"DESIGN OF GUIDE BUNDS & HYDRAULIC SIMULATION OF FLOW AROUND MAJOR RIVER-ROAD BRIDGES"

A DISSERTATION

Submitted in the partial fulfillment of the
Requirements for the award of the degree
Of

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In

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By

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MAY 2018

DECLARATION

I hereby declare and certify that the dissertation entitled "**DESIGN OF GUIDE BUNDS & HYDRAULIC SIMULATION OF FLOW AROUND MAJOR RIVER-ROAD BRIDGES**" is an authentic and genuine record of my own work conducted in my own capacity. It is presented here in partial fulfillment for the award of the degree of **Master of Technology** with specialization in **Water Resource Development and Management (Civil),** submitted to the department of **Water Resource Development and Management, Indian Institute of Technology Roorkee, India,** under the supervision and guidance of **Dr. M. L. Kansal**, Professor, WRDM, IIT Roorkee & **A.C.Pandey**, Former Research officer (Incharge), Irrigation Research Institute IRI, Roorkee.

This report is entitled to acceptance as it has not been presented anywhere for the same purpose by any person.

Date:

Place: **Roorkee**

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CERTIFICATION

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

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(Dr. M. L. Kansal) **(A.C. Pandey)**

ABSTRACT

Bridges over the major rivers are very important and expensive highway hydraulic structures. These Bridges are vulnerable to failure from flood. In order to minimize the risk of failure, the hydraulic requirements during the development, construction, and maintenance highway phases must be recognized and addressed. Some of the important hydraulic analyses of a highway-stream crossing for a particular flood frequency are :- i) Determination of the effects on flow distribution and velocities due to bridge, ii) The Profile of Guide Bunds and its proper protection measures.

Guide Bunds are earthen embankments with stone pitching in the slopes facing water, to guide the river through the bridge. These river training works are provided for rivers flowing in planes, upstream and downstream of the hydraulic structures or bridges built on the river. Marginal Bunds is flood embankments in continuation of guide Bunds designed to contain the floods within the flood plain of the river. They are provided on the upstream in order to protect the area from submergence due to rise in HFL, caused by afflux.

Generally, Guide Bunds in the upstream of bridges are constructed as per conventional guide lines with help of model studies. During the construction of long guide Bunds, beside the cost of construction, very large lands are to be procured. This procurement of land sometimes leads to very long and tedious litigations and huge amount of compensation to the farmers, public owners. To avoid these litigations and to reduce the heavy revenue cost sometimes, deviations from common guide lines are strategically required. At certain locations, it may be possible to obtain a firm and stable topography on one or the other side. In such cases only one Guide Bund on the other side needs to be provided. Obviously the cost of river training is reduced in such cases. No standing guide line can be framed for such strategic positions which are to be solved at hand. With this philosophy, in the present study the existing marginal Bunds is being used as left guide Bund. This marginal bund is suitably tied up with S-Curve with the existing dyke Bund and marginal Bund. Elliptical guide Bund with reduced length is provided on the right side for the Bridge 1. Similarly Elliptical guide Bunds with reduced length are provided on both sides for the Bridge 2 without interfering the hydraulics of the bridge. The Bridge 1 is located near Baghpat & Bridge 2 is located near Faizupur Khadar along the Eastern Peripheral Expressway in the river Yamuna. It is with this objective, so as to review the proposed alignment

of the Guide Bunds and protection work of Yamuna River Bridge. Also to suggest alternate technical measures on the basis of the previous study carried out the Irrigation and Power Research Institute, Punjab; Amritsar. As the time does not permit the new physical model study or the collection of primary data, secondary data only is being used for the analysis.

Similarly the proposed Bridge 3 in the river Ganga near Hastinapur was designed for a flood of 11,250 cumecs based on 3D Physical model studies conducted by Irrigation Research Institute, Roorkee in 2009. But in the year 2013, the flood of 14668 cumec was experienced at a barrage constructed about 32 Km upstream of the bridge. So seeing the importance of the bridge in consideration and under construction the hydraulics analysis of the flow with discharge of 14,500 cumecs is carried out for extra line of defense for the main structure under present scenario. As the time does not permit the new physical model study or the collection of primary data, secondary data only is being used for the analysis through mathematical model.

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Date:

Place: **Roorkee**

(Umesh Kumar Gupta)

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LIST OF ABBREAVIATIONS

3-D:	Three Dimensional
BA	Bridge Axis
Ch	Chainage
CBIP	Central Board of Irrigation and Power
GAD	General Arrangement Drawing
GD Curve	Gauge Discharge Curve
HEC RAS	Hydrologic engineering center's River analysis system
HFL	High Flood Level
IPRI	Irrigation and Power Research Institute, Punjab (India)
IRC	Indian Road Congress
IRI	Irrigation Research Institute, Roorkee (India)
IS	Indian Standard Code
Km	Kilometer
MGB	Modified Guide Bund
n	Manning's coefficient of roughness
OGB	Originally Proposed Guide Bund
ppm	Parts per million
UP	Uttar Pradesh

CHAPTER 1: INTRODUCTION

1.1 GENERAL BACKGROUND OF THE STUDY

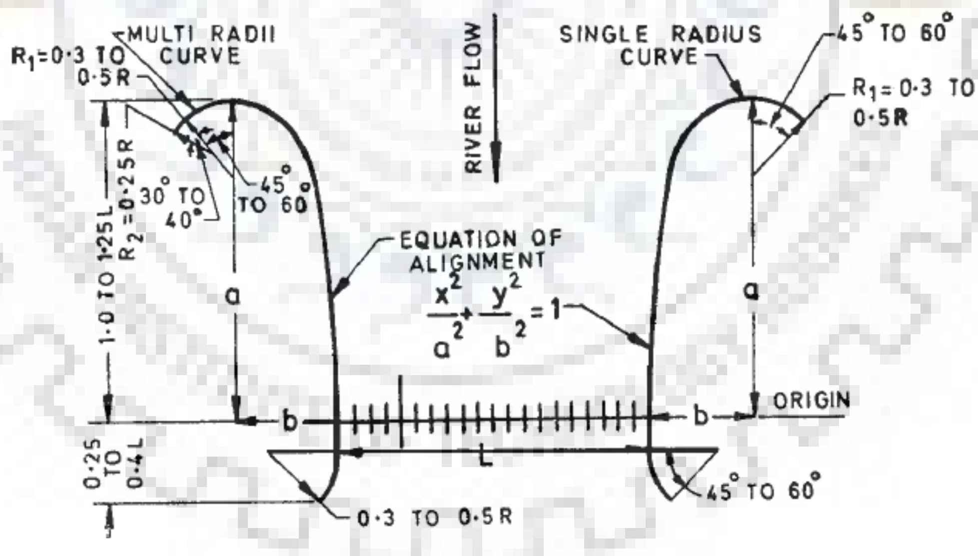
A bridge is defined as a structure, including supports, erected over a depression or an obstruction having a roadway or track for carrying traffic or other moving loads, and having an opening measured along the center of the roadway of more than 20 feet between faces of abutments. They are important and expensive highway hydraulic structures. These Bridges are vulnerable to failure from flood. In order to minimize the risk of failure, the hydraulic requirements during the development, construction, and maintenance highway phases must be recognized and addressed. The importance of hydraulic analysis of a highway-stream crossing for a particular flood frequency involves the following:

- Determination of Design flood and waterway of the bridge (Mazumder, SK).
- Fixing site and orientation of bridge axis (The orientation of a bridge axis should be such that the flow is almost perpendicular to the bridge axis. Sometimes this ideal condition is not possible to achieve due to some or other constraints at site, in these circumstances it must be assured that the flow under frequently occurring flood remain more or less evenly distributed throughout the bridge span).
- Determination of the backwater or afflux after constriction of the river section for different waterway(s).
- Determination of the effects on flow distribution and velocities due to bridge.
- Estimation of scour potential including constriction scour and local scour.
- Profile of guide Bunds and proper protection measures.
- River Training works -if required.

For extra line of defense for the main structure like bridges, the Guide bunds are very important river training works. They are earthen embankments with stone pitching in the slopes facing water, to guide the river through the bridge. These river training works are provided for rivers flowing in planes, upstream and downstream of the hydraulic structures or bridges built on the river. Marginal Bunds is flood embankments in continuation of guide Bunds designed to contain the floods within the flood plain of the river. Both height and length vary according to back water effect caused by the structure. They are provided on the upstream in order to protect the area from submergence due to rise in HFL, caused by afflux. Overall functions of these training works are:

- To provide and non-tortuous approach to bridge.
- To prevent the river from out-flanking the bridge.
- To prevent additional area to be submerged due to afflux.
- To prevent erosion of the river Bunds (protective works).
- To ensure smooth and axial flow of water.

Therefore, the flow in the bridge should be uniformly distributed to avoid any acentric attack of flow on the abutments and piers. The Bridges in India may be classified in many ways, as shown in **Table 1.1**. The Bridges in the present study are designed for the IRC Class A Loading. Its classification based on the length of span is for Major Road Bridges & Materials of construction used for superstructure is of cement concrete type. Similarly the guide Bunds can be classified as Divergent, Convergent, and Parallel guide Bunds according to the form in plan; straight or elliptical with a circular or multi radii curved head according to the Geometric shape. The typical layout of elliptical guide Bunds based on IS guidelines is shown in the **figure 1.1**.



(*Source:* IS, 1994 guidelines)

Figure 1.1: Typical Layout of Elliptical Guide Bunds

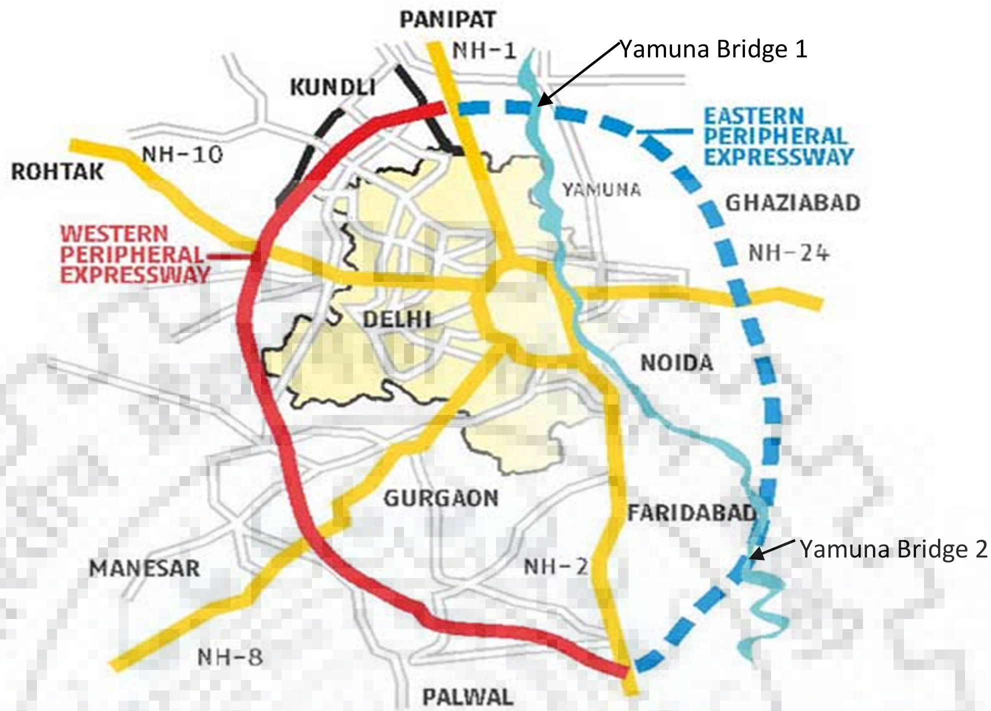
Table 1.1: Classification of Bridges

SN	Classification according to	Types
1.	Flexibility of superstructure	Fixed span bridges, Movable bridges
2.	Inter-span relations	Simple, Continuous or Cantilever bridges
3.	Form or type of superstructure	Arch, beam, Truss, Slab, Rigid frame or Suspension bridges
4.	Materials of construction used for superstructure	Cement concrete, Pre stressed concrete, Steel, masonry, Iron, Timber or Composite bridges
5.	Expected utility period of service	Temporary, Military or Permanent bridges
6.	Function	Road, Railway, Road-cum-railway or Pipeline bridges
7.	Method of connections adopted in steel bridges	Riveted, Welded or Pin-connected bridges
8.	The length of span	Culvert, Minor bridges, Major bridges or Long span bridges
9.	Level of crossing of highways and railways	Over bridges or Under bridges
10.	Loadings	IRC class A, class AA, class B

(Source: compiled from https://www.sefindia.org/bridges.pdf)

Substantial increase in the number of vehicles on Delhi roads in recent years has really worsened the traffic congestion resulting into unnecessary delays, reduction in speed, and wastage of fuel and increasing the pollution. To improve the quality of public transport in the capital, several measures are being taken by the Government. One of these measures is the construction of “Peripheral Expressway” around National Capital Region (NCR) to bye-pass Delhi during interstate commutations. The “Peripheral Expressway” virtually is a ring road around NCR and is a combination of Western Expressway on the western side and Eastern Expressway on the eastern side as shown in **Figure 1.2**. The Eastern Expressway crosses River Yamuna at two places: Bridge No.1 near Baghpat and Bridge No. 2 near village Faizupur Khadar under Tehsil Ballabhgarh in District Faridabad (Haryana). These two bridges require huge land for the construction of guide Bunds and protection work. Since the entire Yamuna River is passing through the private land as per revenue records, there is dispute regarding ownership of land.

Similarly, River Ganga from Gomukh to Ganga Sagar flows through the state of Uttarakhand, Uttar Pradesh, Bihar and West Bengal where it finally mingles into the Bay of Bengal. During its journey the river, forms a number of interstate and inter district boundaries. In Uttar Pradesh, it forms a dividing boundary between the districts of Meerut and Bijnor. At present there is no direct road communication between these two districts as in the upstream the existing bridge across Ganga is 32 Km upstream of Hastinapur and in downstream the bridge exists at Garhmukteshwar which is also about 35Km from Hastinapur. In view of this, the Government of Uttar Pradesh had approved construction of bridge across river Ganga to ease the road communication between Hastinapur (Meerut) and Chandpur (Bijnor). The bridge after construction shall connect Bijnor district's Chandpur with Hastinapur in Meerut. Once completed, the bridge would reduce the distance between Bijnor to Hastinapur by 30 km and Bijnor to Meerut by about 50 km. The U.P. State Bridge Corporation – the construction agency has partially constructed the bridge structure. The P.W.D. of Uttar Pradesh is entrusted protection works like guide Bunds and launching apron etc. So to cope up with these problems and due to the time constraint, in the present study, the hydraulic simulation of flow through mathematical modeling are carried out for these three bridges in the River Yamuna and Ganga and provide the alternate technical measures for the design of guide bunds without hampering the hydraulics of Bridge. 3D physical model studies for these bridges were conducted at IPRI, Amritsar & IRI, Roorkee respectively.



(*Source:* Eastern Peripheral Expressway -Google Image)

Figure 1.2: Location Map of two Bridges over river Yamuna on Eastern Peripheral Expressway

1.2 STUDY AREA

1.2.1 BRIDGE 1 & 2 (IN RIVER YAMUNA)

The bridge site 1 and 2 are located in the National Expressway 2, also known as the Eastern Peripheral Expressway designed to connect Kundli in Haryana to Palwal in Haryana via Ghaziabad. This route would by- pass Delhi on the eastern side and go through Haryana and Uttar Pradesh crossing the districts of Sonipat, Faridabad, Baghpat, Ghaziabad, and Gautam Budh Nagar. When the currently under development, Western Peripheral Expressway connecting Palwal and Kundli via Manesar is complete, both these expressways will form a expressway ring around Delhi and further increase connectivity to the surrounding areas, while reducing the travel time. The bridge 1 in the study area connects baqipur of Sonepat district in Haryana state with Goripur of Baghpat district in Uttar Pradesh state. The bridge 1 is located 8.0 Km downstream of the existing bridge at Baghpat (U.P.).

The location of the bridge 1 is 77° 13’37.81"E & 28° 53’23.35"N. Similarly the Bridge 2 of the study area is proposed to connect Faridabad-Noida-Ghaziabad (FNG) expressway and crosses at Khurrampur/Khata in UP and Faizupur Khadar under Tehsil Ballabhgarh in District Faridabad (Haryana). The location of the bridge 2 is 77° 29’15.39"E & 28° 07’11.23"N.

1.2.2 BRIDGE 3 (RIVER GANGA)

The origin of the river Ganga lies at the Gangotri glacier of the Himalayas in the State of Uttarakhand. In its hilly route through the steep slopes of Siwalik Ranges the river flows north to south and then descends to the plains of Uttarakhand. Here, onwards, the Ganga gradually changes its flow direction from North-South to West-East. On its journey from Gomukh to Ganga Sagar, the holi Ganga flows past the state of Uttarakhand, Uttar Pradesh, Bihar and West Bengal where it finally mingles into the Bay of Bengal. During its journey the river, forms a number of interstate and inter district boundaries. In Uttar Pradesh, it forms a dividing boundary between the districts of Meerut and Bijnor. In view of this, the Government of Uttar Pradesh had approved construction of bridge across river Ganga to ease the road communication between Hastinapur (Meerut) and Chandpur (Bijnor). The bridge after construction shall connect Bijnor district's Chandpur with Hastinapur in Meerut. The bridge is Located at Chetawala Ghat, Hastinapur (UP) and is 840m long The location of the bridge in the Bijnor side & Meerut side are 78° 5’13.8"E, 29° 9’6.21"N & 78° 4’55"E, 29° 9’27"N respectively. The locations of all the three bridges are shown in **figure 1.3**.

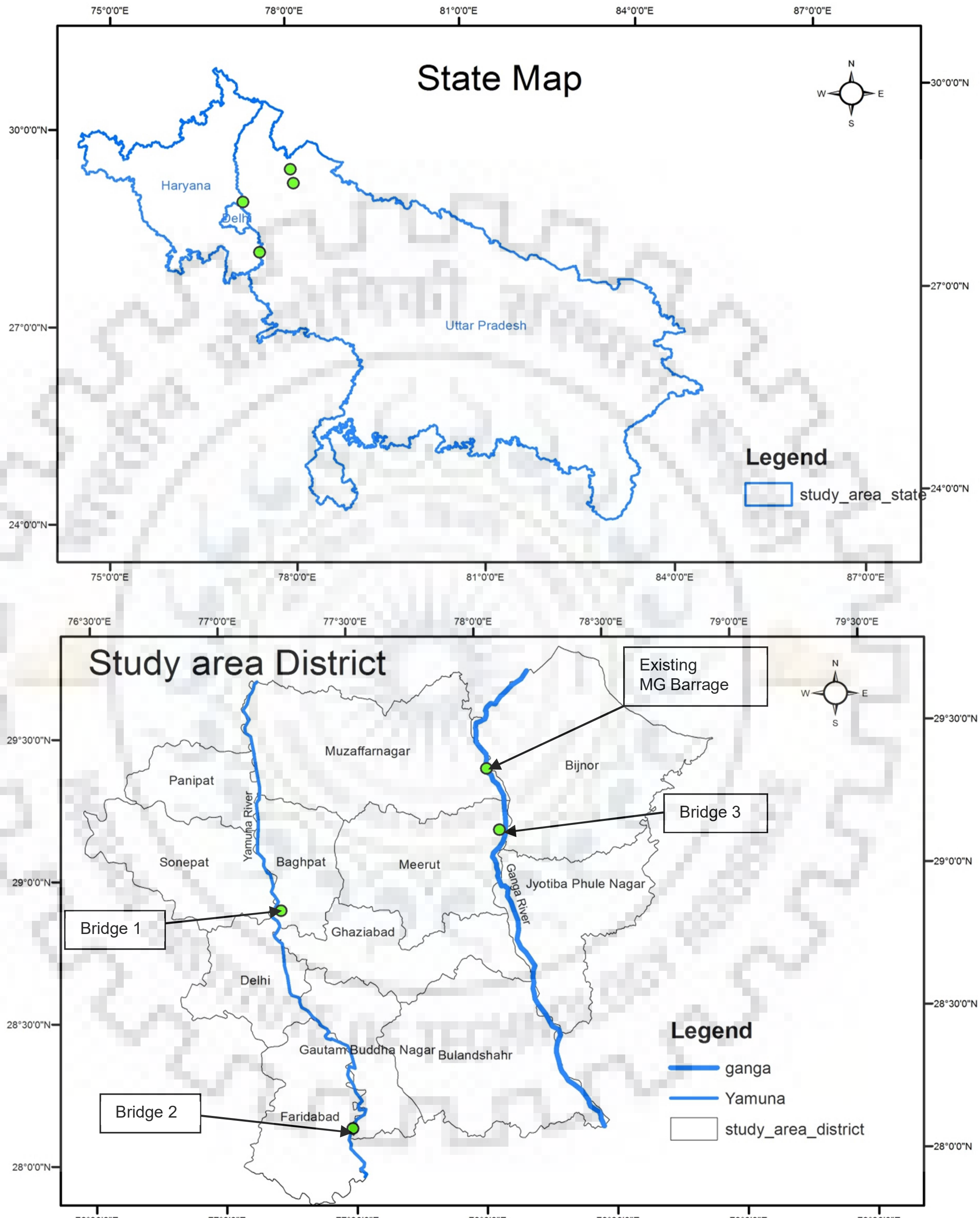


Figure 1.3: Location map of the Bridges in the River Ganga and Yamuna

1.3 RESEARCH GAPS

Many guiding studies, based on physical as well as mathematical modeling are available in the different literature. Generally, guide Bunds in the upstream of bridges are constructed as per conventional guide lines with help of model studies. During the construction of long guide Bunds, beside the cost of construction, very large lands are to be procured. This procurement of land sometimes leads to very long and tedious litigations and huge amount of compensation to the farmers, public owners. To avoid these litigations and to reduce the heavy revenue cost sometimes, deviations from common guide lines are strategically required. At certain locations, it may be possible to obtain a firm and stable topography on one or the other side. In such cases only one guide Bunds on the other side needs to be provided. Obviously the cost of river training is reduced in such cases. No standing guide line can be framed for such strategic positions which are to be solved at hand. With this philosophy, in the present study the existing marginal Bunds is being used as left guide Bunds suitably tied up with S-Curve with the existing dyke Bunds and marginal Bunds, and only elliptical guide Bunds with reduced length is provided on the right side of the bridge without interfering the hydraulics of the bridge. The marginal Bunds in the river Yamuna near Baghpat didn't overtop the high flood in the last 40 years as per field authority.

