# An Integrated Approach for Condition Assessment of Steel Railway Bridges

**Thesis submitted in partial fulfilment**

**for the Award of Degree**

**Doctor of Philosophy**

by

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**20061503** **December, 2023**

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Dedicated to my parents

# Acknowledgement

I express my sincere gratitude and indebtedness to my research supervisor **Professor Krishna Kant Pathak**, Department of Civil Engineering, Indian Institute of Technology (Banaras Hindu University) for his valuable guidance, encouragement and help throughout the tenure of this research work. I am extremely grateful to him for his keen interest in the investigation and the academic help. In course of time, he motivated, inspired and extended the necessary academic help in carrying out my research work. He provided me with invaluable assistance when I was in need of hours, and he also taught me how to make balance during difficult moments. His motivational talks and kind demeanour greatly influenced me. He served as my mentor both academically and socially. Over time, he pushed, inspired, and provided the moral support I needed to complete my research.

I am immensely rejoiced to owe my deep sense of gratitude to members of my doctoral committee, **Professor Sasankasekhar Mandal,** Professor of Civil Engineering, and **Professor Prabhash Bhardwaj**, Professor of Mechanical Engineering for their constant encouragement, invaluable suggestions, and feedback during research work. I am thankful to **Professor Sasankasekhar Mandal**, Head, Department of Civil Engineering, for giving me all the facility during my research work. I extend my gratitude to all the faculty members of the Department of Civil Engineering at the Indian Institute of Technology (BHU) in Varanasi, who accorded me the privilege of pursuing my doctoral degree in such an illustrious institution.

I am thankful to all non-teaching staff members of the Department of Civil Engineering for their kind cooperation and inspiration. I wish to express my deep gratitude to all those who have extended their helping hands in various ways during my tenure at Indian Institute of Technology (Banaras Hindu University), Varanasi, India.

I am filled with profound gratitude and affection for my beloved parents, **Mr. Ram Vishal Patel** and **Mrs**. **Chandra kali Patel.** During this challenging time in your life, you had given me permission to pursue my education. I am eternally grateful for all you gave up to allow me to pursue my PhD without interference. Respected mother, I shall be indebted for the words "believe in hard work" that you have given me. And I will be eternally grateful to my father for shouldering my personal and social burdens while working full-time. **Mr. Gangadin Patel**, my cousin brother, has been my main source of mentorship since I was in eighth grade. I am deeply grateful to my wife, **Mrs. Arti Patel**, who has borne the hardships of this journey alongside me. She is constantly considerate of my time and ensures that she does not interfere with my studies. I understand the loneliness you have endured over the past three years.

I am grateful to **Mr. R M Sonway** (Principal, Government Polytechnic College Balaghat, M.P.) for granting me permission to study. Without his support, achieving my PhD degree would have been considerably more challenging.

In the last but not least extend my sincere gratitude to my seniors **Dr. Abhishek Sharma** and **Dr. Ishan Jha** for their support and encouragement during this PhD journey.

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# List of Symbols and Acronyms

**Acronyms and other notations**

| | |
|---|---|
| CNN | Convolutional Neural Network |
| CSN | Crack Segmentation Network |
| CV | Computer Vision |
| DCNN | Deep Convolutional Neural Network |
| DL | Deep Learning |
| DSPP | Dilated Spatial Pyramid Pooling |
| DTL | Deep Transfer Learning |
| FCN | Fully Convolutional Network |
| FPN | Feature Pyramid Network |
| ML | Machine Learning |
| NN | Neural Network |
| SS | Semantic Segmentation |
| SVM | Support Vector Machine |
| UAV | Unmanned Aerial Vehicle |
| FPN | Feature Pyramid Networks |
| PSPNet | Pyramid Scene Parsing Network |
| VGG | Visual Geometry Group |
| ReLU | Rectified Linear Units |
| RNN | Recurrent Neural Network |
| ResNet | Residual Neural Network |
| IoU | Intersection over Union |
| BCE | Binary Cross Entropy |
| TP | True positive |
| TN | True negative |
| FP | False positive |
| FN | False negative |
| HCF | High cycle fatigue |
| LCF | Low cycle fatigue |
| LEFM | Linear elastic fracture mechanics |
| BGML | Broad gauge main line |
| RBG | Revised broad gauge |

