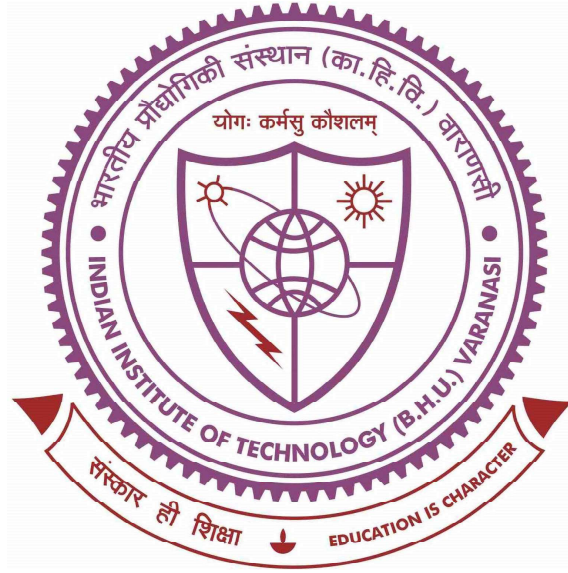


An Integrated Approach for Condition Assessment of Steel Railway Bridges



**Thesis submitted in partial fulfilment
for the Award of Degree
Doctor of Philosophy**

by

SUDHIR BABU PATEL

**DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY
(BANARAS HINDU UNIVERSITY)
VARANASI – 221 005**

20061503

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CHAPTER-7

CONCLUSIONS AND RECOMMENDATIONS

7.1 General

Following tasks have been performed to fulfil objectives of the study:

- Both the stress life method and fracture mechanics-based method on a numerically simulated riveted open web steel girder railway bridge, exploring the impact of different stress bands (5 MPa and 10 MPa) has been done.
- Rail-cum-roadway bridge exceeding one kilometer in length, accommodating both roadway and railway, considering various loadings, speed criteria, and stress bands has been analyzed and pattern of variation in remaining life and per vehicle passage damage (PVPD) for different stress bands has been observed.
- Performance of various deep learning architectures with different backbone networks using metrics like dice coefficient, IoU, and F1 score over masonry surfaces have been evaluated.
- A fuzzy-based system for accurate and efficient condition assessment of railway bridges, overcoming limitations of the current conservative and manual grading practices has been developed.

Finding from chapter-3, chapter-4, chapter-5, and chapter-6 can be summarized as:

7.2 Fatigue analysis of railway bridge

Different methods for fatigue life assessment have been presented. Fatigue based provisions of British standard, European standard, Indian and American codes have been described. Provision of an Equivalent Uniformly Distributed Load (EUDL) in place of the actual axle load is mentioned in the bridge rule (RDSO 2014). However, axle loads are applied as point loads for precise fatigue assessment of the existing steel railway bridge. Following conclusions may be deduced from fatigue study of FEM model of the bridge.

- Both the stress life method and the fracture mechanics approach show that the remaining life of the existing bridge decreases as speed increases at constant GMT.
- In the case of a lower stress band, a more precise and predictable remaining life can be obtained.
- It can also be deduced that when the stress band is smaller, the residual life does not necessarily increase or decrease in comparison to the residual life obtained with a larger stress band.
- The proposed efficient and systematic approach can efficiently be used for the remaining life assessment of existing old steel railway bridges.

7.3 Remaining life assessment and stress band study of rail-cum-roadway bridge

PVPD (per vehicle passage damage) has been calculated for all sorts of vehicles at varied speeds. The remaining life of the bridge has been calculated using several future loadings

operating at different speeds. Statistics of variation in remaining lives and per vehicle passage damage (PVPD) utilising different stress bands with regard to stress band 'SB' has been presented. The best fit distribution for PVPD variation and remaining life variation has also identified after a goodness-of-fit test study for stress bands SB5, SB10, and SB15.

The following conclusions can be drawn from a comprehensive study of an existing rail-cum-roadway bridge.

- For particular speed and stress band, assessed remaining life is minimal, in between, and maximum for 32.5T loading, 25T loading, and CC+8+2T loading.
- The remaining life of the bridge varies from 18.4 to 60.5 years for the Minor span and from 26.5 to 65.6 years for the major span, depending on the type of future loading and its running speed over the concerned bridge.
- In case of per vehicle passage damage (PVPD) and remaining life, variation at wider stress band is more compare to narrower stress band concerning stress band 'SB'.
- The best-fit distribution for PVPD variation for SB5, SB10, and SB15 is the log-logistic distribution.
- The generalized-logistic distribution is the best-fit distribution for variation in remaining life for SB5, SB10, and SB15.
- This study will be helpful in health assessment and timely maintenance of railway, highway, and rail-cum-roadway bridges.

7.4 DL-based crack detection on masonry surfaces

Deep learning (DL)-based semantic segmentation models has successfully been applied in semantic segmentation of cracks over masonry surfaces. The performance of various deep learning architectures with different backbone networks has been investigated to segment

cracks. The performance of trained networks has also been checked over existing small masonry culvert bridges. Result shows that trained networks can detect finer cracks in different environmental conditions. This study presents deep learning-based effective techniques for semantic segmentation of cracks over masonry surfaces. It will be valuable in crack detection over masonry surfaces like masonry buildings, masonry boundary walls, old masonry railway bridges, etc.

Since trained networks semantically segmented even finer cracks in different environmental conditions over existing small masonry culvert bridges, presented techniques can also be used in crack detection over masonry surfaces in old railway bridges. In addition to reducing the time and effort previously required for the inspectors to inspect and document masonry structures, the proposed method also minimizes human error.

7.5 Fuzzy-based bridge rating

In conclusion, the newly developed expert system for analysing railway bridge problems appears to be an effective and appropriate tool for experts. The system is functional, versatile, and easily upgradeable as needed. It adds objectivity to the evaluation process and ensures assessment quality through model validation. While the system's implementation may be difficult and complex, it allows for an organised and systematic review of India's current railway bridge problems. By connecting with a Bridge Management System that keeps a database of all bridges in India, the model's results can be used in future research to define criteria for prioritising bridge inspections and maintenance actions.

Proposed approach outperforms the existing numerical rating scale in the following ways:

- It provides more flexibility for condition rating because it has a 10-point scale rather than the current restrictive 5-point scale.

- The overall bridge rating is calculated using a weighted average rather than the poorest component grade.
- It assigns weightage to each element using fuzzy weights depending on structural relevance, as opposed to the traditional IR rating system's equal weightage.
- Because it is very difficult for experts to provide exact ratings of bridge elements, and deteriorating members/elements can be fitted in between two states, the fuzzy technique can easily handle it.
- In the case of the proposed approach, structural importance is already taken into account by the weight factor, so the expert should only provide a rating based on its condition without worrying about its structural importance. In the existing condition rating method, the expert should take care of its structural importance while providing element or component rating.

7.6 Future scope of study

In the present study different aspects of condition assessment of existing bridges has been investigated. Considering present study, following are the suggested areas of research for extension of the herein study.

1. In the present study remaining life of the bridge is obtained on the basis of member strength. Analysis of connections can also be performed to obtain the remaining life of the bridge. Reliability based methods can be applied to find remaining life of the existing bridges.

2. Present study has focused on masonry surfaces, the proposed techniques could be extended to other types of surfaces with cracks, such as flexible and rigid pavement.

3. Proposed fuzzy rating method can be applied over large number of bridges and then convolutional neural network technique can be used to train the network. A hybrid fuzzy Multi attribute decision making logic technique can be used to assess the condition of existing bridges.