (grip length) = 3.8 meters.

At abutment location depth of foundation = 2.29 meter + 1.75 meter = 4.04 meter however, there is a hard rock strata at 3.5 meters. Therefore depth of foundation will be 3.5 meters plus 0.3 meters (grip length) = 3.8 meters.

■ ■ ■

CHAPTER 7

Deciding Geometry of Bridge

7.1 Type of Foundations

The foundations are broadly classified in 2 categories

1) Shallow foundation 2) Deep foundation

1) Shallow foundations : (Para 204 of Bridge manual)

A bridge foundation having less than 2M depth below bed level in case of arch bridges and 1.2M depth below bed level in case of other bridges is termed as shallow foundation.

Bridges with shallow foundations in sandy soils or soils likely to scour should be protected by stone, brick on edge or CC flooring with drop walls and/or curtain walls to protect foundation from scour. This method is generally suitable in cases where the velocity of flow does not exceed 1.5 meter per second and afflux is negligible.

2) Deep foundations

A foundation which is deep enough, having required grip length below maximum scour level is termed as deep foundation. Normally no protection is required for such foundations.

The river bed between piers should not generally be pitched, as the pitching stones if washed away, may lead to excessive scour downstream, resulting in damage to piers. If warranted by actual conditions, piers and abutments on these bridges can be protected individually by pitching stones around them.

7.2 Choice of Foundations for Bridges : (Para 316 of Bridge manual)

7.2.1General: The following types of foundations are normally provided for Railway Bridges, depending on the site conditions:

I) Open foundations ii) Pile foundations iii) Well Foundations

The decision on span length has to depend upon the ratio of the cost of substructure including the foundation versus the cost of superstructure. Generally it is most economical when this ratio is one.

7.2.2 Open foundation

Open foundation is suitable for bridges where rock or firm subsoil is available at shallow depth and there is not much scour and flowing water in the stream.

The open foundations must rest on a stratum with adequate bearing capacity. In order to reduce the bearing pressure the base can be sufficiently widened by providing footings. The footings will rest on a Lean concrete bed of adequate thickness.

The foundation should be taken to a depth not less than 1.75 meters below the lowest anticipated scoured bed level in ordinary soil. In rocky soil, it will be adequate if it is properly keyed into the rock for a minimum of 0.3 meter in case of hard rock and 1.5 meters in case of soft rock. Sloping rock may be suitably benched. Fissures and weathered rocks should be avoided.

7.2.3 Pile foundation

7.2.3.1 General: It can be quiet economical, particularly where the foundations have to be built very deep or taken through deep layers of soil subjected to little scour. Larger diameter piles can be provided to take care of large horizontal forces when the foundations are deep. Larger diameter piles can also be provided for foundation depths beyond the limit of pneumatic operations.

Socket length for pile foundation	=	1 x D for hard rock strata (where D is diameter of pile)
	=	4 x D for soft rock strata

7.2.3.2 Classification of pile foundations: Piles may be classified as under:

1. Based on the manner of transfer of load:

a) Friction piles: These piles transfer the load primarily by skin friction developed along their surface. They are used in soils not subjected to scour.

b) Bearing piles: These piles transfer the load primarily by bearing resistance developed at the pile tip or base, without taking into account the frictional resistance. They are generally used in hard stratum.

c) Bearing-cum-friction piles: These piles transfer the load both by bearing and friction

2. Based on construction methods:

a) Driven Pre-cast piles;

b) Driven cast in-situ piles;

c) Bored cast-in-situ piles.

3. Large diameter bored piles of more than one meter diameter are normally used for Railway bridge construction.

7.2.3.3 Selection of type of piles : The following factors are to be considered while selecting the type of piles:

1. Availability of space and head room: Driven piles require large area and headroom since they need larger and heavier driving rigs. Bored piles, however, require comparatively smaller space.

2. Proximity to the structure : Driving causes vibration of the ground which may damage nearby structures. Hence bored piles are preferred in these cases.

3. Reliability: Driven precast piles ensure good quality as they are cast under controlled condition. In cast in-situ piles, segregation of concrete is possible in water logged areas.

4. Limitation of length: Cast-in-situ piles can be formed to any desired length. The length of driven piles normally does not exceed 25 to 30 m depending on the capacity of the driving equipment.

7.2.4 Well foundation

7.2.4.1 General : It provides a solid and massive foundation for heavy loads and large horizontal forces. This has a larger cross sectional area and hence the total foundation bearing capacity is much larger than what may be offered by a cluster of piles. The well provides a very good grip when taken sufficiently deep and hence is most suited for river beds subjected to heavy scour.

7.2.4.2 Types of well : The types commonly used are:

i) Circular: This shape is preferred for bridges on single line. The circular well is simple to construct, easy to sink and has uniform strength in all directions. It can be better controlled against tilt and tilt correction is also easier. The only disadvantage is the limitation in size which restricts its use to bridges with smaller piers.

ii) Double - D - Where the pier length is larger as in the case of double line bridges, double - D wells may be used. The shape of Double - D well facilitates easy casting and sinking due to presence of two dredge holes. The overall length of the well generally is restricted to twice the width.

7.3 Choice for Sub Structure: The sub structure can be constructed with stone masonry, cement concrete, Reinforced concrete or Pre stressed concrete

Following important instructions needs to be followed in this regard (Ref Bridge manual para 603)

1) For stone masonry, the proportion of cement mortar used should be minimum 1:4

2) When mass concrete is used, the mix shall be minimum M-20 grade, provided further this should satisfy minimum grade of concrete for various exposure condition based on durability criteria

3) RCC used in the form of thin piers or as a framed structure, can be adopted for viaducts, fly overs, and road over bridges. Cellular piers are suitable if the heights are considerable. For RCC the mix concrete shall be minimum M-25 grade. provided further this should satisfy minimum grade of concrete for various exposure condition based on durability criteria

4) PSC can be used for all piers of viaducts. The mix to be adopted should be according to the design requirements, provided further this should satisfy minimum grade of concrete for various exposure condition based on durability criteria.

   The durability criteria as contained in Concrete bridge code is placed here under

5) Minimum Grade of Concrete – From durability consideration, depending upon the environment to which the structure is likely to be exposed during its service life, minimum grade of concrete shall be as given in Table 4(b). (Ref: Concrete bridge code para **5.4.4**)

Minimum Grade Of Concrete (Ref: TABLE 4(b) Clause 5.4.4 C.B.C)

a) For Bridges In Prestressed Concrete & Important bridges (Except Sub structure)			
Structural member	Moderate Exposure	Severe Exposure	Extreme Exposure
PCC member	M-25	M-30	M-35
RCC member	M-30	M-35	M-40
PSC member	M-35	M-40	M-45
b) For Bridges other than mentioned above & substructure			
PCC member	M-15	M-20	M-25
RCC member	M-20	M-25	M-30