| | |
|---|---|
| MBG | Modified broad gauge |
| DFC | Dedicated freight corridor |
| CC | Carrying capacity |
| PT | Passenger train |
| FTE | Freight train empty |
| FTL | Freight train loaded |
| GMT | Gross metric tonne |
| RDSO | Railway design and standard organization |
| IRICEN | Indian railway institute of civil engineering |
| CDA | Coefficient of dynamic augment |
| EUDL | Equivalent Uniformly Distributed Load |
| SB | Stress band or stress range band |
| PDF | Probability density function |
| BMS | Bridge management system |
| IBMS | Indian bridge management system |
| MF | Membership function |
| FWGM | Fuzzy weighted geometric mean |
| CRN | Condition rating number |
| CCRI | Component's condition rating index |
| ORN | Overall rating number of bridge |
| BRI | Bridge rating index |

**Symbols**

| | |
|---|---|
| N | Number of repetitions to failure at the stress range $\sigma_r$. |
| $\sigma_r$ | Range of stress or stress range in any one cycle |
| $\Delta K$ | Stress intensity factor measured in MPa$\sqrt{m}$ |
| D | Damage |
| $n_i$ | Number of cycles at the i$^{th}$ stress range. |
| $N_i$ | Cycles to failure for the i$^{th}$ stress range |
| $\mu_{\tilde{A}}(x)$ | Membership function of element x in the fuzzy set A |
| $A_\alpha$ | α level set of fuzzy number A |
| $(R_{E_i})_k$ | k$^{th}$ fuzzy rating set of i$^{th}$ element |
| $\tilde{w}_{E_i}$ | Weight or structural importance of i$^{th}$ element. |
| $N_{comb}$ | Number of combinations |
| $R_C$ | Fuzzy rating of bridge component |

| | |
|---|---|
| $R_E$ | Fuzzy rating of element of bridge component |
| $\Delta\sigma$ | normal stress range |
| $\Delta\tau$ | shear stress range |
| $\Delta\sigma_C, \Delta\tau_C$ | Fatigue strength reference value at $N_C$= 2 million cycles |
| $\Delta\sigma_D, \Delta\tau_D$ | Fatigue limit for constant amplitude stress range at $N_D$ |
| $\Delta\sigma_L, \Delta\tau_L$ | cutoff limit for stress ranges at $N_L$ |
| $\gamma_{Mf}$ | partial factor for fatigue strength $\Delta\sigma_C, \Delta\tau_C$ |
| $N_R$ | number of cycles related to constant stress range |
| $n_{Ei}$ | number of cycles corresponding to stress range $\gamma_{Ff}\Delta\sigma_i$ for band i in the factored spectrum |
| $N_{Ri}$ | number of cycles to failure or endurance corresponding to stress range $\gamma_{Ff}\Delta\sigma_i$ for obtained from factored $\frac{\Delta\sigma_C}{\gamma_{Mf}} - N_R$ curve |
| $\sigma_0$ | constant amplitude non-propagating stress range ($\sigma_r$ at $N=10^7$) |
| $f_f$ | Uncorrected normal fatigue stress range for $N_{SC}$ life cycle |
| $\tau_f$ | Uncorrected shear fatigue stress range for $N_{SC}$ life cycle |
| $f_{fn}$ | Normal fatigue strength of the detail at $5 \times 10^6$ cycles, for the given detail category |
| $\tau_{fn}$ | Shear fatigue strength of the detail at $5 \times 10^6$ cycles, for the given detail category |
| $\gamma_{mft}$ | partial safety factor against fatigue failure |
| f | actual normal stress ranges corresponding to detail category |
| $\tau$ | actual shear stress ranges corresponding to detail category |