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Numerical Evaluation of Residual Strength of Corroded Members under Tensile Force

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1. Introduction

Many steel bridge infrastructures of the world are getting old and hence subjected to age-related deterioration such as corrosion wastage, fatigue cracking, or mechanical damage during their service life. These forms of damage can give rise to significant issues in terms of safety, health, environment, and financial costs. Therefore it is of paramount importance to develop advanced technologies which can be used to assist proper management and control of such age-related deterioration.

It has been proved that the corrosion played a significant role in the catastrophic collapses of both the Silver Bridge (Point Pleasant, WV) in 1967 and the Mianus River Bridge (Connecticut) in 1983,USA. Therefore regular evaluation of functions and the conditions of older steel bridges with intensified inspection protocols and numerous eventual retrofits or replacements are of high importance.

Some researchers have done some experimental studies and detailed investigations of the corroded surfaces to introduce methods for estimating the remaining strength capacities of corroded steel plates. But, to develop a more reliable strength estimation technique, only experimental approach is not enough as actual corroded surfaces are different from each other. However in modern practices, numerical simulation is being used to replace the time-consuming and expensive experimental work and to comprehend on the lack of knowledge of mechanical behavior, stress distribution, ultimate behavior and so on.

2. Classification of Corrosion States

Though various types of corrosion shapes and forms in actual steel structures can be seen, it would be important to categorize those different corrosion conditions to few general types for better understanding of their remaining strength capacities considering their visual distinctiveness, amount of corrosion and their expected mechanical and ultimate behaviors.

The Figure 1 shows the relationship between the nominal ultimate stress ratio (σ_{bn}/σ_b) and the percentage minimum thickness ratio (μ), where σ_{bn} is the nominal ultimate stress and σ_b is the ultimate stress of corrosion-free plate. Here, the percentage minimum thickness ratio (μ) is defined as:

$$\mu = \left(\frac{t_{min}}{t_0}\right) * 100 \qquad \text{Eqn. (1)}$$

Therefore, three different types of corrosion levels were identified according to their severity of corrosion and they are classified accordingly as follows:

$\mu \geq 75$; Minor Corrosion
$75 > \mu > 50$; Moderate Corrosion
$\mu \leq 50$; Severe Corrosion

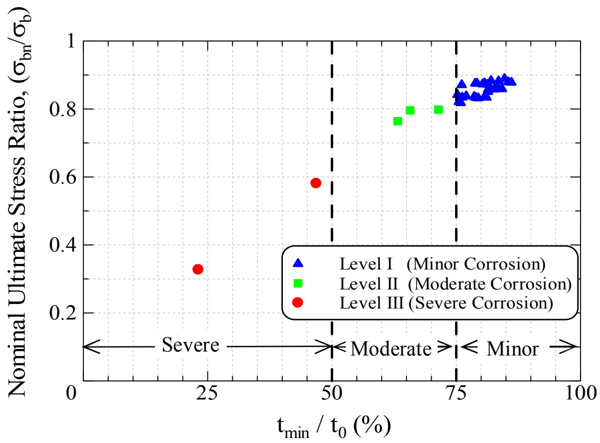


Figure 1: Relationship of ultimate stress ratio & percentage minimum thickness ratio (μ)

3. Numerical Analysis

3.1 Analytical Model

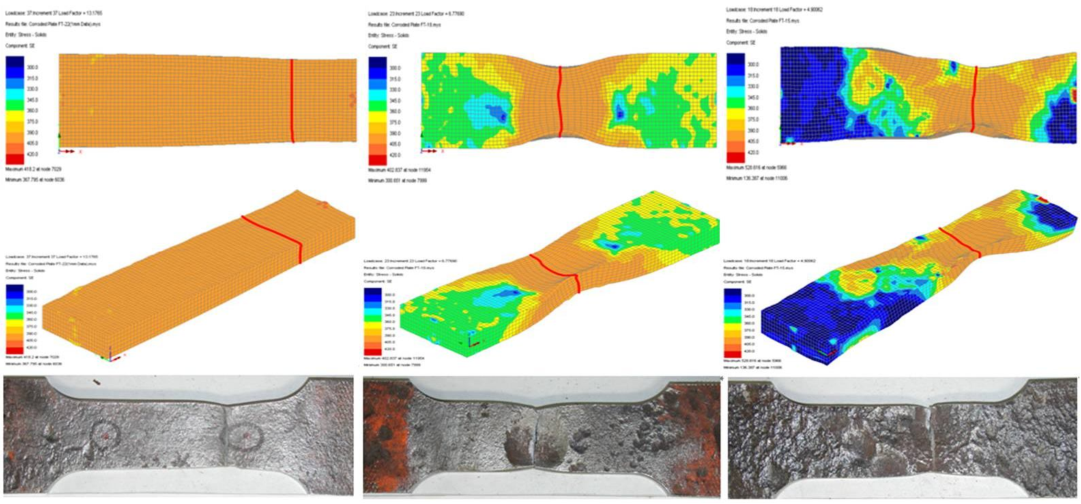
The 3D isoparametric hexahedral solid element with eight nodal points (HX8M) and updated Lagrangian method based on incremental theory were adopted in these analyses. Non linear elastic-plastic material, Newton-Raphson flow rule and Von Mises yield criterion were assumed for material properties. Further, an automatic incremental -iterative solution procedure was performed until they reached to the pre-defined termination limit.

