

“Study the Causes of Failure of Major Bridge Across Wainganga River in Down Stream of Bhimgad Dam at Seoni (M.P.) And Its Remedial Design Solution Using Staad -Pro V8i”

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ABSTRACT

Bridges are essential components of transportation infrastructure, providing safe and uninterrupted connectivity across rivers and other natural obstacles. However, bridges located downstream of dams are frequently exposed to high flood velocities, severe hydraulic forces, and foundation scour, which may adversely affect their structural performance and long-term serviceability. Therefore, a detailed investigation of bridge failures is necessary to understand the governing causes and to develop effective rehabilitation strategies.

This study investigates the causes of distress in Bridge SEY02-03 across the Wainganga River, located downstream of Bhimgad Dam in Seoni District, Madhya Pradesh. The research adopts an integrated approach by combining hydraulic analysis, geotechnical investigation, structural assessment, and remedial design to evaluate the overall performance of the existing bridge and to recommend suitable rehabilitation measures.

Hydraulic analysis was carried out in accordance with the recommendations of IRC: SP:13 and IRC:78, considering design flood discharge, flow characteristics, afflux, and scour depth. The results indicate that hydraulic scour around the bridge foundation is the principal factor affecting structural stability under extreme flood conditions. Geotechnical investigations based on available borehole and soil investigation reports confirmed the suitability of deep pile foundations while emphasizing the importance of adequate embedment and effective scour protection.

The structural behaviour of the bridge was evaluated using a three-dimensional analytical model developed in STAAD.Pro V8i under the loading combinations specified in the relevant IRC and IS codes. The analysis identified deficiencies in the existing structure and provided the basis for developing an integrated rehabilitation scheme comprising foundation improvement, scour protection, strengthening of distressed structural components, bearing rehabilitation, and durability enhancement.

The study demonstrates that combining hydraulic, geotechnical, and structural investigations provides a reliable framework for assessing bridge performance and selecting appropriate rehabilitation measures. The proposed methodology can be effectively applied to similar bridges located in flood-prone river systems and downstream dam environments, thereby contributing to improved structural safety, durability, and sustainable bridge management.

Keywords: Bridge Rehabilitation, Hydraulic Scour, Wainganga River, Bhimgad Dam, Pile Foundation, STAAD.Pro V8i, Structural Analysis, Geotechnical Investigation, Remedial Design.

CHAPTER-1 INTRODUCTION

1.1 BACKGROUND AND MOTIVATION

Bridges play a vital role in transportation infrastructure by providing safe and reliable connectivity across rivers, valleys, and other natural barriers. However, throughout their service life, bridge structures are continuously subjected to hydraulic forces, increasing traffic loads, environmental exposure, and material deterioration. If these factors are not properly considered during design, inspection, and maintenance, they may adversely affect structural performance and serviceability. Bridge failures not only cause economic losses but also interrupt transportation, emergency services, and regional development, particularly in rural areas where alternative routes are often unavailable.

In India, a large number of highway and rural bridges were constructed several decades ago using the design standards applicable at that time. Since then, the Indian Roads Congress (IRC) has introduced significant revisions in provisions related to bridge loading, seismic design, hydraulic analysis, foundation engineering, and durability requirements. Consequently, many existing bridges require reassessment to verify their adequacy under present-day traffic demands and environmental conditions. Among the various causes of bridge failure, hydraulic scour around

foundations is widely recognized as one of the most critical factors affecting bridge safety.