6) Size & shape of sub structure:

a) The size shall depend upon the construction material used

b) Masonry piers are provided with a batter varying from 1 in 24 to 1 in 12. Their width at the top is determined keeping the minimum space required for seating of the bearings of girders as also to provide sufficient distance on the outside of the bearings to resist diagonal shearing

c) For masonry abutments, as front batter of 1 in 16 to 1 in 10 is used, a flatter slope or stepping are provided in the rear as per design requirements

d) When piers are RCC, typical sections used are shown in fig. 7.1 & 7.2

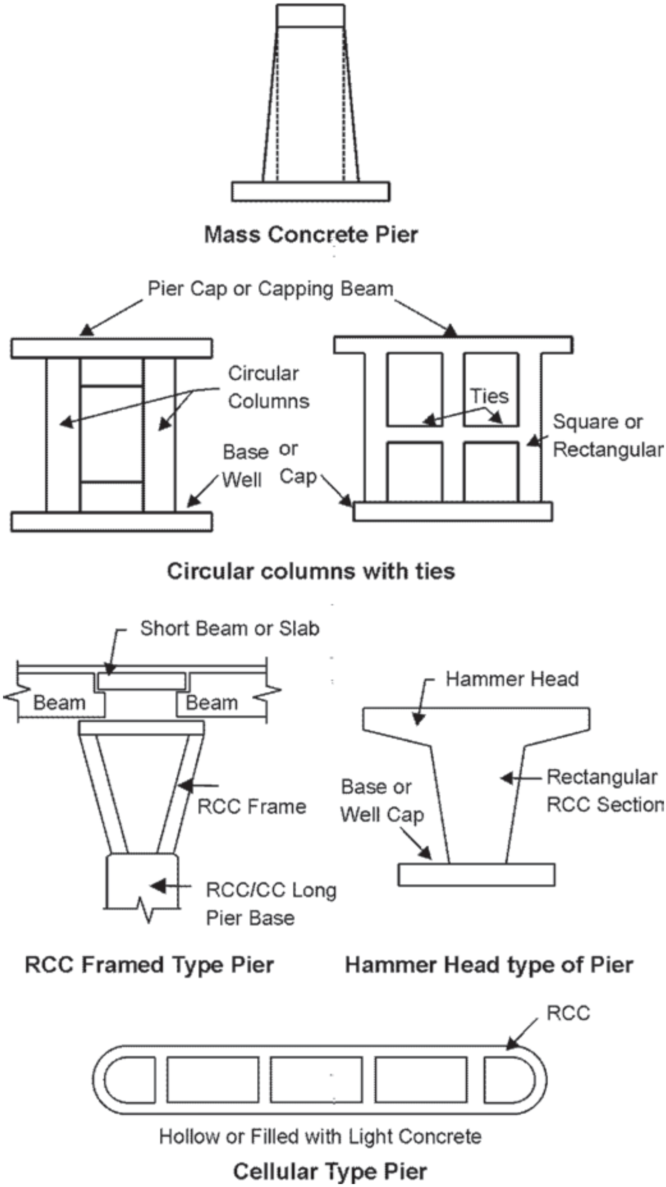

Fig. 7.1 Types of Piers Adopted in Railway Bridges

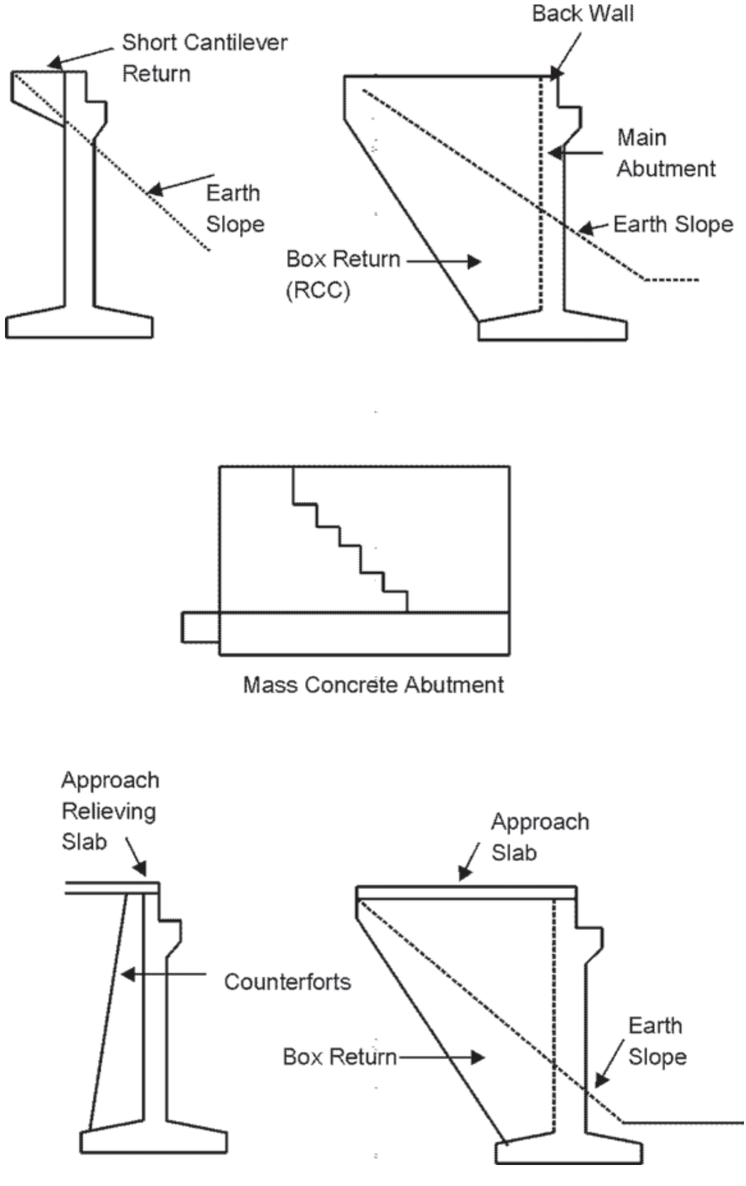

Fig. 7.2 Different types of Abutment

7.4 Choice for Superstructure:

1) Minor bridges are generally provided on local drainage crossings field channels and at canal crossings. Pipes are proposed where sufficient cushion below the sleeper is available.

2) Minor bridges namely RCC box is proposed where velocity of flow is less, i.e. less than 3.0 m/sec, & preferably less than 1.5 m/sec and where soilstrata bearing capacity is 20 to 25 t/m^2. The RDSO standard drawings are available for various BOX sizes with different cushion conditions. However I.R bridge manual has laid down the minimum size of opening to be provided ,which is as given here under:

   "Minimum clear span =1 m for New bridges and Rebuilding of existing bridges.

   Minimum headroom =1.2 m for new bridges, However while constructing / rebuilding new bridges on existing lines all efforts to provide it, otherwise PCE/CBE may permit relaxation."

3) However where the formation bank height is more, it will be uneconomical to provide RC BOX because Box barrel length will be very large in this case. Therefore PSC slab with abutment & pier arrangement shall be a better choice

4) For spans 9.15 m option of providing either PSC slab, or PSC girder is available.

5) For spans 12.2 m & above, PSC girder & Steel girder are the main options available, The issue of whether to provide PSC or steel girder is discussed in detail separately under Para-7.5

7.5 Choice between PSC Girder Bridges vs Steel Girder Bridges

7.5.1 Merits & demerits of PSC girder bridge

Merits of PSC bridge : The PSC girder bridges are having normally following two merits:

- ❖ Initial construction cost is less.
- ❖ PSC girders are maintenance free.

Demerits: As far as demerits of the PSC girders are concerned, these are-

- ❖ Brittle failure nature
- ❖ Less life.
- ❖ Very difficult strengthening/repair/ restoration
- ❖ Possibility of tempering of emergency cables by the miscreant in case the same has been provided as a strengthening measure.
- ❖ Changing of bearings is a problem

7.5.2 Merits & demerits of steel girder bridge

Merits of steel girder bridge

- ❖ Flexibility in strengthening of girders in case of need.
- ❖ Re-use of the plate girders and triangulated girders for smaller spans.
- ❖ Easy restoration of traffic after unusual activities / accidents
- ❖ Easy solution in case of accident/derailment and in keeping reserve stock.
- ❖ Restoration of the bridge in case of washing away due to flood and breaches.

- Easy to repair and maintain.
- Easy to inspect & rehabilitation is easier compare to PSC girder bridge.

Demerits: The main reasons for not preferring steel girder bridges are:

- Its initial cost is more
- It requires recurring expenditure in painting

7.5.3 Repercussion of difference in rail height

The rail height will vary in both cases, which will depend upon span length & type of girder used.

