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RESIDUAL STRENGTH AND SERVICE LIFE ASSESSMENT OF K-TYPE STEEL TRUSS BRIDGE USING INTEGRATED LABORATORY-FIELD CORROSION CORRELATION

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ABSTRACT

Steel truss bridges in service are increasingly affected by corrosion-induced deterioration, necessitating reliable estimation of residual strength and remaining service life for informed maintenance decisions. This paper presents an integrated laboratory–field–analytical framework for condition assessment of the Godavari Rail–cum–Road Bridge, a 51-year-old K-type steel truss bridge located in a chloride-rich riverine environment. Accelerated corrosion tests were conducted on mild steel and bridge steel specimens under immersion, atmospheric exposure, and cyclic wet–dry conditions using 1%, 3%, and 5% NaCl solutions. Field investigations comprising detailed visual inspection and ultrasonic thickness measurements were carried out on a representative 48 m span to quantify in-situ section loss of critical members. Laboratory and field corrosion rates were correlated through acceleration factors ranging from 5.46 to 9.32, establishing equivalence between short-term laboratory exposure and long-term natural corrosion. Residual strength was evaluated using (i) a global stiffness-based load–deflection approach and (ii) a member-level section capacity approach accounting for measured thickness loss. Results indicate that while localized section losses reach up to approximately 33% in certain members, the global residual strength of the truss remains above 97–99% due to structural redundancy, whereas member-level residual strength varies between 87% and 92%. Remaining service life estimates range from about 60 to 130 years, depending on member type and exposure severity. Based on RDSO/IRS guidelines, the bridge is predominantly classified under Condition Rating CR–2 (Fair), suggesting the need for targeted preventive maintenance. The proposed methodology aligns with the practical, scalable framework for performance-based assessment and life-cycle management of aging steel bridges.

Keywords: *Steel truss bridge; corrosion assessment; ultrasonic thickness measurement; acceleration factor; residual strength; remaining service life; condition assessment.*

1. INTRODUCTION

Steel truss bridges form a critical component of railway and roadway infrastructure, particularly for long-span river crossings. In India, many such bridges were constructed between the 1950s and 1980s and continue to serve increasing traffic demands under environmental conditions more severe than those considered in their original design. Progressive corrosion of steel members leads to section loss, stiffness degradation and reduction in load-carrying capacity ultimately affecting structural safety and serviceability.

Conventional bridge inspection practices rely primarily on visual assessment supplemented by limited non-destructive testing. While these methods are effective for identifying visible deterioration, they often fail to quantify hidden corrosion or to provide reliable estimates of residual strength and remaining service life. Consequently, infrastructure agencies face significant uncertainty when deciding between continued operation, repair, strengthening, or replacement of aging steel bridges.

To address these challenges, recent research has emphasized the integration of accelerated laboratory corrosion testing, field-based measurements, and analytical modeling. However, studies that combine laboratory simulations with field data obtained from the same bridge, and further extend the analysis to residual strength and life prediction within a codal framework, remain limited.

This study aims to bridge this gap through a comprehensive investigation of the Godavari Rail-cum-Road Bridge, a K-type steel truss structure that has been in service for over five decades. The specific objectives of this study are to: (i) quantify corrosion rates under controlled laboratory conditions representative of the bridge environment; (ii) measure in-situ thickness loss of critical members using ultrasonic testing; (iii) correlate laboratory and field corrosion behavior through acceleration factors; (iv) evaluate residual strength using both global stiffness-based and member-level capacity-based approaches; and (v) estimate the residual service life of the bridge in accordance with RDSO/IRS guidelines [1].

2. LITERATURE REVIEW

Corrosion assessment of steel bridges has been widely studied using accelerated laboratory testing, field inspection techniques, and analytical or probabilistic deterioration models. Accelerated corrosion tests, particularly cyclic wet–dry exposure, are commonly adopted as they realistically simulate aggressive bridge environments and reproduce corrosion mechanisms comparable to those observed under natural service conditions.

Among field-based non-destructive techniques, ultrasonic thickness measurement (UTM) has emerged as a reliable method for quantifying corrosion-induced section loss in steel members and enabling spatial corrosion mapping. Odrobinak and Gocal demonstrated the effectiveness of UTM for accurate estimation of non-uniform cross-sectional loss in aging steel bridges [2], while Wade et al. validated corrosion monitoring techniques against weight-loss measurements, highlighting the influence of microclimatic conditions on corrosion behavior [3]. Previous studies have also established strong links between corrosion morphology and structural performance. Both uniform corrosion and localized pitting have been shown to significantly influence fatigue life and ultimate strength of steel members, with pitting depth and geometry playing a critical role in performance degradation [4]. At the structural system level, load–deflection-based approaches have been proposed to evaluate global stiffness degradation and residual strength, offering a complementary perspective to traditional member-level capacity assessments [5].