1.2 BACKGROUND OF RETAINING WALLS

Table 1 Bridge Identity Summary, SEY02-03, Wainganga River, Seoni District

PARAMETER	DATA
Bridge ID / Package	SEY02-03 / PMGSY-III Pkg-82, PIU-II Seoni
Road Name	T02-Anjaniya Bhimgad Gangai Ryt Sarekha Tola (Kodia Ryt)
Block / District / State	Chhapara / Seoni / Madhya Pradesh
Coordinates	Lat. 22°23'51" N, long. 79°39'43" E (Chainage: 0+330)
Bridge Type (Collapsed)	RCC Box Girder High Level Bridge
Span Arrangement	6 × 25.0 m = 150.0 m total length
Width (Overall / Carriageway)	8.40 m / 7.50 m
High Flood Level (HFL)	RL 106.375 m
AHFL (with afflux)	RL 105.687 m (afflux = 0.009 m)
FRL / OFL	RL 94.224 m / RL 91.899 m
Min. Bed Level	RL 86.671 m
Flow Depth at HFL	19.704 m
Catchment Area	2,030.30 sq.km (GT Sheets 55N and 55O series)
Design Discharge	16,112 cumecs (adopted); SUH peak: 17,784 cumecs
Velocity at AHFL	4.743 m/s (Manning's formula)
Seismic Zone	Zone III, Z = 0.16g (IRC:6-2017; IS:1893-2016)
IRC Design Loading	Class A (2 lanes) + Class 70R (1 lane)
Founding Level (P3-P7)	RL 71.671 m (existing); RL 64.317 m (required)
Foundation Type	Bored Cast-in-Situ Pile Foundation
Pier Type	Circular RCC Pier
Pier Diameter	2.00 m
Pier Foundation	4 Piles per Pier
Pile Diameter	1.20 m
Pile Depth	18.00 m below Ground Level (GL)
Abutment Type	RCC Box Type Abutment
Abutment Foundation	6 Piles per Abutment
Abutment Pile Diameter	1.20 m

1.3 BRIDGE SITE DESCRIPTION

The failure of Bridge SEY02-03 across the Wainganga River, downstream of Bhimgad Dam in Seoni District, Madhya Pradesh, disrupted an important transportation link connecting nearby rural communities. The bridge failure affected daily travel, emergency services, agriculture, and local economic activities, emphasizing the need for reliable and durable bridge infrastructure.

The bridge is located in a hydraulically sensitive region where reservoir releases, high flood velocities, and scour can significantly influence foundation stability and structural performance. Therefore, a comprehensive investigation was carried out using hydraulic studies, geotechnical data, project records, field observations, bridge drawings, and STAAD.Pro V8i analysis in accordance with the latest IRC and IS standards.

1.4 RESEARCH OBJECTIVES

The main objective of this research is to investigate the causes of distress in Bridge SEY02-03 across the Wainganga River through an integrated hydraulic, geotechnical, and structural assessment, and to develop appropriate rehabilitation measures in accordance with the latest IRC and IS code provisions.

The specific objectives of the study are:

1. To assess the existing condition of the bridge using field observations, departmental records, and available technical reports.
2. To evaluate the hydraulic behaviour of the Wainganga River, including design discharge, flood characteristics, flow conditions, and scour potential in accordance with the relevant IRC guidelines.
3. To investigate the geotechnical performance of the existing pile foundation system using available soil investigation data and foundation details.
4. To develop a three-dimensional structural model in STAAD.Pro V8i and evaluate the behaviour of the bridge under the loading combinations specified in the applicable IRC and IS codes.
5. To identify the major factors responsible for the observed bridge distress through an integrated interpretation of hydraulic, geotechnical, structural, and material investigations.
6. To propose and evaluate suitable rehabilitation measures for improving the structural safety, durability, and long-term serviceability of the bridge.
7. To recommend appropriate inspection, maintenance, and bridge management practices for similar bridges located in flood-prone river systems and downstream of dam reservoirs.