		PSC girder		Steel girder		Level diff in PSC girder & steel girder
SN	Span	Type of girder & drawing number	Total height from bed block to rail level in mm	Type of girder & drawing number	Type of girder & drawing number	
1	12.2m (40ft)	Box Girder B-1533	1780	Welded plate girder B-1528	1730	50mm
2	12.2m (40ft)	I -Girder B-1565	2470	Welded plate girder B-1528	1730	740mm
3	18.3m (60ft)	Box Girder B-1519	2370	Welded plate girder B-1529	2329	41mm
4	18.3m (60ft)	I - Girder BA-10227	3175	Welded plate girderB-1529	2329	846 mm

Table contd....

		PSC girder		Steel girder		Level diff in PSC girder & steel girder
SN	Span	Type of girder & drawing number	Total height from bed block to rail level in mm	Type of girder & drawing number	Type of girder & drawing number	
5	30.5m (100 ft)	Box Girder BA-10222	3050	Riveted triangu-lated girder BA-11341 Welded triangul-ated girder BA-11461	1583	1467 mm
6	45.1m (150 ft)	Box Girder B-1750	4250	Riveted triangulated girderBA-11361 Welded triangulated girder BA-11481	1625/ 1637	2620 mm (Average)

From the table bove, it is seen that when the span lengths are increasing, rail level difference for the PSC girders and the steel girders is increasing tremendously for the same span. Due to increase in rail level, particularly in case of adaptation of PSC girders, height of embankment will have to be raised. Raising of embankment height will cause increase in the earth work quantity & more land width requirement on the approach bank sides.

7.5.4 Cost comparison for Steel & PSC girder bridges

To have a fair comparison among the two, following items should be considerd to compare the cost of steel & PSC girders bridges.

1. Difference in initial cost of steel girder and PSC girder
2. Present day cost of painting (including labour and material)
3. Cumulative capitalized cost for 11 numbers of paintings in the life of bridge with interest
4. Present day cost of scrap steel
5. Cost involved for additional land width requirement with PSC girder bridge (if any)
6. Cost involved for additional earth work requirement with PSC girder bridge (if any)
7. Present day cost involved for replacement of bearings say @ 15 years interval.

Note : *It has been observed that for single span, the steel girder may be cheaper as compared to PSC Girder Bridge. However for two spans and above, position reverses and PSC Girder Bridge becomes cheaper than the steel girder bridge,because the additional quantity of earthwork and land width involved in case of PSC girder bridge will remain the same for multi span bridge & single span bridge. Hence, for multi span bridge PSC girder may be cheaper than steel girder bridge.*

7.5.5 Summary / conclusion on choice between PSC girder bridges vs steel girder bridges

- ❖ A thorough study is required before deciding the type of bridge i.e. whether it should be a steel bridge or concrete bridge, duly considering life cycle cost & not the initial cost alone.
- ❖ In case, where bank is high, steel bridge is more preferable.

- In the zone of high traffic, steel bridges may be provided, which will be cheaper than the PSC girder bridge, after considering operational cost.
- In vulnerable location where disruption is expected, steel bridges are more preferable.

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CHAPTER- 8

Standard of Loading & Bridge Design

8.1 The Loading standards Presently in use on I.R for Railway Bridge / Rail cum Road Bridge are given here under

Loading Standard	Max. Axle load for locomotive	Train Load	Diagram of Std. Loading	EUDL on each track for BM	EUDL on each track for shear	EUDL for various cushion (upto 8m spans)	Tractive effort	Braking Force
			Various Appendices of Bridge Rules					
Broad Gauge:								
DFC	25.0 t	12.13 t/m on both sides of Loco	XXVI	XXXVI	XXVII	XXVII a	XXVIII	XXVIII
25 T	25.0 t	9.33 t/m on both sides of engine	XXII	XXIII	XXIII	XXIII a	XXIV	XXIV
Meter Gauge								
MMG 1988	16.0 t	5.50 t/m on both sides of engine	IV	IV	IV	IV a	VIII	VIII a
MGML 1929	13.2 t	3.87 t/m behind the engine	IV	IV	IV	IV b	VIII	VIII a
MGBL 1929	10.7 t	3.87 t/m behind the engine	IV	IV	IV	IV c	VIII	VIII a

table contd....

Loading Standard	Max. Axle load for locomotive	Train Load	Diagram of Std. Loading	EUDL on each track for BM	EUDL on each track for shear	EUDL for various cushion (upto 8m spans)	Tractive effort	Braking Force
			Various Appendices of Bridge Rules					
Std C 1929		3.87t/m behind the engine	III a	IV	IV	IV d	VIII	VIII a

8.2 Standard of Loadings for B.G Bridges

The Railway Bridges including combined Rail and Road bridges shall be designed for one of the following standards of railway loading:

(a) **For Broad Gauge - (1676mm) - "25t Loading-2008"**
With a maximum axle load of 245.2 kN (25.0t) for the locomotives and a train load of 91.53 kN/m (9.33t/m) on both sides of the locomotives Appendix-XXII)

(b) **For Broad Gauge- (1676 mm) "DFC loading (32.5t axle load)"**
With a maximum axle load of 245.25 kN (25.0t) for the locomotives and a train load of 118.99 kN/m (12.13t/m) on both sides of the locomotives (Appendix-XXVI). The maximum axle load of wagons is 318.825 KN (32.5t).

8.3 Applicability of B.G Loading Standards on Various Routes

The applicability of above loading standards as stipulated under Para 2.2 on various B.G routes is decided as under **(Ref: Bridge Rules Para 2.3.1 (a & b) Foot note (3)**

S. N.		Loading standard
1	BG routes Bridge works of all types (I.e. Building /Rebuilding Strengthening/Rehabilitation): All BG routes Except DFC loading routes & DFC feeder routes.	25 t loading
2	DFC loading routes	DFC loading
3	DFC feeder routes :	
	i) Strengthening/Rehabilitation of bridge	25 t loading
	ii) Building/Rebuilding of super structure	25 t loading
	iii) Building/Rebuilding of Sub structure	DFC loading

Note:

i) The EUDLs shall be used for simply supported spans. In case of continuous super-structures over supports, the Bending Moments and Shear Forces for design purposes at various sections shall be computed for loadings shown in relevant Appendix-XXII (25 t loading)/ XXVI (DFC loading).

ii) A loco with axle loads heavier than standard loading or average trailing loads heavier than those specified in the standard may be considered as falling under the corresponding standards provided the EUDLs of loco or any trailing loads are within the EUDL of the standard loading specified.

8.4 Summary of Load Combinations for 25 t Loading Standard

There are 5 load combinations used in deriving the bending moment, shear force, longitudinal force (i.e. braking force & tractive effort) for 25 t loading standards, the salient features of these load combinations is placed here under:

Load Combinations	Axle load (t)	Axles on a bogie	Spacing of axles (m)	Spacing of bogie	O. L. of Loco	B.F. per Loco	T.E. per Loco Axle	Train Load	B.F. of train load
I	25	3	1.85	9.548	22.415	25% of axle load	63 t	9.33 t/m	13.4% of T.L
II	22.5	3	1.85	8.3	20.562	-do-	52 t	9.33 t/m	13.4% of T.L
III	25	2	2.8	5.65	31.1	-do-	84t	9.33 t/m	13.4% of T.L
IV	25	3	1.95/ 2.05	5.56	19.5	-do-	-	9.33 t/m	13.4% of T.L
V	22.5	3	1.65	6.4	16	-do-	50t	9.33 t/m	13.4% of T.L

8.5 Concept of EUDL

Based on the 5 load combinations considered under 25t/ DFC loading standards, in the bridge rule, the EUDL for bending moment, shear force, longitudinal force (i.e. braking force & tractive effort) has been provided for various spans. The EUDL provided in the bridge rules is based on following concept.

