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Effect of Surface Measurement Intensity on Remaining Strength Prediction of Corroded Steel Members

Graduate School of Science and Engineering, Ehime University ○ J.M.R.S. Appuhamy (Student Member)
Department of Civil and Environmental Engineering, Ehime University Mitao Ohga (Member)
Department of Civil and Environmental Engineering, Ehime University Pang-jo Chun (Member)
Department of Civil Engineering and Architecture, Tokuyama College of Technology Tatsumasa Kaita (Member)

1. Introduction

Corrosion is one of the most important causes of deterioration of steel girder bridges and a major problem currently facing the transportation engineering community in the world. In the past few decades, 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. Due to economic constraints, it is not possible to conduct tests for each and every aged bridge structure within their bridge budgets. Therefore, nowadays, use of numerical analysis method could be considered to have a reliable estimation in bridge maintenance industry.

Further, it is not easy to measure several thousands of points, to accurately reproduce the corroded surface by numerical methods and to predict the behavior of that corroded member with more precisely. Therefore, study the effect of corroded surface data measurement intensity on their present load carrying capacities and investigate the possibility of establishing a simple and accurate procedure to predict the remaining strength capacities of a corroded steel member by measuring lesser number of points with an acceptable accuracy level would be a vital task for the maintenance management of steel infrastructures.

2. Classification of Corrosion States

In this study, 42 specimens (21 each from web and flange) cut out from a steel bridge girder of Ananai River in Kochi Prefecture on the shoreline of the Pacific Ocean, which had been used for about 100 years. Then the thicknesses of all scratched specimens were measured by using a laser displacement gauge and the tensile tests were performed in order to clarify their remaining strength capacities. As it is necessary to categorize the different corrosion conditions into few general types for better understanding of their remaining strength capacities, 3 different types of corrosion levels were identified according to their severity of corrosion and they are classified accordingly as follows:

$\mu > 0.75$; Minor Corrosion
$0.75 \geq \mu \geq 0.5$; Moderate Corrosion
$\mu < 0.5$; Severe Corrosion

Here, the minimum thickness ratio (μ) is defined as:

$$\mu = \frac{t_{min}}{t_0} \tag{1}$$

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 with length and width dimensions of 70mm x 25mm (X and Y directions) were modeled with their respective corrosion conditions. One edge of the member's translation in X, Y and Z directions were fixed and only the Y and Z direction translations of the other edge (loading edge) were fixed to simulate with the actual experimental condition. Then the uniform incremental displacements were applied to the loading 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 Ductile Fracture Criterion

The "Stress Modified Critical Strain Model (SMCS)" was proposed by Kavinde et al. (2006), to evaluate the iniation of ductile fracture as a fuction of multiaxial plastic strains and stresses. This method was adopted in this analytical study. In SMCS criteion, the critical plastic strain ($\varepsilon_p^{Critical}$) is determined by the following expression:

$$\varepsilon_P^{Critical} = \alpha \cdot \mathrm{Exp}\left(-1.5\frac{\sigma_m}{\sigma_e}\right) \tag{2}$$

Where, α is toughness index and the stress triaxiality T = (σ_m/σ_e), a ratio of mean or hydrostatic stress (σ_m) and the effective or von Mises stress (σ_e). The toughness index α is a fundamental material property and hence obtained from the tensile test conducted for the non corroded specimen.

3.3 Analytical Results

Non corroded specimen was modeled at first, with the above described modeling and analytical features and 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. Figure 1(a) shows a very good comparison of experimental and analytical load-elongation behaviors for all 3 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 0.56% in

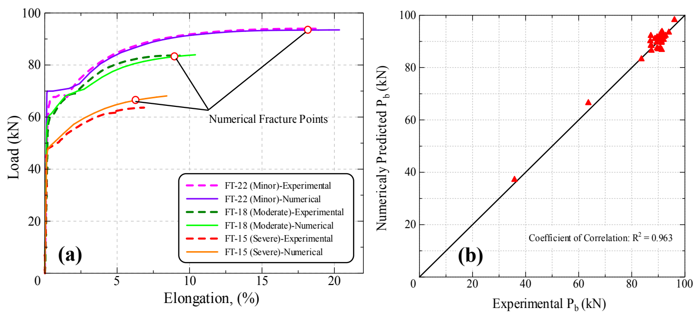

Figure 1: Comparison of experimental and analytical (a) load -elongation curves; (b) ultimate load capacities

FT-22, 0.84% and 0.49% in FT-18 and 0.19% and 4.48% in FT-15 respectively. Further, the Figure 1(b) shows the comparison of ultimate load capacities of all 32 specimens in experimental and numerical analyses. Having a coefficient of correlation of R^2= 0.963 indicate the accuracy and the possibility of numerical investigation method to predict the tensile strength of actual corroded specimens.

