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Prediction of flexural behavior of Artificially time dependent corroded steel beam

Phân tích ứng xử của dầm ăn mòn nhân tạo theo thời gian

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ABSTRACT

In order to properly assess the behavior of Steel beam structures is corroded over time. The experimental program was conducted on a pattern of steel beams and combined the steel plates together. The study focuses on analyzing the behavior of curve (P-δ), whether the bearing capacity of corroded steel beams meet the requirements of using or not, how destructive position appears, function of structural instability and assessing the level of corrosive structure in the study at the same time. The experimental results also evaluating the working behavior of shaped steel beams over time. This method partly supports faster corrosion research to the artificial creation of a mechanically corroded surface, corrosion characteristics and behavior of corroded steel beams, such as force, deflection, deformation, damage, and stability through time, depth, and corrosion distribution parameters, are analyzed and evaluated in a detailed. Additional documents serve to inspect, evaluate, and design corroded steel structures. Since then, it can be evaluated the safety of steel beam structures in construction from being corroded over time.

Keywords: Artificially; corroded steel beam; flexural behavior; prediction.

TÓM TẮT

Để đánh giá đúng sự hoạt động của kết cấu dầm thép bị ăn mòn theo thời gian. Thí nghiệm được thực hiện trên 03 dầm thép hình có sườn gia cường. Nghiên cứu tập trung phân tích ứng xử của đường cong (P-δ), khả năng chịu lực của dầm thép bị ăn mòn có đáp ứng yêu cầu sử dụng hay không, vị trí phá hoại xuất hiện như thế nào, chức năng mất ổn định kết cấu và đánh giá mức độ ăn mòn kết cấu trong nghiên cứu. Ngoài ra, kết quả thực nghiệm còn đánh giá được sự làm việc của dầm thép định hình theo thời gian. Phương pháp này một phần hỗ trợ nghiên cứu ăn mòn nhanh hơn để tạo ra bề mặt bị ăn mòn cơ học một cách nhân tạo, các đặc tính và ứng xử ăn mòn của dầm thép bị ăn mòn như lực, độ võng, biến dạng, hư hỏng và độ ổn định thông qua các thông số phân bố thời gian, độ sâu và ăn mòn được phân tích và đánh giá một cách chi tiết. Nghiên cứu bổ sung phục vụ cho việc kiểm tra, đánh giá và thiết kế kết cấu thép bị ăn mòn. Từ đó có thể đánh giá được độ an toàn của kết cấu dầm thép trong xây dựng bị ăn mòn theo thời gian.

Từ khóa: Nhân tạo; dầm thép bị ăn mòn; ứng xử uốn; dự đoán.

1. INTRODUCTION

Today, steel materials have applied and widely used in industries and construction, which are rising and playing an essential role. Steel structures are an effective solution in terms of cross-section and large spans. More and more steel bridges across rivers and seas, steel overpasses at intersections, and stadiums are being built. Besides the above advantages, steel materials also have disadvantages that limit their use, such as being easily eroded by the impact of the environment, temperature causing corrosion, and poor fire resistance [1-2].

Steel material is easily destroyed by corrosion because the impact of environment and temperature quickly erodes steel. Metal corrosion is defined as the self-destruction phenomenon of materials-metals or alloys- due to the effects of environmental substances. Based on the environment and mechanism of metal corrosion, corrosion is divided into two main types such as chemical and electrochemical. Chemical corrosion is the process of destroying metals due to the chemical effects of the environment on the metal. Therefore, chemical corrosion only occurs in liquid electrolyte environments and air environments. Chemical corrosion can also be defined as metal corrosion due to the simple effect of a chemical reaction between the metal material and the surrounding environment containing aggressive (O2, S2, Cl2, etc.). In other words, chemical corrosion occurs in gaseous and liquid non-electrolyte environments [3].