The EUDL for BM, for spans up to 10 m, is that UDL which produces the BM at the Centre of the span equal to the absolute max BM developed under the standard loads.

For spans above 10 m , the EUDL for BM is that UDL which produces the BM at one sixth of the span equal to the BM developed at that section under the standard loads.

Span	Condition
For spans up to 10 m :	BM of EUDL at Centre = Absolute Maximum BM of standard loads
For spans above 10 m :	BM of EUDL at $1/6^{th}$ span = BM of standard loads at $1/6^{th}$ span

The EUDL for SF is that UDL which produces SF at the end of span equal to max SF developed under the standard loads at that section

Illustration on EUDL Calculation for a particular span (say 12 m)

The total EUDL for BM for 12 m span, as per Bridge rules is 140.4 T (25 t loading Appendix-XXIII). The total load of 140.4 t is equal to a uniformly distributed load (w) of 140.4/12 = 11.7 t/m.

The configuration of 25 t-2008 loading at which this occurs is (combination-5)

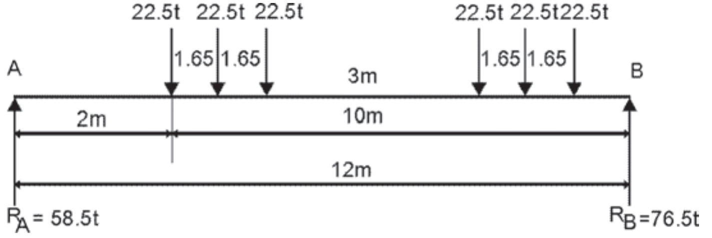


Fig. 8.1

R_B = 22.5 (2 + 3.65 + 5.3 + 8.3 + 9.95 + 11.6) /12
= 76.5 t
R_A = 6 x 22.5-76.5 = 58.5t

BM at Section @ 1/6 of span (2 m from support A) = 58.5 x 2 = 117 tm.

If EUDL is w t/m , then BM at 1/6 of a span shall be equal to $5wL^2/72$.

Therefore $5 w L^2/72 = 117$ t - m

$w = 117 \times 72/ (5 \times 12 \times 12) = 11.7$ t/m

8.6 Bridge Design Aspect

The important codal provision as contained under bridge rule and sub structure code as considered in the bridge design are briefly discussed here under

1) Dead Load (DL) (Bridge Rules 2.2, Sub Str Code Para 5.2)

Density of materials to be considered as under RCC-2.5 T/m^3, C.C-2.4 T/m^3, Steel-7.85 T/m^3 Ballast -1.90 T/m^3, Soil-1.8 T/m^3(Ref: IS 875) Part-I

2) Super Imposed Dead Load (SIDL)

SIDL as per standard RDSO drawings

3) Live Load (LL) (Bridge Rules 2.3, Sub Str Code Para 5.3)

a) The relevant standard of railway loading as per bridge rule for new construction/strengthening/rebuilding of bridges unless otherwise specified.

b) Live load reaction on abutment of simply supported span

Gravity type : - 50% of total EUDL for shear on overall length of span.

Non gravity type:- Minimum vertical LL reaction corresponding to maximum LF

c) Live Load reaction for piers on simply supported span, to be worked out for following condition.

(i) One span fully loaded

(ii) Both span fully loaded

Pier of gravity type:

(i) For one span loaded: - 50% of total EUDL for shear on OL of span.

(ii) Both span loaded with equal span:- 50% of total EUDL for BM on span equal to distance between outermost ends of 2 spans under consideration.

For non gravity piers/gravity piers supporting unequal span: Appropriate axle load giving maximum LF

4) Live Load Surcharge (LLS) (Sub Str Code Para 5.8)

Shall be considered for abutment/ wing wall / Return wall.

LL surcharge = 13.7 t/m for 25 t loading with uniform distribution width of 3m at formation level.

5) Dynamic Augment (1) (Bridge Rules 2.4, Sub Str Code Para 5.4)

For single track spans CDA= $0.15 + \dfrac{8}{(6+L)}$ equation - (1)

subject to maximum of 1.00

L is the loaded length of span (m)

CDA to be multiplied by factor for calculation of pressure/reaction at different level of gravity type substructure (cl. 5.4)

(i) Top surface of bed block = 1.00

(ii) Bottom surface of bed block = 0.50

(iii) Top 3m of substructure, below bed block=0.50 decreasing uniformly to zero

(iv) Beyond a depth of 3m below bed block = No impact need be allowed

For ballast wall: – up to depth of 1.5m = 0.50.

For design of non-gravity type of sub¬structures full dynamic augment effect as per equation (1) should be considered up to scour level.

6) Force Due to Curvature and Eccentricity of Track (CF), (Bridge Rules 2.5)

Clause 2.5.1: On ballasted deck bridges, even on straight alignment an eccentricity of centre line of track from design alignment upto 100 mm shall be considered for the purpose of design.

Clause 2.5.2: Where a track (or tracks) on a bridge is curved, allowance for centrifugal action of the moving load shall be made in designing the member, all tracks on the structure being considered as occupied.

Clause 2.5.3: For railway bridges the following loads must be considered:

(a) The extra loads on one girder due to the additional reaction on one rail and to the lateral displacement of the track calculated under the following two conditions:

(i) Live load running at the maximum speed.

(ii) Live load standing with half normal dynamic augment.

(b) The horizontal load due to centrifugal force which may be assumed to act at a height of 1830mm for "25t Loading-2008" for BG, 3000mm for "DFC loading (32.5t axle load)" for BG and 1450mm for MG above rail level is:

$C = WV^2 / 12.95R$ where C = Horizontal effect (t/m) run of span, W = Equivalent distributed LL in t/m run ie (EUDL for SF for the given span) , V = max speed in kmph, R radius of curve in meter.

7) Temperature effect (Bridge Rules 2.6, Sub Str Code Para 5.5)

Where any portion of the structure is not free to expand or contract under variation of temperature, allowances shall be made for the stresses resulting from this condition.

Temperature effects need not be considered in the design of substructure code and foundation of super structure is free expand or contract.

8) Longitudinal Force (LF) (Bridge Rules 2.8, Sub Str Code Para 5.5)

(a) Tractive force,

(b) Braking force

(c) Resistance to movement of bearings due to change in temperature &deformation.

(d) Forces due to continuation of LWR / CWR over the Bridges

Para 2.8.1: The longitudinal loads arising from any one or more of the following causes:

a) Tractive Effort of driving wheels of loco

b) Braking Force resulting from application of brakes

c) Raesistance to movement of bearing due to change of temperature and deformation of girder

d) Forces due to continuation of LWR/CWR over the bridges.

Para 2.8.1.1: Total longitudinal force transferred to substructure Should not be more than the limiting resistance at the bearing for transfer of LF.

Para 2.8.2.1: The value of L.F due to TE & BF for given loaded length is placed at annex XXIV & XXVIII of Bridge rules.

Para 2.8.2.1: For bridges having simply supported spans , the loaded length shall be taken equal to

a) The length of one span, when considering the effect of longitudinal force on

i) Girders

ii) stability of abutments

iii) Stability of pier carrying sliding /elastomeric bearing sunder one span loaded condition

iv) Stability of pier carrying one fixed/ one free (roller /PTFE) bearing.

b) The length of 2 spans when considering stability of pier carrying fixed / sliding or elastomeric bearings, under the 2 span loaded condition. The total Longitudinal force shall be divided between two spans in proportional to their length, in case of Loaded Length for continuous spans.

Appropriate loaded length, which will give worst effect shall be considered.

Para 2.8.2.2: No increase shall be made in L.F for dynamic effects

Para 2.8.2.3: The longitudinal forces shall be considered as acting horizontally through the knuckle pins in case of bearings having rocking arrangement or through girder seats, in case of sliding, elastomeric or PTFE bearings for the design of bearings and substructure.