CHAPTER-2

(Smith, 1976) Smith investigated several bridge failures reported worldwide and concluded that hydraulic scour around bridge foundations is one of the most common causes of bridge collapse. The study highlighted that flood-

induced erosion reduces foundation stability and may lead to structural failure if timely inspection and maintenance are not carried out. The author recommended periodic hydraulic assessment for improving bridge safety. ⁽⁵⁷⁾

(Wardhana and Hadipriono, 2003) A statistical analysis of 503 bridge failures in the United States showed that hydraulic actions accounted for more than half of the reported failures. Other contributing factors included structural deficiencies, excessive loading, construction errors, and vehicle impacts. The study emphasized that hydraulic conditions should be reassessed throughout the service life of bridges. ⁽⁶¹⁾

(Ponnuswamy, 2008) The author discussed common causes of bridge failures in India and emphasized the influence of hydraulic scour, inadequate foundation depth, and increasing traffic loads. The study recommended regular bridge inspection, updated hydraulic evaluation, and timely strengthening of ageing bridge structures. ⁽⁴⁹⁾

(Mondal and Bhatt, 2018) This study analysed bridge failures occurring in India and reported that hydraulic scour was the dominant reason for collapse during major flood events. Riverbed degradation, insufficient embedment depth, and inadequate waterway provisions were identified as the primary engineering deficiencies affecting bridge stability. ⁽⁴⁶⁾

(Visscher, 2016) Visscher reviewed historical bridge failures from different countries and observed that ageing infrastructure, increased traffic demand, and inadequate maintenance have significantly increased bridge vulnerability. The study recommended continuous structural health monitoring and periodic condition assessment to reduce failure risk. ⁽⁶⁰⁾

(Moskalkov and Mohanta, 2021) A comparative review of bridge failures between 2000 and 2020 showed that hydraulic scour remains the leading cause of bridge collapse worldwide. The authors reported that recent failures are generally associated with multiple interacting factors, including foundation instability, material deterioration, heavy traffic loading, and insufficient maintenance. ⁽⁴⁷⁾

(Garg and Bhagat, 2020) The authors reviewed recent bridge failures in India and concluded that most failures resulted from the combined effects of hydraulic, structural, and maintenance-related deficiencies rather than a single engineering problem. The study recommended integrated bridge management systems involving regular inspection, structural assessment, and rehabilitation planning. ⁽²⁶⁾

(Lacey, 1930) Lacey developed the regime theory for estimating scour depth in alluvial rivers. The study proposed empirical equations relating discharge intensity and bed material characteristics to normal scour depth. Even today, Lacey's method forms the basis of bridge foundation design

in India and is adopted in IRC:78 for estimating design scour depth. ⁽⁴¹⁾

(Richardson, Harrison and Davis, 1991) The FHWA presented comprehensive guidelines for evaluating bridge scour by considering long-term bed degradation, contraction scour and local scour. The report emphasized that the combined effect of these mechanisms should be considered while assessing bridge foundation safety under flood conditions. ⁽⁵²⁾

(Richardson and Davis, 2001) The updated HEC-18 manual provided improved procedures for scour prediction and highlighted the importance of hydraulic investigation, field inspection and periodic monitoring of bridge foundations. The study recommended detailed scour assessment for bridges located on major rivers and flood-prone areas. ⁽⁵³⁾

(Ashida and Bayazit, 1973) The authors investigated sediment movement in steep channels and explained the relationship between flow velocity, bed roughness and initiation of sediment transport. Their findings contributed to a better understanding of erosion processes influencing bridge foundation stability. ⁽⁴⁾

(Breusers and Raudkivi, 1991) This study explained the hydraulic mechanisms responsible for local scour around bridge piers and abutments. The authors showed that sediment transport, riverbed characteristics and flow turbulence significantly influence scour development and foundation performance. ⁽¹⁷⁾

(Melville and Sutherland, 1988) The researchers proposed a practical design method for estimating local scour around bridge piers. The study demonstrated that pier geometry, flow depth, approach velocity and bed material are the principal parameters governing scour depth and has become one of the most widely cited references in bridge hydraulics. ⁽⁴⁵⁾

(Melville and Coleman, 2000) The authors presented a detailed explanation of bridge scour mechanisms, including clear-water scour, live-bed scour and contraction scour. The publication emphasized that hydraulic conditions, sediment characteristics and foundation geometry collectively determine the stability of bridge foundations. ⁽⁴⁴⁾