Despite these developments, most studies address laboratory testing or field investigations independently. Limited research has correlated accelerated laboratory corrosion rates with long- term field measurements obtained from the same bridge and subsequently linked these results to residual strength and remaining service life assessment within a codal framework. The present study addresses this gap by integrating laboratory corrosion testing, field-based UTM measurements, and analytical residual strength and life evaluation in a unified framework applied to a real, aging K-type steel truss bridge.

3. DESCRIPTION OF BRIDGE AND STUDY AREA

The Godavari Rail-cum-Road Bridge (Bridge No. 248A) is a K-typesteel truss bridge located at Rajahmundry, Andhra Pradesh, India. Commissioned in the early 1970s, the bridge carries both railway and roadway traffic across the Godavari River and is exposed to a humid, chloride-rich riverine environment. A representative 48 m span was selected for detailed investigation based on accessibility and observed corrosion severity. The study focused on primary load-carrying members, including bottom chords, top chords, verticals, diagonals, cross girders, and stringer beams [6].

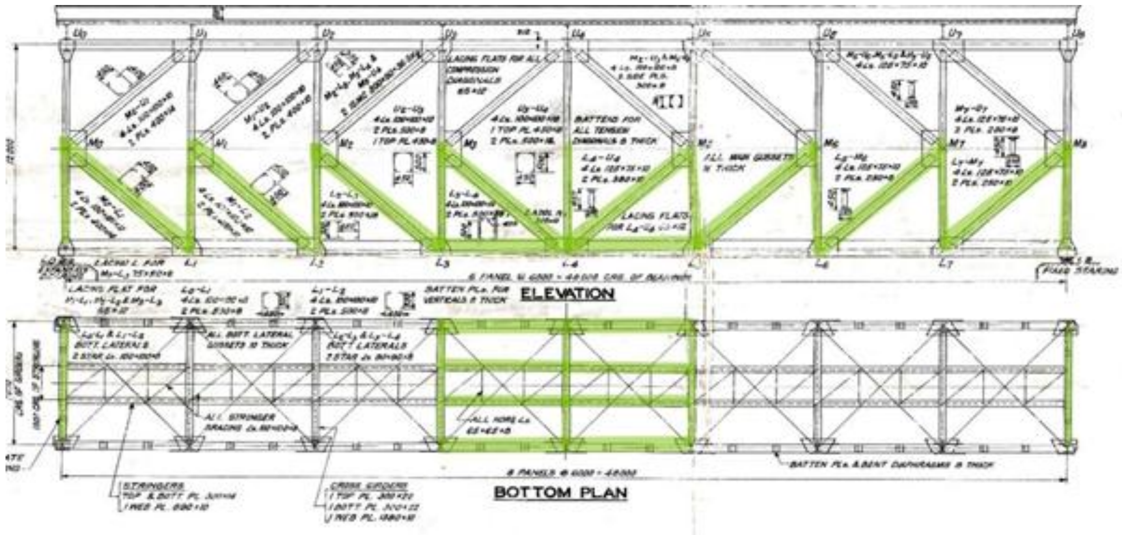

Fig. 1: Godavari Rail-cum-Road Bridge and selected 48m span

4. EXPERIMENTAL PROGRAM AND METHODOLOGY

4.1 Laboratory Corrosion Testing

Accelerated corrosion tests were conducted on mild steel specimens and bridge steel samples (painted and unpainted). Three exposure conditions were considered: immersion, atmospheric exposure, and cyclic wet–dry exposure [7]. Sodium chloride solutions of 1%, 3%, and 5% concentration were prepared in accordance with ASTM G31 [8]. Specimens were exposed for durations up to 28 days, with periodic weight loss measurements taken at predefined intervals.

Corrosion rates were calculated as per ASTM G1 using standard weight- loss equation and expressed in mm/year [9].

$$CR = \frac{K \times W}{A \times T \times D}$$

Where K = Constant, W = weight loss (mg), A = exposed area (cm²), T = time (h), D = density.

Fig. 2: Laboratory test setup (immersion, cyclic wet-dry, atmospheric)

4.2 Field Investigation and Non-Destructive Testing

Field investigations comprised systematic visual inspection and ultrasonic thickness measurement of selected members within the chosen span. Visual inspection identified corrosion patterns, coating deterioration, and areas of water stagnation. Ultrasonic thickness measurements were carried out using a calibrated pulse-echo thickness gauge in accordance with ASTM E797 [10]. Multiple readings were taken at each location, and average values were used to estimate remaining thickness and corrosion rates.