Para 2.8.2.4.1: For sub-structure having sliding or elastomeric bearings, following percentage of net longitudinal force from the loaded spans after allowing for dispersion as per Clauses 2.8.3.1, 2.8.3.2 and 2.8.3.3 of Bridge rules shall be considered for the design:

Abutment 50%

Pier 40%

In case of multi-span bridges, the design of sub-structure shall also be checked for 20% of net longitudinal force transferred from the span adjoining to the spans directly supported by the sub-structure under consideration and considering the directly supported spans as unloaded. However, this force shall not be more than the limiting resistance of the bearings on the substructure for the transfer of longitudinal force under unloaded condition.

Para 2.8.2.4.2: For spans having roller or PTFE bearings at one end, the whole of the net longitudinal force after allowing for dispersion as per Clauses 2.8.3.1, 2.8.3.2 and 2.8.3.3 of Bridge rules shall be considered to act through the fixed end.

Dispersion and distribution of longitudinal forces.

Para 2.8.3.1: In case of bridges having open deck provided with through welded rails, rail-free fastenings and adequate anchorage of welded rails on approaches (by providing adequate density of sleepers, ballast cushion and its consolidation etc., but without any switch expansion joints) the dispersion of longitudinal force through track, away from the loaded length, may be allowed to the extent of 25% of the magnitude of longitudinal force and subject to a minimum of 16t for BG and 12t for MMG or MGML and 10t for MGBL.

This shall also apply to bridges having open deck with jointed track with rail-free fastenings or ballasted deck, however without any switch expansion or metered joints in either case.

Where suitably designed elastomeric bearings are provided the aforesaid dispersion may be increased to 35% of the magnitude of longitudinal force.

Note: *Length of approach for the above purpose shall be taken as minimum 30m.*

Para 2.8.3.2: The dispersion of longitudinal force indicated in Clause 2.8.3.1 above shall not exceed the capacity of track for dispersing the longitudinal force to the approaches nor shall it exceed the capacity of anchored length of the track on the approaches to resist dispersed longitudinal force. This aspect may be given special attention for the stability of track in case of multi-span bridges provided with elastomeric bearings on all spans.

Para 2.8.3.3: In case of multi-span bridges having continuous spans, or flexible supports such as tall or hollow RCC piers or steel trestles, or flexible bearings (elastomeric bearings) on all supports, or any other special features, which are likely, to affect the distribution of longitudinal forces significantly, the dispersion and distribution of longitudinal forces shall be determined by suitable analysis. The analysis shall take into account stiffness and frictional characteristics of various resisting elements viz., supports, bridge girders, bearings, rail-girder fixtures, track on bridge and approaches etc.

Para 2.8.3.4: For the design of new bridges and in case of rebuilding of existing bridges, dispersion of longitudinal force shall not be allowed.

Para 2.8.5: When considering seismic forces, only 50% of gross tractive effort/braking force, to be reduced by taking dispersion and distribution of longitudinal forces, shall be considered along with horizontal seismic forces along/across the direction of the traffic. i.e.

With Seismic forces:

Only 50% T.E./B.F. after distribution/dispersal

9) Derailment load (Bridge Rules 2.14)

As per appendix XXV for 25T loading.

10) Wind Loads (Bridge Rules 2.11, Sub Str Code Para 5.11)

Wind pressure shall be taken into account for bridges of span 18 m and over (Ref: sub structure code Para 5.11)

Basic Wind pressure: Equivalent static pressure in the windward direction

It depends on appropriate wind velocity chosen as per local meteorological records & degree of exposure map given in IS 875-Part 3 be used in absence of meteorological records.

Wind pressure specified shall apply to all loaded / unloaded bridges except bridges shall not be considered to be carrying any live loads when wind pressure at deck level exceeds, 150 kg/sqm for BG, 100 kg/sqm for MG &NG,

for Foot Bridges =75 kg/sqm (Para 2.11.2 B.R)

2.11.3.1 (a) Net exposed area for unloaded spans:

i) Unloaded span & trestles except plate girders : $1\frac{1}{2}$ times of horizontal projected area of the span or trestle.

ii) For Plate girders: Area of windward girder + Area of leeward girder x factor (depending on spacing v/s depth of girder)

b) Net exposed area for loaded span

$1\frac{1}{2}$ times of that portion of horizontal projected area of the span not covered by moving load except plate girder where it is : Area of windward girder above or below moving load + Area of leeward girder not covered by moving load x factor (depending on spacing v/s depth of girder) & the horizontal projected area of moving load

The wind pressure effect is considered as horizontal force acting in such direction that the resultant stresses in the member under consideration are maximum. The effect of wind pressure be considered as follows :

- ❖ Lateral effect on the top chords and wind bracing considered as a horizontal girder
- ❖ Same effect on lower chords
- ❖ Vertical loads on the main girders due to overturning effect of wind pressure
- ❖ Bending & direct stresses in members transmitting the wind load from top to the bottom chords or vice-versa.

11) Seismic loads : (Ref. Important provisions of IRS seismic code 2017)

1.0 Type of Bridges - Bridges are classified in 3 categories.

1.1 Regular Bridge - A regular bridge has no abrupt or unusual changes in mass, stiffness or geometry along its span and has no large differences in these parameters between adjacent supports (abutments excluded). A bridge shall be considered regular for the purpose of this standard, if-

a) It is straight or it describes a sector of an arch which subtends an angle less than 90° at the center of the arch;

b) The adjacent piers do not differ in stiffness by more than 25 percent (Percentage difference shall be calculated based on the lesser of the two stiffness); and

c) Girder bridges, T-beam bridges, truss bridges, hammer head bridges, bridges having single or multiple simply supported spans with each span less than 120 m and pier height above foundation level less than 30 m.

1.2 Special Regular Bridge - The bridges specified under regular bridges but single span more than 120 m or pier height measured from founding level to the top of pier cap to be more than 30 m. In case of pile foundation pier height shall be considered from the point of fixity.

1.3 Special and Irregular Types of Bridges - The bridges with innovative designs and bridges such as suspension bridge, cable stayed bridge, arch bridge, bascule bridge and irregular bridges such as skew bridge of angle 30° and above with span more than 60 m shall be categorized under these types.

2.0 Method of Calculating Seismic Forces

The following methods of seismic analysis may be employed for calculation of seismic forces in bridges:

a) Seismic coefficient method (SCM);
b) Response spectrum method (RSM);
c) Time history method (THM); and
d) Nonlinear pushover analysis (NPA).

The recommended method of analysis for different category of bridges and earthquake level is given in Table 1 below. The linear analysis considering elastic behavior is required for DBE.

Table 1 – Method of Seismic Analysis of Bridges

<table>
<tr><th rowspan="2">Earthquake level</th><th colspan="3">Category of Bridge type</th></tr>
<tr><th>Regular</th><th>Special Regular</th><th>Special Irregular</th></tr>
<tr><td>Design Basic Earthquake (DBE)</td><td>Seismic Coefficient Method (SCM)</td><td>Response Spectrum Method (RSM)</td><td>RSM

THM

NPA</td></tr>
<tr><td colspan="4">Note : In case of MCE (Maximum considered earthquake), Non-linear analysis and Time History Method shall be adopted for regular, special regular and special irregular bridges.</td></tr>
</table>

2.1 Seismic Coefficient Method

The seismic force to be resisted by bridge components shall be computed as follows:

$$F=A_h W$$

where

F = horizontal seismic force to be resisted;

W = weight of mass under consideration ignoring reduction due to buoyancy or uplift; and

A_h = design horizontal seismic coefficient

Note : For embedded portion of foundation at depths exceeding 30 m below scour level, the seismic force due to foundation mass may be computed using design seismic coefficient equal to $0.5A_h$.