Electrochemical corrosion is a corrosion process in which an electric current is generated. Therefore, electrochemical corrosion of metals only occurs when the metal comes into contact with an electrolytic environment where the solvent is water. Electrochemical corrosion can also be understood as corrosion caused by electrochemical reactions occurring in two different areas on the metal surface. The electrochemical corrosion process generates a flow of electrons moving in the metal and a flow of ions moving in the electrolyte solution in a specific direction from one electrode area to another electrode area of the metal. The rate of electrochemical corrosion occurs quite intensely compared to chemical corrosion. Corrosion of steel reduces the weight, bearing capacity, and stability of the structure, reducing the design's lifespan. Corrosion causes significant economic losses and costs for applying anti-corrosion techniques such as painting and metallization. In addition, corrosion also causes environmental pollution due to corrosion products. Protective materials are destroyed and washed away by rain, dissolved and seeped into soil, water, etc., causing damage to the ecological environment or human health. Therefore, the issue of considering structural performance, cost and environmental issues, and corrosion characteristics needs to be clarified and believed in the design, construction, and maintenance of steel structures [4]. Manuel Morcillo [5] researched the corrosion of steel materials, and the results provided a formula to determine the rate of material deterioration of steel beam structures over time under the impact of environmental conditions. In-Tae Kim and colleagues [6] researched the tensile capacity of steel plates corresponding to the percentage of rusted surface area, and the results of building a correlation graph between tensile force and elongation correspond to the portion of corrosion area. Amanda Bao and colleagues [7] conducted experimental research on four models of steel beams losing cross-section due to corrosion using finite element modeling and compression tests. Evaluate the load-bearing capacity and stability of steel beams corresponding to the percentage of corrosion area. Miyashita and colleagues [8] conducted a study investigating corroded steel beam ends and restoring them by gluing CFRP panels. The results of the shear load-bearing capacity at the beam ends can be determined and converted using CFRP panels appropriately. E. Yamaguchi and T. Akagi [9] conducted research on the impact of steel beam end corrosion using a nonlinear FEM model and found that the load-bearing capacity of one beam end tends to decrease linearly with increasing corrosion thickness at the beam end. Tatsuro Nakai and his colleagues [10] conducted a study on the effects of localized pitting corrosion on the performance of steel frames, and the results showed that the tensile strength gradually decreased and the total elongation decreased sharply with the increase.

Based on the research and analysis of previous studies, this study adds several new points: experiments with shaped steel beam specimens with typical locations and corrosion levels that closely reflect the corrosion condition. Actual wear in natural environments, from experimental results evaluating the working behavior of shaped steel beams over time. This method partly supports faster corrosion research thanks to the artificial creation of a mechanically corroded surface. Corrosion characteristics and behavior of corroded steel beams, such as force, deflection, deformation, damage, and stability through time, depth, and corrosion distribution parameters, are analyzed and evaluated in a detailed. Additional documents serve to inspect, evaluate, and design corroded steel structures.

2. EXPERIMENTAL PROCEDURES

2.1. Material properties

The experimental model was established based on previous research and laboratory conditions. The experimental specimence is designed with a length of 3m, and an H-shaped steel beam is made from a CT3 steel plate. To achieve the most accurate testing results while controlling the quality of materials and specimence processing, all factors affecting the experimental results, such as steel plate accuracy when processing specimens, are all tested by existing standards, from which the material parameters are reflected most clearly, and the experimental results are the most realistic.

The results of the steel tensile test presented in (Table 1), the parameters of the specimence reach the steel input requirements CT3 of the standard TCVN 5575: 2012 Steel structures - design standards [16], from here, specimence manufacturing is carried out.

2.2. Test specimens

Based on the goal of this study, which is to evaluate the corrosion characteristics of H-shaped steel beams over time. There are two main factors that affect the behavior of the structure is considered to analyzed as follows:

- Corrosion distribution level of steel beam parts.
- Corrosion depth of steel beams over time.

In this study, the testing will be conducted on 03 steel beam specimences with a length of 3 meters and labeled M1, M2, M3. The 3 steel beam specimences with corrosion depth parameters as shown in (Table 1) and corrosion distribution level as shown in (Figure 1) to evaluate the corrosion characteristics of shaped steel beams over time.

Table 1. The depth of the corroded specimens ratio of the steel beam

Specimens	Corrosion depth	Years
M1	1,5 mm	10
M2	5 mm	30
M3	9 mm	50

Material and structure parameters of 3 steel beam specimences M1, M2, M3 are shown in detail in (Figure 2-4).