Similarly the proposed bridge in the river Ganga near Hastinapur was designed for a flood of 11,250 cumecs. A barrage namely, Madhya Ganga barrage, is functioning over river Ganga at 32km upstream of the proposed bridge. It has been reported that waterway of the barrage & energy dissipation arrangements are designed for 15,000 cumecs. Furthermore gauge discharge data provided by site authority indicate that a discharge of 5,17,500 cusec (14,668 cumecs) pass through the barrage on 18th June 2013 at a water level of 220.30 m in the downstream of barrage. The literature does not show any guidelines for the design discharge for the guide Bunds and its protection works. But in the present study, seeing the importance of the bridge in consideration and under construction the hydraulics analysis of the flow with discharge of 14,500 cumecs is carried out through the mathematical model and the design of guide Bunds are done for the same discharge 14,500 cumecs. The flood of 14668 cumec is already experienced at a barrage constructed about 32 Km upstream of the bridge. In case of major bridges, the design of guide Bunds and protection measures for experienced discharge shall produce an extra line of defense for the main structure.

In the present study, Mathematical model HEC RAS is being used for the hydraulic simulation of flow in the above mentioned major Road bridges and with the help of computer program developed based on guidelines for river training works, the guide Bunds and its protection works are carried out. HEC-RAS, is one of the mostly widely used computer program for bridge scour one dimensional hydraulic analyses program with scour estimation modules . The method is cost effective, less time consuming & gives the acceptable results.

1.4 OBJECTIVES

The objective of dissertation work is as follow:-

- To review the design guidelines for Guide Bunds for bridges over major alluvial river.
- To prepare a computer program for design of Guide Bunds in the major river.
- To study the hydraulics of flow around the major bridges through mathematical modeling HEC-RAS.
- To carry out the case studies of simulation of major bridges on the river Ganga & Yamuna.

1.4.1 SCOPE OF WORK

The Bridge 1 & Bridge 2 in the river Yamuna along the Eastern Peripheral Expressway requires huge land for the construction of guide Bunds and protection work. Since the entire Yamuna River is passing through the private land as per revenue records, there is dispute regarding ownership of land. So the study of guide Bunds and the protection measures done by Irrigation and Power Research Institute (IPRI), Punjab; Amritsar are reviewed in the present study in order to provide alternate technical measures.

Similarly A 3-D physical model study for the Bridge 3 near Hastinapur, Meerut in the River Ganga was conducted at Irrigation Research Institute (IRI) Roorkee in 2009 but the scenario of river flow had been changed as a flood of 14668 cumecs experienced in the river Ganga in the year 2013. To cope up with this problem and due to the time constraint, in the present study, the hydraulic simulation of flow through mathematical modeling are carried out for this bridge and other two bridges in river Yamuna with different alternatives without hampering the hydraulics of Bridge.

1.5 ORGANIZATION OF THESIS

Chapter 1: Describes the General Background of the Study and the importance of the topic. The chapter also includes description of the Study area, Research gaps, Objectives & Scope of Work.

Chapter 2: Discuss the definition of HEC RAS, its hydraulic capability and description of the total scour in bridge piers and abutment. This chapter also includes Literatures Review by the different authors based on the scour, waterway and the guidelines for the design of the guide bunds.

Chapter 3: Discuss the materials and method adopted for the hydraulic simulation of flow around the major three bridges in River Ganga & Yamuna. This chapter also includes results with and without bridge including graphs and tables and finally the results are analyzed for the three bridges in the river Yamuna and Ganga.

Chapter 4: This chapter emphasis on design of guide bunds based on the IS, IRC guidelines and the results obtained from the HEC RAS model. Finally the conclusions for the three bridges are incorporated in this chapter.

Chapter 5: The overall conclusions derived from the analysis of the mathematical model HEC RAS are presented along with the scope of the future are also briefed in this chapter.

CHAPTER 2: SELECTION OF MATHEMATICAL MODEL

2.1 INTRODUCTION

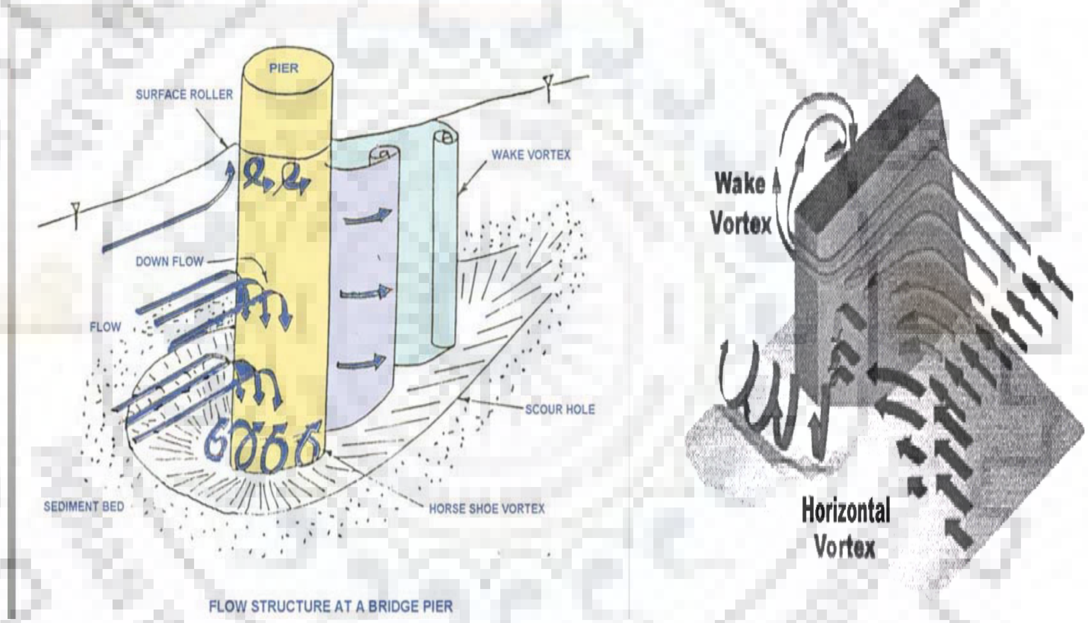
In the present study, a popular and well known model, namely, Hydrologic Engineering Center's River Analysis System (HEC RAS) is used for Hydraulic simulation of flow around major river road bridges in the river Ganga & Yamuna. This model is developed by the U.S. Army corps of Engineers and it allows performing one-dimensional steady, unsteady flow hydraulics, sediment transport/mobile bed computations for quantifying the effects of new structures and their operation in the river. HEC-RAS is an integrated system of software, designed for interactive use in a multi-tasking, multi-user network environment. The system is comprised of a graphical user interface (GUIC), separate hydraulic analysis components, data storage and management capabilities, graphics and reporting facilities. The HEC-RAS system contains many one-dimensional river analyses including the components for: (1) steady flow water surface profile computations; (2) unsteady flow simulation; (3) movable boundary sediment and transport computations. A key element is that all the components use common geometric data representation and common geometric and hydraulic computation routines. In addition to the four river analysis components, the system contains several hydraulic design features that can be invoked once the basic water surface profiles are computed.

2.2 HYDRAULIC CAPABILITY OF HEC-RAS

General Capability of the HEC-RAS is to calculate the water surface profiles for steady and gradually varied flow. The system can handle a single river reach or a full network of channels. The steady flow component is capable of modeling subcritical, supercritical, and mixed flow regime water surface profiles. The computational procedure is based on the solution of the one-dimensional energy equation. Energy losses are evaluated by friction (Manning's equation) and contraction/expansion (coefficient multiplied by the change in velocity head). The momentum equation is utilized in situations where the water surface profile is rapidly varied. These situations include hydraulics of bridges, and evaluating profiles at river confluences (stream junctions). The effects of various obstructions such as bridges and other structures on the flood plain are considered in the computations. The steady flow system is designed for application in floodway encroachments. Also, capabilities are available for assessing the change in water surface profiles due to channel improvements, and levees. Unsteady Flow Simulation component of the HEC-RAS modeling system is capable of simulating one dimensional unsteady flow through a full network of open channels. The hydraulic calculations for cross-sections, bridges, and other hydraulic structures that had been developed for the steady flow component are incorporated into the unsteady flow module. Additionally, the unsteady flow component has the ability to model storage areas and hydraulic connections between storage areas, as well as between stream reaches. Sediment Transport/Movable Boundary Computations: This component of the modeling system is intended for the simulation of one dimensional sediment transport/movable boundary calculations resulting from scour and deposition over moderate time periods; typically days, months or years. Applications to single flood events are also possible. The sediment transport potential is computed by grain size fraction, thereby allowing the simulation of hydraulic sorting and armoring, if the case be. The model is designed to simulate long-term trends of scour and deposition in a stream channel that might result from modifying the frequency and duration of the water discharge and stage, or modifying the channel geometry.

2.3 HEC RAS IN BRIDGE SCOUR

HEC-RAS, is one of the mostly widely used computer program for bridge scour one dimensional hydraulic analyses program with scour estimation modules. It predicts scour at bridge crossing reasonably well for simple regular channel. It provides predictive scour depth computations using parameters from a one-dimensional hydraulic analysis. Field observations show that bridge scour predicted by HEC-RAS generally overestimated the actual scour depth. One of the reasons is that scour prediction equations used in HEC-RAS was developed based on scaling up the laboratory results, which are difficult to satisfy both the hydraulic and hydrodynamic similitude. The assumption of one dimensional flow is another potential source of over estimation. **The basic computational procedure in HEC-RAS is based on solving the one dimensional energy equation. Energy losses are accounted for by friction (Manning's equation) and contraction/expansion (coefficient multiplied by the change in velocity head). The momentum equation is utilized in situations where the water surface profile is rapidly varied.** These situations include mixed flow regime calculations (i.e., hydraulic jumps), hydraulics of bridges, and evaluating profiles at river confluences (stream junctions). Scour occurring at bridge crossing generally include three components: 1) Long-term aggradation and degradation of the river bed, 2) general scour at bridge (including contraction scour and other general scour), and 3) local scour at the piers or abutments. Local scour in bridge piers (Kothyari 2007, Mazumder 2008) occur due to obstruction by pier and pier foundation and the consequent changes in the flow field around the piers. Because of variation in velocity from top to bottom of a pier, the stagnation pressure head is the highest at top and lowest at the bottom of pier, thereby inducing a pressure gradient, since the potential head is highest at the top and lowest at the bottom of the pier. This causes a downward vertical flow impinging the bed. At the pier base, two horse-shoe vortices develop due to flow separation. It is primarily due to the vortex formation and the downward flow impinging on the bed that causes scour at the base of the pier as shown in **Figure 2.1**.



(*Source: Umesh C Kothyari, 2007*)

Figure 2.1: Local Scour around Pier and Abutment

Based on the existence of sediment transportation, scour is classified as clear-water scour and live-bed scour. Two of the scour prediction formulas (i.e., Froehlich equation) and HEC-18 equation (CSU equation) are available in HEC-RAS. Depending upon the angle of flow towards the bridge, HEC has capability to calculate scours around each pier and each abutment with contraction scour also.

2.4 LITERATURE REVIEW

There are many published literatures based on physical as well as mathematical modeling for the hydraulic simulation of flow through the bridges. Determination of the effects on flow distribution and velocities due to bridge, estimation of scour potential including constriction scour and local scour, Profile of guide Bunds and proper protection measures are the important factors in order to safeguard the bridge from failure. Also there are many literatures based on scour around the piers & abutment of the bridge and methods to reduce the scour depth at bridge sites (Vittal et al., 1995; Kumar et al., 1999). Scouring phenomenon at bridge piers and abutments may lead to instability of the bridge foundation and failure of the bridge. An accurate prediction of scour depth at piers and abutments is therefore essential for the safe design of bridges. On the other hand, over estimation of the scour depth results in unnecessary construction costs (Fathi et al. 2011). Some of the papers related with the scour near the bridge piers and abutments are illustrated below:

- (Mazumder, SK 2017) suggested using the mathematical model for the computation of the scour depth in non-cohesive fine and coarse soil as these mathematical model is quite conservative and scientific. The Lacey, Blench, Inglis, Lindsley, and others method give higher scour depth compared with the mathematical model.
- (Pandey et al. 2017) paper mainly deals Maximum scour depth around bridge pier with cohesion less sediment gravel particles. They checked the three latest bridge pier scour models in their study. Three new relationships are proposed by them for computing maximum scour depth, maximum scoured length and maximum affected scoured width in cohesion less sediment at equilibrium scour condition.
- (Pandey et al. 2015) gave three new relationships to estimate the maximum scour depth and maximum scour length upstream and downstream of spur dike. Also the accuracy of existing equations for the computation of maximum scour depth has been checked with available data in the literature and data collected using graphical and statistical performance indices. The new relationships for maximum scour depth are shown to perform better than other existing equations.
- (Brandimarte et al. 2012) paper offers a broad review of the main aspects to be taken into account when analyzing bridge pier scour: 1) processes: an analysis of the type of scour occurring at bridge piers, the most influencing factors, failure mechanisms and local pier scour dynamics; 2) measurements: the latest techniques available for the measurements of the scour depth at bridge piers; 3) estimates: different approaches for the estimate of the

maximum local scour depth and discusses the difficulty to address uncertainty in the estimates.

- Lacey's silt factor (f) originally introduced by Lacey (1930) in his famous regime equations is not applicable for gravelly and bouldery river bed. (Mazumder, SK 2008) analyzed & gave the solution for the local scour in bridge piers for gravelly and bouldery river bed based on the four popular mathematical models. The total maximum scour was found by adding General scour and constriction/contraction scour determined separately by using appropriate methods. Based on Mazumder model it is observed that IRC method overestimates the maximum scour in all the bridges and the error is found to vary from 5% to 275%.
- Mutlu Sumer, 2007 article "Mathematical modeling of scour: A review" deals with the mathematical modeling of scour around piers/piles and pipelines, structures such as groins, breakwaters and sea walls.
- (Kothyari 2007) illustrated the limitations that exist in the code of practices for the estimation of the design scour depth around bridge elements such as pier, abutment, guide bank, spur and groyene. In his paper a critical note on the Codal practices followed in India for estimating the design scour depth is provided.
- In (Barbhuiya and Dey 2004) paper, a detailed review of the up-to-date work on scour at abutments is presented including all possible aspects, such as flow field, scouring process, parameters affecting scour depth, time-variation of scour and scour depth estimation formulae.
- (Karaki 1961) studied the application of guide banks upstream of abutments at clear water conditions and in rivers with flood plains. He showed that locating the guide bank right at the nose of the abutment reduces the scour depth at bridge section more efficiently. He also studied circular and elliptic guide walls with different lengths, and showed that an elliptical guide wall is more effective than a circular one.

Guide banks are one of the effective methods to control hydraulics at bridge constrictions. Guide banks change the flow direction gradually from wider upstream river section to the bridge constriction and ensure almost axial flow near the bridge site. They also help the velocity distribution at the bridge section more uniform by distributing the flow discharge evenly in the section and therefore reduce losses and afflux upstream of the bridge section (Zarrati and Hadian 2000). Some of the papers related with the waterway and occurrence of the backwater due to the constriction of the bridge are illustrated below:

- (Mazumder SK) discussed the limitations of different methods of flood estimation in determining the waterway under the bridges. Determination of waterway under a bridge requires proper investigation and data collection at site for economy, efficiency and safety. He also suggested the Procedure for computing waterway for bridges in mountainous, trough, meandering and deltaic terrains. He also illustrated some case studies for computation of waterway for some new and existing bridges under different terrains in the Himalayan region.
- (Mazumder SK) disused about the Morphology of the river and its aggradation/degradation process with reference to flow of water and sediments in the river. He also explained the Migration of meander laterally due to secondary current and cross-slope developed in a typical meandering bend and the parameters affecting the migration in his paper. Also the Problems encountered in Koshi and Farakka barrages both upstream and downstream have been narrated and the future problems of river training have been discussed with figures and photographs.
- Brandimarte & Woldeyes, 2013 article "Uncertainty in the estimation of backwater effects at bridge Crossings" aims at approaching the prediction of backwater effects at bridge crossings by accounting for the main sources of uncertainty affecting the hydraulic modeling exercise. At the stage of design a new bridge, a specific investigation on the backwater effect has to be also undertaken to analyze its effect on the flooding of its vicinity.
- In (Seckin and Atabay 2005) paper, the performances of six different methods for computing backwater around bridge waterways were compared using the experimental data carefully taken on many combinations of cases. The results of the energy method, momentum method, WSPRO method, Yarnell's method, USBPR method, and arch bridge method were compared with experimental results. The results showed that energy method was able to simulate more accurately the measured backwater values than the other methods.
- (Kaatz and Wesley P . James 1997) investigated the performance and reliability of HEC-2 Normal Bridge Method, HEC-2 Special Bridge Method, WSPRO, and Modified Bradley Method for one-dimensional flow analysis of bridges. The results showed that the HEC-2 Normal Bridge Method was able to accurately simulate the measured backwater values when the recommended 4: 1 expansion ratio assumption was not applied.

To avoid the problem of land acquisition and to reduce the heavy revenue cost sometimes, deviations from common guide lines are strategically required. At certain locations, it may be possible to obtain a firm and stable bank on one side. In such cases only one guide bund on the other side needs to be provided,(N. Koshi, 1992). Obviously the cost of river training is reduced in such cases. With this philosophy, guide banks have been ignored on several occasions on some or other bank of the river, if hydraulics of the bridge is not disturbed.

The upstream and downstream length of the guide Bunds generally depends on the waterway of the bridge. The total scour computed & velocity distribution at the abutments & piers governs the length & thickness of the launching apron & revetment works of the guide Bunds. The different parameters of the guide Bunds based on "Guidelines for Design and Construction Of river Training and Control Works for Road Bridges", (IRC:89-1997) & "Planning and design of guide Bunds for alluvial rivers-Guidelines", (IS, 1994) are shown in the **Table 2.1**:

Table 2.1: Different Parameters of Guide Bund based on IS & IRC Guidelines

SN	Description	As per IS guidelines	As per IRC guidelines
1	Upstream length for guide Bunds	1L to 1.25L	
2	Downstream length of guide Bunds	0.2L to 0.4L	
3	Radius of curved head	0.45L	
4	Radius of curved tail	(0.3 to 0.5)*0.45L	
5	Upstream Angle of sweep	120° to 145°	
6	Downstream Angle of sweep	45° to 60°	
7	Diameter of stone for face slope 2:1		$d=0.0282*V^2$
8	Weight of stone required on sloping surface	$W=(0.02323S_s*V^6) / (K(S_s-1)^8)$	Curve is provided
9	Thickness of crates on slope	$T=V^2/(2g*(S_s-1))$	$T=0.06Q^{1/3}$
10	Equivalent diameter of stone for		$V=4.893d^{1/2}$
11	Weight of stone required for apron		Curve is provided
12	Design scour depth for Upstream curved head of Guide Bunds	2D to 2.5D	
13	Design scour depth for straight reach to nose of Downstream Guide Bunds	1.5D	
14	Design scour depth for downstream curved tail of Guide Bunds	1.5D to 1.75D	
15	Top width of the guide Bunds	6 to 9m	

Where, L= length of waterway, V=Velocity of flow in m/s, d=diameter of stone in m. D=Scour Depth

J Hoyle, et.al. article "Modeling Reach-Scale Variability In Sediment Mobility: An Approach For Within Reach Prioritization Of River Rehabilitation Works" provides a method of prioritizing rehabilitation at the within-reach scale by using a high-resolution reach-scale modeling approach to examine the relative entrainment potential of sediment stores.

R. Bonner & W. Brunner, 1996 Paper "Bridge hydraulic analysis with HEC RAS." US army corps of engineers provides the bridge modeling approach, available method, & research results on flow transitions & associated modeling guidelines. Arcement Jr, Schneider, Arcement, & Schneider, 1989, "Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains" provides Manning's roughness coefficient, *n,* for stream channels. All these papers have been used as references for the present study.

2.5 CONCLUSION

The present chapter gives the brief introduction on Mathematical Model namely Hydrologic Engineering Center's River Analysis System (HEC RAS). In this study this model is used for Hydraulic simulation of flow around major river road bridges in the river Ganga & Yamuna. This model is developed by the U.S. Army corps of Engineers and it allows performing one-dimensional steady, unsteady flow hydraulics, sediment transport/mobile bed computations for quantifying the effects of new structures and their operation in the river. The General Capability of the HEC-RAS is to calculate the water surface profiles for steady and gradually varied flow. Unsteady Flow Simulation component of the HEC-RAS modeling system is capable of simulating one dimensional unsteady flow through a full network of open channels. HEC-RAS, is one of the mostly widely used computer program for bridge scour one dimensional hydraulic analyses program with scour estimation modules. It predicts scour at bridge crossing reasonably well for simple regular channel. It provides predictive scour depth computations using parameters from a one-dimensional hydraulic analysis. Basically Froehlich equation is used in the present study for scour prediction around the piers and abutment. This chapter also covers the different published literatures based on the scour depth near the bridge piers and abutments. Some of the papers related with the waterway and occurrence of the backwater due to the constriction of the bridge are discussed in this chapter. The different parameters of the guide Bunds based on the design guidelines for the design of Guide Bunds are provided in this chapter. The input data required for hydraulic simulation of flow using the mathematical model HEC RAS with its methodology, the results with and without bridge including graphs and tables are illustrated in the next chapter.

CHAPTER 3: HYDRAULIC SIMULATION OF FLOW AROUND MAJOR BRIDGES

3.1 INTRODUCTION

To prevent the river from out-flanking the bridge, the Guide bunds are very important river training works. They are earthen embankments with stone pitching in the slopes facing water, to guide the river through the bridge. These river training works are provided for rivers flowing in planes, upstream and downstream of the hydraulic structures or bridges built on the river. There are altogether three Bridges for the hydraulic simulation of flow through mathematical model HEC RAS. The Bridge 1 is located near Baghpat & Bridge 2 is located near Faizupur Khadar along the Eastern Peripheral Expressway in the river Yamuna. Similarly the Bridge 3 is located near Hastinapur at Chetawala Ghat; Meerut in the river Ganga. It is with this objective, so as to review the proposed alignment of the Guide Bunds and protection work of these Bridges. Also to suggest alternate technical measures on the basis of the previous study carried out by IPRI, Amritsar & IRI, Roorkee respectively. The materials and method adopted for these analyses, results with and without bridges including graphs and tables are discussed in this chapter.

3.2 MATERIALS AND METHOD

The input data required and used for the mathematical simulation of flow for the three bridges are illustrated below:

Bridge 1

- Survey of River Yamuna from 2 Km upstream to 1 Km downstream of the Bridge.
- General Arrangement Drawing (GAD) of the bridge.
- Location and alignment of marginal bunds.
- Alignment of guide bunds.
- Design calculations of the bridge and hydrology of the catchment.
- Gauge discharge data from the IPRI model study report at different locations at upstream and downstream of the bridge axis.