(Johnson and Dock, 1998) This study introduced probabilistic methods for bridge scour estimation and highlighted the uncertainties associated with hydraulic parameters and riverbed characteristics. The authors recommended incorporating safety margins into foundation design to improve bridge reliability. ⁽³⁸⁾

(Sheppard, Melville and Demir, 2014) The authors evaluated several empirical equations used for predicting local scour around bridge piers. The comparative analysis indicated that no single equation is universally applicable and recommended selecting prediction methods based on site-specific hydraulic conditions. ⁽⁵⁵⁾

(Bateni, Borghei and Jeng, 2007) Artificial neural network and neuro-fuzzy models were developed for estimating scour depth around bridge piers. The study reported that intelligent prediction techniques provide better accuracy than conventional empirical equations under complex hydraulic conditions. ⁽⁷⁾

(Lee and Sturm, 2009) The study investigated the influence of sediment size scaling on physical modelling of bridge pier scour. Experimental results confirmed that sediment characteristics play a significant role in predicting scour depth and should be carefully considered during hydraulic modelling. ⁽⁴²⁾

CHAPTER 3

SITE INVESTIGATION AND EXISTING BRIDGE DETAILS

3.1 PROJECT BACKGROUND

The present study focuses on Bridge SEY02-03, an existing High-Level RCC Box Girder Bridge constructed across the Wainganga River on the rural road connecting Anjaniya–Bhimgad and Gangai Ryt Sarekha Tola (Kodia Ryt) in Chhapara Block, Seoni District, Madhya Pradesh. The bridge serves as an important transportation link by providing year-round connectivity for nearby villages and supporting passenger movement, agriculture, education, healthcare, and other essential services.

The bridge is located near Chainage 0+330 of the project road under the Pradhan Mantri Gram Sadak Yojana (PMGSY-III) implemented by the Madhya Pradesh Rural Road Development Authority (MPRRDA). Its location approximately 8.5 km downstream of Bhimgad Dam makes it hydraulically significant, as reservoir releases influence downstream flow conditions, sediment transport, and scour around the bridge foundations.

A detailed engineering survey was carried out to establish the hydraulic and topographical characteristics of the river reach. The survey covered approximately 500 m upstream and 500 m downstream of the bridge and included longitudinal and cross-sectional profiles for hydraulic evaluation. River geometry, bed profile, bank conditions, and surrounding terrain were documented to support the subsequent hydraulic, geotechnical, and structural investigations.

All elevations presented in this study are referenced to the Reduced Level (RL) system adopted in the official project

survey. Two permanent Temporary Bench Marks (TBMs) were used for vertical control during the investigation:

- TBM-01: RL 96.312 m
- TBM-02: RL 96.040 m

Table 2 Project Location Details

Parameter	Description
Project Name	Bridge across Wainganga River (Bridge ID: SEY02-03)
Road Name	Anjaniya–Bhimgad to Gangai Ryt Sarekha Tola (Kodia Ryt)
District	Seoni
Block	Chhapara
State	Madhya Pradesh
Project Scheme	PMGSY-III
Package Number	82
Chainage	0+330
Latitude	22°23'51" N
Longitude	79°39'43" E
Distance from Bhimgad Dam	Approximately 8.5 km downstream

