EXPERIMENTAL AND NUMERICAL INVESTIGATION OF RESIDUAL STRENGTH OF CORRODED STEEL PLATES IN TENSILE FORCE

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***ABSTRACT*:**

Corrosion of the members of a steel structure leads to impairment of its operation and progressive weakening of that structure. Therefore, the effect of corrosion on the strength, stability and serviceability of hydraulic steel structures are of high concern among the bridge Engineers at present. The consequences of corrosion are many and varied and effects of these on the safe, reliable and efficient operation of structures are often considered than simply loosing of mass of metal. Various kinds of failures and the need of expensive replacements may occur even though the amount of metal destroyed is quite small. One of the major harmful effects of corrosion is the reduction of metal thickness leading to loss of mechanical strength and structural failure, causing severe disastrous and hazardous injuries to people.

Since actual corroded surfaces are different from each other, only experimental approach to estimate the remaining strength of corroded members is not enough. Therefore, using of numerical analysis method should also be considered to have a reliable estimation, concerning the mechanical behavior, stress distribution and ultimate behavior which are not been clarified yet. But these analytical results will give important knowledge for not only the strength estimation but also subsequent repair and retrofitting plan. So a simple method to calculate the remaining yield and tensile strength by using a concept of representative effective thickness (t_{eff}) with the correlation of initial thickness (t_0) and the standard deviation of thickness (σ_{st}) is presented in this paper and the proposed effective thickness and strength estimation method, which based on the results of many tensile coupon tests of actual corroded plates and verified by numerical modeling results as well.

Key Words: *Corrosion, Effective thickness, Numerical analysis, Strength estimation*

1. INTRODUCTION

In Japan, there are more than 50,000 steel railway bridges, where more than half of them have been used over 60 years and some bridges are aged over 100 years. With aging, Corrosion becomes one of the major causes of deterioration of steel bridges, and its' damages seriously affect on the durability of steel bridges. It is very difficult to retrofit or rebuild those aged bridges at the same time. Therefore, it is important to evaluate the residual remaining strength capacities of those bridges, in order to keep them in-service until they required necessary retrofit or rebuild in appropriate time.

Furthermore, many damage examples, such as corrosion and fatigue had reported recently. The deterioration due to corrosion could generally range from progressive weakening of a steel structure over a long time, to rapid structural failure. Though it's a maintenance issue, it can be addressed appropriately by specification of a proper corrosion system in the design phase. It has been proved that the corrosion played a significant role in the catastrophic collapse of both the Silver Bridge (Point Pleasant, WV) in 1967 and the Mianus River Bridge (Connecticut) in 1983, USA. Those collapses indicated the paramount importance of attention to the condition of older bridges, leading to intensified inspection protocols and numerous eventual retrofits or replacements. Therefore corrosion is not an issue to be taken lightly either in design phase or in maintenance stage. Further, as some recent earthquakes demonstrated the potential seismic vulnerability of some types of steel bridges, it would be very important to understand the behavior of existing steel bridges which are corroding for decades, in future severe seismic events as well.

Significant developments are already appeared on the better understanding of the causes of corrosion, enhancing corrosion-resistance of new steel structures, and providing structural evaluation methods to assess the safe strength of the existing corroded structures. Indeed, many codes now specifically require corrosion protection in steel structures, especially those located in environments where conditions are favorable for corrosion. Such protection is provided by means of suitable alloying elements in the steel, protective coatings, provision of extra thickness as a corrosion allowance, or other approved methods. However, using current corrosion control technologies in conjunction with maintenance and monitoring guidelines can easily prevent their decay and extend the lifespan of bridges to a certain extent, but with multiple corrosion protection system strategies, the lifespan can be extended by decades.

It is known that the corrosion wastage and the stress concentration caused by the surface irregularity of the corroded steel plates influence the remaining strength of the corroded steel plates. Therefore, the effect of different forms of corrosion to the remaining strength capacities of the existing structure is a vital task for the maintenance management of steel highway infrastructures.