For portion of foundation between the scour level and up to 30 m depth, the seismic force due to that portion of foundation mass may be computed using seismic coefficient obtained by linearly interpolating between Ah at scour level and 0.5 A_h at a depth 30 m below scour level.

2.2 Response Spectrum Method (RSM)

a) Formulation of an appropriate mathematical model consisting of lumped mass system using 2D/3D beam elements. The mathematical model should suitably represent dynamic characteristics of superstructure, bearings, sub-structure, foundation and soil/rock spring. In rock and very stiff solid fixed base may be assumed.
b) Determination of natural frequency and mode shapes following a standard transfer matrix, stiffness matrix, finite element method or any other standard approach.
c) Determine total response by combining responses in various modes by (1) by mode combination procedure such as SRSS, COC, etc, or (2) time-wise superposition of responses using ground motion time history(s).

2.3 Time History Method (THM)

The dynamic analysis of a bridge by time history method may be carried out using direct step-by-step method of integration of equations of motion. At least three spectrum compatible time histories shall be used, when site-specific time histories are not available. The spectrum used to generate these time histories shall be the same as used for the modal analysis. The duration shall be consistent with their magnitude and source characteristics of design basis earthquake. The total duration of time history shall be about 30s of which the strong motion part shall be not less than 6s. This analysis can be carried out using a standard software package.

2.4 Non-linear Pushover Analysis (NPA)

It is a static non-linear analysis carried out to determine lateral load versus displacement at control point in the structure for the purpose of determining capacity of the structure. The analysis can be performed using a standard software package. The method can be employed for design of special bridges and to determine capacity of existing structures for the purpose of retrofitting.

3.0 General Principles and Design Criteria

3.1 General Principles

3.1.1 All components of the bridge, that is, superstructure, sub-structure, bearing, foundation and soil are susceptible to damage in the event of strong ground shaking. The earthquake resistant design shall consider the effect of earthquake motions on each component of the bridge following the provisions of this standard.

3.1.2 The design shall ensure that seismic resistance of the bridge and its components are adequate to meet the specified design requirement so that emergency communication after an earthquake shall be maintained for the design basis earthquake.

3.1.3 Masonry and plain concrete arch bridges with spans more than 10m shall not be built in the seismic Zones IV & V.

3.1.4 Box, pipe and slab culverts need not be designed for earthquake forces. Bridges of total length not more than 60mand individual span not more than 15 m need not be designed for earthquake forces other than in Zones IV & V.

3.1.5 Seismic forces on aqueduct structures and flyover bridges shall be calculated as for any other bridge. The effect of inertia force of flowing water mass in aqueduct shall be calculated.

3.1.6 Hydrodynamic pressure on walls of water trough in case of aqueduct shall be considered on the basis of provision of 1S1893 (Part 2).

3.1.7 The liquefaction potential of foundation soil shall be investigated where necessary.

3.1.8 When relative movement between two adjacent units of a bridge are designed to occur at a separation/expansion joint, sufficient clearance shall be provided between them, to permit the relative movement under design earthquake conditions to freely occur without inducing damage. Where the two units may be out of phase, the clearance to be provided may be estimated as the square root of the sum of squares of the calculated displacements of the two units under maximum elastic seismic forces.

3.1.9 Special design studies shall be called for the following cases:

a) Consideration of asynchronous ground motion when, (1) geological discontinuities or marked topographical features are present; and (2) single span is greater than 600 m, even if there are no geological discontinuities.

b) In case of bridges over potentially active tectonic faults, the probable discontinuity of the ground displacement shall be estimated and accommodated either by adequate flexibility of the structure or by provision of suitable movement of joints.

c) Bridge located in near-field, that is, within 10 km near fault area of known active tectonic fault.

3.2 Design Criteria

3.2.1 Site Specific Spectrum

For special bridges i.e. Special regular and special irregular in seismic Zones IV and V where soil conditions are poor consisting of marine clay or loose fine sand and silt (for example where the soil up to 30 m depth has SPT (N values - uncorrected) equal to or less than 20 and for bridges located near a known fault (near field) or the area is known for complex seismo-tectonic geological setting, detailed investigations shall be carried out to obtain the site specific spectrum. Site specific spectrum is also required for bridges with spans greater than 150 m. Such a spectrum shall be used for design in place of code spectrum subject to minimum requirements specified in this standard.

4.0 Assumptions

The following assumptions shall be made in the earthquake analysis of bridges:

a) The seismic forces due to design basis earthquake (DBE) should not be combined with design wind forces.

b) The scour to be considered for design shall be based on mean design flood. In the absence of detailed data, the scour to be considered for design shall be 0.9 times the maximum design scour depth.

   NOTE - The designer is cautioned that the maximum seismic scour case may not always govern in design condition.

c) The earthquake accelerations should be applied to full mass in case of submerged structures and not on buoyant mass.

d) The seismic force on live load in bridges should not be considered in longitudinal direction. The seismic force on live load should be considered in transverse direction.

e) The seismic force on flowing mass of water in the longitudinal direction in case of aqueducts should not be considered, however seismic force on this water mass be considered in transverse direction. The hydrodynamic action of water on the walls of water carrying trough shall be considered according to the provisions of code on liquid retaining structures.

f) The earthquake accelerations on embedded portion of bridge foundations should be reduced as per 9.3 of IRS Seismic Code 2017.

g) The value of static elastic modulus of material, where required, may be taken for dynamic analysis unless a more definite value is available for use in seismic condition.

5.0 Seismic Coefficient Method:

A) Horizontal Seismic Force - The seismic force to be resisted by bridge components shall be computed as follows:

$$\mathbf{F = A_h\ W}$$

Where

F = horizontal seismic force to be resisted;

W = weight of mass under consideration ignoring reduction due to buoyancy or uplift; and

A_h = design horizontal seismic coefficient

Note: 1. For embedded portion of foundation at depths exceeding 30 m below scour level, the seismic force due to foundation mass may be computed using design seismic coefficient equal to $0.5A_h$. For portion of foundation between the scour level and up to 30 m depth, the seismic force due to that portion of foundation mass may be computed using seismic coefficient obtained by linearly interpolating between A_h at scour level and 0.5 A_h at a depth 30 m below scour level.

2. The seismic force due to live load shall not be considered when acting in the direction of traffic. It shall be considered in the direction perpendicular to traffic @50% of design live load (without impact).(Ref Para 7.1 of IRS Seismic Code 2017).

Horizontal Seismic Co-efficient A_h

The design horizontal seismic coefficient, Ah shall be determined from following expression

$$A_h = \frac{Z}{2} \cdot \frac{1}{R} \cdot \frac{S_a}{g}$$

Provided that for any structure with T <0.1s, the value of A, shall not be taken less than 2/2, whatever be the value of I/R.

where, Z = zone factor;

I = importance factor (see Table 3);

R = response reduction factor (see Table 4); and

S_a/g = average acceleration coefficient for rock or soil sites as given in Fig. 8.2

i) Zone Factor (Z) for Horizontal Motion

For the purpose of determining design seismic forces, the country is classified into four seismic zones. The peak ground acceleration (PGA) (or zero period acceleration, ZPA), associated with each zone, is called zone factor, Z. The zone factor is given in Table - 2 below.