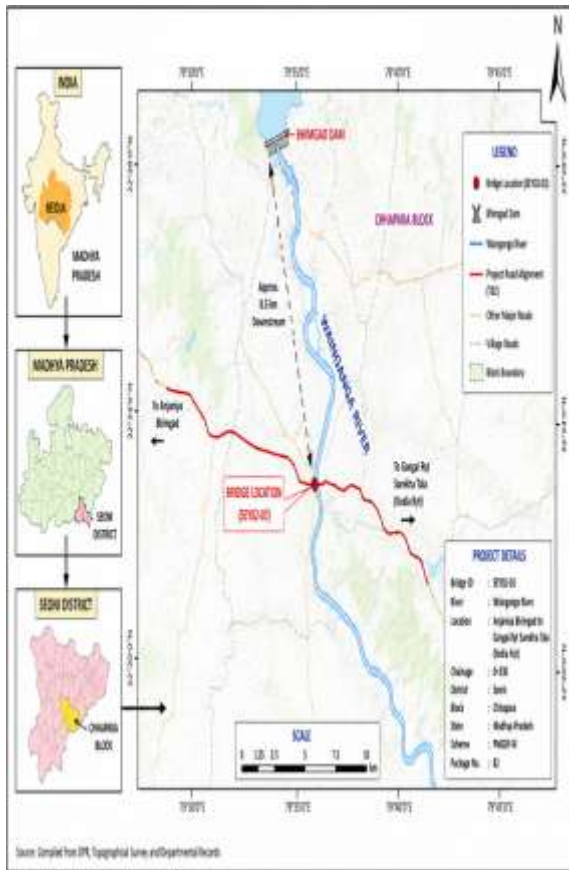


Figure 1 Project Location Map

CHAPTER 4

EXPERIMENTAL ANALYSIS

4.1 INTRODUCTION

Experimental analysis plays an important role in identifying the factors responsible for the distress and reduced performance of bridge structures. For existing bridges, a systematic investigation combining field observations with engineering analysis provides a reliable basis for evaluating structural condition and planning suitable rehabilitation measures. In the present study, an integrated approach has been adopted to examine the hydraulic, geotechnical, and structural behaviour of Bridge SEY02-03 across the Wainganga River.

The objective of this chapter is to evaluate the existing bridge using available engineering data and analytical techniques in order to determine the principal causes of distress. The investigation includes assessment of foundation conditions, hydraulic behaviour of the river, and structural response under the applicable loading conditions. The results obtained from these analyses form the basis for developing the remedial measures presented in the subsequent chapters.

The study has been carried out using information collected from the Detailed Project Report (DPR), hydraulic investigation reports, geotechnical investigation reports, bridge drawings, survey records, and field observations available for the project. These data have been supplemented

with independent engineering calculations and structural evaluation using STAAD.Pro V8i, following the relevant provisions of the latest IRC and IS codes.

The experimental investigation has been divided into three major components: geotechnical investigation, hydraulic failure analysis, and structural failure analysis. The geotechnical investigation evaluates the subsurface conditions and adequacy of the existing pile foundation. Hydraulic analysis examines flood characteristics, flow behaviour, and scour potential around the bridge foundations, while structural analysis evaluates the response of the bridge under the prescribed loading combinations. The combined interpretation of these investigations provides a comprehensive understanding of the mechanisms responsible for bridge distress.

The methodology adopted for the experimental investigation is illustrated in Figure below which presents the sequence followed for data collection, engineering evaluation, analytical modelling, and interpretation of results.



Figure 2 Methodology Adopted for Hydrological Analysis

4.2 GEOTECHNICAL INVESTIGATION

A geotechnical investigation was carried out to assess the subsurface conditions and evaluate the suitability of the existing foundation system. The investigation was based on the available borehole records, soil investigation report, Standard Penetration Test (SPT) results, and foundation drawings. These data were used to determine the engineering characteristics of the foundation strata and their influence on bridge performance.

The borehole investigation identified the sequence of soil and rock layers beneath the bridge. The upper strata mainly comprise sandy gravel and weathered material, while competent basalt rock was encountered at greater depths, providing the primary bearing stratum for the bored cast-in-situ pile foundation.