2. PROBLEM STATEMENT

In terms of estimating the remaining strength capacities, some researchers have done several experimental studies and their durability estimation techniques are performed with detailed investigations of the corroded surface. Namely, Matsumoto *et al.* (1989) investigated the tensile strength, using tensile coupons with corrosion. They predict the remaining tensile strength of the corroded plates, using the minimum value of average thickness (t_{sa}) of the cross section perpendicular to the loading axis as a representative thickness. Further, Muranaka *et al.* (1998), proposed a representative thickness $t_R = t_{avg} - 0.7\sigma_{st}$ for estimating the tensile and fatigue strength, based on the tensile test. Also, Kariya *et al.* (2003) conducted some tensile tests of corroded plates and proposed a representative thickness $t_R = t_{avg} - 1.3\sigma_{st}$ to estimate the tensile strength.

Thus, it is very clear that, many researchers usually use representative thickness based on several statistical parameters to estimate the remaining strength. The all above described representative thickness methods were derived with relation to the average thickness of the corroded plate (t_{avg}) which eventually depends on the accuracy of the thickness measurements. It is not easy to measure several thousands of points to numerically reproduce the corroded surface accurately and to predict the behavior of that corroded member with more precisely. Therefore, it is important to establish 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. So it would be interesting to identify a relationship between the representative thickness and easily measurable dimension like initial thickness (t_0), minimum thickness (t_{min}) or etc.

To obtain more accurate remaining strength capacity estimation of corroded steel plates, only experimental approach is not enough as actual corroded surfaces are different from each other. Hence, a verification by using of numerical analysis of various corrosion surfaces will be required for reliability of the estimation method due to the lack of knowledge of mechanical behavior, stress distribution, ultimate behavior and so on.

3. EXPERIMENTAL ANALYSIS

3.1 Test Specimen

A steel girder from the Ananai River Bridge in Kochi Prefecture on the shoreline of the Pacific Ocean, which had been used for about hundred years, was used for this experimental study. This bridge was constructed as a railway bridge in 1900, and in 1975 changed to a pedestrian bridge, when the reinforced concrete slab was cast on main girders. The bridge was dismantled due to serious corrosion damage in year 2001. The tensile tests were carried out by using the 42 specimens which are cut out from that girder to clarify the relationship between the representative effective thickness (hereafter used as: t_{eff}) which was used to estimate the remaining mechanical strength properties of the corroded plate and the degree of the corrosion state.

Equal no of specimens (21 from each), obtained from web and flange of this girder were fabricated in order to use for the tensile test. Four corrosion-free specimens were cut down smoothly from both sides of corroded steel plate also fabricated in order to clarify the material properties. The JIS No.5 test specimen is shown in Figure 2.

As shown in Table 1, the material properties of corrosion-free specimens were obtained from the tensile tests. The standard values by JIS are also indicated in the table as the reference. It is noted that these specimens have the equality with the SS400 Japanese Industrial Standards. And also the web and flange have the same properties.

3.2 Corroded Surface Measurements

The thicknesses of all scratched specimens were measured by using a laser displacement gauge before the tensile loading test. The measurement was performed in the shaded area (70mm x 25mm) as

Photo 1: Condition of thickness measurement

shown in Figure 1. The intervals of measurement data are 1mm and 0.3 mm in X and Y directions respectively. The condition of thickness measurement is shown in Photo 1. The statistical parameters such as average thickness (t_{avg}), standard deviation (σ_{st}) and coefficient of variability (CV) were calculated from the measurement results.

3.3 Classification of Corrosion States

Corrosion damage can take place many shapes and forms and therefore, various types of corrosion conditions in actual steel structures can be seen. But, 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. Therefore, three basic corrosion conditions were introduced during this study to be used for reliable remaining strength estimation of actual corroded steel structures. They are:

1. Minor Corrosion
2. Moderate Corrosion
3. Severe Corrosion

The Figure 2 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:

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

In this study, 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

Even though 42 specimens were tested in this study some of the specimens were broken outside the gauge length. Therefore only the successful specimens were considered for this research study and they are classified into those three corrosion types according to μ, as shown in Table 2. There, the initial thickness of the flange specimens and web specimens are 10.5mm and 10.0 mm respectively.