Table 3.1: Salient features of proposed Bridge 1 over river Yamuna

Location:	200 Km downstream of Tajewala Head works and about 8.0 Km downstream of the existing bridge at Baghpat (U.P.). Ch. 12+300 to 12+900 of National Expressway-II.	
Design Discharge	11000 cumec	
HFL	216.65m	
Finished Road Level	225.524m	
Top Level of Abutment	218.52m	
Length of Bridge	600 m (10 Spans of 60m each)	
Foundation	Concrete foundation, 8.0 m dia., 40.0 m deep (approx.)	
Guide Bunds: (Originally Proposed)		
	Left	**Right**
Upstream:	straight Portion 375m Curved Head 240m Sweep Angle 120^0	elliptical Portion 600m Curved Head 240m Sweep Angle 120^0
Downstream:	Straight Portion 48m Curved tail 72m Sweep Angle 120^0	Straight Portion 48m Curved tail 72m Sweep Angle 120^0
Guide Bunds: (Modified/Recommended)		
Upstream:	**Upstream portion of the guide bank** is a circular curve of radius (R1= 230 m) and angle 120°, then has S curve with radius (R2= 181 m) and angle 53° so that it can meet the existing bund tangentially. A small part (approx. 50m) is straight & meets another existing bund which is approximately parallel to Yamuna. Strengthening of parallel bund has	Elliptical guide bund (a=360m and b=180m) Curved Head 100m Sweep Angle 45^0

	been proposed by rising, by piles & by launching apron.	
Downstream:	Straight Portion 80m Curved tail 70m with radius 100.0m Sweep Angle 45^0	Straight Portion 80m Curved tail 70m with radius 100m Sweep Angle 45^0

Bridge 2

- Cross section extracted from the images obtained from Google earth Pro for the River Yamuna from 2 Km upstream to 1 Km downstream of the Bridge.
- General Arrangement Drawing (GAD) of the bridge including Guide Bund.
- Alignment of guide bunds.
- Design calculations of the bridge and hydrology of the catchment.
- Gauge discharge data from the IPRI model study report at different locations at upstream and downstream of the bridge axis.

Table 3.2: Salient features of proposed Bridge 2 over river Yamuna

Location:	50 Km. downstream of Okhla Barrage and 40 Km upstream of the existing bridge at Palwal Ch. 102+575 to 103+175 of National Expressway-II.	
Design Discharge	13462 cumec	
HFL	197.200m	
Finished Road Level	208.200m	
Top Level of Abutment	201.32m	
Length of Bridge	600 m (10 Spans of 60m each)	
Foundation	Concrete foundation, 8.0 m dia., 43.0 m deep (approx.)	
Overall width of each carriageway	20.65m	
Guide Bunds: (Originally Proposed)		
	Left	**Right**
Upstream:	elliptical Portion (a=600m and b=400m) Curved Head 200m Sweep Angle 77^0	Straight portion 21m Curved Head 60m Sweep Angle 90^0
Downstream:	Straight Portion 48m Curved tail 72m Sweep Angle 120^0	Straight portion 21m Curved Head 60m Sweep Angle 90^0
Guide Bunds: (Modified/Recommended)		
Upstream:	elliptical Portion (a=360m and b=180m) Curved Head 100m Sweep Angle 45^0	Straight portion 21m Curved Head 60m Sweep Angle 90^0
Downstream:	Straight Portion 48m Curved tail 72m Sweep Angle 120^0	Straight portion 21m Curved Head 60m Sweep Angle 90^0

Bridge 3

- Field survey data of the year 2007 showing the bridge axis for Bridge 3.
- General Arrangement Drawing (GAD) of the bridge, Design discharge of the bridge 11,250 cumecs, HFL 212.98m of the river ganga at 11,250 cumecs, Water surface slope of the river - 0.22m / km provided by the field authority.
- Discharge data of Madhya Ganga barrage as provided by the field authority for the month of June 2013 shows 14,668 cumec discharge passed through the barrage.
- Gauge discharge data from the ((IRI) 2009) model study report at different locations at upstream and downstream of the bridge axis.

Table 3.3: Salient features of proposed Bridge 3 over river Ganga

Location:	**Near Chetawala Ghat (Hastinapur Side)** (32 Km downstream of Madhya Ganga Barrage (Bijnor))	
Design Discharge	11,250 cumec	
HFL	212.98m	
Finished Road Level	216.71m	
Top Level of Abutment	214.24m	
Length of Bridge	**Span No. from Left**	**Width of span from c/c of pier**
	1	32.675 m
	2 & 3	34.000 m
	4	10.150 m
	5-27	30.400 m
	28	29.075 m
	Total Length	**840.40m**
Foundation	Concrete foundation, 5.5 m dia., 40.0 m deep (approx.)	

Guide Bunds: (originally Proposed)	
Upstream:	elliptical Portion (a=650m and b=250m) Curved Head 200m Sweep Angle 90^0
Downstream:	Straight Portion 100m Curved tail 150m Sweep Angle 45^0
Guide Bunds: (Modified/Recommended)	
Upstream:	elliptical Portion (a=850m and b=300m) Curved Head 114m Sweep Angle 45^0
Downstream:	Straight Portion 100m Curved tail 150m Sweep Angle 45^0

3.2.1 Preparation of HEC-RAS model - The geometric data:

The HEC-RAS mathematical model for river Yamuna and Ganga were set up by providing, as inputs, the cross sectional geometric data at the longitudinal spacing of about 2+000m upstream to 1+000m downstream for the Bridge 1 and Bridge 2.Similarly 4+200m upstream to 2+400m downstream For Bridge 3. The channel cross sections were laid as used by IPRI, Amritsar Punjab and IRI Roorkee in earlier model studies. The cross sections were extrapolated up to such an elevation to accommodate design flood under consideration. The values of Manning's n 0.030 for bridge 1, 0.030 for bridge 2 and 0.030 for bridge 3 were used uniformly for the channel and 0.040 for bridge 1, 0.035 for bridge 2 and 0.035 for bridge 3 for floodplains on both sides. Various other parameter values like contraction coefficient of 0.1 and expansion coefficient = 0.3, value of computational step length etc. also were specified. The file thus produced is called *.geo files and governs the topography and GAD of the project. The survey plan for the Bridge 3 in the study area is shown in **figure 2.2.**

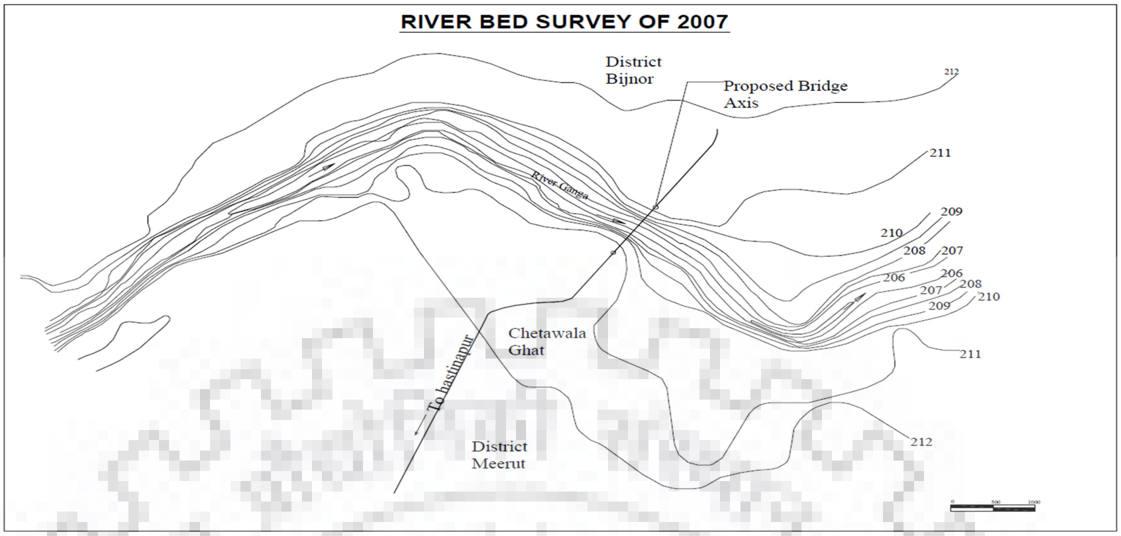


Figure 3.1: Survey plan for the Bridge 3 in river Ganga

3.2.2 Preparation of flow data and carrying out analysis:

3.2.2.1 Steady state Flow Analysis:

For Bridge 1 and Bridge 2 in River Yamuna **maximum discharge of 14,000 cumecs and 14,500 cumecs** are assumed respectively **(Table 3.4 & Table 3.5)**.

The proposed bridge is designed for flood of 11,250 cumecs as reported by field authority. A barrage namely, Madhya Ganga barrage, is functioning over river Ganga at 32km upstream of the proposed bridge. It has been reported that waterway of the barrage & energy dissipation arrangements are designed for 15,000 cumecs. Furthermore gauge discharge data provided by site authority indicate that a discharge of 5,17,500 cusec (14,668 cumecs) pass through the barrage on 18th June 2013 at a water level of 220.30 m in the downstream of barrage. Therefore, for the analysis of bridge & guide Bunds at Hastinapur, **maximum discharge of 14,500 cumecs is assumed** for the Bridge 3 **(Table 3.6).** In order to carry out the steady flow analysis, the discharge values are arbitrary single peak flow hydrograph & the time duration of flow hydrograph were kept as 1 year.

Boundary Conditions:

For Subcritical flow regime, downstream boundary condition is required. Here normal depth is taken as downstream boundary condition. The average slope at the downstream cross-section and are taken as 0.3m/km, 0.2m/km, and 0.22m/km for Bridge 1, Bridge 2, and Bridge 3 respectively.

3.2.2.2 Sediment Analysis:

The bed gradation of sediment is defined in the sediment data editor. Left & right Bunds stations are also defined for all the reaches. The minimum elevation up to which the bed scour is expected is arbitrary allowed and in this study is taken as 10m below the deepest bed level.

Boundary conditions:

The bed gradation of sediment for all the sets of discharges needs to be defined. In addition, the sediment loads (ppm) in the different duration of time series are defined and the file is saved as the sediment data. The discharge and its time duration along with graded sediment passing during the interval needs to be defined for sediment analysis. In the quasi-unsteady flow data editor, the boundary conditions for the upstream & downstream reach are defined. The increment for calculating the bed changes is also fixed. The temperature variation for the different duration of time series is also defined. File is saved as the quasi-unsteady flow data. Sediment load with corresponding discharge as considered in study are shown in **Table 3.4 to Table 3.6.**

Table 3.5: Sediment load with corresponding discharge for Bridge 1

Increasing Flood		Decreasing Flood	
Discharge (cumecs)	Sediment (ppm)	Discharge (cumecs)	Sediment (ppm)
200	200	12500	2200
225	250	11000	1800
350	250	9000	1500
500	300	7000	1200
800	500	5000	1000
1500	750	4000	800
2000	800	3500	600
3000	850	3000	500
3000	1000	2800	300
4000	1000	2500	300
7000	1500	2000	250
9000	2000	1000	250
10000	2000	800	250
11000	2500	500	200
12500	3000	250	100
14000	4000		

Table 3.4: Sediment load with corresponding discharge for Bridge 2

Increasing Flood		Decreasing Flood	
Discharge (cumecs)	Sediment (ppm)	Discharge (cumecs)	Sediment (ppm)
200	200	12500	2300
225	250	10000	1800
350	250	9000	1500
500	300	7000	1200
800	500	5250	1000
1300	750	3900	800
2000	800	3500	600
2600	850	3000	500
3000	1000	2800	300
3900	1000	2600	300
5250	1500	2000	250
6000	2000	1300	250
7000	2000	800	250
10000	2200	500	200
12500	2500	250	100
14500	2600		

Table 3.6: Sediment load with corresponding discharge for Bridge 3

Increasing Flood		Decreasing Flood	
Discharge (cumecs)	Sediment (ppm)	Discharge (cumecs)	Sediment (ppm)
200	200	13000	2200
350	250	11000	1800
500	300	9000	1500
800	500	7000	1200
1500	750	5000	1000
2000	800	4000	800
3000	850	3500	600
3000	1000	3000	500
4000	1000	2800	300
7000	1500	2500	300
9000	2000	2000	250
10000	2000	1000	250
11250	2200	800	250
13000	2300	500	200
14500	2500	250	100

3.2.2.3 Running of model for Hydraulic Analysis

For getting a correct analysis, the simulated model needs to be validated. For this, the simulated model is run without any proposed structure / event. Running of the sediment Analysis will save the output in .dss format files, which can be saved in any editable format. Thus obtained, rating curve without the bridge is matched with the real data observed at site. If the values vary under the acceptable limit, the model is taken validated and can be used for further analysis. The bridge is then fixed at appropriate location. There is no clear methodology mentioned in HECRAS for simulating guide Bunds in the model. A simple and feasible method is therefore adopted to simulate guide Bunds by appending the cross sections with geometry of guide Bunds. Again, the sediment analysis is run with the addition of bridge system. The results of model run with respect to velocity along the guide Bunds, bridge spans, afflux etc. are taken. Hydraulic calculations for bridge scour is performed through choice of formulae and the total scour for the abutment & the piers can be obtained by knowing the constriction scour, abutment scour, & piers scour. The design of the guide Bunds thus can be analyzed in the computer program with the parameters derived from the model studies and taking account into the guidelines provided by the IS and IRC guidelines for the design of guide bunds. The flow chart of the Hec-Ras model for the hydraulic flow simulation is shown in the **figure 3.2**.

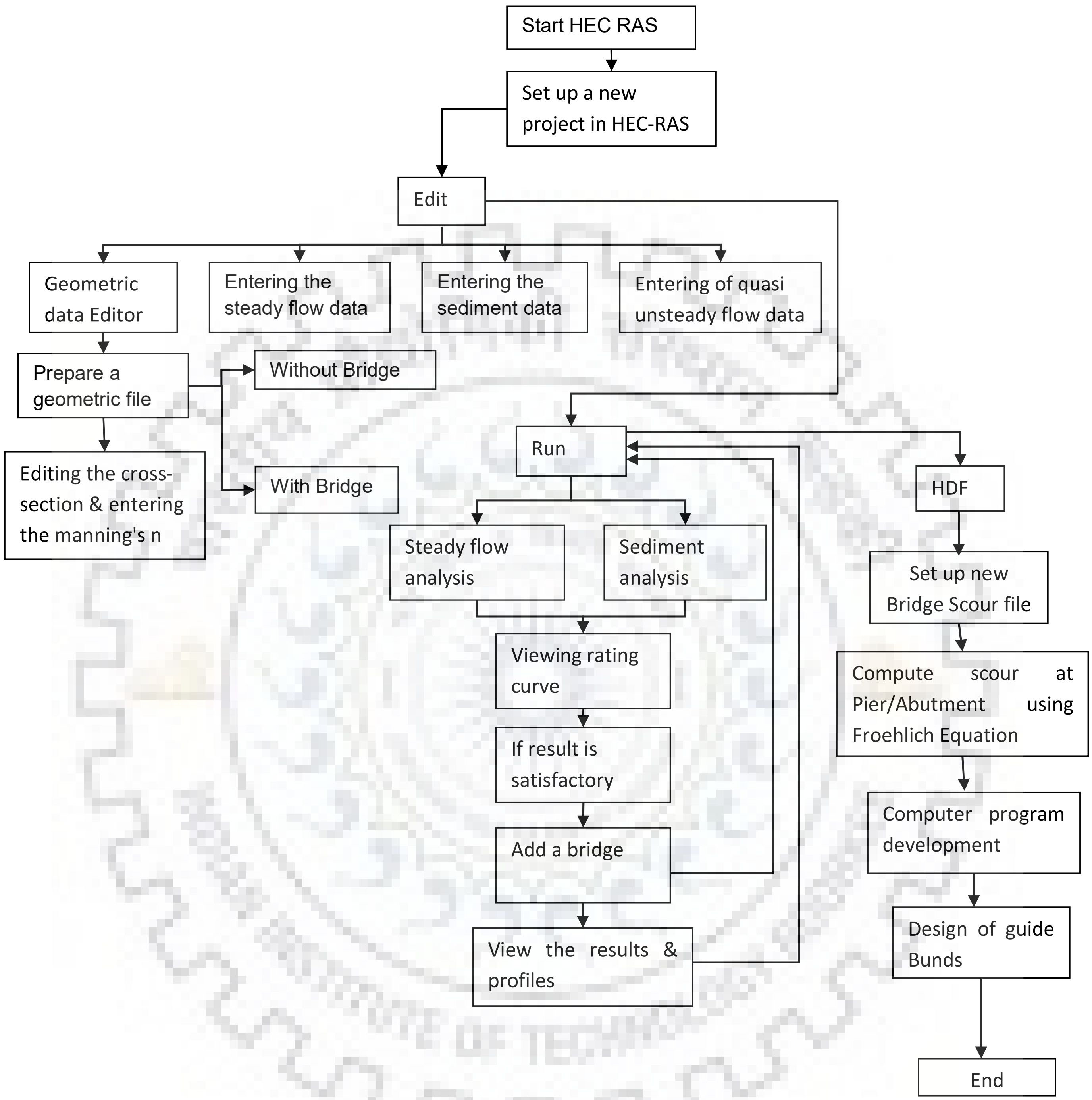


Figure 3.2: Flow chart of the HEC-RAS model

3.2.3 Validation of model(s) and model run without bridge(s):

In order to validate the model, a geometry file with cross sections (without bridge) as provided was prepared and the HEC-RAS model was run up to design discharge. After run of the model for full hydrograph of one year, rating curves were obtained. Water levels obtained from the rating curves were compared with the water levels recorded by 3-D physical model studies. The water levels were compared with water levels obtained by HEC-RAS model as shown in **Table 3.7 to Table 3.9**:-

Table 3.7: Comparison of water level observed in 3D Model & HEC RAS for Bridge 1

DISCHARGE (CUMEC)	Water levels Observed at 300 M UPSTREAM OF BRIDGE AXIS		Water levels Observed at Bridge Axis		Water levels Observed at 500 downstream of Dam Axis	
	IPRI Model	HEC-RAS	IPRI Model	HEC-RAS	IPRI Model	HEC-RAS
2750	213.55	213.35	213.50	213.29	213.50	213.20
5500	214.55	214.30	214.50	214.30	214.35	214.21
8250	215.45	215.20	215.35	215.20	215.30	215.00
11000	216.30	215.90	216.15	215.82	216.05	215.72

Table 3.8: Comparison of water level observed in 3D Model & HEC RAS for Bridge 2

Discharge (Cumecs)	Water level observer at 1+780 US of Bridge axis		Water level observer at 0+650 US of Bridge axis		Water level observer at 0+105 US of Bridge axis		Water level observer at 0+461 DS of Bridge axis	
	HEC-RAS Model	IPRI Model	HEC-RAS Model	IPRI Model	HEC-RAS Model	IPRI Model	HEC-RAS Model	IPRI Model
1300	190.352	190.600	190.345	190.300	189.543	190.100	188.659	190.900
2600	191.720	191.800	191.705	191.600	190.419	191.600	190.792	191.200
3900	192.981	192.200	192.955	191.900	192.534	191.900	192.320	191.800
5250	194.054	192.500	194.024	192.200	193.740	192.000	193.566	191.900
6000	194.492	192.800	194.024	192.700	194.199	192.600	194.022	192.400
7000	195.006	193.100	194.971	192.900	194.727	192.850	194.554	192.800

Table 3.9: Comparison of water level observed in 3D Model & HEC RAS for Bridge 3

Discharge (Cumecs)	Water levels Observed at 2200 m upstream of Bridge Axis		Water levels Observed at Bridge Axis		Water levels Observed at 2400 m downstream of Bridge axis	
	IRI Model	HEC-RAS Model	IRI Model	HEC-RAS Model	IRI Model	HEC-RAS Model
1500	210.83	210.54	210.40	210.13	210.20	209.62
3000	213.23	211.91	211.44	211.20	211.00	210.75
6000	213.11	213.00	212.50	212.30	212.10	211.80
9000	213.44	213.50	212.85	212.92	212.44	212.40
11250	213.65	213.87	213.00	213.28	212.55	212.73

The table indicates that the water levels given by HEC-RAS are in close conformity with the observations made on 3-D model. Therefore, the mathematical model(s) is taken to be validated. Some difference in the water levels obtained from 3D physical and mathematical model for Bridge 3 might be due to difference in years of survey used in both models.

The graphical representation of G-D curve at the proposed Bridge Axis is shown in **Figure 3.3 to Figure 3.5**.

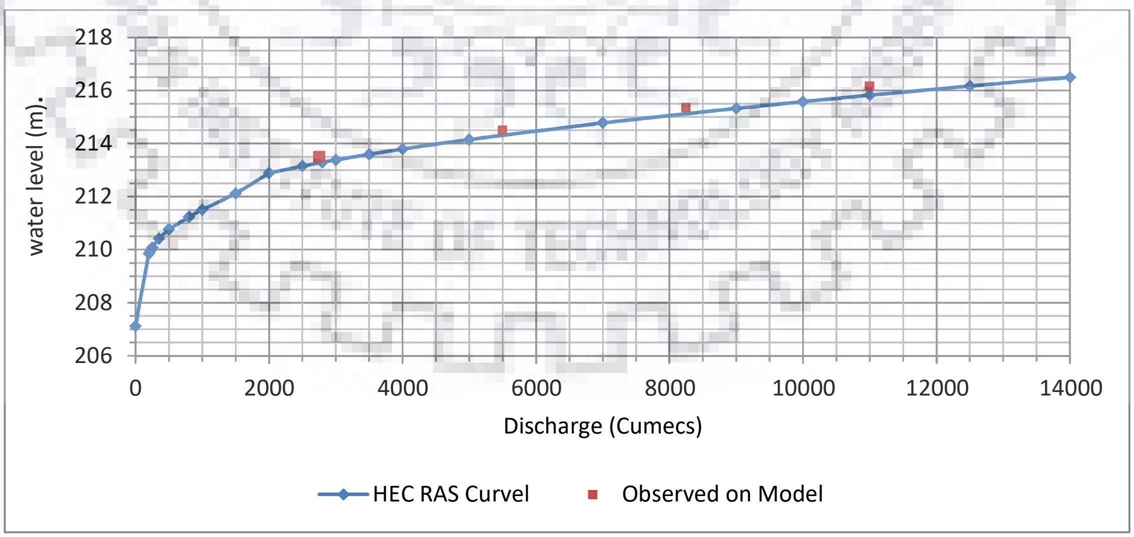


Figure 3.3: GD Curve at Bridge Axis without Bridge (Bridge 1)

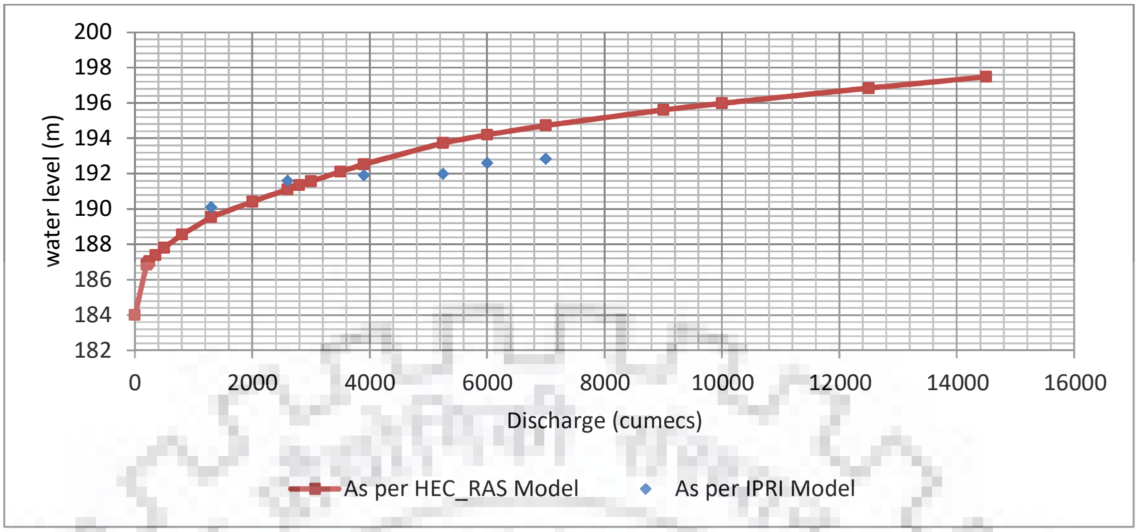


Figure 3.4: GD Curve at Bridge Axis without Bridge (Bridge 2)

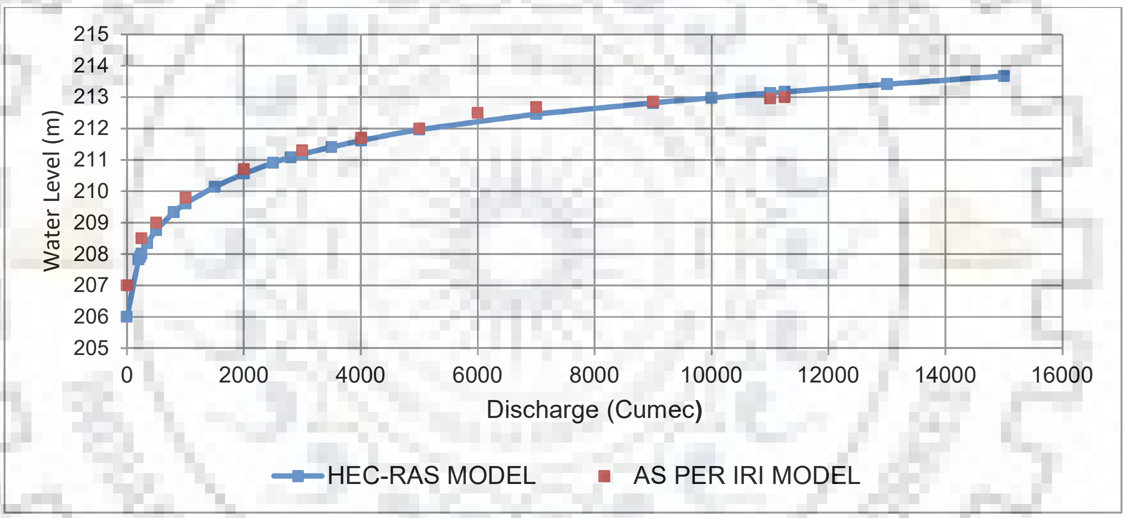


Figure 3.5: GD Curve at Bridge Axis without Bridge (Bridge 3)

The water surface profiles for all bridges at different discharges from 500 cumec to 14500 cumec are shown in **Figure 3.6 to Figure 3.8**. Similarly, Velocity and discharge distribution in the channel, on right and left over bunds is further shown in **Figure 3.9** and **Figure 3.14** respectively.