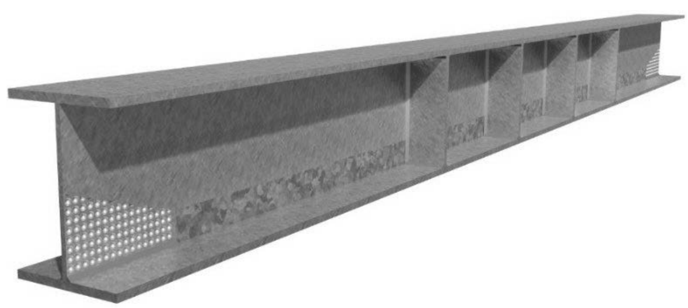


Figure 1. Detail of machine-simulated corrosion H beam

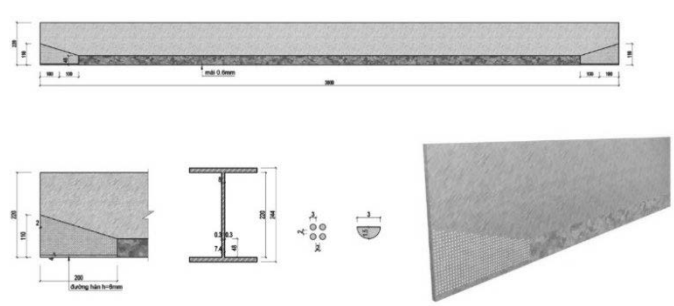


Figure 2. Details drilling to create corrosive holes M1 (10 years)

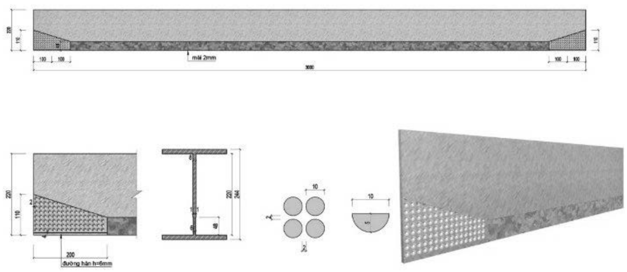


Figure 3. Details drilling to create corrosive holes M1 (30 years)

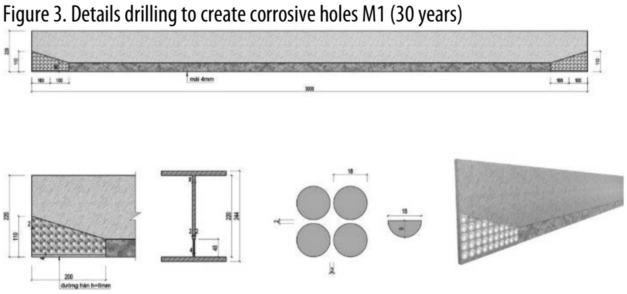


Figure 4. Details drilling to create corrosive holes M1 (50 years)

2.4. Test set up

After processing, the specimence is put into the experiment that the 4-point inflection model is applied. Based on the conditions in the laboratory and references from previous studies, the experimental model is presented in detail in (Figure 5). In which:

• LVDT1, LVDT2, LVDT3, LVDT4: For measuring beam deflection, thereby building a relationship between force and displacement. This LVDT has a base placed on the foundation, the top part is in contact with the bottom of the steel beam

• LVDT5, LVDT6: For the purpose of recording the horizontal displacement of steel beams, thereby building a relationship between force and displacement. This LVDT has a base placed on the foundation, the top part is in contact with the steel beam web

• Strain Gauges (SG) SG1, SG2, SG3, SG4, SG5, SG6, SG7, SG8, SG9, SG10 are SHOWA brand Strain Gauges, type N11-FA-10-120-11, with gauge length 10mm, designed Pasted on the wings and web of the steel beam, to record the deformation of the steel beam when subjected to load

• Load cell is used to record force values during testing.

• Data recording device - Data Logger, used to record the results of force, LVDT, SG

• All measuring equipment is installed, checked, and calibrated carefully before conducting the experiment. Experimental data is automatically recorded by the computer system with a frequency of 1 time/s.

The process of installing LVTD and strain gauges (SG) on beams is shown in (Figure 6).