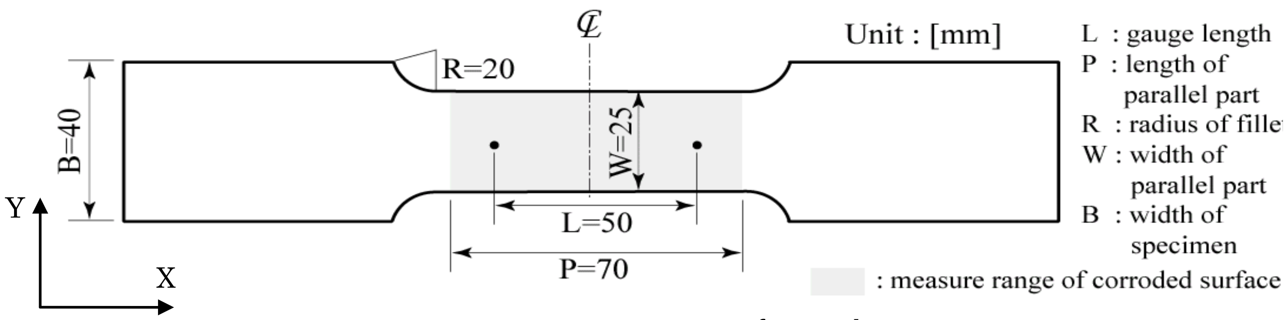


Figure 1: JIS No.5 Specimen for tensile test

Table 1: Material properties

Specimen	Elastic modulus /(GPa)	Poisson's ratio	Yield stress /(MPa)	Tensile strength /(MPa)	Elongation at maximum load /(%)	Elongation after breaking /(%)
Corrosion-free plate	195.8	0.278	299.9	417.1	20.05	39.88
SS400 JIS	200.0	0.300	245~	400~510	21.00	–

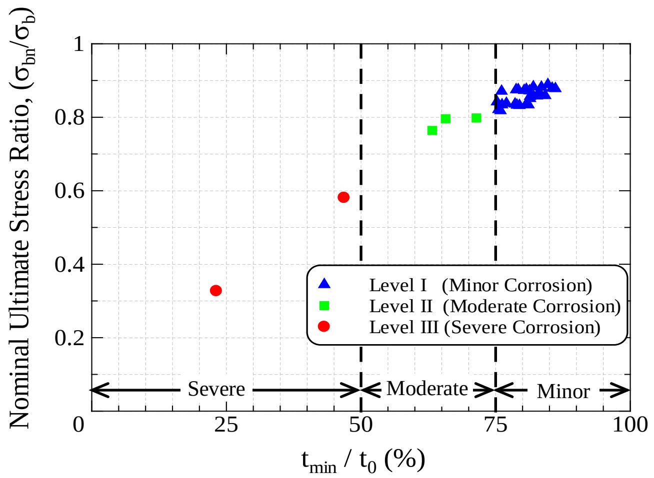


Figure 2: Relationship of ultimate stress ratio & percentage minimum thickness ratio (μ)

Table 2: Measurement & Categorization of Specimens

Member	σ_{st} /(mm)	t_{avg} /(mm)	μ (%)	Corrosion Type
FT-1	0.21	9.25	75.2	Minor
FT-2	0.21	9.86	86.1	Minor
FT-5	2.01	7.54	23.1	Severe
FT-6	0.56	9.25	65.7	Moderat
FT-8	0.20	9.16	80.7	Minor
FT-9	0.26	9.39	79.4	Minor
FT-10	0.21	9.03	79.0	Minor
FT-11	0.47	8.97	71.4	Moderat
FT-12	0.18	8.73	76.2	Minor
FT-13	0.27	8.76	75.5	Minor
FT-14	0.23	8.82	75.9	Minor
FT-15	0.97	7.77	46.9	Severe
FT-18	0.60	9.01	63.2	Moderat
FT-22	0.11	9.40	82.7	Minor
WT-1	0.22	9.26	84.2	Minor
WT-2	0.37	9.41	83.1	Minor
WT-3	0.27	9.46	80.7	Minor
WT-4	0.2	9.26	83.5	Minor
WT-5	0.31	9.16	78.8	Minor
WT-6	0.22	9.48	85.5	Minor
WT-7	0.43	9.32	78.6	Minor
WT-8	0.25	9.27	79.2	Minor
WT-9	0.29	9.09	81.1	Minor
WT-11	0.25	9.31	81.3	Minor
WT-12	0.18	9.31	84.7	Minor
WT-13	0.29	8.82	76.1	Minor
WT-15	0.24	9.22	81.4	Minor
WT-16	0.24	9.02	81.4	Minor
WT-17	0.24	9.13	81.8	Minor
WT-18	0.16	9.17	82.0	Minor
WT-19	0.38	8.86	77.0	Minor
WT-21	0.19	9.16	80.3	Minor