Table 2 : Zone Factor Z for Horizontal Motion

Seismic Zone	II	Ill	IV	V
Z	0.10	0.16	0.24	0.36

Note: Near Source Effect: For bridges which are within a distance of 10 km from a known active fault, seismic hazard shall be specified after detailed geological study of the fault and the site condition. In absence of such detailed investigation, the near-source modification in the form of 20% increase in zone factor may be used.

ii) Importance Factor

Table 3 : Importance Factor for railway bridges

(Ref. Clause 9.4.4 - Table 2 of IRS Seismic Code 2017)

S. No.	Seismic Class	Illustrative Examples of Bridges	Importance Factor 'I'
i)	Railway bridges	a) All important bridges irrespective of route.	1.5
		b) Major bridges on group A, B and C routes (Route classification as per IRP way manual)	1.5
		c) Major bridges on all other routes.	1.25
		d) All other bridges on group A,B, and C routes	1.25
		e) All other bridges	1.0

iii) Response reduction factor (R)

Table 4 : Response Reduction Factor (R) for Bridge Components
(Ref. Cl. 9.4.5 Table 3 of IRS Seismic code)

SN	Structure, Component or Correction	R
1.	Superstructure	2
2.	Substructure	
	a) Reinforced concrete piers with ductile detailing cantilever type, well type	1.0
	b) Reinforced concrete piers without ductile detailing, cantilever type, well type	2.5
	c) Masonry piers (un reinforced) cantilever type, well type	1.5
	d) Reinforced concrete, framed construction in piers, with ductile detailing columns of RCC bents, RCC single column piers	4.0
3.	Abutments of mass concrete and masonry	1.0
4.	R.C.C. Abutment	2.5
5.	Bearings (Elastomeric, pot, knuckle, roller-rocker)	2.0
6.	Foundations (well, piles or open)	2.0

iv) Spectral Acceleration Coefficient ($\frac{S_a}{g}$) – It depends upon natural period of bridge, which is calculated for horizontal motion as under:

Calculation of Natural period of Bridge for Horizontal motion:

a) For Simply Supported Bridges

Where the vibration unit of sub-structure can be idealized as a single cantilever pier carrying the superstructure mass, resting on well, pile or open foundation, the fundamental period shall be calculated from the following equation:

$$T = 2\pi\sqrt{\frac{\delta}{g}}$$

Where δ = horizontal displacement at the top of pier due to horizontal force (= mg)

Where m = lumped mass at the top of pier

In general pier shall be considered fixed at the foundation level. However, in case of soft soil or deep foundations, soil flexibility may be considered in the calculation of natural period.

b) For Other Types of Bridges

Where idealization by a single cantilever pier model is not possible, the natural periods of vibration may be calculated by free vibration analysis of an appropriate mathematical model of bridge superstructure, bearing, sub-structure, foundation and soil.

Based on natural period calculated above the value of ($\frac{S_a}{g}$) is worked out using the fig. 8.2 given below.

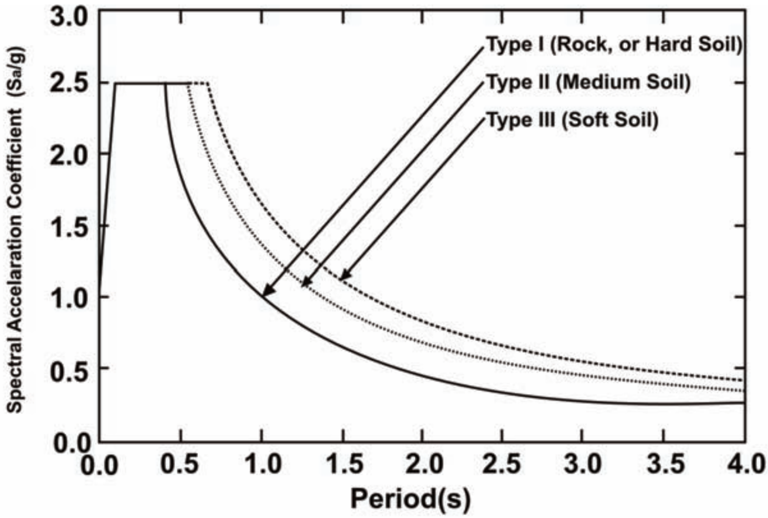


Fig 8.2 Response Spectra for Rock and Soil sites for 5 Percent Damping

B) Vertical Seismic Force

The vertical seismic force to be resisted by bridge components shall be computed as follows:

$$F_v = A_v\ W$$

Where

F_v = vertical seismic force to be resisted;

W = weight of mass under consideration ignoring reduction due to buoyancy or uplift; and

A_v = design vertical seismic coefficient

Note: 1. The seismic force due to live load shall be considered @50% of design live load (without impact).(Ref Para 7.1 of IRS Seismic Code 2017).

2. The effect of vertical seismic component on substructure and foundation may as a rule be omitted in Zone II and III (Ref Para 7.3.1 of IRS Seismic Code 2017).

However the vertical accelerations should be specially considered in bridges with large spans, those in which stability is the criteria of design and in situations where bridges are located in near field. However the effect of vertical seismic component is particularly important in the following components/ situations and needs to be investigated:

a) Pre-stressed concrete decks; b) Bearings and linkages; and c)Horizontal cantilever structural elements.

Calculation of Design Vertical Seismic Coefficient, Av

The design vertical seismic coefficient shall be calculated similar way as horizontal seismic coefficient with following differences.

(i) The value of Zone factor to be considered shall be 2/3rd of horizontal motion as given in Table 2 above.

(ii) The time period for superstructure is to be worked out separately using the characteristics of superstructure for vertical motion, in order to estimate Sa/g for vertical acceleration.

The natural time period of superstructure can be estimated using appropriate modelling and free vibration analysis using computer. However, for simply supported superstructure with uniform flexural rigidity, the fundamental time period Tv, for vertical motion can be estimated using the expression:

$$T_V = \frac{2}{\pi} l^2 \sqrt{\frac{m}{EI}}$$

where

l	= Span ;
m	= mass per unit length; and
EI	= flexural rigidity of the superstructure.

C) Hydrodynamic Force on Sub-Structure

(i) The hydrodynamic force on submerged portion of pier and foundation up to mean scour level shall be assumed to act in a horizontal direction corresponding to that of earthquake motion. The total horizontal force is given by the following formula:

$$F = C_e A_h W_e$$

where

C_e = Confficient (see table 4);

A_h = design horizontal seismic coefficient;

W_e = weight of the water in the enveloping cylinder,

= $P_w \pi a^2 H$, **See 10.3**

P_w = unit weight of water;

H = height of submerged portion of pier; and

a = radius of enveloping cylinder.

(ii) Hydrodynamic Pressure Distribution

The hydrodynamic pressure distribution on submerged portion of bridge pier is given in Fig. 2. The coefficients C1, C2, C3 and C4 are given in Table 5. The pressure distribution, Fig. 2, along the height of pier is drawn by assuming the value of C1 from 0.1 to 1.0 in Table 6;

Table 5 Values of c (Clause 10.1 of IRS Seismic Code 2017)

S.No. (1)	H/a (2)	Ce (3)
i)	1.0	0.390
ii)	2.0	0.575
iii)	3.0	0.675
iv)	4.0	0.730

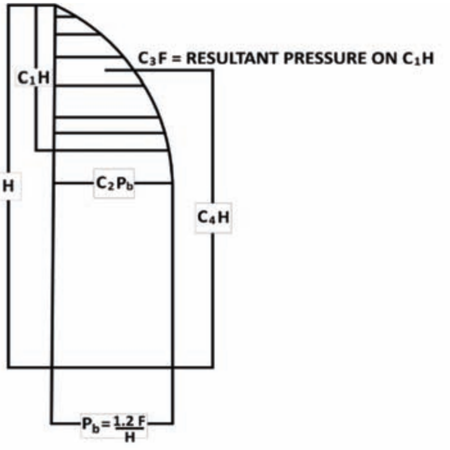


Fig. 8.3 Diagram Showing Hydrodynamic Pressure Distribution

This implies selecting a point on the vertical axis origin at top, then other coefficients are read horizontally from the table to generate the pressure curve and determine other coefficients mentioned on the curve.