Figure 3 Representative Borehole

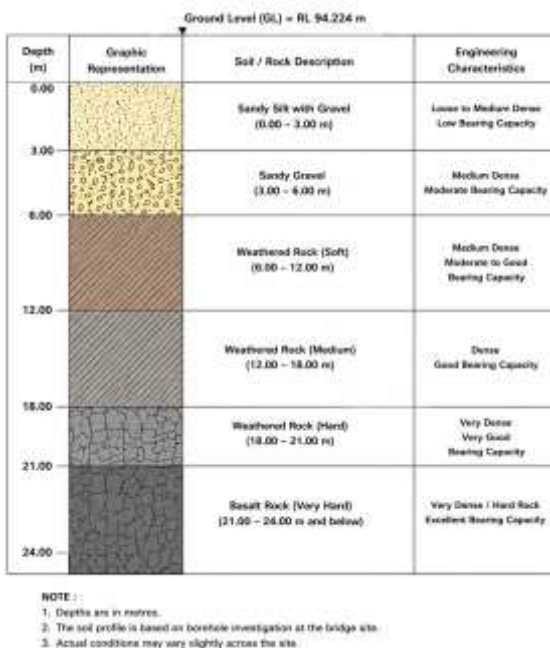


Figure 4 Typical Soil Profile

4.3 HYDRAULIC FAILURE ANALYSIS

Hydraulic analysis was carried out to evaluate the influence of flood flow on the performance of the existing bridge across the Wainganga River. The assessment was based on the available hydraulic investigation report, topographical survey, river cross-sections, and the relevant provisions of IRC: SP:13 and IRC:78. The objective was to determine

whether the hydraulic conditions at the bridge site contributed to the observed foundation distress.

The design flood was estimated using standard hydrological procedures, including the Rational Method, Manning's Formula, and the Synthetic Unit Hydrograph (SUH) method. The governing discharge obtained from these analyses was adopted for evaluating the hydraulic behaviour of the river during extreme flood events.

Hydraulic parameters such as High Flood Level (HFL), flow velocity, waterway adequacy, hydraulic radius, and riverbed slope were assessed to understand the flow characteristics at the bridge location. Particular attention was given to the bridge's location downstream of Bhimgad Dam, where controlled reservoir releases increase flow velocity and reduce sediment availability, thereby enhancing the potential for clear-water scour.

The design scour depth was determined in accordance with IRC:78 using Lacey's scour equation. The analysis indicated that the computed scour level was lower than the existing founding level of the bridge, suggesting inadequate embedment of the pile foundation during severe flood conditions. Progressive riverbed degradation and local scour around the pier foundations are therefore considered the principal hydraulic factors responsible for reducing foundation stability.

4.4 STRUCTURAL FAILURE ANALYSIS

The structural behaviour of the existing bridge was evaluated using analytical calculations and a three-dimensional model developed in STAAD.Pro V8i. The assessment was carried out in accordance with the latest provisions of IRC:6–2017, considering dead load, live load, impact, wind, seismic loading, and other applicable load combinations. The objective of the analysis was to compare the structural demand with the available capacity of the existing bridge and identify the critical deficiencies responsible for its distress.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 FAILURE CAUSE ATTRIBUTION

The investigation of Bridge SEY02-03 shows that the observed distress was caused by the combined effect of hydraulic, geotechnical, structural, and material-related deficiencies rather than a single factor. The findings from field observations, hydraulic analysis, geotechnical investigation, and STAAD.Pro analysis indicate that several deterioration mechanisms acted together, reducing the overall stability and serviceability of the bridge.

Hydraulic scour was identified as the primary cause of foundation instability. The analysis showed that the existing foundation level was higher than the required scour-safe level, resulting in progressive loss of lateral soil support during severe flood conditions. This condition was further

intensified by long-term riverbed degradation caused by regulated releases from the upstream Bhimgad Dam.

Structural analysis demonstrated that the existing bridge no longer satisfies the loading requirements of IRC:6–2017. Increased traffic loading, ageing of structural components, and reduced stiffness resulted in higher bending moments, shear forces, and deflections. Material investigation also confirmed deterioration of concrete and reinforcement, which reduced the durability and residual strength of the bridge.