3.4 Experimental Results

The examples of load-elongation curves for three different corroded specimens and one corrosion-free plate are shown in Figure 3. FT-22 and the FT-18 have comparatively lesser standard deviation of the thickness (0.11 mm and 0.60 mm respectively) and the specimen FT-15 has comparatively larger value of it (σ_{st} = 0.97 mm). Further it can be seen that the steel plate FT-5, in which the corrosion progression was more severe and the irregularity of surface deviation is also violent (σ_{st} = 2.01 mm).

Herein, the specimen (FT-22) with minor corrosion has almost same mechanical properties as the corrosion-free specimen (FM-5). On the other hand, the moderately corroded specimen (FT-18) or the severe corroded (in this case, locally) specimen (FT-15) shows obscure yield strength (Figure 3). And the elongation of the specimen (FT-15) decreases too. The reason for this is believed to be that the local section with a small cross-sectional area yields at an early load stage because of the stress concentration due to irregularity of corroded steel plate which elongates locally and reach to the breaking point. Therefore, the local statistical parameters with the influence of stress concentration should be used for the yield and tensile strength estimations.

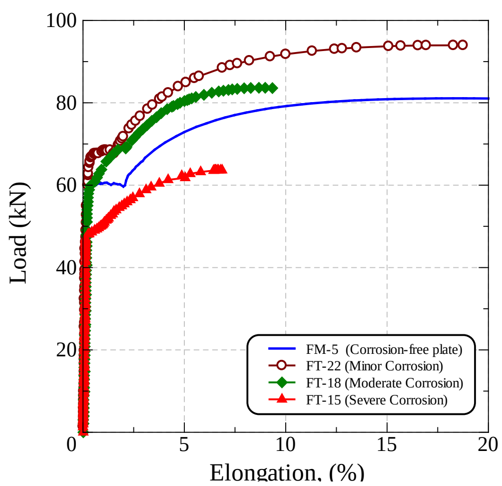


Figure 3: Load-elongation curves

4. RESIDUAL STRENGTH ESTIMATION

4.1 Estimation of yield and tensile strength

In this study, a representative effective thickness (t_{eff}) based on the initial thickness (t_0) and the standard deviation of thickness (σ_{st}) was introduced as a new trial. So the aim is to use the standard deviation as the only variable parameter to represent the condition of corrosion in the process of estimating remaining strength capacities.

The correlations between the effective thickness (t_{eff}) and measureable statistical parameters (such as average thickness t_{avg}, minimum thickness t_{min}, standard deviation of thickness σ_{st} etc.) were examined and a better relationship was found with the standard deviation of thickness as described below.

The x-axis in both Figure 4 and Figure 5 is the standard deviation of thickness normalized by the initial thickness of the plate (σ_{st}/t_0) and the y-axis shows the nominal stress ratio normalized by yield stress in Figure 4 (σ_{yn}/σ_y) and tensile stress in Figure 5 (σ_{bn}/σ_b) respectively.

From the figures 4 and 5, it can be observed that a good linear relationship exists between the normalized nominal stress ratio and the standard deviation of thickness in both yield and tensile stress conditions. Also it is noted that an average unique relationship for both yield and tensile stress conditions can be obtained. From this relationship, a formula for representative effective thickness (t_{eff}) can be obtained as described below.

From Figure 4,

$$\left(\frac{\sigma_{yn}}{\sigma_y}\right) = 0.91 - 2.90^* \left(\frac{\sigma_{st}}{t_0}\right)$$

$$\left(\frac{\frac{\sigma_y{}^* B^* t_{eff}}{B^* t_0}}{\sigma_y}\right) = 0.91 - 2.90^* \left(\frac{\sigma_{st}}{t_0}\right)$$

$$\mathbf{t_{eff} = 0.91^* t_0 - 2.90^* \boldsymbol{\sigma}_{st}} \qquad \text{Eqn. (2)}$$

In same way from Figure 5,

$$\mathbf{t_{eff} = 0.93^* t_0 - 3.05^* \boldsymbol{\sigma}_{st}} \qquad \text{Eqn. (3)}$$

Where, σ_{yn}; Nominal yield stress, σ_y; Yield stress of corrosion-free plate, B; Width of the plate, t_0; Initial thickness of the plate, t_{eff}; Representative effective thickness and σ_{st}; Standard deviation of thickness respectively.

