Design of RCC Bridge Against Flash Flood

Chaki Sahil Kasam[1] Krish Gadhvi[2]
[1,2]Department of Structural Engineering
[1,2]Mewar University, India

Abstract — Flash floods pose a significant threat to RCC bridges by causing scour, foundation instability, and structural damage. This study focuses on the design and analysis of an RCC bridge under flash flood conditions. It examines hydraulic forces, scour mechanisms, bridge pier performance, and flood-resistant design measures. CSI Bridge software is used for structural analysis, and suitable scour protection techniques are discussed. The study concludes that proper foundation design, streamlined pier shapes, and effective scour protection improve the safety, stability, and durability of RCC bridges during flash floods.

Keywords: RCC Bridge, Flash Flood, Scour, Hydraulic Analysis, CSI Bridge, Foundation Design

I. INTRODUCTION

A. General

Bridges are among the most important civil engineering structures that provide connectivity between regions separated by rivers, valleys, canals, railways, and highways. The development of transportation infrastructure is directly related to the economic growth of a nation. Bridges play a crucial role in facilitating trade, transportation, communication, and regional development.

In recent years, extreme weather events have increased due to climate change. Among these events, flash floods have become one of the major threats to bridge infrastructure. Flash floods occur suddenly with little warning and generate high-velocity water flow capable of causing severe damage to bridge foundations, piers, abutments, and approach roads.

The design of Reinforced Cement Concrete (RCC) bridges must therefore consider hydraulic forces, scour depth, debris impact, uplift pressure, and dynamic flood loading. Failure to account for these factors can result in catastrophic bridge collapse.

This study focuses on the design and analysis of RCC bridges subjected to flash flood conditions. Special attention is given to scour development around bridge piers, foundation stability, and the influence of pier shape on hydraulic performance.

B. Background of Study

India experiences frequent flooding due to monsoon rainfall, cloudbursts, cyclones, and dam releases. States such as Gujarat, Rajasthan, Uttarakhand, Kerala, Maharashtra, and Assam regularly face flash flood events.

Many bridge failures reported worldwide are directly associated with foundation scour caused by floodwater. Scour removes soil around bridge foundations, reducing their bearing capacity and leading to instability.

According to bridge failure investigations, foundation scour accounts for nearly 60–70% of flood-related bridge failures. Therefore, proper design against scour is one of the most important aspects of bridge engineering.

C. Need of Study

The increasing occurrence of extreme rainfall events has highlighted the need for flood-resistant bridge structures. Traditional bridge design approaches often underestimate the effects of flash floods, resulting in inadequate safety margins. The need for this study arises due to:

- Increasing frequency of flash floods.
- Growing bridge failure incidents.
- Economic losses due to infrastructure damage.
- Need for safer transportation networks.
- Requirement of sustainable bridge design practices.

D. Objectives of Study

The main objectives of this study are:

1) To understand flash flood behavior and its effects on bridges.
2) To investigate scour mechanisms around bridge foundations.
3) To evaluate different bridge pier shapes.
4) To analyze RCC bridge components under flood loading.
5) To identify suitable scour protection measures.
6) To develop safe and economical bridge design recommendations.

E. Scope of Study

The scope of the present study includes:

- Hydraulic analysis of flood conditions.
- Structural analysis of RCC bridges.
- Scour depth estimation.
- Comparison of pier shapes.
- Design according to IRC provisions.
- Use of CSI Bridge software for analysis.

II. LITERATURE REVIEW

A. Introduction

Several researchers have studied bridge performance under flood conditions. Their investigations focus on scour formation, hydraulic loading, debris accumulation, and foundation failures.

B. Studies on Scour Around Bridge Piers

Researchers observed that local scour develops due to the formation of horseshoe vortices around bridge piers. These vortices remove sediment from the riverbed and create scour holes.

The depth of scour depends on:

- Flow velocity
- Water depth
- Pier shape
- Sediment size
- Foundation geometry

C. Influence of Pier Shape

Experimental studies indicate that streamlined pier shapes significantly reduce scour depth.
Performance ranking:
1) Elliptical Pier
2) Circular Pier
3) Triangular Nosed Pier
4) Oblong Pier
5) Rectangular Pier

D. Debris Loading Studies

Floodwater often carries logs, rocks, vegetation, and man-made debris.
Accumulated debris:
- Increases hydraulic pressure
- Alters flow pattern
- Enhances scour formation
- Increases structural stress

E. Research Gap

Although many studies focus on scour analysis, limited research combines:
- Structural design
- Hydraulic analysis
- Scour estimation
- Software modeling

within a single framework.