Table 2 Principal Causes of Bridge Distress

Sr. No.	Failure Category	Principal Observation	Relative Influence
1	Hydraulic Scour	Foundation instability due to excessive scour	Very High
2	Structural Overloading	Increased traffic loading and revised IRC provisions	High
3	Material Deterioration	Carbonation, corrosion and reduction in concrete strength	Moderate
4	Design Deficiency	Older design provisions and inadequate durability measures	Moderate
5	Dam-Induced Hydraulic Effects	Long-term riverbed degradation downstream of Bhimgad Dam	Moderate

The results indicate that hydraulic scour was the governing cause of distress, while structural overloading and material deterioration further reduced the safety margin of the bridge.

5.2 EFFECTIVENESS OF THE PROPOSED REHABILITATION MEASURES

The rehabilitation measures presented were evaluated through hydraulic assessment and structural analysis. The proposed strengthening includes foundation rehabilitation, scour protection, pier jacketing, bearing replacement, and improvement of structural durability.

The analysis confirms that these measures significantly improve the structural behaviour of the bridge under the governing load combinations prescribed in IRC:6–2017. The rehabilitated foundation provides improved resistance against scour and lateral loading, while the strengthened

superstructure and substructure enhance stiffness, load-carrying capacity, and overall serviceability.

Table 3 Effectiveness of the Proposed Rehabilitation Measures

Bridge Deficiency	Rehabilitation Measure Adopted	Expected Improvement
Foundation Instability	Rehabilitation of pile foundation and improved scour protection	Improved foundation stability
Hydraulic Scour	Riprap protection, filter layer and toe wall	Reduced local scour around piers
Structural Capacity	Rehabilitation of structural members	Improved load-carrying capacity
Material Deterioration	Repair of deteriorated concrete and corrosion protection	Enhanced durability
Bearing Deterioration	Replacement of existing bearings	Improved load transfer and movement
Long-Term Performance	Inspection and maintenance programme	Increased service life

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 PRINCIPAL CONCLUSIONS

The major conclusions drawn from the present investigation are as follows:

1. The distress of Bridge SEY02-03 resulted from the combined effects of hydraulic, structural, geotechnical, and material deterioration rather than a single failure mechanism.
2. Hydraulic scour was identified as the primary cause of foundation instability. The analysis confirmed that the existing foundation was vulnerable during severe flood conditions because of inadequate embedment below the design scour level.
3. Sediment-deficient releases from the upstream Bhimgad Dam increased riverbed degradation and further intensified the scour around the bridge foundation.
4. STAAD.Pro V8i analysis showed that the existing bridge does not satisfy the present loading requirements of IRC:6–2017, indicating inadequate structural capacity under current traffic loading.
5. Material investigation revealed deterioration of concrete and reinforcement due to ageing, carbonation and corrosion, reducing the durability and residual strength of the bridge.
6. The proposed rehabilitation measures, including foundation strengthening, scour protection, pier jacketing and bearing replacement, significantly improve the structural safety and serviceability of the bridge.
7. The analytical verification confirmed that the rehabilitated bridge satisfies the requirements of IRC:6–2017, IRC:78–2014, IS:2911, IS:456, and IS:1893 (Part 3).
8. The study concludes that rehabilitation is a technically feasible and economically preferable alternative to complete bridge reconstruction.

6.2 RECOMMENDATIONS

Based on the findings of the study, the following recommendations are proposed:

- Carry out regular inspection of bridge foundations, particularly after major flood events.
- Monitor scour depth periodically to identify possible foundation exposure.
- Inspect bearings, concrete surfaces, and reinforcement condition at regular intervals.
- Implement preventive maintenance in accordance with relevant IRC guidelines.

- Coordinate bridge operation with Bhimgad Dam authorities during high discharge releases.
- Apply similar assessment procedures to other bridges located downstream of dams.

6.3 SCOPE FOR FUTURE RESEARCH

Future investigations may focus on the following aspects:

- Three-dimensional finite element modelling of bridge substructure and foundation.
- Advanced hydraulic analysis using HEC-RAS 2D or similar software.
- Nonlinear seismic assessment of rehabilitated bridge systems.
- Bridge Health Monitoring (BHM) using modern sensor technologies.
- Comparative evaluation of different bridge rehabilitation techniques under river environments.

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