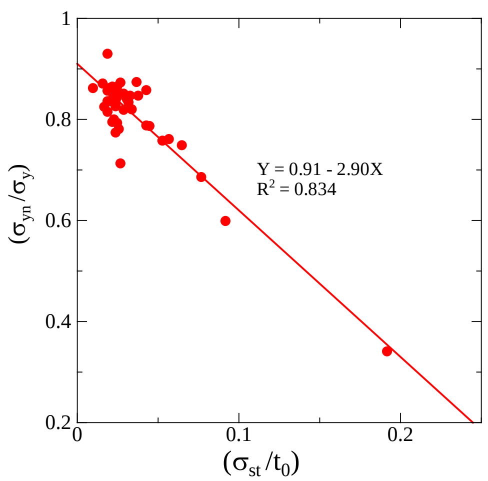


Figure 4: Relationship of Yield stress ratio and (σ_{st}/t_0)

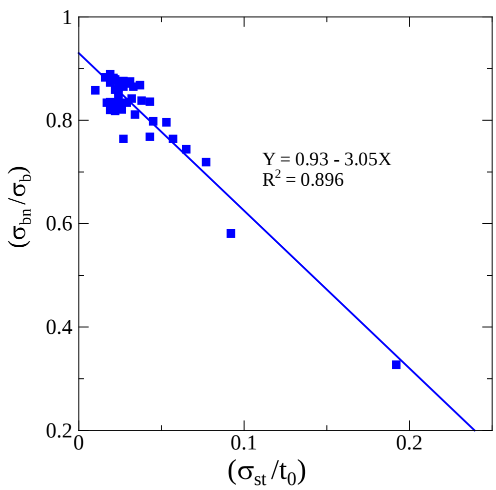


Figure 5: Relationship of Tensile stress ratio and (σ_{st}/t_0)

Considering the equation (2) and (3), the following relationship can be obtained for representative effective thickness (t_{eff}), which can be used to estimate the remaining yield and tensile strengths of a corroded steel plate. The coefficients α and β are constants which are related with the type of corrosion and the environmental conditions.

$$\mathbf{t_{eff} = \alpha^* t_0 - \beta^* \sigma_{st}} \qquad \text{Eqn. (4)}$$

By considering an average behavior for the yield and tensile stress conditions, from the equation (2) and (3), it can be noted that β = 3.0 is a reasonably acceptable value for estimating the remaining strengths. So the equation (6) will become as:

$$\mathbf{t_{eff} = \alpha^* t_0 - 3\sigma_{st}} \qquad \text{Eqn. (5)}$$

The coefficient α should be equal to 1.0 for the ideal case of corrosion-free specimen, in which the effective thickness (t_{eff}) is equal to the initial thickness (t_0) for σ_{st} = 0. But it can be clearly observed from the Figure 8 and 9 that the coefficient α is little bit bellow the value of 1.0 which indeed could be due the deterioration process of the steel plate due to corrosion.

Further, it is noted from Figures 4 and 5 that the coefficient α is reduced with the severity of corrosion. Also, the Figure 6 and Figure 7 show the behavior of the proposed relationship with the experimental results using α = 0.9, gives a good comparison. Hence, α = 0.9 can be defined as a reasonably good average value for a steel bridge member with majority of moderate to minor corrosion conditions at different locations. Therefore, the Equation (5) will become as:

$$\mathbf{t_{eff} = 0.9t_0 - 3\sigma_{st}} \qquad \text{Eqn. (6)}$$

A further detailed study comprises with experimental and numerical analysis of members with wider dimensions is deemed necessary to understand the significance of the α-value and verify this for different corroded levels and environmental conditions.

4.2 Comparison of proposed effective thickness with other representative thicknesses

The experimentally predicted thickness and the representative thickness which were valued by different methods were examined and compared to understand the effectiveness of the proposed method of estimating the remaining strength capacities for corroded steel plates. Figure 6 and 7 show the behavior of proposed effective thickness (t_{eff}) with the experimental yield and tensile effective thicknesses (t_{e_y} and t_{e_b}) respectively.