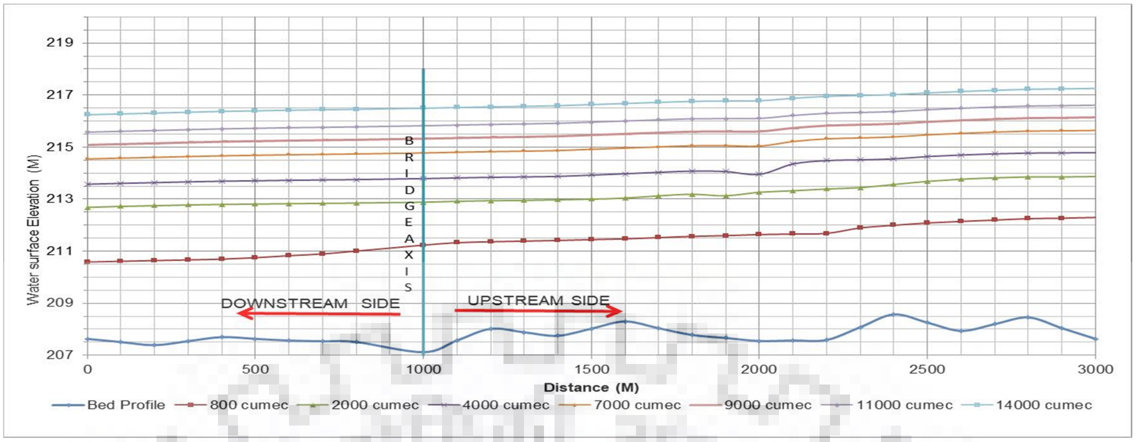


Figure 3.6: Water Surface Profiles at different discharges without Bridge (Bridge 1)

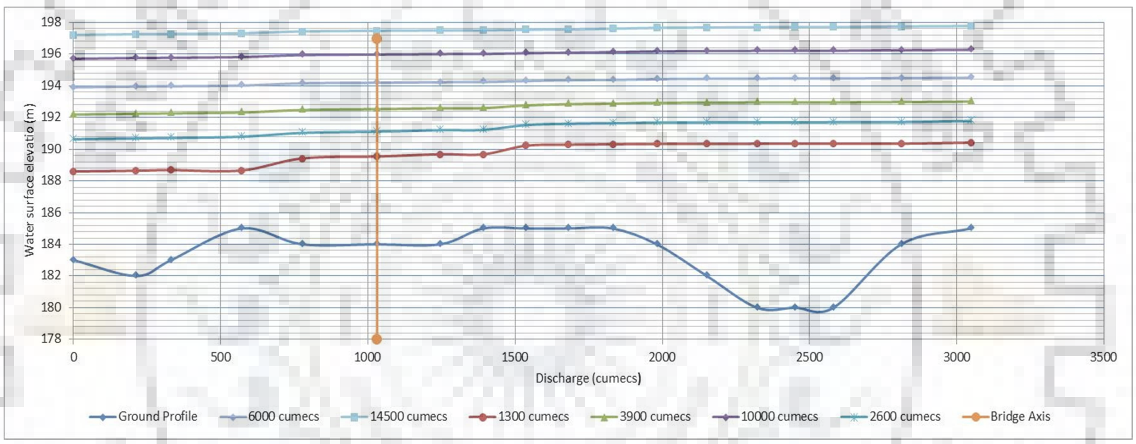


Figure 3.7: Water Surface Profiles at different discharges without Bridge (Bridge 2)

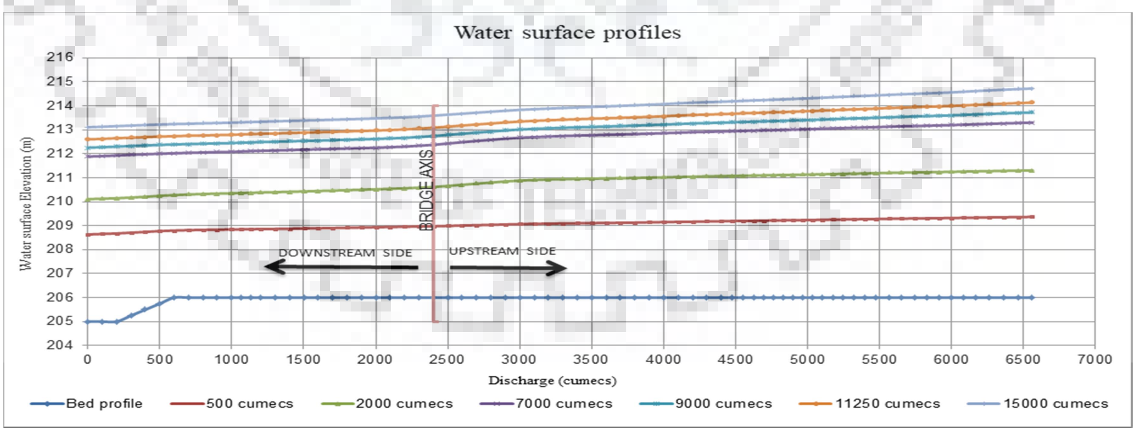


Figure 3.8: Water Surface Profiles at different discharges without Bridge (Bridge 3)

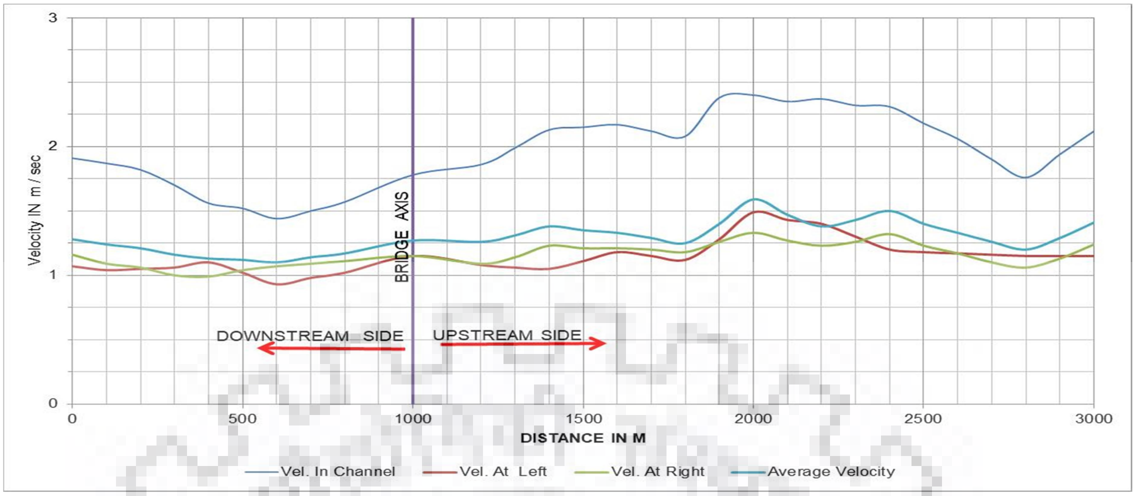


Figure 3.9: Spatial Distribution of Velocity at 14000 cumec without Bridge (Bridge 1)

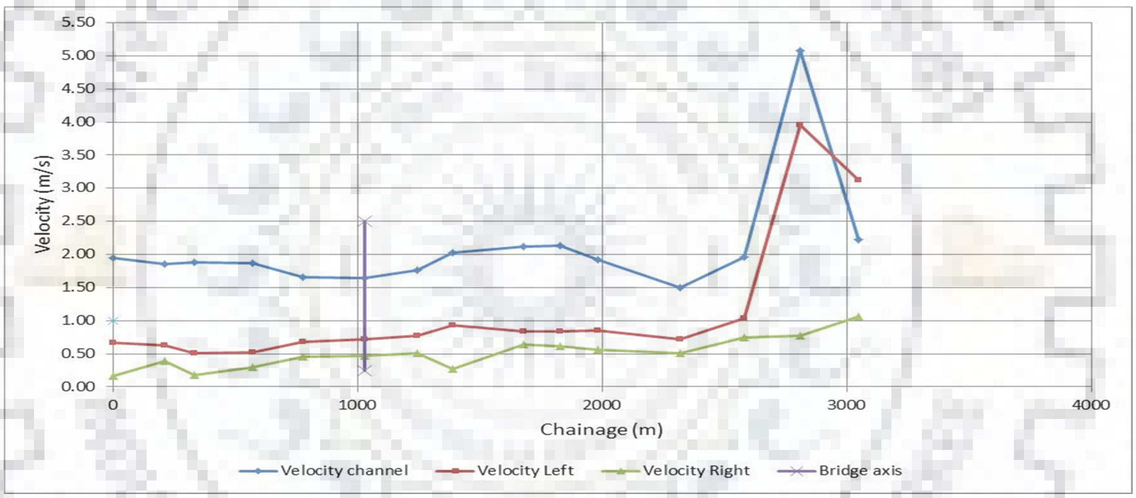


Figure 3.10: Spatial Distribution of Velocity at 14500 cumec without Bridge (Bridge 2)

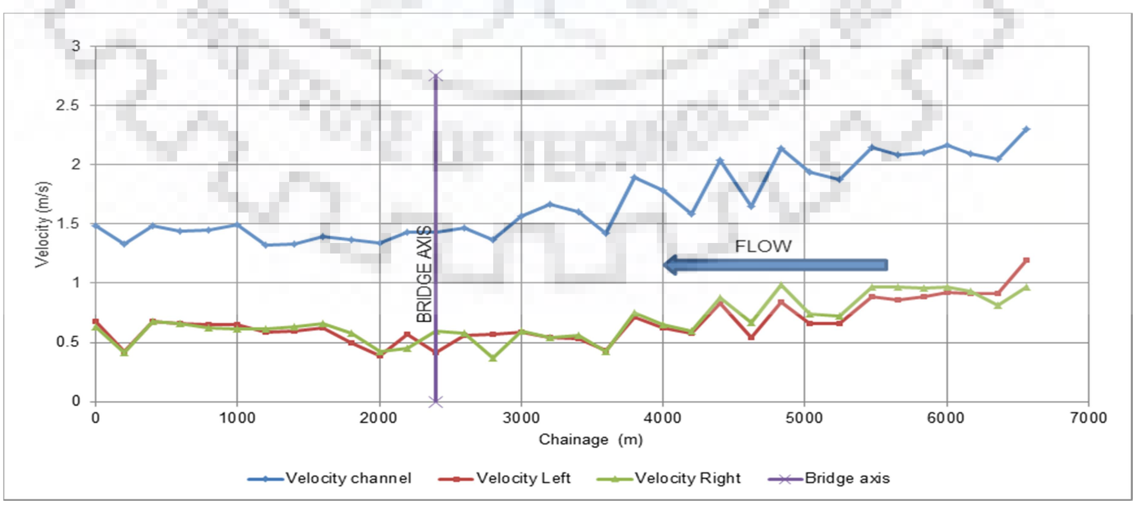


Figure 3.11: Spatial Distribution of Velocity at 14500 cumec without Bridge (Bridge 3)

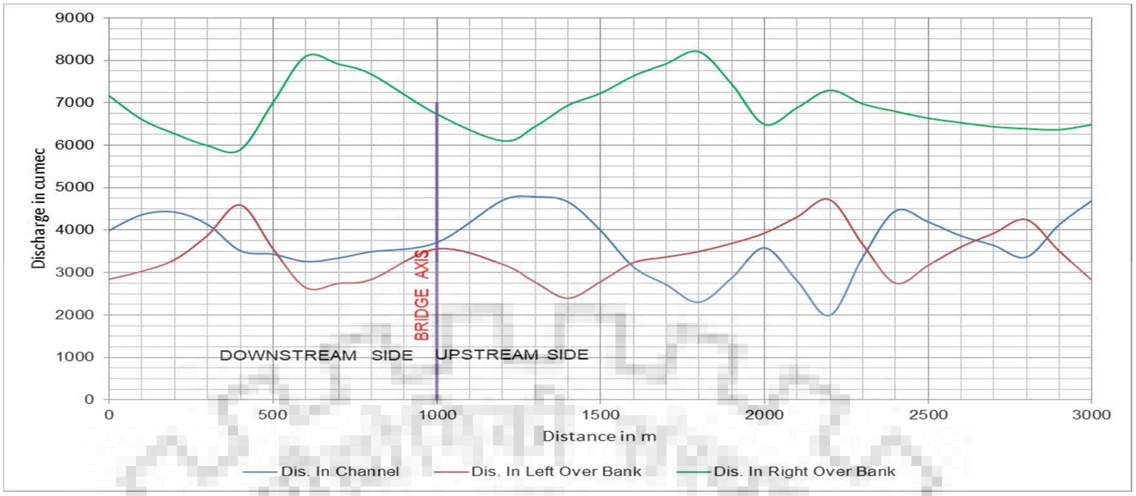


Figure 3.12: Spatial Distribution of Discharge at 14000 cumec without Bridge (Bridge 1)

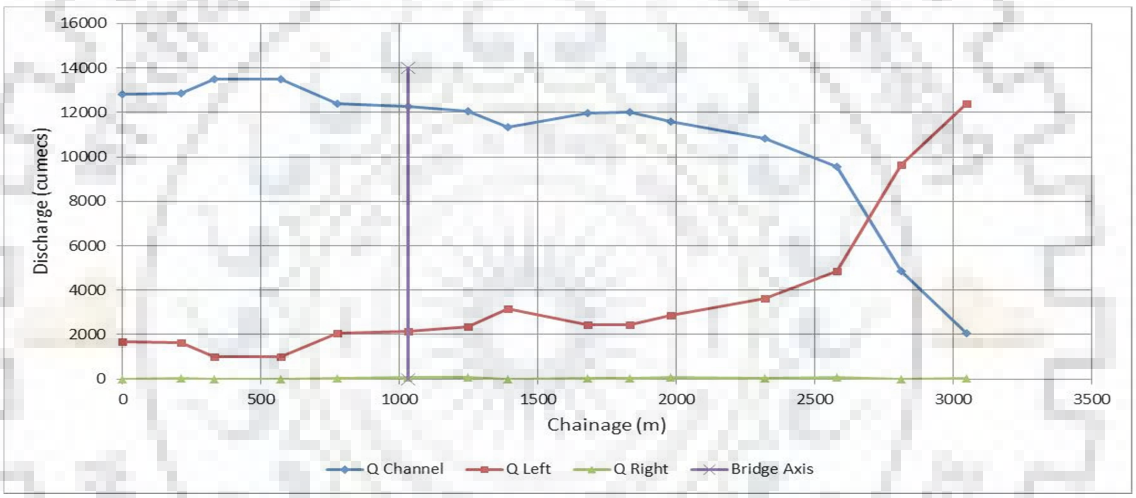


Figure 3.13: Spatial Distribution of Discharge at 14500 cumec without Bridge (Bridge 2)

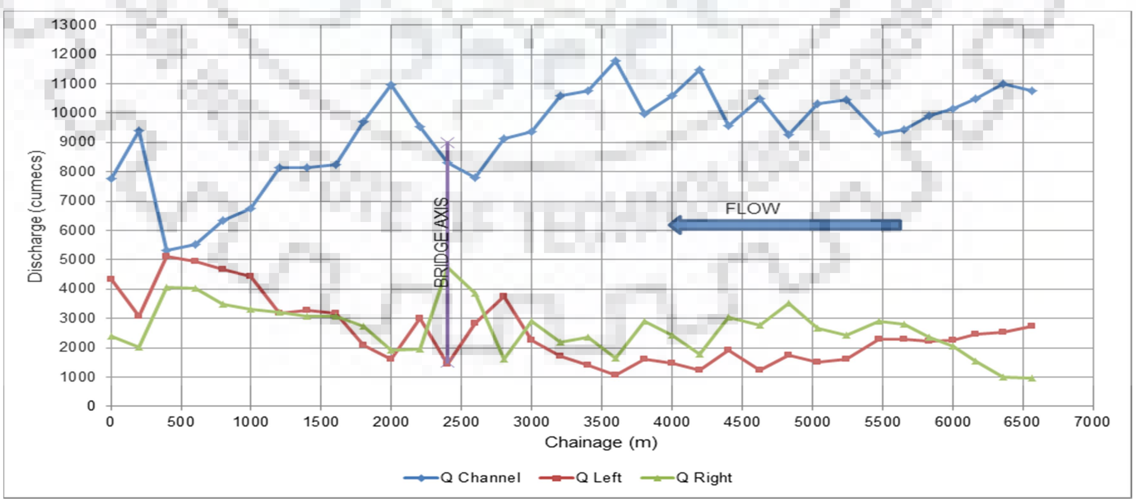


Figure 3.14: Spatial Distribution of Discharge at 14500 cumec without Bridge (Bridge 3)

3.2.4 Bridge simulation (Originally Proposed and Modified Guide Bunds)

After the validation of model, the bridge, bridge piers, abutments and embankment were simulated in the geometrical file data. Bridge spans, bridge piers, vertical abutments etc. were simulated as per GAD provided by site officers.

3.2.4.1 Afflux and G-D Curve with Bridge

After running the hydrograph with bridge and guide Bunds up to discharge 14000 cumecs for Bridge 1, discharge 14500 cumecs for Bridge 2 and discharge 14500cumec for Bridge 3, G-D curves were generated. The obtained GD curve at upstream of bridge as shown in **Figure 3.15 to Figure 3.20** indicates certain water level at different discharges with originally proposed and modified guide bunds producing afflux. The afflux for two different cases of Guide bund is shown in **Table 3.10.** The table below indicates that the change in the layout of guide Bunds does not make any morphological change in the river behavior.