The analytical models of 70mm x 25mm in length and width dimensions respectively were modeled with different corrosion conditions for respective specimens. 1mm regular mesh pattern was adopted for all analytical models. One edge of the member's translation in X direction was fixed and the central point of that edge was fully fixed. The central point of the other edge's (free edge) translations in Y & Z directions are fixed in order to simulate with the actual experimental conditions. Then the uniform prescribed incremental displacements were applied to the free edge. Yield stress σ_y = 299.9 [MPa], Elastic modulus E = 195.8 [GPa], Poisson's ratio ν = 0.278 were applied to all analytical models, respectively.

3.2 Analytical Results and Discussion

First, a non corroded specimen was modeled with the above described modeling and analytical features to understand the accuracy of the procedure adopted. It was found that the analytical model results were almost same as the experimental results with having a negligible percentage error of 0.03% and 0.02% in yield and tensile strength respectively.

Then, all other experimentally successful specimens were modeled accordingly and their yield and ultimate strengths and failure surfaces were compared with the



(a) FT-22 [Minor Corrosion] (b) FT-18 [Moderate Corrosion] (c) FT-15 [Severe Corrosion]

Figure 3: Stress distribution of the corroded specimens at ultimate load

experimental behaviors. The percentage error in yield and tensile strength in analytical predictions are calculated respectively as follows:

$$\%\ \text{Error in } P_y = \left| \frac{P_{y[\text{Analytical}]} - P_{y[\text{Experimental}]}}{P_{y[\text{Experimental}]}} \right| \text{x } 100 \qquad \text{Eqn. (2)}$$

$$\%\ \text{Error in } P_b = \left| \frac{P_{b[\text{Analytical}]} - P_{b[\text{Experimental}]}}{P_{b[\text{Experimental}]}} \right| \text{x } 100 \qquad \text{Eqn. (3)}$$

where, P_y and P_b are the yield and tensile loads respectively. The Figure 2(a) shows a very good comparison of the experimental and the analytical load-elongation behaviors for all three classified corrosion types. Here, the percentage errors in yield and tensile strength predictions of the analytical models of three corrosion types are 2.11% and 0.54% in FT-22, 0.84% and 0.48% in FT-18 and 0.19% and 5.26% in FT-15 respectively. So, it is clear that the numerical modeling technique can be used to accurately predict the remaining strength capacities of actual corroded members. Further, the Figure 2(b) shows the comparison of ultimate load capacities of all 32 specimens in experimental and numerical analyses. Having a coefficient of correlation of R2= 0.902 indicate the accuracy and the possibility of numerical investigation method to predict the tensile strength of actual corroded specimens.

Figure 3 shows the stress distribution of the three corroded specimens [(a) FT-22: member with Minor corrosion, (b) FT-18: member with Moderate corrosion and (c) FT-15: member with severe corrosion respectively] at their respective ultimate loads. The above results indicate that the failure surfaces of all three specimens have a very good comparison with the experimental results and also this fact signifies the accuracy of the adopted numerical modeling method.

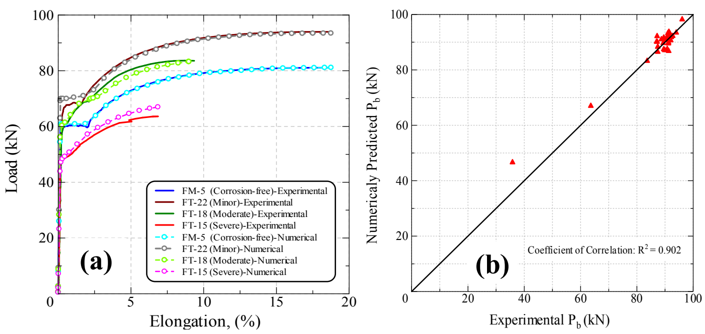


Figure 2: Comparison of experimental and analytical (a) load -elongation curves; (b) ultimate load capacities

4. Conclusions

1. The corrosion causes strength reduction of steel plates and percentage minimum thickness ratio (μ) can be used as a measure of the level of corrosion and their strength degradation.
2. Non linear FEM Analytical results indicated a very good comparison of the experimental and the analytical load-elongation behaviors for all three classified corrosion types. Further, failure surfaces of those specimens too showed a very good comparison with the experimental results. So, it can be concluded that the adopted numerical modeling technique can be used to predict the remaining strength capacities of actual corroded members accurately.

References

Bruneau, M. and Zahrai, S.M. (1997), "Effect of Severe Corrosion on Cyclic Ductility of Steel", Journal of Structural Engineering, pp 1478-1486.

Fujii, K., Kaita, T., Nakamura, H. and Okumura, M. (2003), "A Model Generating Surface Irregularities of Corroded Steel Plate for Analysis of Remaining Strength in Bridge Maintenance", The 9th East Asia-Pacific Conference on Structural Engineering and Construction (EASEC-9), Vol. 9, pp 32-38.

Kaita, T., Appuhamy, J.M.R.S., Fujii, K. and Ohga, M. (2009), "Remaining Strength Estimation of Corroded Steel Bridge Plate under Tensile Force", 15th Asian-Pacific Corrosion Control Conference (15th APCCC), Manila, Philippines, Paper CB-07, CD-ROM.

Kaita, T., Kawasaki, Y., Isami, H., Ohga, M. and Fujii, K. (2008), "Analytical Study on Remaining Compressive Strength and Ultimate Behaviors for Locally-corroded Flanges", EASEC-11, Taiwan, CDROM.

Muranaka, A., Minata, O. and Fujii, K. (1998), "Estimation of Residual Strength and Surface Irregularity of the Corroded Steel Plates", Journal of Structural Engineering, vol. 44A, pp 1063-1071 (In Japanese).