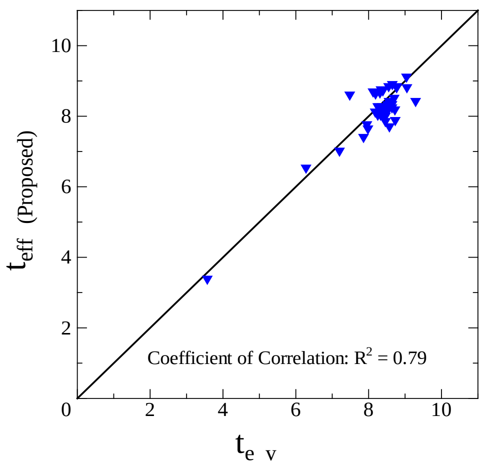


Figure 6: Relation between t_{eff} and t_{e_y}

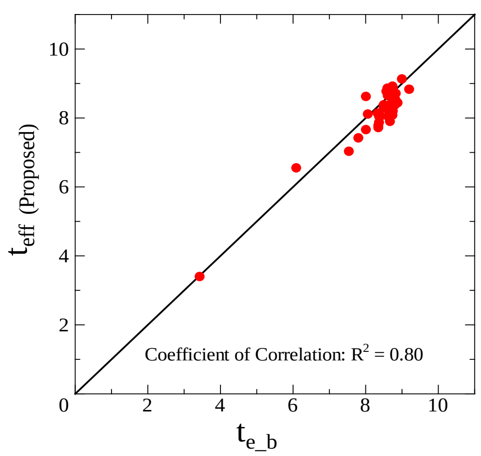


Figure 7: Relation between t_{eff} and t_{e_b}

Table 3: Comparison of correlation coefficients of different representative thickness prediction methods

Method		Matsumoto et al. 1989	Muranaka et al. 1998	Kariya et al. 2003	Proposed, t_{eff}
Equation of thickness		t_{sa}	$t_{avg} - 0.7\sigma_{st}$	$t_{avg} - 1.3\sigma_{st}$	$0.9t_0 - 3\sigma_{st}$
Correlation Coefficient	Yield	0.63	-0.74	0.51	0.79
	Tensile	0.79	-0.30	0.71	0.80

The Table 3 shows the coefficient of correlation values of the available different methods and the proposed method of effective thickness in estimating remaining yield and tensile strengths. It clearly shows that the proposed effective thickness parameter gives more reliable and closer prediction with the experimentally analyzed results.

5. NUMERICAL ANALYSIS

5.1 Finite Element Analysis

In order to clarify the yield and tensile strengths, failure surfaces and the ultimate behaviors of corroded members, non-linear finite element analyses were performed for the all successful flange and web specimens with different corrosion conditions. 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.

5.2 Analytical Model

The analytical models with length and width dimensions of 70mm x 25mm (as shown in Figure 1and 8) were modeled for 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 as shown in Figure 8.

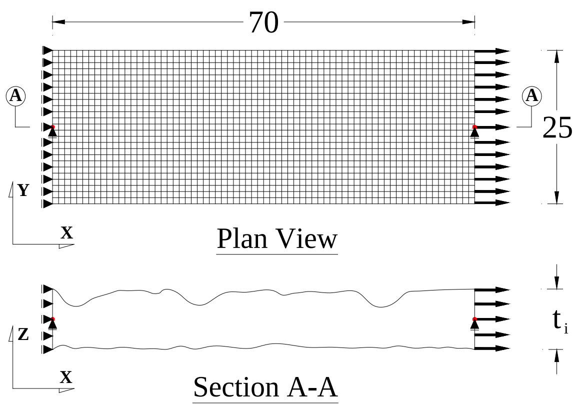


Figure 8: Analytical model of corroded member

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.

The non-linear elastic-plastic material properties were obtained from the non corroded specimen's tensile test results (Figure 3).