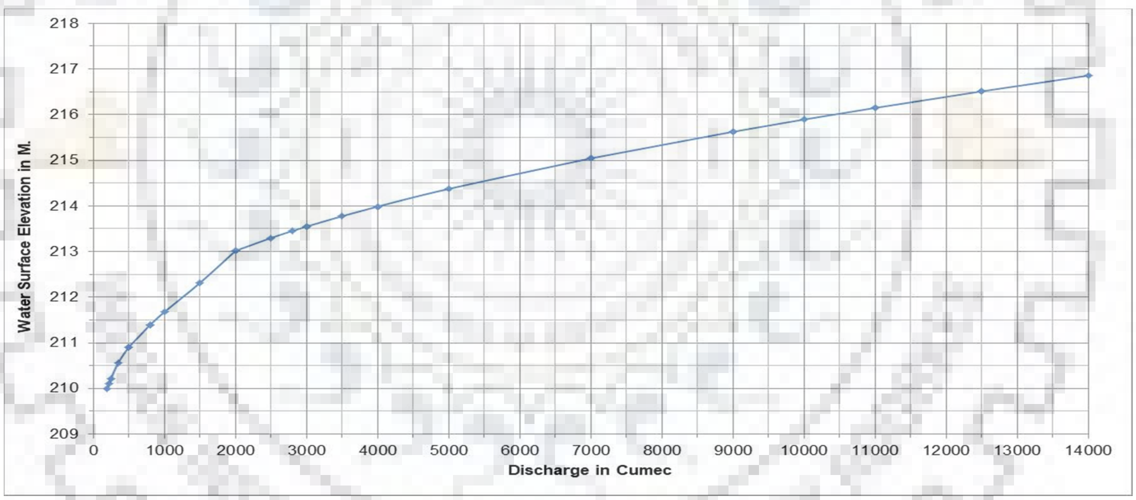


Figure 3.15: GD Curve obtained at 200m upstream of BA for OGB (Bridge 1)

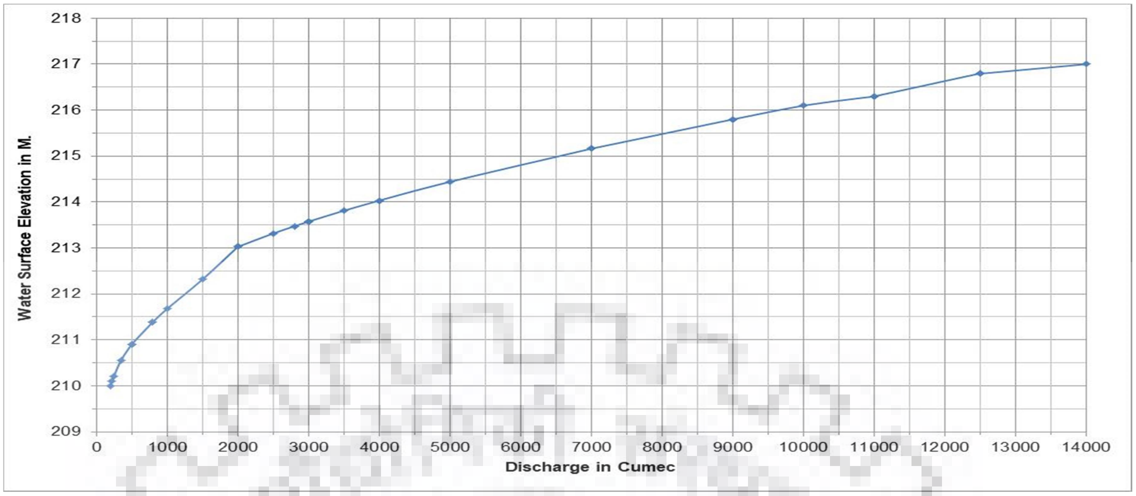


Figure 3.16: GD Curve obtained at 200m upstream of BA for MGB (Bridge 1)

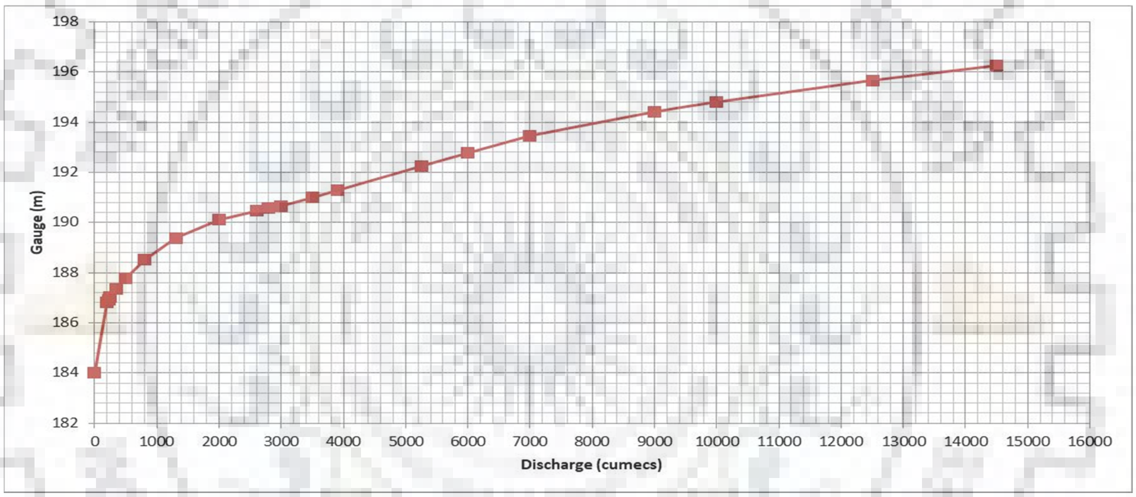


Figure 3.17: GD Curve obtained at 215m upstream of BA for OGB (Bridge 2)

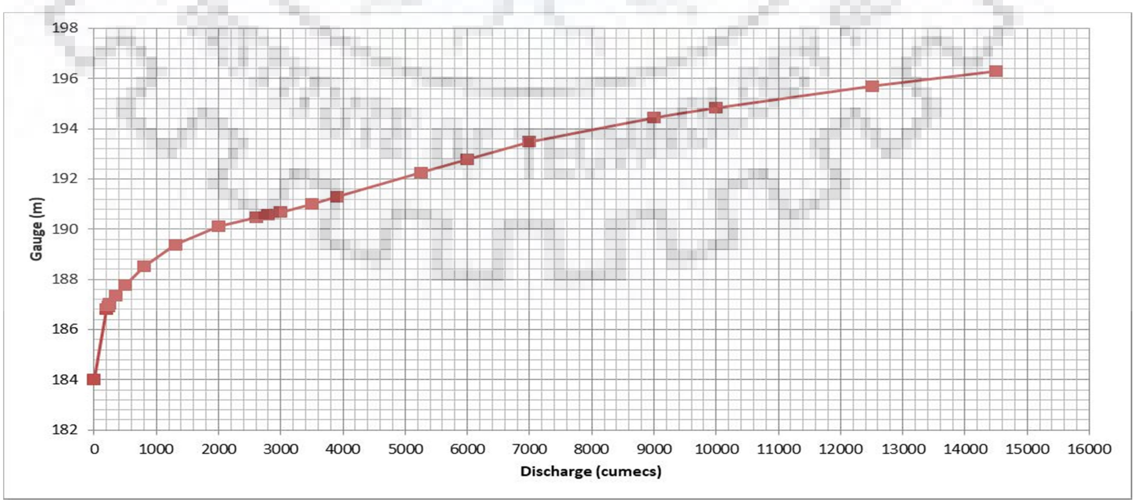


Figure 3.18: GD Curve obtained at 215m upstream of BA for MGB (Bridge 2)

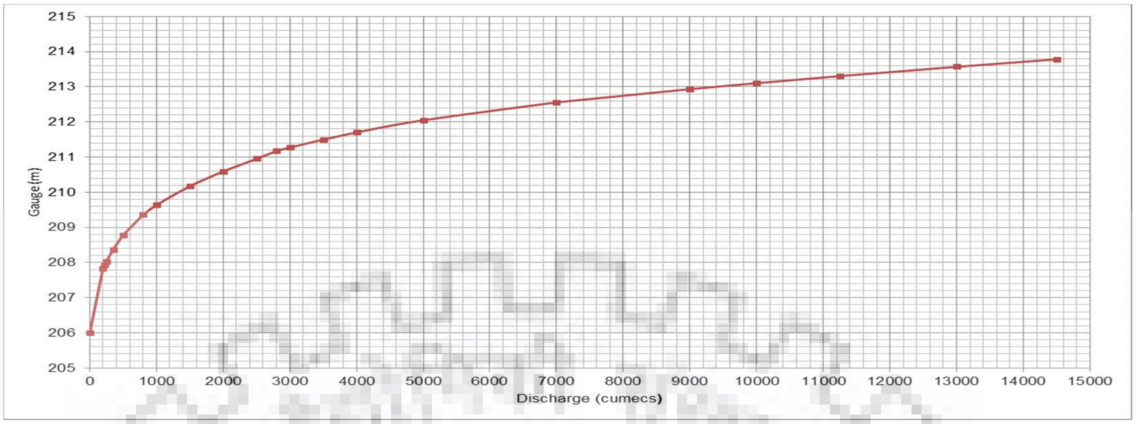


Figure 3.19: GD Curve obtained at 40m upstream of BA for OGB (Bridge 3)

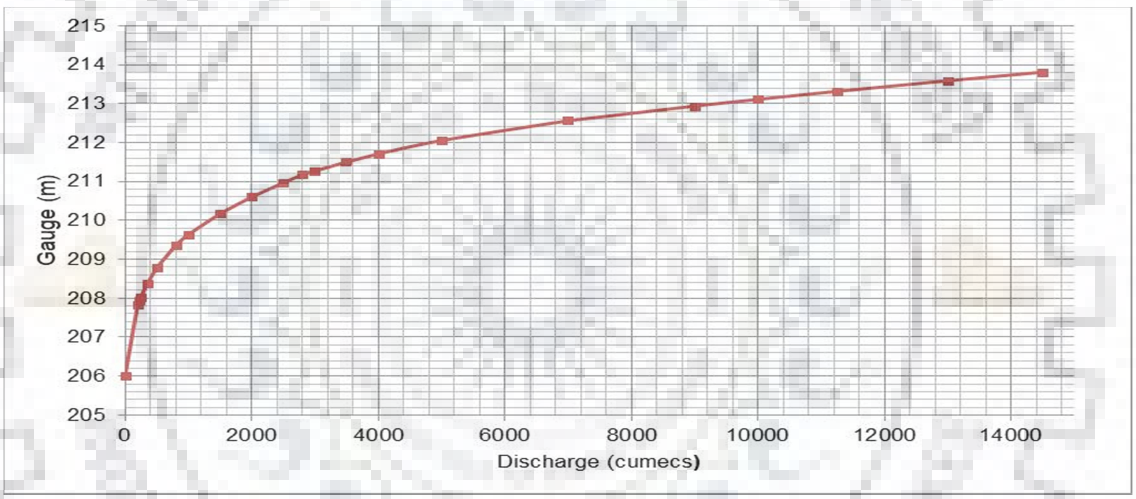


Figure 3.20: GD Curve obtained at 20m upstream of BA for MGB (Bridge 3)

Table 3.10:- Afflux for originally proposed and Modified Guide Bund

Bridge Number	Originally Proposed Guide Bund		Modified Guide Bund		Remarks
	Water level in HEC RAS	Afflux (m)	Water level in HEC RAS	Afflux (m)	
Bridge 1	216.50 at upstream of BA	0.35	216.50 at upstream of BA	0.35	At 11000 cumecs, water level of 216.15 in 3D Model
	216.90 at upstream of BA	0.75	217.00 at upstream of BA	0.85	At 14000 cumecs
Bridge 2	196.263 at 215m upstream of BA	0.16	196.296 at 215m upstream of BA	0.193	At 14500 cumecs, water level of 196.103 without bridge
Bridge 3	213.31 at 40m upstream of BA	0.31	213.15 at 40m upstream of BA	0.15	At 11250 cumecs, water level of 213.00 in 3D Model
	213.80 at 40m upstream of BA	0.80	213.80 at 20m upstream of BA	0.80	At 14500 cumecs

3.2.4.2 Velocity and Discharge Distribution along the reach and cross-sections:

Bridge 1

In the case of originally proposed guide Bunds, Average velocity of 1.94 m/sec to 2.80m/sec and 1.4 m/sec to 3.38 m/s for modified guide Bunds prevails along left and right guide bunds in a reach of 800m upstream of bridge at 14000 cumecs, however in main channel the velocities are higher and vary from 2.4m/s to 4.66 for originally proposed guide bunds and from 1.41m/s to 4.20m/s for modified guide bunds in the same reach. The spatial distribution of velocity in a reach about 2.0Km upstream to 1.0 Km downstream of the bridge for two different cases of guide Bunds are plotted in **Figure 3.21 and Figure 3.22**. The velocities in upstream reach of the bridge for 14000 cumec are shown in **Table 3.11**. Cross sectional distribution of velocity, near the abutments and in bridge spans were also extracted for 14000 cumec discharge for two different cases. It is observed that in the bridge velocities vary from 3.5m/s to 3.90m/s along abutments for originally proposed and from 3.20 m/sec to 3.5m/s for modified guide Bunds respectively as shown in **Figure 3.23 to Figure 3.24.** The maximum velocity of 6.21 m/sec is observed in the 2nd bay from left for originally proposed and 6.02 m/sec is observed in 2nd bay from left for modified guide Bunds. **It is clear**

therefore, that proposed modification of guide bund does not produce any adverse change in the hydraulics in the vicinity of bridge even at maximum discharge 14000 cumecs. The velocities, in different spans of the bridge, are shown in **Table 3.12** for two different cases of guide Bunds.

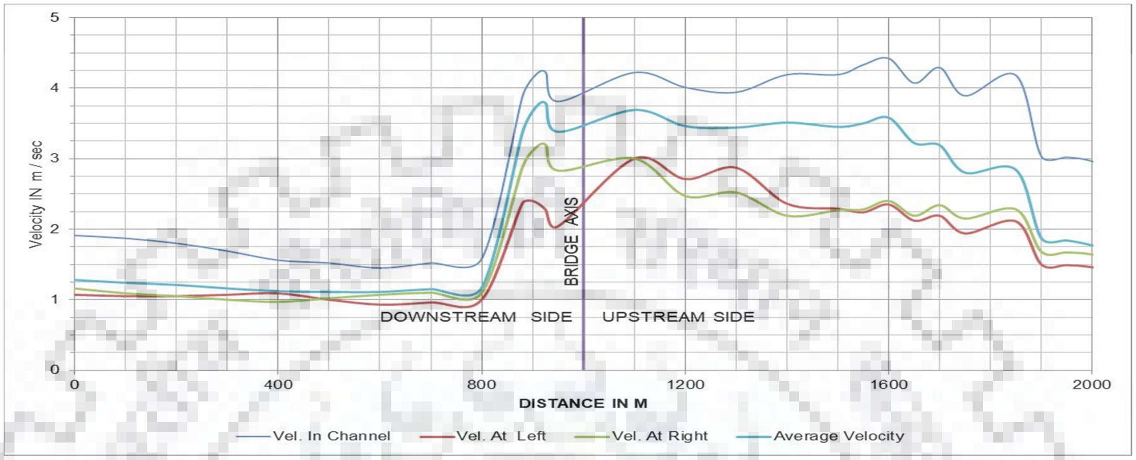


Figure 3.21: Spatial Distribution of Avg. Velocity at a discharge of 14000 cumec for Bridge 1

(With 375m long Left straight curved head and 600 m long Right elliptical guide Bunds)

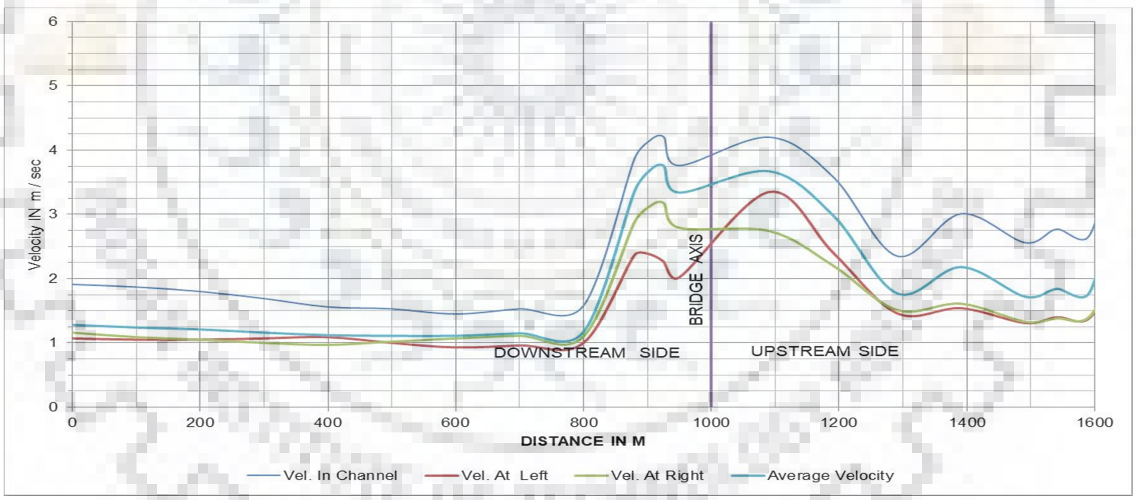


Figure 3.22: Spatial Distribution of Avg. Velocity at a discharge of 14000 cumec for Bridge 1

(With Left S curve tied with marginal bund and 360 m long Right elliptical guide Bunds)

Table 3.11: Vel. in the upstream of Bridge at different locations at 14000 cumec for Bridge 1

Location (m Upstream)	Originally Proposed guide Bunds					Modified guide Bunds				
	Left Guide Bunds	Left Flow	Centre flow	Right Flow	Right Guide Bunds	Left Guide Bunds	Left Flow	Centre flow	Right Flow	Right Guide Bunds
100	2.80	4.36	3.80	4.27	2.75	3.35	3.38	4.20	3.30	2.70
150	2.60	4.19	4.09	4.15	2.77	3.00	3.31	4.15	3.25	2.60
200	2.47	4.04	4.15	4.29	2.70	2.40	3.20	3.58	3.14	2.27
300	2.40	4.21	4.06	4.25	2.52	1.60	2.81	2.91	2.83	1.60
400	2.36	4.66	4.16	4.51	2.19	1.70	3.15	3.00	3.10	1.80
500	2.27	4.08	4.40	4.06	2.27	1.40	3.20	3.20	3.00	1.40
600	2.40	2.40	2.84	2.73	2.40	1.41	1.41	2.92	2.89	1.41
800	1.94	2.40	2.84	2.73	2.15					

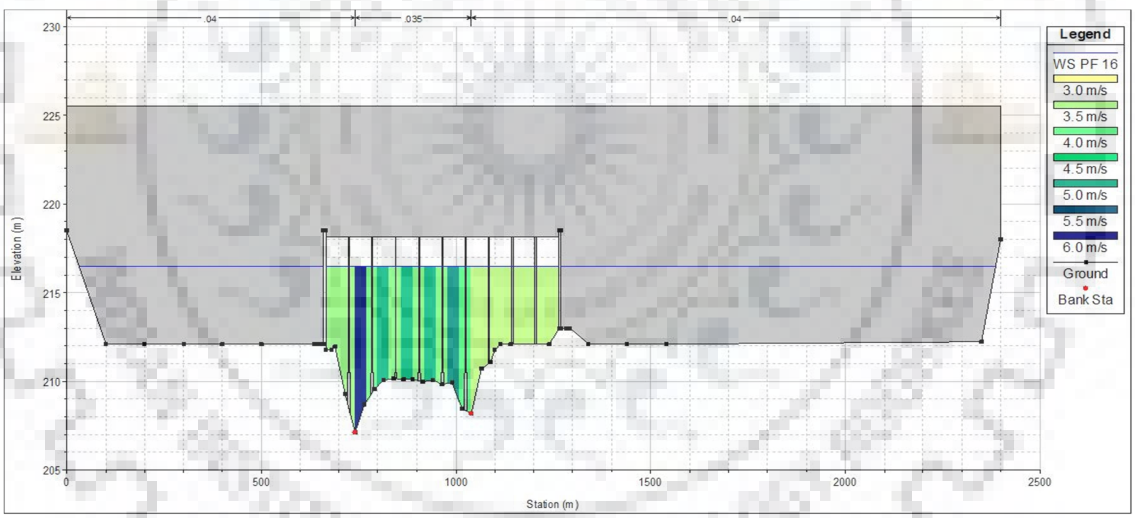


Figure 3.23: Distribution of Velocity in Bridge Spans for OGB (Bridge 1)

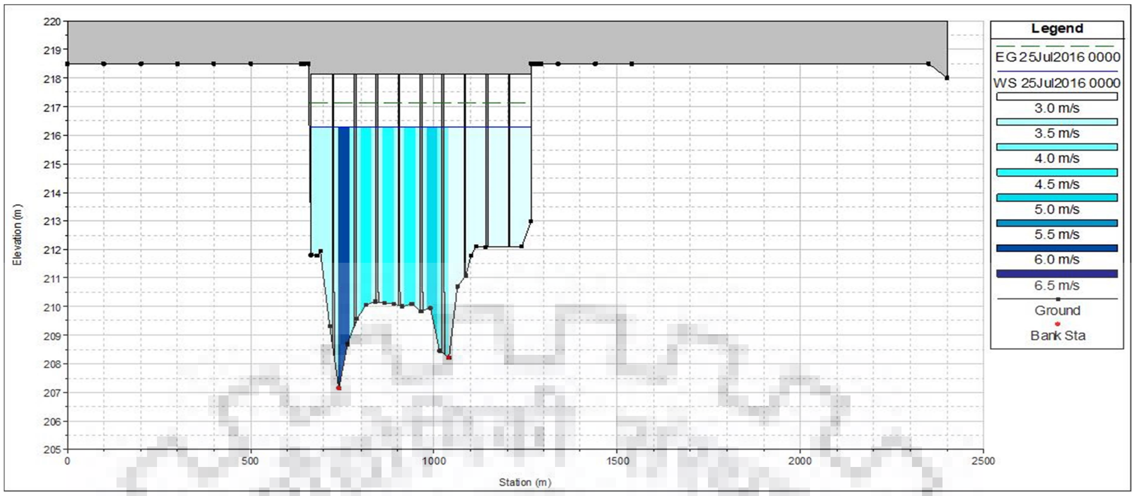


Figure 3.24: Distribution of Velocity in Bridge Spans for MGB (Bridge 1)

Table 3.12: Velocity (m/sec) distribution in Bridge Spans at 14000 cumec for Bridge 1

Originally Proposed guide Bunds				Modified guide Bunds			
Span No. (L to R)	Velocity (m/s)	Span No. (L to R)	Velocity (m/s)	Span No. (L to R)	Velocity (m/s)	Span No. (L to R)	Velocity (m/s)
1	3.91	6	5.42	1	3.52	6	4.99
2	6.21	7	3.52	2	6.02	7	4.00
3	5.16	8	3.52	3	5.50	8	3.21
4	5.11	9	3.52	4	4.57	9	3.21
5	5.14	10	3.52	5	4.62	10	3.21

Bridge 2

In the case of originally proposed guide Bunds, Average velocity of 0.41 m/sec to 2.76m/sec and 0.34 m/sec to 2.21 m/s for modified guide Bunds prevails along left and right guide bunds in a reach of 800m upstream of bridge at 14500 cumecs, however in main channel the velocities are higher and vary from 1.67m/s to 2.76 for originally proposed guide bunds and from 1.66m/s to 2.21m/s for modified guide bunds in the same reach. The spatial distribution of velocity in a reach about 2.0Km upstream to 1.0 Km downstream of the bridge for two different cases of guide Bunds are plotted in **Figure 3.25 and Figure 3.26**. The velocities in upstream reach of the bridge for 14500 cumec are shown in **Table 3.13**. Cross sectional distribution of velocity, near the abutments and in bridge spans were also extracted for 14000 cumec discharge for two different cases. It is observed that in the bridge velocities are almost same and is 3.04m/s for originally proposed and 3.03m/s for modified guide Bunds as shown in **Figure 3.27 to Figure 3.28. It is clear therefore, that proposed modification of guide bund does not produce any adverse change in water level or velocity profile in the vicinity of bridge even at maximum discharge 14500 cumecs.** The velocities, in different spans of the bridge, are shown in **Table 3.14** for two different cases of guide Bunds.