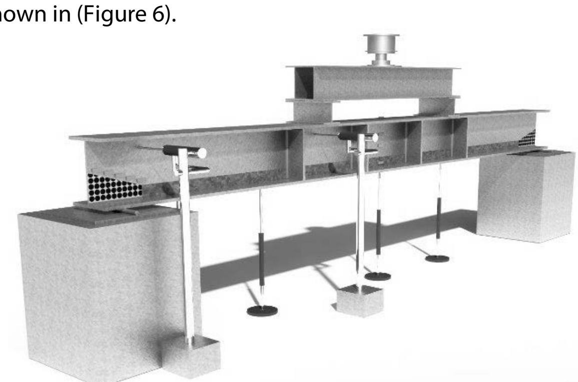


Figure 5. Experimental set up model

Figure 6. Experimental set up

3. SUMMARY OF EXPERIMENT RESULTS AND DISCUSSION

3.1. General results

The results extracted from Data Logger are summarized in (Table 2) as follows:

Table 2. General experiment results

Specimens	Ultimate load (kN)	Displacement (mm)	Failure mode
Dầm M1	250,73	14,14	Failure due to instability
Dầm M2	201,28	11,64	Failure due to instability
Dầm M3	81,9	5,17	Failure due to instability

The elastic limit load is $P_{elastic}$ = 260kN. It is concluded that beams M1, M2, M3 are damaged due to instability. The destructive load due to instability of beam M1 is 250.73 kN, beam M2 is 201.28kN, beam M3 is 81.9kN.

The deflection at elastic limit load is $P_{elastic}$ is 10.7mm. The deflection of beam M1 when damaged is 14.14mm, beam M2 is 11.64mm, beam M3 is 5.17mm, showing that when the section is corroded, the stiffness will decrease.

3.2. Failure mode of corroded beams.

At the end of the destructive test of all three specimences, it was observed that the failure occurred due to instability at the beam end. This is appropriate because the corrosion level at the beam end position is large, so the cross-section is easily damaged at the beam end in (Figure 7).

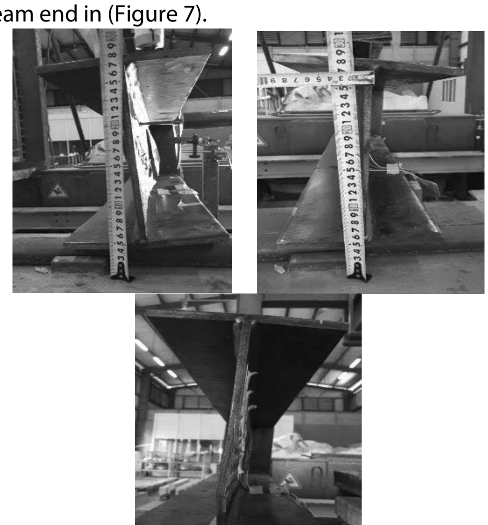


Figure 7. Failure mode of specimens M1, M2, M3

3.3. Beam displacement

The deflection of the beam was recorded by 4 LVDTs: LVDT1, LVDT2, LVDT3, LVDT4, which installed at positions 0.35m 0.75m 1.5m 2.0m from the edge of the beam. Thereby, the analysis and discussion for the behavior of beams according to deflection are presented in (Figure 8). That is, the deflection of the beam at the section far from the support is larger than the deflection of the section near the support.

Figure 9 shows that the deflection of the beam changes with each load level, and the displacement increases steadily with each load level. This can explain that the beam still works in an elastic state, but due to corroded cross-section, the structure is damaged in the form of instability.

