Thin-Walled Structures 100 (2016) 48–61

Contents lists available at ScienceDirect

Thin-Walled Structures

journal homepage: www.elsevier.com/locate/tws

Full length article

Load-carrying capacity of locally corroded steel plate girder ends using artificial neural network

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ARTICLE INFO

Article history:
Received 28 May 2015
Received in revised form
18 November 2015
Accepted 8 December 2015
Available online 17 December 2015

Keywords:
Corrosion damage
Bridge girder
Buckling
Nonlinear analysis

ABSTRACT

In aged steel bridges, an area of local damage may be created in girders nearby the bearing region due to corrosion. The existence of local corrosion damage in the plate girder end can reduce the load-carrying capacity of bridge. A three-layer Back-Propagation neural network (BPNN) has been developed to predict the residual buckling strength of such damaged members. In this paper, train, test and validation sets of the neural network were obtained by using the finite element software ABAQUS. The accuracy of the nonlinear finite element method (FEM) to evaluate the residual bearing capacities of damaged beams is discussed. Buckling and post-buckling behavior of plate girders ends were quantitatively evaluated from nonlinear finite element analyses (FEA) model varying the corrosion scenario. A parametric study is achieved based on FE and an empirical equation is proposed based on BPNN to estimate the residual bearing capacity of deteriorated steel plate girder by local corrosion damage. The obtained results show that the prediction of the residual bearing capacity of the locally corroded steel plate girder ends is accurate and effective.

1. Introduction

Bridges, as well as other structures in nature, are often in a severely deteriorated condition due to natural aging. Environment and fatigue cracking are the two most important causes of damage in aging bridge structures. For steel bridges one of the most dominant forms of deterioration is corrosion [1]. The primary cause of corrosion is the accumulation of water and salt (marine environment or deicing media) on bridge steel. The source of water and salt is either from deck leakage or from the accumulation of road spray and condensation [2].

Bridges field inspection show the places most commonly found with corrosion are the top surface of the bottom flange and on the web near the abutments and joints. It has been indicated by Kayser [3] that severe corrosion may take place at the bottom quarter of the web. Therefore the top surface of the bottom flange and the bottom part of the web are the regions where severe corrosion may take place, as shown in Fig. 1. Corrosion also takes place in the top flange and the top part of the web but the loss is much less as compared to that of the web's bottom part [4].

It is evident that corrosion influences the load-carrying capacity of a damaged steel girder' bridge as well as mode of failure. It may reduce the resistance of the beam to shear, bending or buckling. Corrosion can result in an increase in stress, change in geometric properties, buildup products, and the reduction in member cross-section properties, such as section modulus or slenderness ratio [2]. Therefore, various studies on the corrosion of steel bridges have been investigated prolifically by several researchers [1–14].

As it mentioned previously, corrosion affects load-carrying capacities of a damaged steel girder bridge in modes of shear, bending, bearing and buckling. The web thickness loss near the support due to corrosion would reduce the shear buckling and axial loads [5]. As one knows, bearing forces are primarily resisted by the web, immediately above the supports. The strength of the web depends on the presence of stiffeners. The installation of stiffeners is mandatory for plate girders and rolled girders above intermediate supports. For rolled simple-span steel girders, installation is necessary only in some situations [16,17]. Although a girder may not require a stiffener at the time it is constructed, after serious corrosion a stiffener may be necessary to maintain the original design capacity [2]. Therefore, it is essential to predict the residual strength of damaged steel bridge girders to investigate the safety level and the retrofitting and rehabilitation strategies in due course.

With regard to the corrosion of the steel bridges, however, it can be considered to be sufficient as its paint coating, which is generally used to prevent corrosion. However, there are numerous existing structures which have not preserved so far. Beside this, in

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http://dx.doi.org/10.1016/j.tws.2015.12.007
0263-8231/

Fig. 1. An example of local corrosions in end panels [15].

several points these preservations such as painting break down and the corrosive environment attack to the pure steel and make it damaged [11]. For example, Fig. 1 shows a plate girder bridge that collapsed owing to severe corrosion [6]. Therefore, assessment the residual strength of these structures is an important issue to keep them in a reliable and safe utilization.

Thickness loss due to corrosion of steel plate girder bridges results in ultimate strength of the steel plate girder bridges degrade significantly. Totally, corrosion divided into two principal types, that is, general and localized corrosions in the land-based structures, marine, offshore and industry structures. For general corrosion, which uniformly reduces plate thickness, the plate ultimate strength calculations are typically carried out excluding the thickness loss due to corrosion. However, in the case of localized corrosion, the strength calculation procedure can be more complex. In the case of steel bridges, local corrosion should be considered [8]. According to the literature review on corroded bridge girders, there are no specific reports on the buckling of corroded plate girder ends. In other words, no guidelines are available for predicting the sensitivity of corrosion characteristics on the amount of reduction of their load-carrying capacity. However, there are a small number of reports on buckling of corroded plate girder ends subjected to shear [5–7] as well as bearing stiffeners [12,13].

Therefore, this study presents the effect of local corrosion damage on the load-carrying capacity of steel plate girders in term of bearing strength in critical area near end. For this purpose, a large number of FEA were conducted on damaged steel plate girders with different damage parameters to investigate the load-carrying capacity of a corroded plate girder end. The observed buckling behaviors and buckling strength of the corroded specimens were compared with those of an un-corroded plate girder end. Neural networks are simplified mathematical models of the biological nervous system that has been developed as robust computing tool for solving linear or nonlinear problems. ANNs are modeling techniques that are especially useful to solve complex phenomenon by applying information obtained from past experiences to new problems. Neural networks have been used in a wide range of applications in science and engineering. With the development of modern digital computers, neural network techniques have been effectively used to simplify complex problems. Because of their fast response in comparison with FEMs, they are extensively employed in structural analysis and design [18–27]. Modeling methods based on ANNs combined with FEMs have been employed by many researchers for many structural applications [28–36]. In this study, ANN method is developed using the results of FEA to derive new empirical formulae for better predicting the residual ultimate capacity of damaged steel I-beams with local corrosion Fig. 2.

2. Corrosion rate modeling

It is well known that the cost of materials deterioration due to corrosion is immense and thus being widely studied. Corrosion is the chemical degradation of materials, such as metals, semiconductors, insulators, and even polymers, due to the exposure to environment [37]. Practically all environments are corrosive to some degree. Some examples are air and moisture; fresh, distilled, salt, and mine water; rural, urban, and industrial atmosphere; steam and other gases such as chlorine, ammonia, hydrogen sulfide, sulfur dioxide, and fuel gases; mineral acids; organic acids; alkalies; soils; solvents; vegetable and petroleum oils; and a variety of food products [38].

Corrosion is a highly complex phenomenon. There are many environmental and material factors that can influence the corrosion rate. Therefore, it is very difficult to predict the corrosion rate [39].

Many studies have been conducted on the corrosion modeling [40–46]. Paik and Kim [40] proposed an advanced method for the development of an empirical model to predict time-dependent corrosion wastage. In the proposed method, the statistical scatter of corrosion wastage at any exposure time is analyzed in a refined manner and formulated using the Weibull function. Both the shape and scale parameters of the Weibull function are determined as a function of time through the curve fitting of a corrosion measurement database [40]. Fig. 3 is a flow chart of the proposed method for the empirical development of a time-dependent corrosion model which predicts the reduction of plate thickness due to corrosion [40]. Eq. (1) shows the 3-parameter

Fig. 2. Collapsed plate girder bridge reported by Ahn et al. [6].