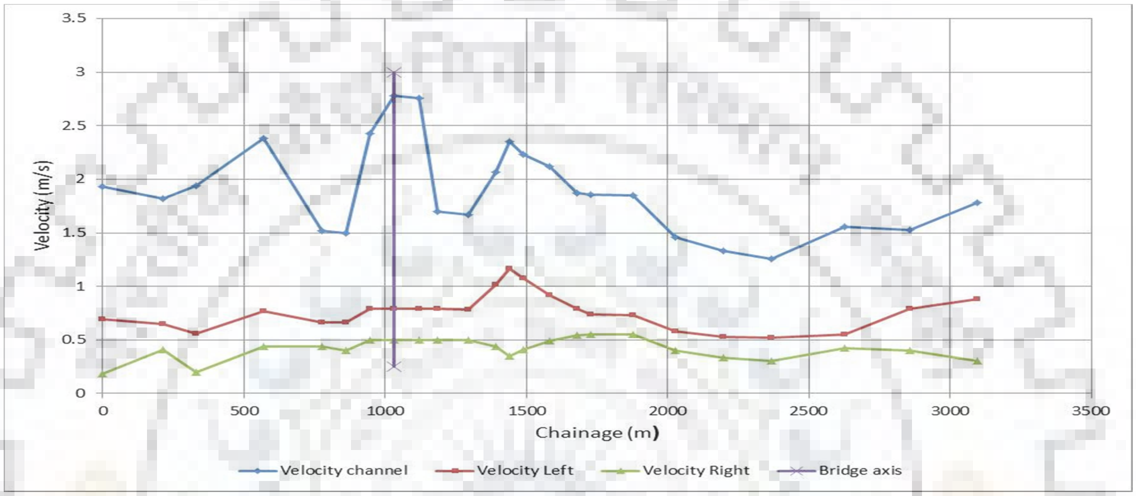


Figure 3.25: Spatial Distribution of Avg. Velocity at a discharge of 14500 cumec for Bridge 2

(With 600 m long left elliptical guide Bund)

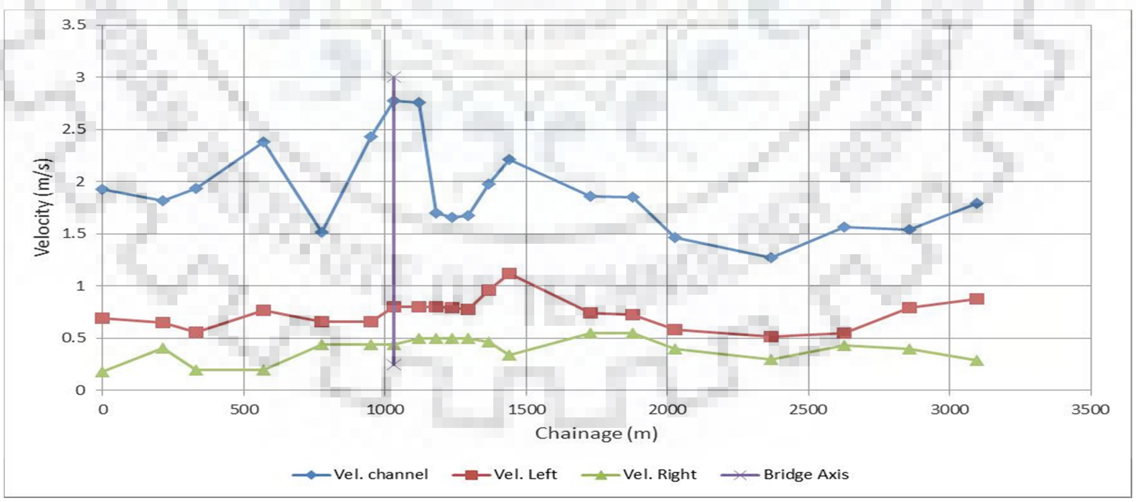


Figure 3.26: Spatial Distribution of Avg. Velocity at a discharge of 14500 cumec for Bridge 2

(With 360 m long left elliptical guide Bunds)

Table 3.13: Vel. in the upstream of Bridge at different locations at 14500 cumec for Bridge 2

Location Upstream (m)	Originally Proposed guide Bunds					Location Upstream (m)	Modified guide Bunds				
	Left Guide Bunds	Left Flow	Centre flow	Right Flow	Right Guide Bunds		Left Guide Bunds	Left Flow	Centre flow	Right Flow	Right Guide Bunds
100	2.76	2.76	2.76	2.76	2.76	100	1.7	1.7	1.7	1.7	0.4
215	1.70	1.70	1.70	1.70	1.70	157	1.66	1.66	1.66	1.66	0.5
300	1.67	1.67	1.67	1.67	0.5	215	1.68	1.68	1.68	1.68	0.5
400	2.07	2.07	2.07	2.07	0.44	287	1.98	1.98	1.98	1.98	0.47
500	2.24	2.24	2.24	2.24	0.41	360	2.21	2.21	2.21	2.21	0.34
600	2.12	2.12	2.12	2.12	0.49	650	1.86	1.86	1.86	1.86	0.55
800	1.86	1.86	1.86	1.86	0.54						

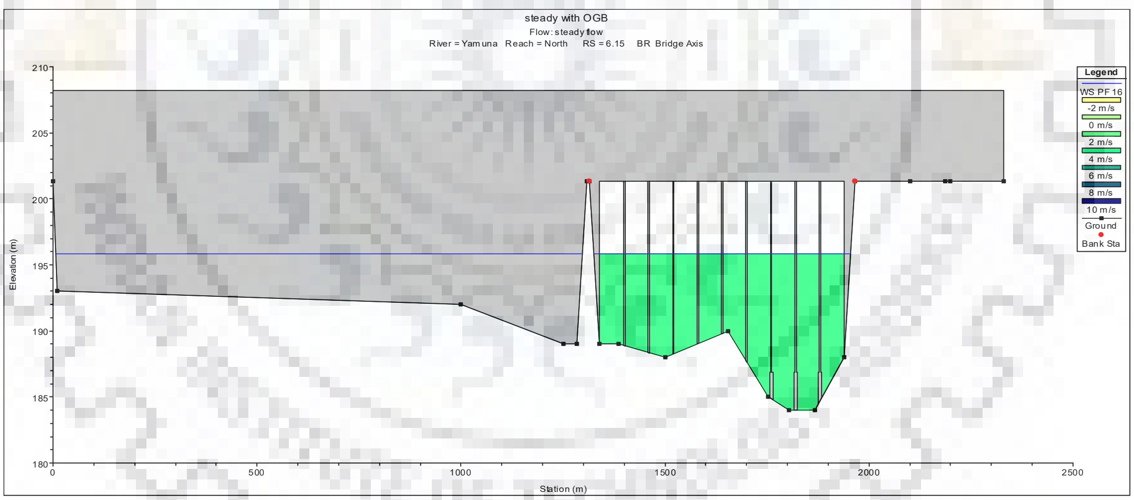


Figure 3.27: Distribution of Velocity in Bridge Spans for OGB (Bridge 2)

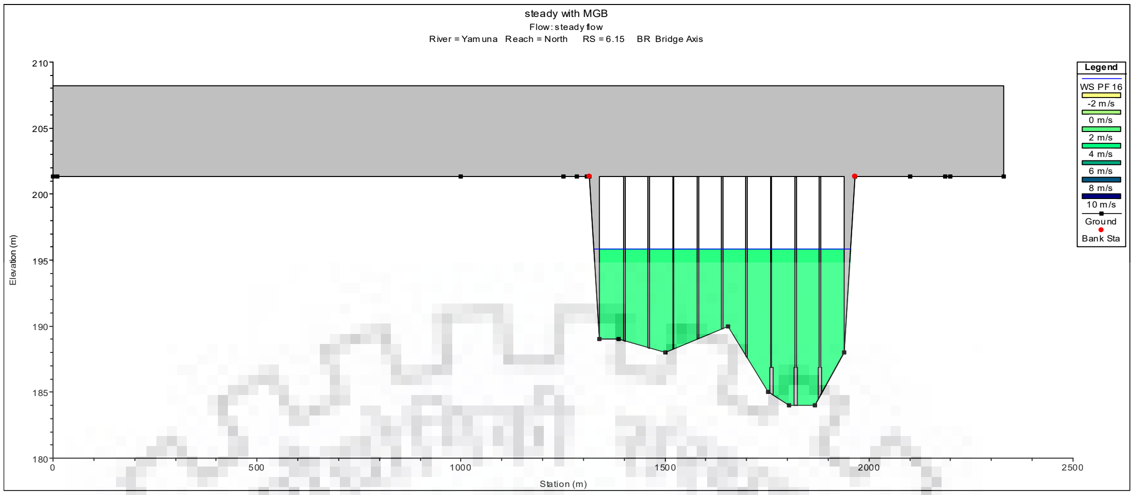


Figure 3.28: Distribution of Velocity in Bridge Spans for MGB (Bridge 2)

Table 3.14: Velocity (m/sec) distribution in Bridge Spans at 14500 cumec for Bridge 2

Originally Proposed guide Bunds				**Modified guide Bunds**			
Span No. (L to R)	**Velocity (m/s)**	**Span No. (L to R)**	**Velocity (m/s)**	**Span No. (L to R)**	**Velocity (m/s)**	**Span No. (L to R)**	**Velocity (m/s)**
1	3.04	6	3.04	1	3.03	6	3.03
2	3.04	7	3.04	2	3.03	7	3.03
3	3.04	8	3.04	3	3.03	8	3.03
4	3.04	9	3.04	4	3.03	9	3.03
5	3.04	10	3.04	5	3.03	10	3.03

Bridge 3

In the case of originally proposed guide Bunds, Average velocity of 1.90 m/sec to 3.94m/sec and 1.5 m/sec to 4.3 m/s for modified guide Bunds prevails within guide Bunds at 14500 cumecs. The spatial distribution of velocity in a reach about 4.2 Km upstream to 2.4 Km downstream of the bridge for two different cases of guide Bunds are plotted in **Figure 3.29 and Figure 3.30**. The velocities in upstream reach of the bridge for 14500 cumec are shown in **Table 3.15**. Cross sectional distribution of velocity, near the abutments and in bridge spans were also extracted for 14500 cumec discharge for two different cases. It is observed that in the bridge velocities are of the order of 2.95 m /sec along abutments for originally proposed and 2.97 m /sec for modified guide Bunds respectively as shown in **Figure 3.31.** The maximum velocity of 5.0 m/sec is observed in the 9th and 10th bay from left for originally proposed and 4.97 m/sec is observed in bay no. 8 & 9 from left for modified guide Bunds. . **It is clear therefore, that proposed modification of guide bund does not produce any adverse change in water level or velocity profile in the vicinity of bridge even at maximum discharge 14500 cumecs** .The velocities, in different spans of the bridge, are shown in **Table 3.16** for two different cases of guide Bunds.

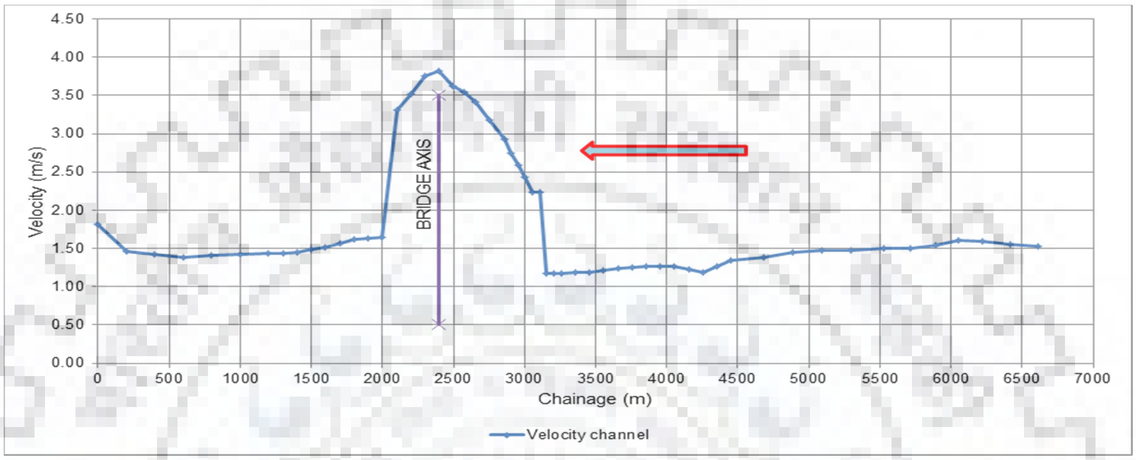


Figure 3.29: Spatial Distribution of Av.Velocity at a discharge of 14500 cumec for Bridge 3

(With 840.40m wide bridge and 650 m long elliptical guide Bunds)

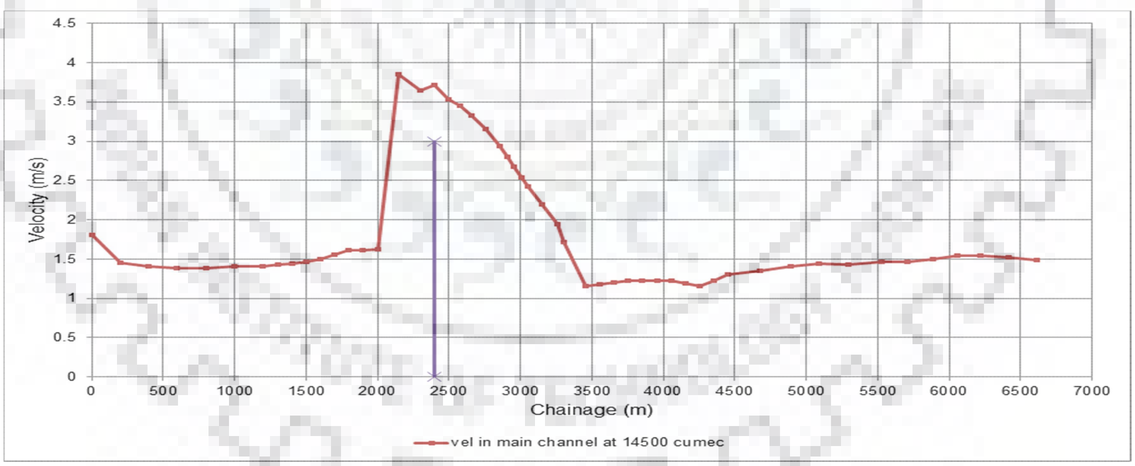


Figure 3.30: Spatial Distribution of Av.Velocity at a discharge of 14500 cumec for Bridge 3

(With 840.40m wide bridge and 850 m long elliptical guide Bunds)

Table 3.15: Vel. in the upstream of Bridge at different locations at 14500 cumec for Bridge 3

Location Upstream (m)	Originally Proposed guide Bunds (650m Long)					Modified guide Bunds (850m Long)				
	Left Guide Bunds	Left Flow	Centre flow	Right Flow	Right Guide Bunds	Left Guide Bunds	Left Flow	Centre flow	Right Flow	Right Guide Bunds
100	2.22	3.19	4.35	3.16	2.25	2.27	3.49	4.37	3.17	2.25
200	2.18	3.14	4.21	3.35	2.21	2.28	3.59	4.2	3.51	2.21
300	2.26	3.10	3.94	3.11	2.12	2.27	3.03	3.95	3.19	2.14
400	2.12	2.88	3.63	2.82	2.00	2.16	2.94	3.66	2.97	2.03
500	1.92	2.54	3.19	2.1	1.9	2.06	2.42	3.31	2.22	1.85
600	1.92	2.3	2.8	2.28	1.9	1.99	2.28	2.98	1.82	1.69
700						1.96	2.15	2.69	1.8	1.53
800						1.75	1.95	2.39	1.54	1.54
850						1.57	1.76	2.17	1.67	1.45

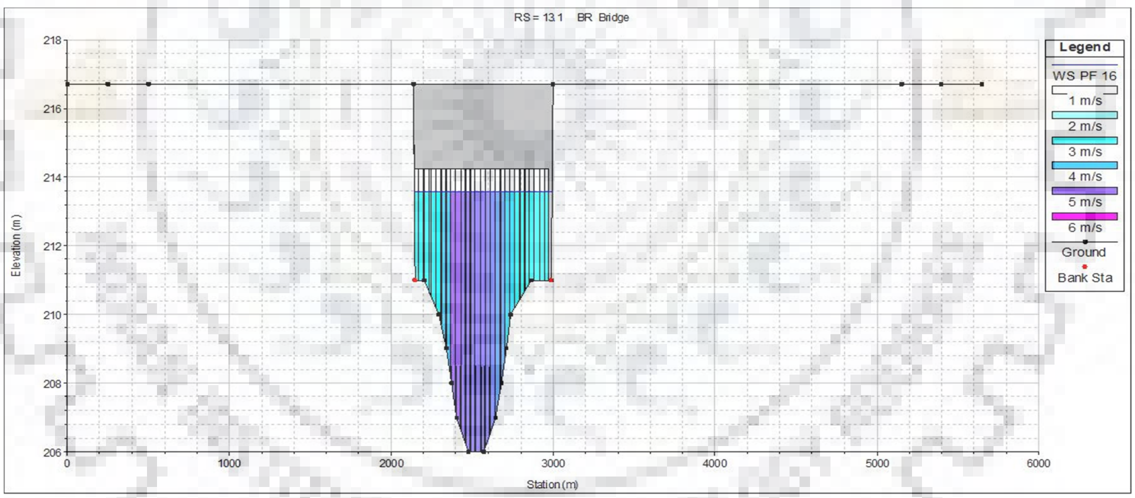


Figure 3.31: Distribution of Velocity in Bridge Spans for MGB (Bridge 3)

Table 3.16: Velocity (m/sec) distribution in Bridge Spans at 14500 cumec for Bridge 3

Span No. (L to R)	Velocity (m/s)	Span No. (L to R)	Velocity (m/s)	Span No. (L to R)	Velocity (m/s)	Span No. (L to R)	Velocity (m/s)
1	1.66 to 2.94	15	4.78	1	2.93	15	4.75
2	2.94	16	4.70	2	2.95	16	4.73
3	2.96	17	4.64	3	2.95	17	4.60
4	2.96	18	4.35	4	2.95 to 3.38	18	4.30 to 4.60
5	3.00 to 3.40	19	4.35	5	3.38	19	4.30
6	3.40	20	3.77	6	3.87	20	3.75 to4.30
7	3.40 to 3.90	21	3.77	7	3.87	21	3.75
8	3.90	22	3.31	8	4.97	22	3.30
9	5.00	23	3.31	9	4.97	23	2.93 to 3.30
10	5.00	24	2.94	10	4.90	24	2.93
11	4.85	25	2.94	11	4.84	25	2.85 to 2.93
12	4.85	26	2.86	12	4.80	26	2.85
13	4.80	27	2.98	13	4.75	27	2.85 to 2.97
14	4.80	28	2.98	14	4.75	28	2.97

3.2.5 Scour around Abutment and Pier

Bridge 1

Scour around pier and abutment are computed depending upon shape of the pier and abutment, angle of attack and gradation of the sediment. Contraction scour is also computed and is taken into account for predicting maximum scour. Results for discharges 14000 cumec were obtained using Froehlich equation both for piers and abutments. It is indicated that a maximum scour of 9.93 m for originally proposed and 10.51 m for modified guide Bunds at Left abutment. Graphical representation of the scour pattern for 14000 cumec is given in **Figure 3.32 to Figure 3.33** and the scour values for the two cases of guide Bunds are tabulated below in **Table 3.17** for 14000 cumecs discharge.

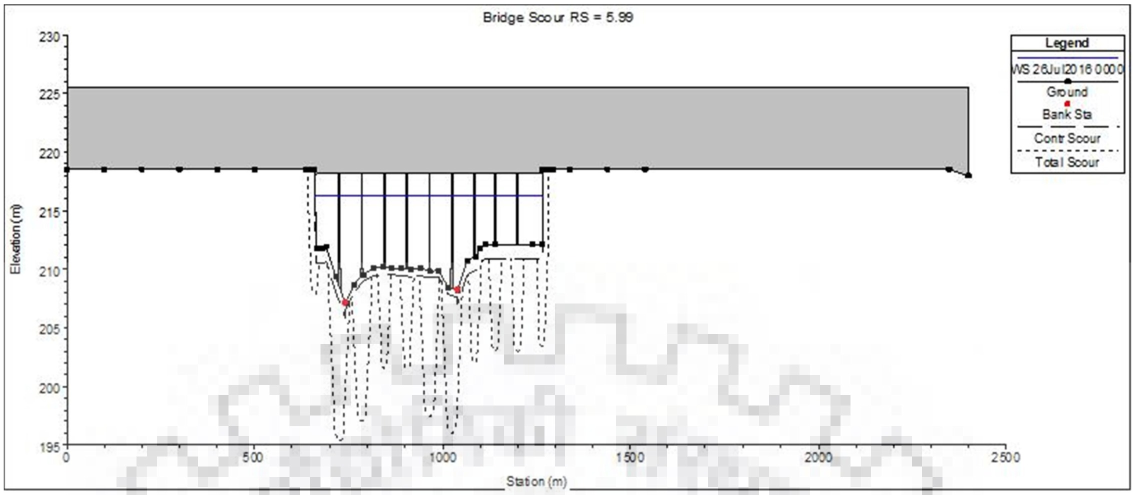


Figure 3.32: Scour around bridge abutment and piers at 14000 cumec for Bridge 1

(With 375m long Left straight curved head and 600 m long Right elliptical guide Bunds)

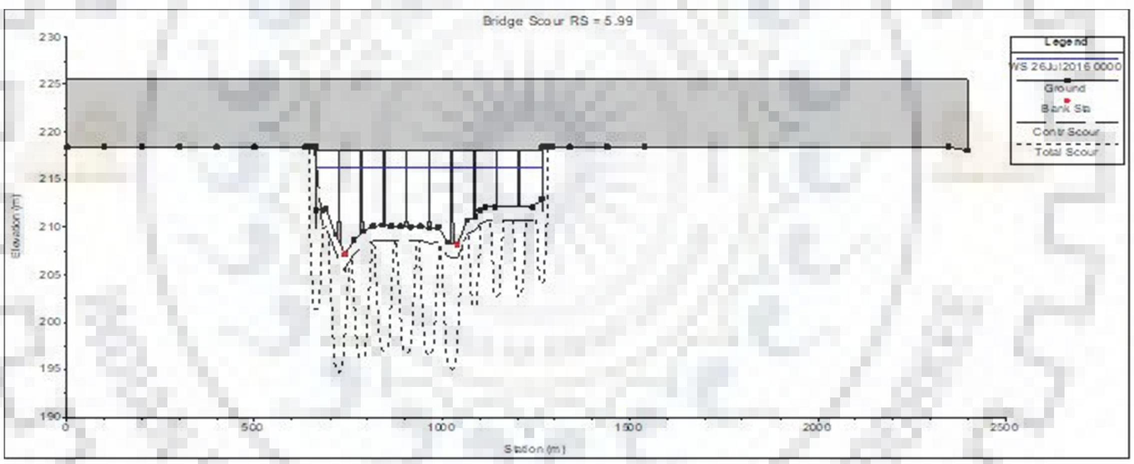


Figure 3.33: Scour around bridge abutment and piers at 14000 cumec for Bridge 1

(With Left S curve tied with marginal bund and 360 m long Right elliptical guide Bunds)

Table 3.17: Scour around piers and abutments for Bridge 1

SCOUR DETAILS FOR ORIGINALLY PROPOSED GUIDE BUND (14000 cumecs)				SCOUR DETAILS FOR MODIFIED GUIDE BUND (14000 cumecs)			
Contraction Scour (m)	Left	Channel	Right	Contraction Scour (m)	Left	Channel	Right
	1.29	0.62	1.17		1.90	1.51	1.44
Scour Around Piers				Scour Around Piers			
Pier No.	Pier Scour	Combined Scour (Contr.+Pier Scour)		Pier No.	Pier Scour	Combined Scour (Contr.+Pier Scour)	
1	11.74	13.04		1	11.75	13.65	
2	11.74	12.36		2	11.75	13.26	
3	7.94	8.56		3	11.75	13.26	
4	7.94	8.56		4	11.75	13.26	
5	11.74	12.36		5	11.75	13.26	
6	11.74	12.36		6	11.75	13.26	
7	7.94	9.11		7	7.95	9.39	
8	7.94	9.11		8	7.95	9.39	
9	7.94	9.11		9	7.95	9.39	
Scour Around Abutments				Scour Around Abutments			
Location of Abutment	Abutment Scour	Combined Scour (Contr.+Abut. Scour)		Location of Abutment	Abutment Scour	Combined Scour (Contr.+Abut. Scour)	
Left	8.64	9.93		Left	8.61	10.51	
Right	7.49	8.66		Right	7.38	8.82	

Bridge 2

Scour around pier and abutment are computed depending upon shape of the pier and abutment, angle of attack and gradation of the sediment. Contraction scour is also computed and is taken into account for predicting maximum scour. Results for discharges 14500 cumec were obtained using Froehlich equation both for piers and abutments. It is indicated that a maximum scour of 10.72m for originally proposed and 10.67 m for modified guide Bunds at Right abutment. Graphical representation of the scour pattern for 14500 cumec is given in **Figure 3.34 to Figure 3.35** and the scour values for the two cases of guide Bunds are tabulated below in **Table 3.18** for 14500 cumecs discharge.