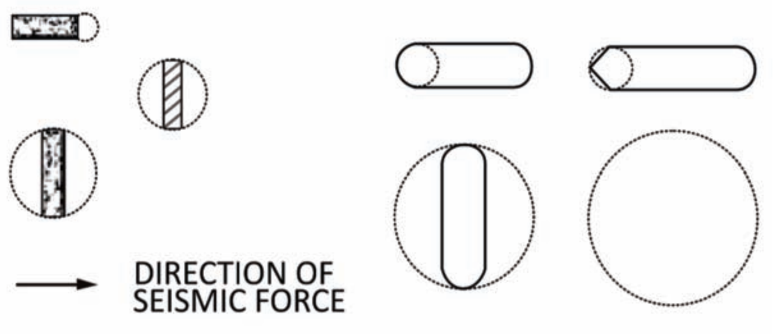


Fig. 8.4 Cases of Enveloping Cylinder

Table 6 Coefficients C1, C2, C3, and C4 (Clause 10.1 Of IRS Seismic Code 2017)

SN	C1	C2	C3	C4
1	0.1	0.410	0.026	0.934
2	0.2	0.673	0.093	0.871
3	0.3	0.832	0.184	0.810
4	0.4	0.922	0.289	0.751
5	0.5	0.970	0.403	0.694
6	0.6	0.990	0.521	0.639
7	0.8	0.999	0.760	0.532
8	1.0	1.000	1.000	0.428

6.0 Superstructure

(i) The superstructure shall be designed for the design seismic forces as specified in para 9 of IRS Seismic Code 2017 plus other loads required in design load combinations.

(ii) Under simultaneous action of horizontal and vertical accelerations, the superstructure shall have a factor of safety of at least 1.5 against overturning under DBE condition.

(iii) The superstructure shall be secured, when necessary to the sub-structure in all zones through bearings possessing adequate vertical holding down devices and/or unseating prevention system for superstructure. These devices should be used for suspended spans also with the restrained portion of the superstructure. However, frictional forces in the devices should not be relied upon for preventing dislodging and jumping of superstructure.

6.1 Bearings

(i) The fixed bearings should be designed to withstand the horizontal and vertical seismic forces, which are expected to transmit these forces in the event of ground motion.

(ii) In the case of movable bearings, the bearings shall be able to accommodate designed displacements. The displacements beyond design values shall be restrained by stoppers.

(iii) Any out of phase motion of piers, if envisaged, shall be considered in working out design seismic displacement in bearings.

(iv) The bearings that are permitted to move in longitudinal direction but restrained in transverse direction shall be designed for estimated design seismic force in transverse direction.

7.0 Seismic Load Combinations

a) The seismic forces shall be assumed to come from any horizontal direction. For this purpose, two separate analysis shall be performed for design seismic forces acting along two orthogonal horizontal directions. The design seismic force resultant {that is axial force, bending moments, shear forces, and torsion) at any cross-section of a bridge component resulting from the analyses in the two orthogonal horizontal directions shall be combined according to the expressions below:

a) $\pm EL_X \pm 0.3EL_Y$

b) $\pm 0.3EL_X \pm EL_Y$ where

EL_x = force resultant due to full design seismic force along x direction, and EL_Y = force resultant due to full design seismic force along y direction.

When vertical seismic forces are also considered, the design seismic force resultants at any cross-section of a bridge component shall be combined as below:

1. $\pm EL_X \pm 0.3EL_y \pm 0.3EL_Z$
2. $\pm 0.3EL_X \pm EL_Y \pm 0.3EL_Z$
3. $\pm 0.3EL_X \pm 0.3EL_y \pm EL_Z$

Where Elx and EL_y are as defined above and EL_Z is the force resultant due to full design seismic force along the vertical direction.

As an alternative to the procedure given above, the forces due to the combined effect of two or three components can be obtained on the basic of square root of sum of square (SRSS), that is

$$\sqrt{EL_x^2 + EL_y^2} \quad or \quad \sqrt{EL_x^2 + EL_z^2 + EL_y^2}$$

b) Load Factors (Ref Para 7 of IRS Seismic Code 2017)

When earthquake forces are combined with other forces such as dead load and live load, the load factor for plastic design of steel structures and partial safety factors for limit state design of reinforced concrete structures and pre-stressed concrete structures shall be considered.

Load factors may be used as in IRC/IRS codes with the provision that when earthquake load (EL) and dead load (DL) are combined, load factor shall be minimum 1.5; and when seismic load is combined with all other loads, load factor shall be minimum 1.2.

12) Earth Pressure All earth retaining structures should be designed for active pressure due to earth fill behind the structures as per clause 5.7 of SSC.

13) Earth Pressure due to Surcharge (Sub Str Code Para 5.8.2 to 5.8.4)

It shall be calculated for Abutment /Wing / Return wall as applicable. LL surcharge = 13.70 t/m for 25T loading on width of uniform distribution at formation level equal to 3.0m.

14) Earth Pressure increase due to Seismic Effect (Sub Str Code Para 5.12)

In this case the state of earth fill VIZ. saturated/submerged earth fill shall be given due consideration.

Increase in Earth pressure (as contained of SSC 5.12.6.1 and Increase in earth pressure due to surcharge under 5.12.6.3 & 5.12.6.4 shall be considered.

15) Forces due to Water current (Wc) (Sub Str Code Para 5.9)

Water pressure on piers parallel to direction of water current

$P = KAV^2$

- ❖ Suitable cut water be provided to reduce water pressure
- ❖ Max. mean value of velocity (V) of current is taken from past records

In absence of past record

i) For alluvial beds, calculated by formula

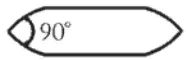
$V = [\,Qf^2/140]^{1/6}\,[A/a]$

Note : In absence of data assume velocity of current as 3m/sec

ii) For other than alluvial beds

Estimate from observation / past record of adjacent sites.

Value of K (Table 4 of SSC)

S.N	Description	Figure
1	Square ended piers	 79
2	Circular piers or piers with semi-circular ends	 35
3	Piers with traingular cut and ease waters, the angle included be tween the forces being 60 degree.	 37
4	Piers with traingular cut and ease waters, the angle included between the forces being 90 degree.	 47
5	Piers with-cut and ease waters of equi-lateral arcs of circle at 60 degree.	 24
6	Piers with arcs of the cut and ease waters intersecting at 90 degree	 26

Where current strikes at an angle, velocity shall be resolved in two component, one parallel and other normal to pier and pressure calculated.

SSC 5.9.2.4 To provided against effect of possible variation in direction of current, allowance shall be made for an additional force acting normal to pier with intensity of pressure per unit area of exposed surface of the pier equal to 20% of the intensity of pressure taken as acting in direction parallel to pier.

SSC 5.9.2.6 The point of application shall be taken as 1/3 of the distance measured from the top between the upper and lower wetted limits of the surface under consideration

16) Buoyancy Effect (Sub Str Code Para 5.10)

For Design of Foundation

- ❖ Full buoyancy effect upto HFL or LWL, depending on most critical combination.
- ❖ Can be reduced upto 50% of buoyancy at the discretion of Engineer if foundation are resting on rock and have adequate bond with it.

SSC 5.10.1.1 Checking stability against overturning Effect of buoyancy upto HFL (min dead load / stabilizing force)

SSC 5.10.1.2 For calculation of foundation pressure

- ❖ Upto LWL for max. foundation pressure (max dead load condition) (LWL means least buoyancy effect)
- ❖ Upto HFL for min. foundation pressure (min vertical load condition) (HFL means max buoyancy effect)

SSC 5.10.2 Design of submerged masonry / concrete substructure:

Buoyancy effect through pore pressure upto 15% of full buoyancy

- ❖ Upto LWL for checking compressive strength
- ❖ Upto HFL for checking tensile strength

17) PQRS Load (Sub Str Code Para 2.15)

Load due to Plasser's quick relay system (PQRS) shall be considered as per clause no. 2.15 Bridge Rules

■ ■ ■

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For any suggestions, errors etc, please contact
Email : mail@iricen.gov.in

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