Thickness Loss Calculation*,

$$\Delta t = t_{orginal} - t_{measured}$$

Corrosion rate Field Calculation*,

$$CR_{field} = \frac{\Delta t}{T_{service}}$$

Where Δt = Thickness Loss, $T_{service}$ = Service years.

Fig. 3: UTM field measurement on bridge members

4.3 Laboratory–Field Correlation And Acceleration Factor

To relate accelerated laboratory results to natural field exposure, an acceleration factor (AF) was defined as the ratio of laboratory corrosion rate to field corrosion rate. AF values were evaluated for different chloride concentrations under cyclic wet–dry exposure, enabling estimation of equivalent field exposure corresponding to laboratory test durations.

$$AF = \frac{CR_{lab}}{CR_{field}}$$

4.4 Residual Strength Assessment*

Residual strength was evaluated using two complementary methods. The first method is a global stiffness-based approach, in which residual load-carrying capacity is derived from the ratio of intact to damaged maximum deflections obtained from analytical models. The second method is a member-level section capacity approach, in which corrosion-induced thickness loss is used to compute reduced cross-sectional area and corresponding residual strength based on yield capacity.

$$P_{residual} = A_{residual} \times f_y$$

(Where: $A_{residual}$ = Reduced area, f_y = Yield strength of steel).

4.5 Residual Service Life Estimation

Residual service life is estimated by comparing current measured thickness with critical allowable thickness defined as a fraction of the original section, and dividing the remaining allowable loss by the measured corrosion rate. Results were interpreted in accordance with RDSO/IRS bridge inspection and condition rating guidelines.

$$RL = \frac{t_r - t_{critical}}{c_R}$$

(Where: t_r = Thickness remaining, $t_{critical}$ = Critical Thickness).

5. RESULTS AND DISCUSSION

5.1 Summary of Corrosion, Residual Strength, and Remaining Life

Table 1 summarizes the key results obtained from laboratory–field corrosion assessment, residual strength evaluation, and remaining service life estimation for critical structural members of the bridge. The table provides a concise decision-oriented overview linking measured thickness loss to structural performance indicators, facilitating maintenance prioritization and life-cycle planning.

Table 1. Residual Strength Estimation of Field inspection on Rail–cum–Road bridge – Critical Members.

Year	Bottom Chord (%)	Diagonal Member (%)	Vertical Member (%)	Cross Girder (%)	Stringer / Rail Girder (%)
0	100	100	100	100	100
1	99.75	99.85	99.82	99.79	99.85
5	98.75	99.26	99.12	98.97	99.25
10	97.51	98.53	98.24	97.94	98.51
20	95.02	97.06	96.47	95.88	97.02
30	92.53	95.59	94.71	93.82	95.52
40	90.04	94.12	92.94	91.76	94.03
50	87.55	92.65	91.18	89.71	92.54
51	87.3	92.5	91	89.5	92.39
60	85.06	91.18	89.41	87.65	91.05
70	82.57	89.71	87.65	85.59	89.55
80	80.08	88.24	85.88	83.53	88.06
90	77.59	86.76	84.12	81.47	86.57
100	75.1	85.29	82.35	79.41	85.08

Table 2. Summary of corrosion severity, residual strength, and remaining service life of critical members.

S. No	Member Type	Average Thickness Loss (%)		Residual Strength (%)		Residual Life (Years)		Critical Observations
1.	Bottom Chord Members	-25	33	-87	90	-40	60	Highest corrosion due to water stagnation and poor drainage; governs life assessment
2.	Diagonals Members	-18	25	-90	94	-70	100	Moderate corrosion; localized pitting observed
3.	Verticals Members	-12	20	-92	95	-90	130	Relatively uniform corrosion distribution
4.	Cross Girder	-20	28	-88	92	-60	90	Exposure to splashing and debris accumulation
5.	Stringer Beam	-15	22	-90	94	-80	120	Coating deterioration at connections