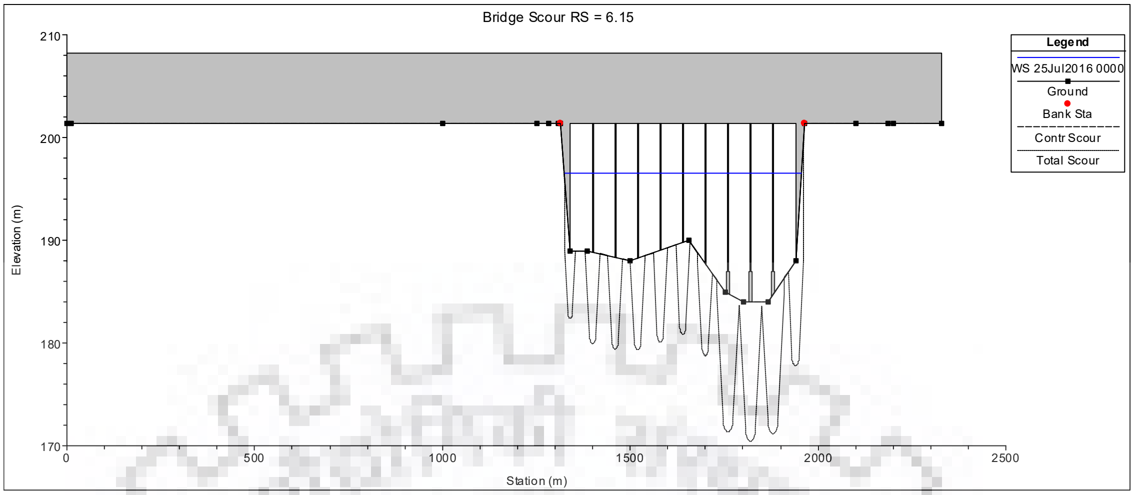


Figure 3.34: Scour around bridge abutment and piers at 14500 cumec for Bridge 2

(With 600 m long left elliptical guide Bund)

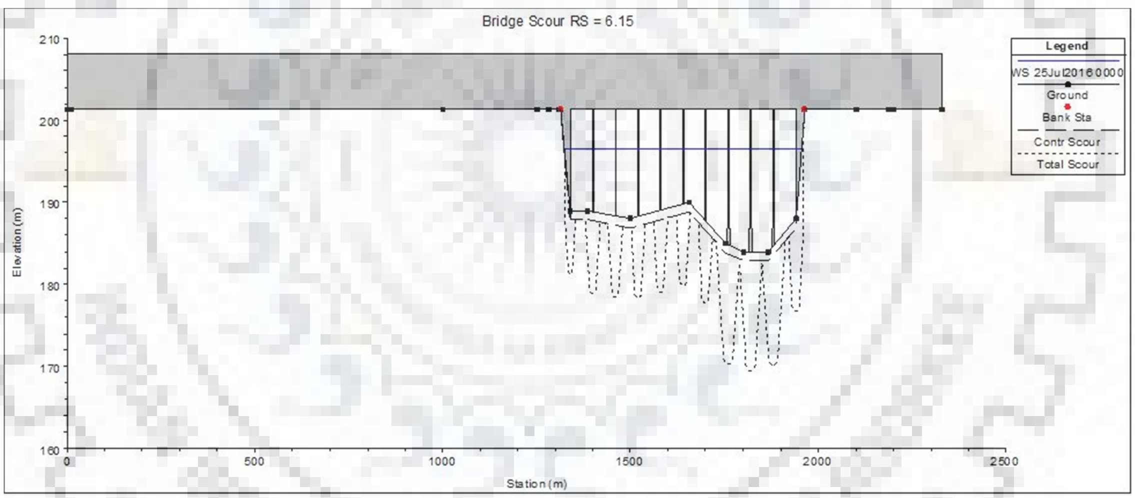


Figure 3.35: Scour around bridge abutment and piers at 14500 cumec for Bridge 2

(With 360 m long left elliptical guide Bund)

Table 3.18: Scour around piers and abutments for Bridge 2

<table>
<tr><th colspan="4">SCOUR DETAILS FOR ORIGINALLY PROPOSED GUIDE BUND (14500 cumecs)</th><th colspan="4">SCOUR DETAILS FOR MODIFIED GUIDE BUND (14500 cumecs)</th></tr>
<tr><td rowspan="2">Contraction Scour (m)</td><td>Left</td><td>Channel</td><td>Right</td><td rowspan="2">Contraction Scour (m)</td><td>Left</td><td>Channel</td><td>Right</td></tr>
<tr><td>0.5</td><td>1.14</td><td>0.5</td><td>0.5</td><td>1.14</td><td>0.5</td></tr>
<tr><td colspan="4">Scour Around Piers</td><td colspan="4">Scour Around Piers</td></tr>
<tr><td>Pier No.</td><td>Pier Scour</td><td colspan="2">Combined Scour (Contr.+Pier Scour)</td><td>Pier No.</td><td>Pier Scour</td><td colspan="2">Combined Scour (Contr.+Pier Scour)</td></tr>
<tr><td>1</td><td>8.94</td><td colspan="2">10.08</td><td>1</td><td>8.85</td><td colspan="2">9.99</td></tr>
<tr><td>2</td><td>8.94</td><td colspan="2">10.08</td><td>2</td><td>8.85</td><td colspan="2">9.99</td></tr>
<tr><td>3</td><td>8.94</td><td colspan="2">10.08</td><td>3</td><td>8.85</td><td colspan="2">9.99</td></tr>
<tr><td>4</td><td>8.94</td><td colspan="2">10.08</td><td>4</td><td>8.85</td><td colspan="2">9.99</td></tr>
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<tr><td>6</td><td>8.94</td><td colspan="2">10.08</td><td>6</td><td>8.85</td><td colspan="2">9.99</td></tr>
<tr><td>7</td><td>13.54</td><td colspan="2">14.68</td><td>7</td><td>13.45</td><td colspan="2">14.59</td></tr>
<tr><td>8</td><td>13.54</td><td colspan="2">14.68</td><td>8</td><td>13.45</td><td colspan="2">14.59</td></tr>
<tr><td>9</td><td>13.54</td><td colspan="2">14.68</td><td>9</td><td>13.45</td><td colspan="2">14.59</td></tr>
<tr><td colspan="4">Scour Around Abutments</td><td colspan="4">Scour Around Abutments</td></tr>
<tr><td>Location of Abutment</td><td>Abutment Scour</td><td colspan="2">Combined Scour (Contr.+Abut. Scour)</td><td>Location of Abutment</td><td>Abutment Scour</td><td colspan="2">Combined Scour (Contr.+Abut. Scour)</td></tr>
<tr><td>Left</td><td>6.61</td><td colspan="2">7.11</td><td>Left</td><td>6.64</td><td colspan="2">7.14</td></tr>
<tr><td>Right</td><td>10.22</td><td colspan="2">10.72</td><td>Right</td><td>10.17</td><td colspan="2">10.67</td></tr>
</table>

Bridge 3

Scour around pier and abutment are computed depending upon shape of the pier and abutment, angle of attack and gradation of the sediment. Contraction scour is also computed and is taken into account for predicting maximum scour. Results for discharges 14500 cumec were obtained using Froehlich equation both for piers and abutments. It is indicated that a maximum scour of 13.93 m for originally proposed and 13.82 m for modified guide Bunds at right abutment. Graphical representation of the scour pattern for 14500 cumec is given in **Figure 3.36 to Figure 3.37** and the scour values for the two cases of guide Bunds are tabulated below in **Table 3.19** for 14500 cumecs discharge.

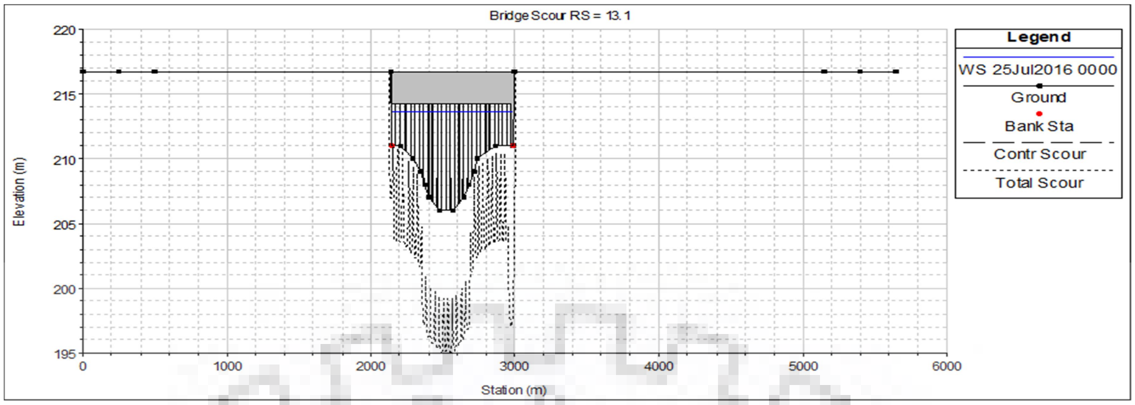

Figure 3.36: Scour around bridge abutment and piers at 14500 cumec for Bridge 3

(With 840.40m wide bridge and 650 m long elliptical guide Bunds)

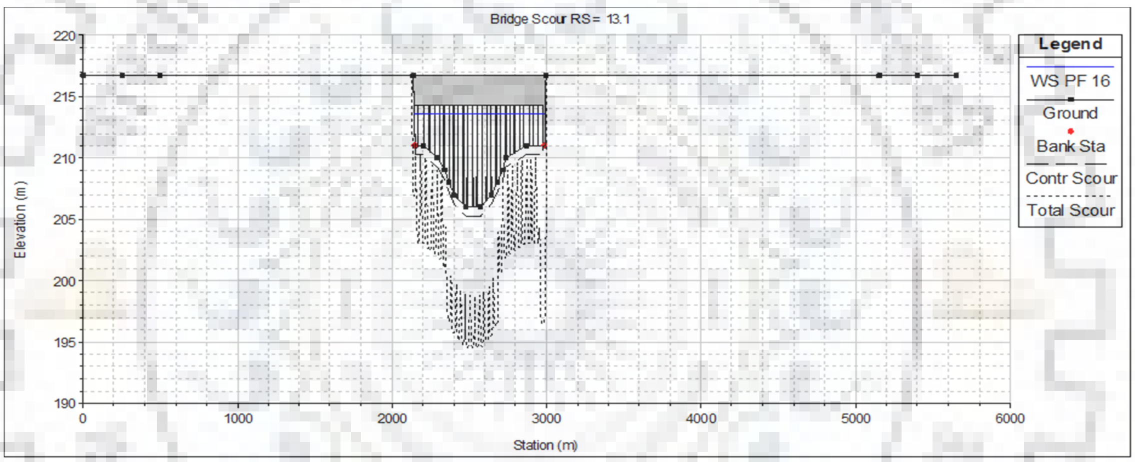

Figure 3.37: Scour around bridge abutment and piers at 14500 cumec for Bridge 3

(With 840.40m wide bridge and 850 m long elliptical guide Bunds)

Table 3.19: Scour around piers and abutments for Bridge 3

Originally Proposed Guide Bunds				**Modified Guide Bunds**			
Scour Details at 14,500cumecs				Scour Details at 14,500cumecs			
Contraction scour (m)	Left	Channel	Right	Contraction scour (m)	Left	Channel	Right
	0.42	0.78	0		0.41	0.77	0
Scour around piers				Scour around piers			
Pier No.	Pier scour	combined scour (Contr.+Pier scour)		Pier No.	Pier scour	combined scour (Contr.+Pier scour)	
1	7.44	8.22		1	7.22	7.99	
2	7.44	8.22		2	7.22	7.99	
3	7.44	8.22		3	7.22	7.99	
4	7.44	8.22		4	7.22	7.99	
5	7.44	8.22		5	7.22	7.99	
6	7.44	8.22		6	7.22	7.99	
7	7.44	8.22		7	7.22	7.99	
8	10.94	11.72		8	10.72	11.49	
9	10.94	11.72		9	10.72	11.49	
10	10.94	11.72		10	10.72	11.49	
11	10.94	11.72		11	10.72	11.49	
12	10.94	11.72		12	10.72	11.49	
13	10.94	11.72		13	10.72	11.49	
14	10.94	11.72		14	10.72	11.49	
15	10.94	11.72		15	10.72	11.49	
16	10.94	11.72		16	10.72	11.49	
17	10.94	11.72		17	10.72	11.49	
18	10.94	11.72		18	10.72	11.49	
19	7.44	8.22		19	7.22	7.99	
20	7.44	8.22		20	7.22	7.99	
21	7.44	8.22		21	7.22	7.99	
22	7.44	8.22		22	7.22	7.99	
23	7.44	8.22		23	7.22	7.99	
24	7.44	8.22		24	7.22	7.99	
25	7.44	8.22		25	7.22	7.99	
26	7.44	8.22		26	7.22	7.99	
27	7.44	8.22		27	7.22	7.99	
Scour around Abutment				**Scour around Abutment**			
Location of Abutment	Abutment Scour	combined scour (Contr.+Pier scour)		Location of Abutment	Abutment Scour	combined scour (Contr.+Pier scour)	
Left	7.26	7.68		Left	6.92	7.33	
Right	13.93	13.93		Right	13.82	13.82	

3.3 SUMMARY AND DISCUSSION OF RESULTS

3.3.1 Bridge 1

1. Usually guide bunds are constructed in pairs to guide the river flow between them and also to keep abutments away from the direct attack of flow. Their relative position could be parallel, divergent or convergent, depending on the river behavior at site. The length of guide bunds may depend upon river regime, main channel situation, position and alignment of embankments. At several places, where river is flowing in straight reach, guide bunds are either shortened or even eliminated**. For example, Bridges across same river Yamuna on upstream at**
   - **Baghpat - about 12 Km upstream of this bridge** – where left marginal bund is very close to left end of the bridge, does not include abutment on left bank, and
   - **Yamuna bridge at Karnal** (about 100 Km upstream of this bridge), where left end of the bridge is very near to embankment, the abutment is not provided. For this bridge, the design discharge was 16000 cu. m/sec and the overall length of the bridge was 600 m (same as in the existing Bridge 1). At this bridge also, it was decide that the marginal embankment and spurs on the left hand side would be raised and strengthened and no guide bund be provided on that side while on the Right hand side an elliptical guide bund with straight length of 360 m and 80 m on the upstream and downstream respectively was provided. No problem has been reported on the hydraulic performance of the bridge.
2. In the proposed bridge over Yamuna, river behavior and topography similar to above two bridges persists. River Yamuna flows in a straight channel, mainly on the left bank and near to marginal bund of the bridge. Besides, there is one dyke bund which almost joins the abutment with marginal bund. Top of both these bunds are at 215 - 216 amsl. Therefore, these bunds can be used to train the river by proper and suitable joining the bunds with left abutment.
3. The proposal with modified guide bunds makes proper and efficient use of left marginal bunds. When tested on mathematical model, the proposal does not show any remarkable changes either in velocity or in scour pattern within or in the vicinity of the bridge. It may be compared from above **Table 3.17** that with modification in guide bunds, the total scour around the piers is increased by 0.28 m to 0.9m only. The

point of maximum scour around any pier is above the well foundation. Similarly the scour around right abutment remains more or less same but increased by about 0.58m around **left** abutment with modified guide bunds.

4. Similarly the velocity, in the bridge, remains almost same with both the cases tested on mathematical model. **Table 3.12** shows a comparison of velocities observed with both proposals at 14000 cumec. Velocity trend indicates higher velocities in span no. 2 to 6 as compared with other spans for both proposals of guide bunds. In both proposals maximum velocity is observed in second span from the left. Comparison reveals that velocities in the upstream of bridge are of the order of 3.8 m/sec at a discharge of 14000 cumec and **do not change remarkably with modification in the layout of guide bunds.**

3.3.2 Bridge 2

1. Bridge No. 2 is located near village Faizupur Khadar under Tehsil Ballabhgarh in District Faridabad (Haryana). This bridge is nearly 93km downstream of Bridge 1 at Baghpat, 50 Km. downstream of Okhla Barrage and 40 Km upstream of the existing bridge at Palwal. The bridge 2 is designed for a discharge of 13462 cumecs, so the guide bunds and protection works for this Bridge is carried out for a discharge of 14500 cumec for the extra safety of the bridge structure**.**
2. This bridge requires huge land for the construction of guide Bunds and protection work. Since the entire Yamuna River is passing through the private land as per revenue records, there is dispute regarding ownership of land. Also the land of the same owner is bifurcated when the originally proposed guide bund and its protection work are carried out. So the study of guide Bunds and the protection measures are reviewed in order to provide alternate technical measures.
3. Left elliptical guide bunds following equation $\frac{X^2}{600^2} + \frac{Y^2}{400^2} = 1$ followed by a circular head of 200m with subtended angle of 770 in upstream and a Straight Portion 48m and Curved tail with a radius of 72m at Sweep Angle of 1200 is proposed for downstream side**. But, under the changed scenario**, the length of guide bunds may be decreased to $\frac{X^2}{360^2} + \frac{Y^2}{180^2} = 1$ follow by a circular head of 100m with subtended angle of 45^0 in upstream. However, no change in the downstream guide bunds is proposed. The right hand side guide bund is considered to be same in both the cases

4. When analyzed on mathematical model for 14500 cumec, no vast difference is seen in the hydraulic performance of bridge with 600 m long and 360 m long elliptical guide bunds. A Comparison of scour around piers and abutments with both guide bunds at 14500 cumec is given above in **Table 3.18**.
5. Similarly the velocity, in the bridge, remains almost same with both the cases tested on mathematical model. **Table 3.14** shows a comparison of velocities observed with both proposals at 14500 cumec. Comparison reveals that velocities in the upstream of bridge are of the order of 2.0 m/sec at a discharge of 14500 cumec and do not change remarkably with modification in the layout of guide bunds.

3.3.3 Bridge 3

1. The water way and protection works of Madhya Ganga Barrage at Bijnor- which is about 32 Km upstream of the proposed Chetawala Bridge at Hastinapur- is designed for 15000 cumec while its free board is designed for 18000 cumec based on technical report provided by the concerned authority. Furthermore, by the field authority it is revealed that on 18 June 2013, 14660 cumec passed through Madhya Ganga Barrage, Bijnor, at a water level of 220.40m in the downstream of Barrage. **Keeping this in view, it is very much advisable that guide bunds and protection works of the Bridge at Hastinapur should be designed for a discharge no less than 14500 cumec.**
2. With the help of provided slope of 0.22m/Km and gauge discharge observations in the downstream of Madhya Ganga Barrage, a gauge discharge curve prepared **Figure 3.38**, indicates that a discharge of 14500 cumec could pass at water level of 213.40m. The finished road level of the bridge is at 216.71 m., therefore, the flood of 14500 cumec can pass through the bridge with some encroachment in free board provided for design discharge of 11250 cumec.

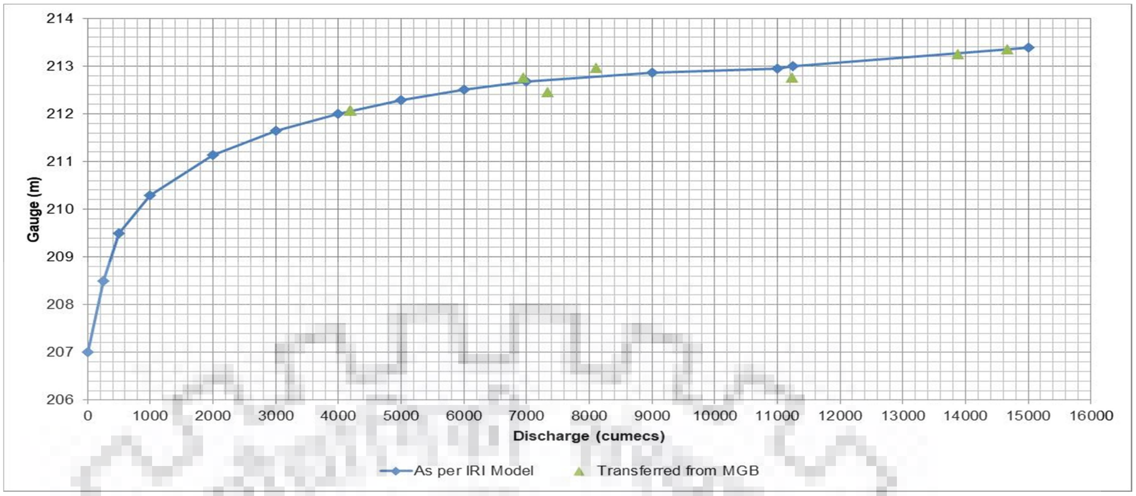

Figure 3.38: G.D Curve at proposed Bridge Site showing transferred proto type water levels from Madhya Ganga Barrage Bijnor

3. A pair of elliptical guide bunds following equation $\frac{X^2}{650^2} + \frac{Y^2}{250^2} = 1$ followed by a circular head of 200m with subtended angle of 90^0 in upstream and a Straight Portion 100m and Curved tail with a radius of 150m at Sweep Angle of 45^0 is proposed for downstream side. **But, under the changed scenario of discharge**, the length of guide bunds may be increased to $\frac{X^2}{850^2} + \frac{Y^2}{250^2} = 1$ follow by a circular head of 200m with subtended angle of 90^0 in upstream. However, no change in the downstream guide bunds is proposed.
4. When analyzed on mathematical model for 14500 cumec, no difference is seen in the hydraulic performance of bridge with 650 m long and 850 m long elliptical guide bunds. A Comparison of scour around piers and abutments with both guide bunds at 14500 cumec is given above in **Table 3.19**.