4. Effect of Corroded Surface Measurement Intensity

4.1 Analytical Models

Six different finite element models with different corroded surface measurement intervals in X and Y directions were modeled and analyzed for each corroded specimen and compared them with the results of Model 1 with 1mm mesh data to understand the effect of corroded surface data intensity with their remaining yield and tensile strength capacities. Table 1 shows the maximum data measurement interval and total no of measuring points in each model. The same modeling features and analytical procedure as described in chapter 3 were adopted for all analyses.

Table 1: Data interval and total no. of measuring points

Model No.	Maximum data interval /(mm)	Total measuring points
1	1	1846
2	2	504
3	5	90
4	10	32
5	15	18
6	25	8

4.2 Analytical Results and Discussion

The Figure 2 shows the percentage errors in yield and tensile strength estimations of different models for the three members FT-22, FT-18 and FT-15 with minor, moderate and severe corrosion conditions respectively. It can be seen that the data intensity for minor corrosion members is not very significant for their remaining strength estimation. This fact can be comprehended as the overall amount of corrosion or the corrosion attack for a particular location is very small in minor corrosion members.

But, it can be noted that the percentage errors in both yield and tensile strength estimations are increased with the reduction of intensity of corroded surface measurement in moderate and severe corrosion members. Further, it is visible that those errors of the remaining strength prediction are increased with the severity of the corrosion as well. The reason for this could be the missing of the maximum corroded location or some severe corroded portions during this kind of regular data measurement. So the effect of stress concentration will diminish in some of the models considered in this study, which are having smaller number of measuring points. So the remaining strengths are over estimated with the increase of coarseness of the data measurement, and this could lead the infrastructure in danger with decision taken regarding its maintenance management plan. So, a special surface measurement method with few data points, concerning the severity of corrosion and stress concentration is required for moderate and severe corrosion members.

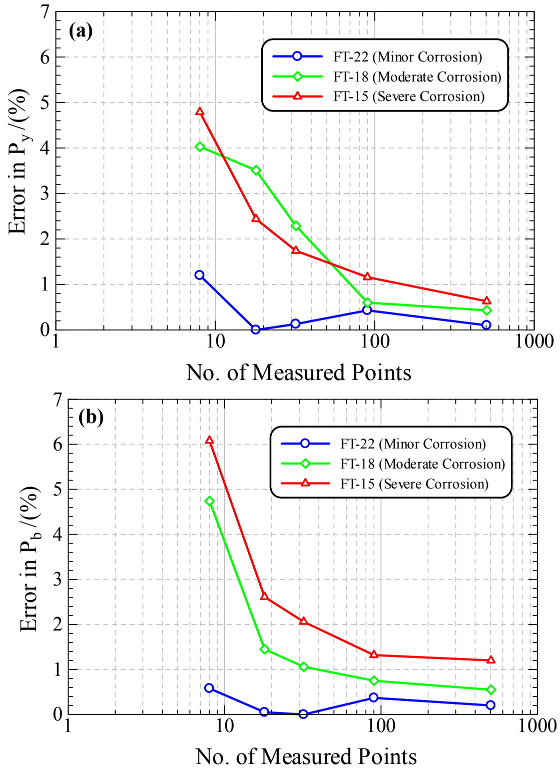

Figure 2: Comparison of %errors in (a) yield and (b) tensile strength estimation

5. Conclusions

1. A very good agreement between the experimental and analytical results can be seen for all three classified corrosion types. So, the adopted numerical modeling technique can be used to predict the remaining strength capacities of actual corroded members accurately.
2. Though the corroded surface measurement intensity is not very significant for minor corrosion members, it affects for moderate and severe corrosion members considerably in prediction of their remaining strengths.
3. So, a regular coarse surface measurement would be sufficient for minor corrosion members. But, a surface measurement method with few data points, concerning the severity of corrosion and stress concentration will be investigated for moderate and severe corrosion members in future studies.

References

Appuhamy, J.M.R.S., Kaita, T., Ohga, M., Fujii, K. and Dissanayake, P.B.R. (2010), 'Experimental and Numerical Investigation of Residual Strength of Corroded Steel Plates in Tensile Force', International Symposium on Society for Social Management Systems (SSMS2010), Kochi, Japan, Paper SMS10-120, Web.

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.

Kavinde, A.M. and Deierlein, G.G. (2006), 'Void Growth Model and Stress Modified Critical Strain Model to Predict Ductile Fracture in Structural Steels', Journal of Structural Engineering, Vol.132, No.12, pp 1907-1918.

Kitada, T. (2006), 'Considerations on recent trends in, and future prospects of, steel bridge construction in Japan', Journal of Constructional Steel Research, Vol. 62, pp. 1192-1198.