III. FLASH FLOODS AND BRIDGE HYDRAULICS

A. Flash Floods

A flash flood is a rapid flooding event occurring within a short period following intense rainfall.
Characteristics:
- High velocity
- Short warning time
- High sediment transport
- Severe erosion

B. Causes of Flash Floods

- Cloudbursts
- Intense rainfall
- Dam failures
- Landslides
- Urbanization

C. Hydraulic Forces Acting on Bridges

During flash floods, bridges experience:
- Water Current Force
- Horizontal force exerted by flowing water.
- Hydrostatic Pressure
- Pressure due to standing water.
- Hydrodynamic Pressure
- Pressure due to moving water.
- Debris Impact Force
- Force caused by collision of floating objects.
- Uplift Force
- Upward pressure acting on bridge decks.

D. Effects on Bridges

- Scour around foundations
- Deck displacement
- Pier instability
- Bearing damage
- Structural collapse

IV. COMPONENTS OF RCC BRIDGE

A. Superstructure

The superstructure includes all components above the bearings.
Components:
- Deck slab
- Longitudinal girders
- Cross girders
- Footpaths
- Railings

B. Substructure

Components:
- Bearings
- Pier cap
- Piers
- Abutments
- Foundation

C. Deck Slab

The deck slab transfers vehicle loads to girders.
Functions:
- Load distribution
- Riding surface support
- Structural stability

D. Girders

Girders carry loads from deck slabs and transfer them to piers.
Types:
- RCC girders
- Prestressed girders
- Steel girders

E. Piers

Piers support bridge spans between abutments.
Functions:
- Transfer loads to foundation
- Resist water current
- Maintain stability

F. Abutments

Abutments support bridge ends and retain earth pressure.

V. SCOUR ANALYSIS

A. Definition

Scour is the removal of soil around bridge foundations due to flowing water.

B. Types of Scours

- Local Scour
- Occurs around piers and abutments.

- Contraction Scour
- Occurs when river width reduces.
- Degradation Scour
- General lowering of riverbed.

C. Factors Affecting Scour

- Water velocity
- Pier shape
- Sediment size
- Foundation depth
- River geometry

D. Scour Calculation

- IRC recommends considering:
- Maximum Scour Depth = 2 × Normal Scour Depth
- Foundation depth should be below maximum scour level.

E. Effect of Pier Shape

- Pier Shape| Relative Scour
- Rectangular| Highest
- Circular| Moderate
- Triangular| Low
- Elliptical| Lowest

VI. RCC BRIDGE DESIGN

A. Design Data

- Concrete Grade = M30
- Steel Grade = Fe500
- Clear Cover = 50 mm

B. Loads Considered

- Dead Load
- Self-weight of structure.
- Live Load
- IRC Class AA Loading.
- Impact Load
- Dynamic vehicle effect.
- Wind Load
- Horizontal force due to wind.
- Flood Load
- Hydraulic force due to water flow.

C. Design of Deck Slab

Design involves:

- Bending moment calculation
- Effective depth calculation
- Reinforcement design

D. Design of Girder

Checks include:

- Flexural strength
- Shear strength
- Deflection control

E. Design of Pier

Checks include:

- Axial load
- Bending moment
- Combined loading

F. Design of Foundation

Foundation must resist:

- Vertical load
- Horizontal load
- Overturning
- Scour effects

VII. CSI BRIDGE ANALYSIS

A. Introduction

CSI Bridge is a specialized software for bridge modeling and analysis.

B. Modeling Procedure

Steps:

1) Define geometry.
2) Assign material properties.
3) Define supports.
4) Apply loads.
5) Run analysis.

C. Load Combinations

Load combinations include:

- DL + LL
- DL + LL + Impact
- DL + Flood Load
- Ultimate Load Combination

D. Results

Outputs obtained:

- Bending Moment Diagram
- Shear Force Diagram
- Deflection Diagram
- Stress Distribution

VIII. SCOUR PROTECTION MEASURES

A. Riprap Protection

Large stones placed around foundations.

B. Gabion Walls

Wire mesh boxes filled with rocks.

C. Launching Apron

Protects riverbed from erosion.

D. Guide Bund

Controls river flow direction.

E. Streamlined Piers

Reduce vortex formation.

IX. RESULTS AND DISCUSSION

The analysis indicates:

- Flash floods significantly increase scour depth.
- Elliptical piers perform best hydraulically.
- Circular piers offer economical solutions.
- Proper foundation depth improves stability.
- Scour protection measures increase service life.

X. CONCLUSION

The study concludes that flash floods are one of the most critical threats to bridge safety. Scour remains the primary cause of foundation failure during flood events. The use of streamlined pier shapes, adequate foundation depth, and effective scour protection measures significantly improves bridge performance.

RCC bridges designed according to IRC standards and verified through CSI Bridge software can safely withstand flash flood conditions. Elliptical and circular piers demonstrate superior hydraulic characteristics and reduced scour depth compared to rectangular piers.

Future bridge projects should incorporate flood-resilient design strategies to ensure long-term safety, durability, and sustainability.

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