CHAPTER 4: DESIGN OF GUIDE BUNDS

4.1 INTRODUCTION

Guide Bunds are earthen embankments with stone pitching in the slopes facing water, to guide the river through the barrage, these river training works are provided for rivers flowing in planes, upstream and downstream of the hydraulic structures or bridges built on the river. Marginal Bunds is flood embankments in continuation of guide Bunds designed to contain the floods within the flood plain of the river. Both height and length vary according to back water effect caused by the structure. They are provided on the upstream in order to protect the area from submergence due to rise in HFL, caused by afflux.

4.2 GEOMETRY OF GUIDE BUNDS AND DESIGN OF PROTECTION WORKS

A computer program is also developed to design coordinates of elliptical guide Bunds and protection measures i.e. protection of the slope and apron. The program has been developed on the basis of guidelines provided in IS 10751:1994 and as per IRC 89:1997. The simple MS Excel program requires following input data **Table 4.1** for Bridge 1**,** **Table 4.3** for Bridge 2 **and Table 4.5** for Bridge 3 to provide complete design parameters. After calculation performed in the Excel, the following results **Table 4.2, Table 4.4** and **Table 4.6** can be obtained for the protection works of guide Bunds for Bridge 1, Bridge 2, and Bridge 3 respectively.

Table 4.1: Data required for Guide Bunds protection works For Bridge 1

INPUTS		
Discharge	14000	cumec
Adopted Water Way	600	m
HFL OF RIVER	216.65	M (asl)
Bed Level	208	M (asl)
Free Board above HFL	1.35	m
Top Level of Guide bund	218	M (asl)
Silt factor	1.25	
Manning's "n"	0.03	
Slope of River	0.3	m/km
Actual observed vel.(model)m/s after construction of structure	3.8	m/sec
Angle of Repose of material Φ	30.02	degree
Angle of Sloping bank φ	26.57	degree
Sp. Gravity of boulder	2.65	
value of 'g'	9.81	
Side Slope on guide bund Pitching U/S Side) Value of H for 1 V	2	
Side Slope on guide bund Pitching (D/S Side) Value of H for 1 V	2	
Unobstructed Sectional Area of river	6000	Sq. M
obstructed Sectional Area of river	5400	Sq. M
Av. Vel in Unobstructed Section of river (m/sec)	2.33	m/sec

Table 4.2: Guide Bunds protection works For Bridge 1

SUMMARY OF GUIDE BUND AND PROTECTION DETAILS		
Top width of Guide Bund	6	m
Adopt top width as 6.0 m but at curve head the width may be increased to facilitate turing of vehicle.		
Size of boulder (Side Pitching)	0.35	m
Weight of boulder (Side Pitching)	60	kg
Thickness of pitching) (Side Pitching)	0.38	m
Size of boulder (Apron)	0.51	m
Wt.of stone (Apron)	184	kg
Thickness of pitching (M) (Apron)	0.8	m
Length of Apron (u/s curve)	27	m
Length of Apron (straight reach)	20	m
Length of Apron (d/s curve)	20	m

Table 4.3: Data required for Guide Bunds protection works For Bridge 2

INPUTS		
Discharge	14500	cumec
Adopted Water Way	600	m
HFL OF RIVER	199.82	M (asl)
Bed Level	184	M (asl)
Free Board above HFL	1.5	m
Top Level of Guide bund	201.32	M (asl)
Silt factor	1.25	
Manning's "n"	0.045	
Slope of River	0.2	m/km
Actual observed vel.(model)m/s after construction of structure	2.8	m/sec
Angle of Repose of material Φ	30.0	degree
Angle of Sloping bank φ	26.6	degree
Sp. Gravity of boulder	2.65	
value of 'g'	9.81	
Side Slope on guide bund Pitching (U/S Side) Value of H for1 V	2	
Side Slope on guide bund Pitching (D/S Side) Value of H for1 V	2	
Unobstructed Sectional Area of river	9000	Sq. M
obstructed Sectional Area of river	7500	Sq. M
Av. Vel in Unobstructed Section of river (m/sec)	1.61	m/sec

Table 4.4: Guide Bunds protection works For Bridge 2

SUMMARY OF GUIDE BUND AND PROTECTION DETAILS		
Top width of Guide Bund	6	m
Adopt top width as 6.0 m but at curve head the width may be increased to facilitate turing of vehicle.		
Size of boulder (Side Pitching)	0.3	m
Weight of boulder (Side Pitching)	40	kg
Thickness of pitching) (Side Pitching)	0.38	m
Size of boulder (Apron)	0.38	m
Wt.of stone (Apron)	76	kg
Thickness of pitching (M) (Apron)	0.5	m
Length of Apron (u/s curve)	20	m
Length of Apron (straight reach)	10	m
Length of Apron (d/s curve)	10	m

Table 4.6: Data required for Guide Bunds protection works For Bridge 3

INPUT DATA		
Discharge	14500	cumec
Adopted Water Way	840.4	m
HFL	213.8	m
Free Board above HFL	1.8	m
Top Level of Guide bund	215	m
Finished Road Level	216.71	m
Silt Factor	1.25	
Manning's "n"	0.03	
Slope of River	0.22	m/Km
Av bed level at site	208	m
Actual observed Vel. (model/site) m/sec after construction ofstructure	3.5	m/sec
Angle of Repose of materialΦ	0.52	radians
Angle of Sloping bank φ	0.46	radians
Sp. Gravity of boulder	2.65	t/cum
value of 'g' (m k s)	9.81	
Side Slope on guide bund Pitching (U/S Side) Value of H for1 V	2	
Side Slope on guide bund Pitching (D/S Side) Value of H for1 V	2	
Low Water Level	208.48	m
Unobstructed Sectional Area of river	6000	m2
obstructed Sectional Area of river	4000	m2
Av. Vel in Unobstructed Sectional Area of river	2.42	m/sec

Table 4.5: Guide Bunds protection works For Bridge 3

SUMMARY OF GUIDE BUND AND PROTECTION DETAILS			
Top width of Guide Bund	6	m	
Adopt top width as 6.0 m but at curve head the width may be increased to facilitate turing of vehicle.			
Size of boulder (Side Pitching)	0.35	m	where the required size/weight of stones are not economically avilable , stones in wire crates or preferably C.C. blocks may be used in place of isolated stone.
Weight of boulder (Side Pitching)	60	kg	
Thickness of pitching) (Side Pitching)	0.38	m	
Size of boulder (Apron)	0.51	m	
Wt.of stone (Apron)	184	kg	
Thickness of pitching (M) (Apron)	0.8	m	
Length of Apron (u/s curve)	35	m	
Length of Apron (straight reach)	25	m	
Length of Apron (d/s curve)	25	m	

4.3 **CONCLUSION**

4.3.1 Bridge 1

The guide bunds in the upstream of Yamuna bridge no.1 for Eastern Peripheral Expressway may be constructed as per drawings number **4.1** along with various cross-sections. Some of the salient points are as follows:

- **Key Plan** of the proposed Guide Bank System is shown in **drawing number 4.1**.
- **In the Left Hand Side (LHS) guide bank, upstream portion of the guide bank** is a circular curve of radius (R1= 230 m) and angle 120°, then has S curve with radius (R2= 181 m) and angle 53° so that it can meet the existing bund tangentially. A small part (approx. 50m) is straight & meets another existing bund which is approximately parallel to Yamuna. Strengthening of parallel bund has been proposed by raising, by piles & by launching apron. **Downstream portion of guide bund** is 150m long downstream of the end of road embankment. About 80.0m is straight & 70.0m is curved tail with radius (R3=100.0m) and angle 45°.
- It has top width of 6m with 1V:2H side slopes on its both sides. The existing bund has also been strengthen by raising up to an elevation of 218m, providing piles, providing CC block & stone, and a total 4m launching apron. The launching apron provided for this guide bank is 20m wide generally & 27m wide at curved tail.
- **In the Right Hand Side (RHS) guide bank ,** The length of Upstream (elliptical) portion of the guide bank is kept as one quarter of an ellipse (a=360m & b=180m) with curved head (circular, R=100m,angle 45°) and downstream of bridge is 80m straight & rest 70m is curved tail (circular R=100m,angle 45°).
- The top level is 218m, top width is 6m with side slopes both sides 1V:2H. The plan also shows 3m high, 1200m long retaining wall on the upstream side of road embankment up to an existing bund. This wall has been provided by the field authority. Below the retaining wall, the piles (dia. 0.3m, depth 10m below wall) have been provided. A 4m wide launching apron, one row (2m wide) of stone filled in wire crates of size (3*2*1) m has also been provided.
- The marginal bunds should be raised up to El.218 m and suitably strengthened.

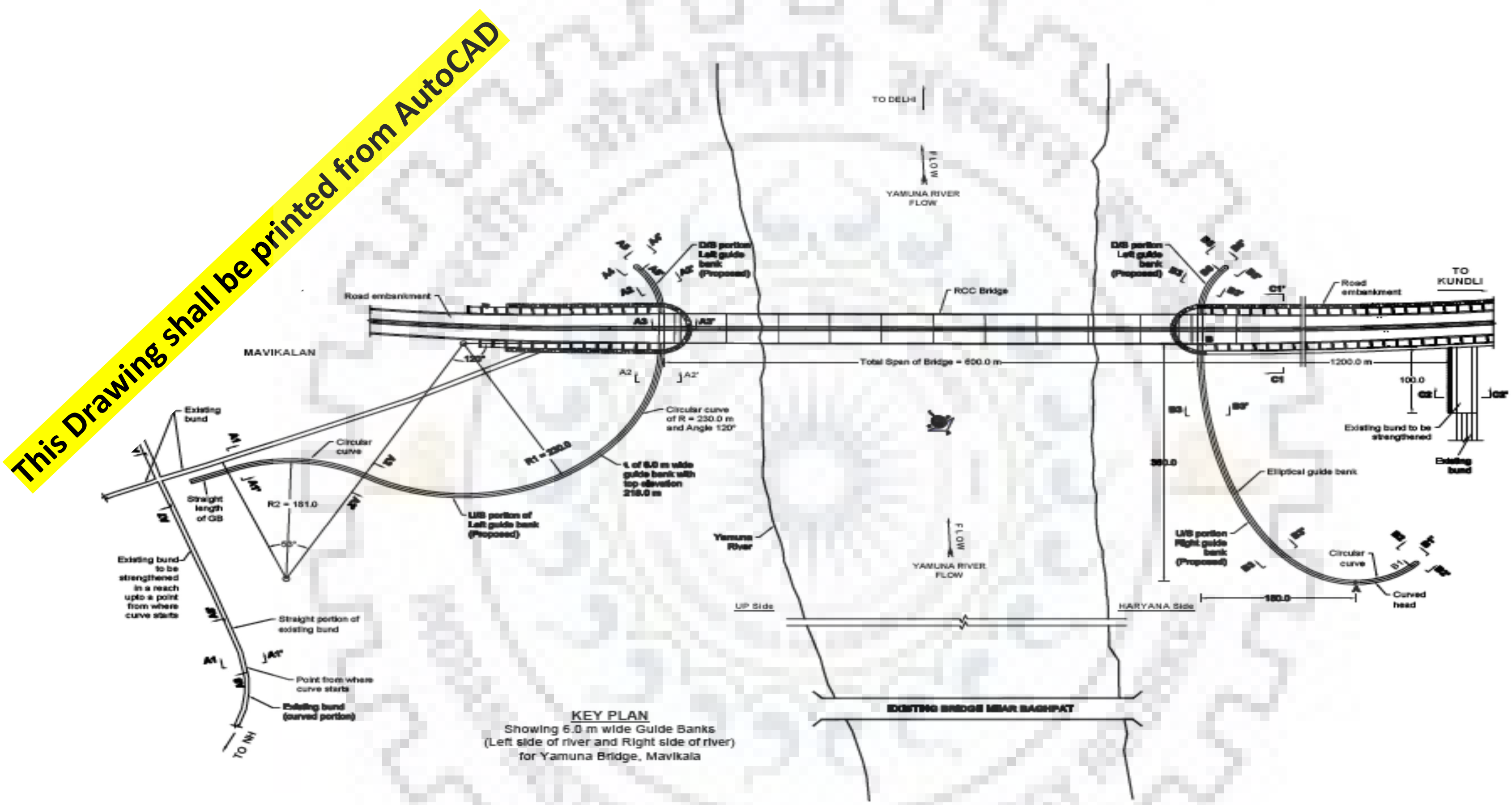

Figure 4.1: Key Plan of the proposed Guide Bank System for Bridge 1

4.3.2 Bridge 2

The guide bunds in the upstream of Yamuna bridge no.2 for Eastern Peripheral Expressway may be constructed for a design discharge of 14,500 cumecs as per **Table 4.4.** Some of the salient points are as follows:

- The Summary details of guide bunds and its protection work is given in **Table 4.4**.
- **The proposed left guide bunds** is 360 m long elliptical shaped with **upstream circular head of 100 m radius with subtended angle of 45°. Downstream portion of guide bund** is 48m long straight with curved tail with of 72m radius and angle 120
- **The proposed Right guide bunds** is 21 m long straight upstream and downstream with curved head of 60m radius and angle 90^0. The top of both guide bunds is kept at El.201.32m.
- The launching apron provided for this guide bank is 20m wide in the upstream curve & 10m wide at straight & curved tail
- It has top width of 6m with 1V:2H side slopes on its both sides.

4.3.3 Bridge 3

The guide bunds in the upstream of Chetawala Bridge on river Ganga at may be designed for 14500 cumec. Some of the salient points are as follows:

- **Key Plan** of the proposed Guide Bund System is shown in **drawing number 4.2.**
- **The proposed bunds** are 850 m long elliptical shaped with **upstream circular head of 200 m radius with subtended angle of 90°. Downstream portion of guide bund** is 100m long straight with curved tail with of 150m radius and angle 45°. The top of both guide bunds is kept at El.215.0m.
- It has top width of 6m with 1V:2H side slopes on its both sides.
- The launching apron provided for this guide bank is 35m wide in the upstream curve & 25m wide at straight & curved tail.
- Toe line of upstream guide bund should be joined with upstream toe of abutment. The upstream slope of guide bund (2H:1V) should be provided with concrete blocks of 3.0m X 2.0m X 0.50m instead of stone pitching in a reach of 30 m from the upstream edge of abutment.

- Toe line of downstream guide bund should be joined with downstream toe of abutment. The downstream slope of guide bund (2H:1V) should be provided with concrete blocks of 3.0m X 2.0m X 0.50m instead of stone pitching in a reach of 30 m from the downstream edge of abutment.
- Concrete blocks of 3.0m X 2.0m X0.50m may be provided in the extreme bays of the bridge.

This Drawing shall be printed from AutoCAD

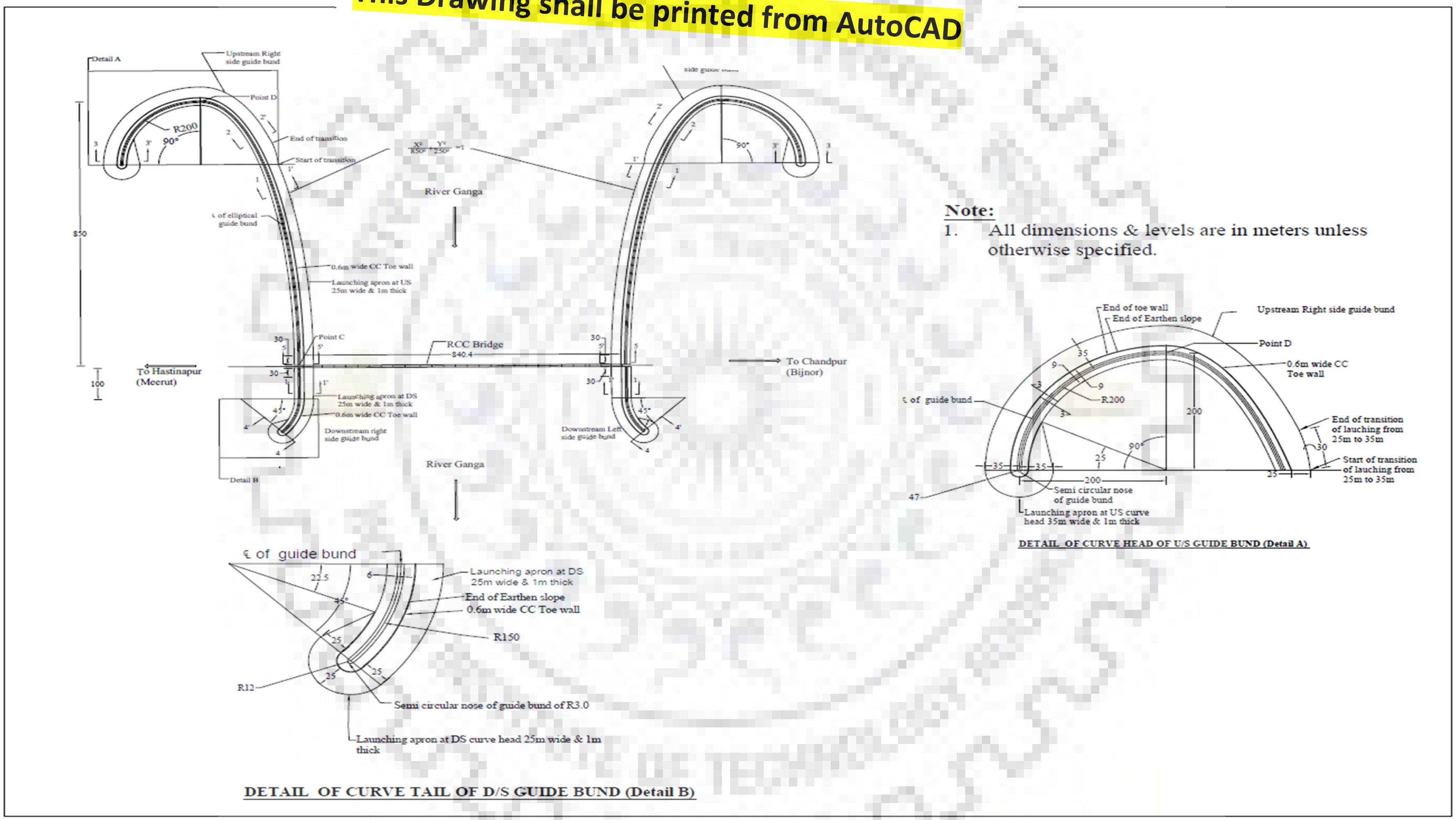

Figure 4.2: Key Plan of the proposed Guide Bank System for Bridge 3

CHAPTER 5: CONCLUSION OF THE THESIS

5.1 SUMMARY AND CONCLUSION FOR THE THREE MAJOR BRIDGES

There are altogether three Bridges for the analysis, The Bridge 1 is located near Baghpat & Bridge 2 is located near Faizupur Khadar along the Eastern Peripheral Expressway in the river Yamuna. Similarly Bridge 3 is located near Hastinapur, at Chetawala Ghat in the river Ganga. As the time does not permit the new physical model study or the collection of primary data, secondary data only is being used for the analysis through mathematical model HEC RAS to suggest alternate technical measures on the basis of the previous study carried out the IPRI; Amritsar and IRI, Roorkee respectively. A computer program is also developed to design coordinates of elliptical guide Bunds and protection measures i.e. protection of the slope and apron. The program has been developed on the basis of guidelines provided in IS 10751:1994 and as per IRC 89:1997 and the parameters obtained from the mathematical model.

Usually guide bunds are constructed in pairs to guide the river flow between them and also to keep abutments away from the direct attack of flow. Their relative position could be parallel, divergent or convergent, depending on the river behavior at site. The length of guide bunds may depend upon river regime, main channel situation, position and alignment of embankments. At several places, where river is flowing in straight reach, guide bunds are either shortened or even eliminated. For example, Baghpat - about 12 Km upstream of Bridge 1, Yamuna bridge at Karnal. In the proposed Bridge 1 over River Yamuna, river behavior and topography similar to above two bridges persists. So for the Bridge 1 the existing left marginal Bund is being used as Left Guide Bund suitably tied with S Curve with dyke bund and Marginal Bund. As a flood of 14668 cumecs experienced in the year 2013 upstream of the existing Bridge 3 in river Ganga, the guide bund and its protection measures is carried out for the discharge of 14500 cumec although the bridge was designed for a discharge of 11250 cumec. The summary and conclusion obtained for the three major bridges in the River Ganga & Yamuna are listed below:

1. For the Bridge 1, the upstream left side guide bund meets the existing marginal bund with S curve with suitable radius & angle. The length of the right side elliptical guide bund is reduced. Suitable protection measures for the existing marginal bund, left guide bund and right guide bund are provided.
2. For Bridge 2, the length of left side guide bund is reduced to 360m long elliptical guide bund. There are no changes in the right side & downstream guide bund. Suitable protection measures for left guide bund and right guide bund are provided.
3. For Bridge 3, 850m long elliptical guide bund with upstream circular head and subtended angle are provided with Suitable protection measures. Also Concrete blocks instead of stone pitching in a reach of 30m upstream and downstream edge of abutment and in the extreme bays of the bridge are provided.
4. When all these three bridges tested on mathematical model, the proposal with modified guide bund does not show any remarkable changes either in velocity or in scour pattern within or in the vicinity of the bridge.
5. For all the three Bridges, the top width of 6m is provided with side slopes of 1V:2H on both side of guide bund.

5.2 SCOPE OF FUTURE WORKS

Literature is available in abundance regarding river training works and guide bunds of bridges. In India mostly the design of guide bunds and river training works are governed by IS 10751:1994 and IRC 89:1997 codes besides manuals issued by Central Board of Irrigation and Power (CBIP) India time to time. Land acquisition required for the construction of guide bund, marginal bund, embankment etc. is nowadays being a tedious and lengthy process due to the social, political and economic pressures. Sometimes it becomes an unending legal procedure also.

1. Therefore, it is advisable to optimize the length of guide bunds on both or one side strategically on the merit of problem in hand.
2. If topography permits and high rigid land is available then guide bunds can even be avoided on one or other bank of the river (for example: Bridges across same river Yamuna on upstream at Baghpat - about 12 Km upstream of this bridge – where left marginal bund is very close to left end of the bridge, does not include abutment on left

bank, and Yamuna bridge at Karnal (about 100 Km upstream of this bridge), where left end of the bridge is very near to embankment, the abutment is not provided)

3. If either or both abutment can be suitably tied with nearby existing some bund or embankment, the length of guide bunds may be drastically reduced without hampering the hydraulics of the bridge or without increasing the scour around the piers. However, any major reduction in length of conventional guide bunds should be suitably tested on physical or mathematical model against any adverse effect on the bridge hydraulics.
4. Suitable passage or under passage should be provided at suitable interval across the guide bunds for easy access to the cultivated land for the farmers. The under passage may also be used to release the hydrostatic pressure during the monsoon season through any existing drainage.
5. For bridges over major rivers the guide bunds and other protection measures should be designed at least for floods which has already been experienced in the vicinity or for the flood which any upstream structures has been designed.
6. Increasing necessity and cost of land, time consuming litigations calls for a review of Conventionally recommended length of guide bunds.

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