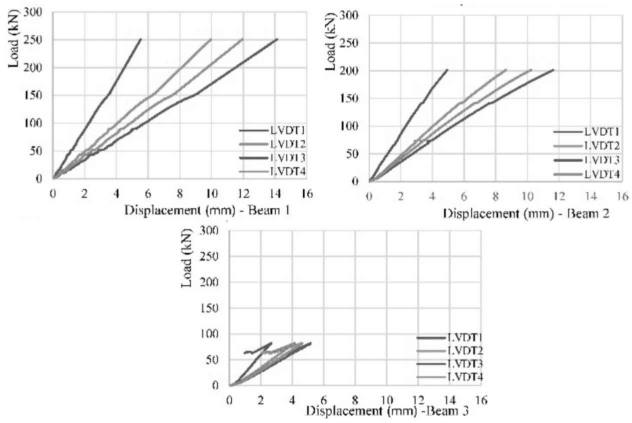


Figure 8. Load–displacement relationships

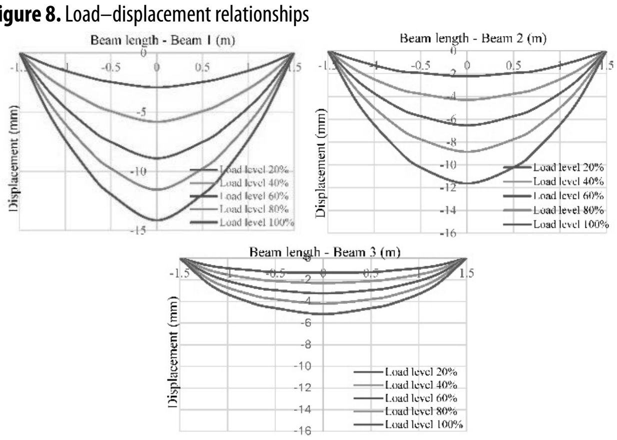
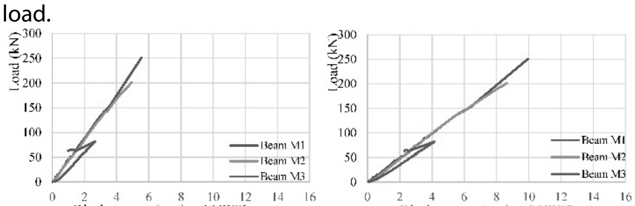


Figure 9. Load levels–deflection relationships

3.4. Compare displacement between specimens

The force-deflection relationship chart at measurement locations LVDT1 to LVDT4 in (Figure 10) and (Figure 11) shows the reasonableness of the corrosion effect on the performance of steel beams. To achieve the same deflection value, it is necessary to Beam M1 must use a larger load than beams M2 and M3.

Beams M1, M2, M3 still work in an elastic state before failure occurs, the deflections in all three beams tend to be linear with the load.



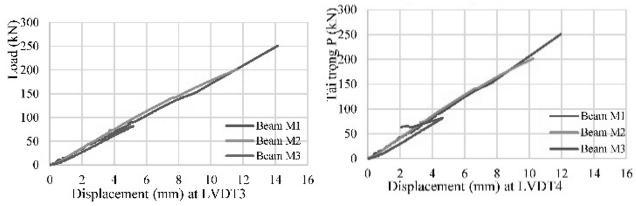


Figure 10. Load–displacement relationships at each LVDT

The deflection decreases with increasing corrosion level. At 100% load level in the middle of beam LVDT3, the deflection of specimence M1 is larger than specimence M3, the results are shown in (Table 3).

Table 3. Comparision of deflection at LVDT3 models M1 and M2, M1 and M3

Specimens	Displacement (mm)	Error (mm)	Error ratio
M1	14,13	2,49	Reduction 17,6%
M2	11,64		
Specimens	Displacement (mm)	Error (mm)	Error ratio
M1	14,14	8,97	Reduction 63,4%
M3	5,17		

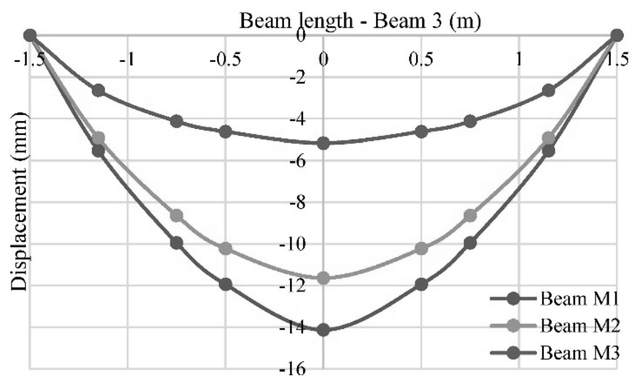


Figure 11. Comparison of maximum load vs. deflection at mid-span curves of beams M1, M2, and M3

The maximum deflection value at the force points causing beam instability is shown in (Table 4)

Table 4. Table of deflection values at force points causing beam instability

Specimens	M1	M2	M3
Load P_b (kN)	250,73	201,28	81,9
δ_{dismax} (mm)	14,14	11,64	5,17
μ_w	0,15	0,47	1
μ_d	0,18	0,63	1

3.6. Beam stability analysis.

The stability of the beam is investigated using LVDT5 and LVDT6, the assessment is through the relationship chart between force - horizontal displacement in (Figure 12). Thereby, the analysis and Evaluations for the behavior of the beam according to stability are drawn by the relationship chart between force - horizontal displacement.