5.3 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 experimental behaviors. Comparison of load-elongation curves of three typical corroded specimens and one corrosion-free plate with the experimental curves are shown in Figure 9. The percentage error in yield and tensile strength in analytical predictions are calculated respectively as follows:

$$\%\ \text{Error in } P_y = \left| \frac{P_{y[\text{Analytical}]} - P_{y[\text{Experimenta}]}}{P_{y[\text{Experimental}]}} \right| \text{x } 100$$

Eqn. (7)

$$\%\ \text{Error in } P_b = \left| \frac{P_{b[\text{Analytical}]} - P_{b[\text{Experimenta}]}}{P_{b[\text{Experimental}]}} \right| \text{x } 100$$

Eqn. (8)

Where, P_y and P_b are the yield and tensile loads respectively. The Figure 9 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.

Although the results of numerical predictions for yield and ultimate strengths of Minor and Moderate corroded members show a very good comparison with the experimental results, Severe corrosion members show a little bit deviation. The reason could be that, some microscopic cracks could also build-up with the development of corrosion which they could eventually results a loss of strength. Hence, there we can see a loss of tensile strength in experimental analyses than expected or predicted by analytical models in severely corroded specimens. So, careful microscopic observations for severe corroded surfaces and smoothing them neatly could reduce such errors with analytical prediction.

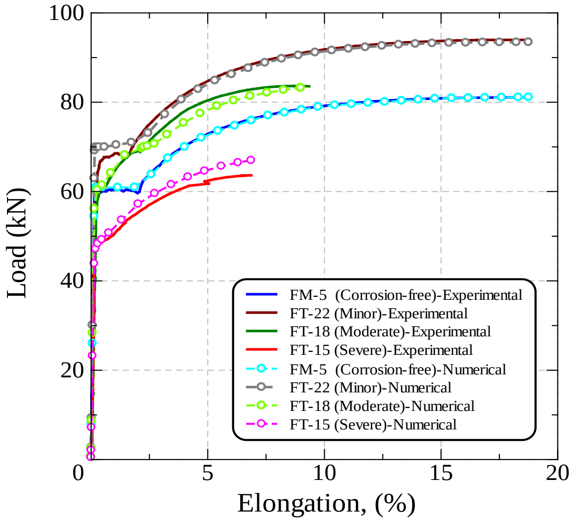


Figure 9: Comparison of experimental and analytical load-elongation curves

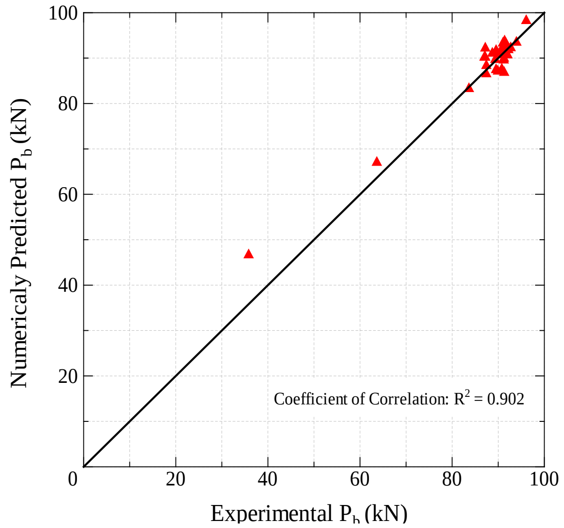
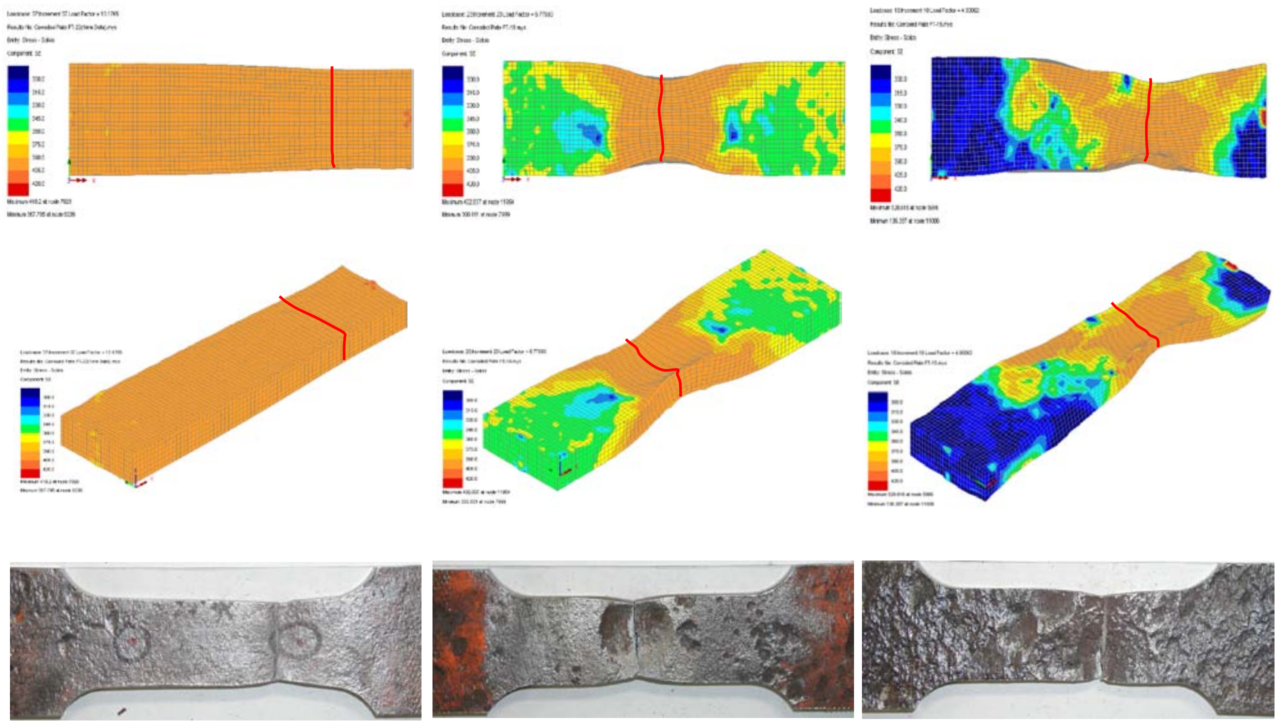