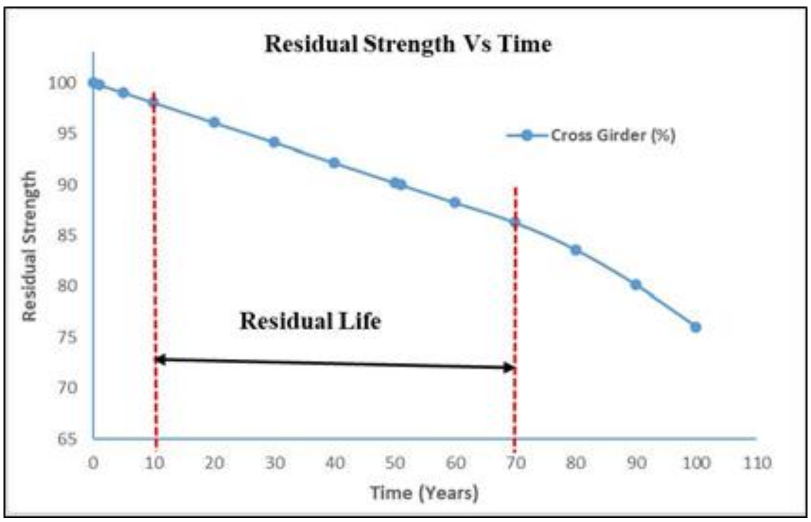

Fig. 4: Residual strength degradation with service time for Cross Girder

5.2 Laboratory Corrosion Behavior

Cyclic wet–dry exposure produced the highest corrosion rates, with a maximum of approximately 0.191 mm/year at 3% NaCl concentration. Immersion and atmospheric exposure resulted in significantly lower corrosion rates. Painted bridge steel specimens exhibited negligible corrosion, highlighting the effectiveness of intact protective coatings.

5.3 Field Corrosion Characteristics

Field measurements revealed non- uniform corrosion, with the highest thickness losses observed in bottom chord flange plates, cross girders, and stringer beams, particularly in zones prone to water stagnation. Measured field corrosion rates ranged from approximately 0.018 to 0.032 mm/year.

5.4 Acceleration Factor and Correlation

Acceleration factors ranged from 5.46 to 9.32, with the highest value corresponding to 3% NaCl cyclic wet–dry exposure. These results indicate that 28 days (4 weeks) of laboratory testing simulate approximately 5–9 months of natural field exposure, validating the relevance of the accelerated test protocol.

Table 3. Acceleration factor (AF) Values correlated CR_lab & CR_field

S. No	Environment	CR_{lab} (mm/yr)	CR_{field} (mm/yr)	AF
1	1% NaCl	0.11195	0.0205	**5.46**
2	3% NaCl	0.19112	0.0205	**9.32**
3	5% NaCl	0.14332	0.0205	**6.99**

5.5 Residual Strength

Global stiffness-based analysis showed that the residual strength of the truss remains about 97-99% for the investigated damage scenarios, reflecting the inherent redundancy of the K-type truss system. Member-level capacity analysis indicated residual strength values between 87% and92%, with bottom chord flange plates identified as the most critical components, as detailed below.

5.6 Residual Life and Condition Rating

Estimated residual service life varies widely among members, ranging from approximately 60 years for heavily corroded bottom chord components to over 130 years for less exposed members. Based on RDSO guidelines (Clauses 2.3, 3.1, 6.2), the bridge is predominantly classified under Condition Rating CR–2 (Fair), suggesting that targeted preventive maintenance is required to arrest further deterioration.

Table 4. RDSO / IRS Bridge Inspection Guidelines for condition rating (Clauses 2.3, 3.1, 6.2).

S. No	Rdso Condition Rating	Section Loss Range	Residual Life Reduction	Condition	Description
1	CR 0 -			Excellent	No Corrosion
2	CR 1 -	< 1%	< 5%	Good	Minor surface corrosion
3	CR 2 -	1 - 5%	5 - 15%	Fair	Moderate corrosion, Minor section loss
4	CR 3 -	5 -15%	15 - 35%	Poor	Severe corrosion, Measurable section loss
5	CR 4 -	> 15%	> 35%	Very Poor / Critical	Advanced corrosion, Strength compromised

6. CONCLUSIONS

This study presents a comprehensive laboratory–field–analytical framework for corrosion assessment, residual strength evaluation, and remaining service life prediction of aging steel truss bridges. The key conclusions are as follows:

1. Cyclic wet-dry exposure is the most aggressive corrosion mechanism, with peak corrosion rates occurring at 3% NaCl concentration.
2. Laboratory corrosion behavior correlates well with field observations when interpreted through acceleration factors ranging from 5.46 to 9.32.
3. Despite localized section losses, the global residual strength of the K-type truss remains about 97-99% due to structural redundancy.
4. Member-level residual strength varies significantly, with bottom chord flange plates identified as critical components requiring priority attention.
5. The bridge is currently in RDSO Condition Rating CR-2 (Fair), indicating that preventive maintenance and monitoring are essential to ensure long-term safety.

The proposed methodology offers a practical and scalable approach for infrastructure agencies to assess and man age aging steel bridges, supporting informed, condition-based maintenance decisions. The proposed framework can be extended to span-wise or network-level bridge management applications.

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