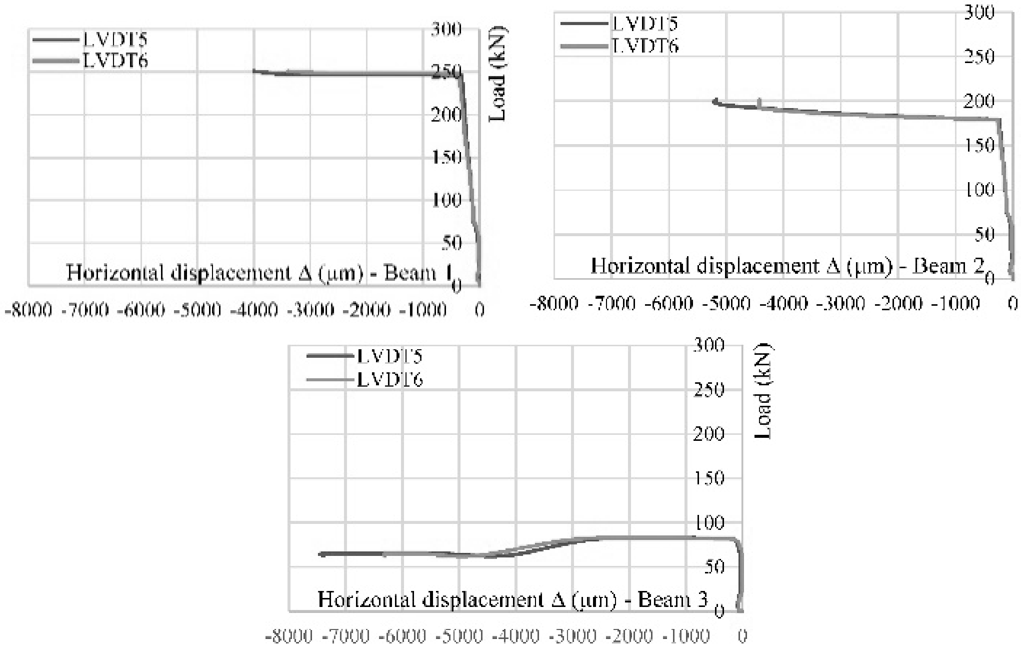


Figure 12. Load - horizontal displacement relationships

The horizontal displacement of the beam increases with increasing corrosion level. At 100% load level, at LVDT5, the horizontal displacement of beam M3 is larger than beams M2 and M1 as shown in (Table 5).

Table 5. Compare of the stability of steel beams

Specimens	Strain (μm)	Error (μm)	Error ratio
M1	4000	1177	Increase
M2	5177		29,5%
Specimens	Strain (μm)	Error (μm)	Error ratio
M1	4000	3395	Increase
M3	7395		84,8,%

4. CONCLUSION

The extent of corrosion distribution of steel bridge girders over time depends on the environment. Specifically, the two ends of the girder are always most affected by corrosion, and tend to spread out. The coefficient of corrosion level of the component by volume and depth of corrosion evaluates thelevel of corrosion of the component over time. Based on the measurement of volume and depth of corrosion, then looking at the corrosion level will know the working corrosion characteristics of shaped steel beams over time.

In general, the effects of corrosion on the structural performance in terms of deflection, deformation, and stability are as follows:

• The decrease in deflection, deformation, and stability increases with the degree of corrosion

• During the period from 0 to 25 years, the corrosion level coefficient of the structure is about, the decrease in deflection, deformation, and uniform stability over the years.

• From 25 years onwards, the corrosion coefficient of the structure is in the range of, the decrease in deflection, deformation, and stability increases very rapidly.

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