Figure 10: Comparison of experimental and analytical ultimate load capacities



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

Figure 11: Stress distribution of the corroded specimens at ultimate load

The Figure 10 shows the comparison of ultimate load capacities of all 32 specimens in experimental and numerical analyses. Having a coefficient of correlation of R^2= 0.902 indicate the accuracy and the possibility of numerical investigation method to predict the tensile strength of actual corroded specimens.

Figure 11 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. From those results, it can be seen that the failure surfaces of all three specimens have a very good comparison with the experimental results and hence this fact too signifies the accuracy of the adopted numerical modeling method.

6. CONCLUSIONS

The tensile tests, performed to 42 specimens taken out of the scrapped plate girder which had been used for about 100 years with severe corrosion to clarify the relationship between the representative effective thickness (t_{eff}) to estimate the mechanical properties of corroded plates and their level of corrosion. The representative effective thickness is proposed by using initial thickness and statistical parameter, standard deviation of thickness to estimate their remaining yield and tensile strengths are discussed from those experimental results. Further, a non-linear FEM analysis was carried out to understand the mechanical behavior, stress distribution, ultimate behavior etc. for members with different corroded conditions.

The main conclusions are as follows:

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. Therefore, three basic corrosion categories were introduced according to severity of corrosion and they are:
   (i) Minor Corrosion ; $\mu \geq 75$
   (ii) Moderate Corrosion ; $75 > \mu > 50$
   (iii) Severe Corrosion ; $\mu \leq 50$

2. A representative effective thickness (t_{eff}), based on the initial thickness (t_0) and the standard deviation of thickness (σ_{st}) can be used to estimate the remaining yield and tensile strength of corroded steel plate. In estimation of both remaining yield strength and tensile strength, the proposed relationship revealed a good comparison with the experimental results and the derived equation is as follows:

$$\mathbf{t_{eff} = 0.9t_0 - 3\sigma_{st}}$$

   As the proposed effective thickness has only a single variable (standard deviation of thickness, σ_{st}) and the value of initial thickness, t_0 is a well known parameter, it will reduce the contribution of the errors occurred during the practical investigation of a corroded member. Also it is necessary to note that the t_{max} should be applied for very old bridges which t_0 could be unknown in very rare situations. Further this method is simple and gives more reliable and closer results compared to the other available methods.

3. 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. Therefore, it is evident that this numerical modeling procedure can be extended to establish 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 in future studies.

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