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Investigation of Existing Steel Bridges in Ho Chi Minh City

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Abstract— Corrosion is one of the most important causes of deterioration of steel bridges. The primary cause of corrosion is the accumulation of water and salt (marine environment or deicing media) on bridge steel. For steel structures, such as bridges, the severity of deterioration will depend on how long the metal is exposed to water, oxygen, and salt. The rate of corrosion will be considerably increased by the presence of salt from a marine environment or the use of deicing materials. Currently, the deterioration of bridge conditions is causing many problems. This paper describes common defects based on investigation data of site inspections. Finding the defects depicts an overall picture of steel bridges in Ho Chi Minh City that are in poor physical conditions, thus providing poor serviceability. Besides structural failure, local defects were already identified, consisting of corrosion, functional obsolescence, human actions and missing elements. It is widely considered that overload of traffic volume, collision impacts, adverse climate conditions and poor maintenance are the main causes. It suggests that maintenance efforts should be prioritized to eliminate these deficiencies.

Index Terms— Steel bridges, deterioration, corrosion, inspection

1 Introduction

The development of transport infrastructure and transport systems belongs between fundaments of competitiveness. The use of steel in bridges goes back to 100 years. Steel as a bridge construction material is available as wire, cable, plates, bars, rolled shapes (I beams) and built-up shapes. Rolled shapes are used as structural beams and columns and are made in various shapes, mainly as an I shape in many size and weights, with a straight or tapered flange thickness. Other common steel shapes include I-girders, box girders, and truss members. The steel bridges are much larger than both the reinforced concrete bridges and the prestressed concrete bridges.

Many reports mentioned situation of exiting bridges in Vietnam recently [1], [2]. Having been built decades ago and with the impact of the adverse climate, traffic loads, etc., many existing steel bridges in Ho Chi Minh City (HCMC) are now in poor conditions. This has created a situation of a general lack of safety and degraded physical and functional capacities. In addition, it requires substantial expenditures to remedy these damages. Deficiencies such as structural failure and local defects prevent a bridge from qualifying within the realm of clarified standards or of being in conformity of performance against expectation.

There are only small quantities of steel bridges which are located in HCMC so far. They are classified in terms of their lengths, standards, have a wide range of shapes and commissioning dates. Steel composite bridges in HCMC as listed in Table 1 (according to statistics of the year 2010 reported by HCMC Department of Transport) consist of a total 42 bridges, running a total length of 2462.95m over the entire suburb of city and most of those bridges were designed for lighter loads than are common today.

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TABLE 1
Total of Steel Bridges Located in HCMC

Loading capacity (tons)	Quantity	Length (meter)	Ratio (%)
0.5	2	143.6	4.76
1	1	16.0	2.38
2	1	24.0	2.38
3.5	1	31.0	2.38
5	6	519.8	14.29
8	3	177.4	7.14
10	7	207.0	16.67
13	14	538.7	33.33
15	1	24.0	2.38
20	1	39.0	2.38
25	2	312.5	4.76
30	3	430.0	7.14

Several historical stages of steel bridges in HCMC are described as the following.

- Period 1954–1975: HCMC was known as Sai Gon, the bridges served mostly military purposes. US standards have been applied for all steel bridges in that time.
- Period 1975–2000s: A high demand of transportation has developed with the country's renovation, and the economic boom since the 1990s has increased the number of bridges significantly. Bridge-related standards originated by local authorities based on So Viet (Russian) standard.

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- Period 2000s–present day: With merits of steel bridge as flexibly shape, easy handling, harmony in city landscape, rapid construction etc, some steel bridges were newly constructed as Ong Lon bridge, Binh Loi bridge, and a lots of steel flyover projects have been embarking as every inch solution to deal with traffic congestion in the city as shown in Fig.1.

Fig. 1. Severe deterioration of an old steel bridge compared to new steel flyover bridge.

Not withstanding existing a small amount of steel bridges, data management has still been totally ineffectively in preserving and bringing current bridges condition up to date. By carrying out investigation and evaluation of the current status of existing steel bridges based on several criteria, this study is going to represent several features and conditions of steel bridges in HCMC, deficiencies and major factors affecting working condition of bridges.

2 Methodology

Focusing on common problems of steel bridges, specifically, deficiencies occurring and current working conditions; many preliminary inspections and visual investigations have been conducted on 20 steel bridges located in HCMC. All signs of deficiencies occurring in every aspect, position and component have been recorded; thereby, an analysis of their main causes is also carried out for each case.

The output of data analysis includes the mean average scores of damages on a scale of 1–3, categorized into three groups: A-C. These groups are classified according to the frequency of damage as "rare", "sometimes" and "frequent", and respectively. On the other hand, the degree of seriousness of detected defects is divided into "working normally", "maintenance required" and "replacement required".

3 Visual Inspection Analysis

Generally, existing bridges in HCMC are in poor physical conditions and functionality, which are represented by several severe deficiencies. Some common deficiencies are listed in Table 2 have been recorded and mentioned as below:

3.1. Some Common Deficiencies

3.1.1. Coating Damage – Steel Corrosion

There are four main forms of corrosion which can affect a steel girder bridge. The most prevalent form is a general loss of surface material; this condition will lead to the gradual thinning of members. General corrosion accounts for the largest percentage of corrosion damage. Pitting corrosion also involves loss of material at the surface. However, it is restricted to a very small area. Crevice corrosion occurs in small confined areas, such as beneath peeling paint or between faying surfaces. It is usually caused by a low concentration of dissolved oxygen in the moisture held within a crevice. Deep pits can also provide locations for crevice corrosion to occur. Stress corrosion occurs when metal is subjected to tensile stress in a cor- rosive environment. For mild carbon steel in ordinary bridge environments, stress corrosion is usually not a problem.

Generally, HCMC has a wide range of temperatures going from around 25 to $39^{o}C$ and high atmospheric moisture (80 % average) containing many active ions (e.g. Cl^-, SO_2). This adverse climate creates a good condition for corrosion to occur on steel elements. Lack of proper surface protection is also claimed as a cause of corrosion. The steel surface has been poorly coated to withstand corrosion. In addition, they are not repainted in a timely manner to replace depreciated previous layers due to lack of maintenance funds.

3.1.2. Missing Structural Elements

There are three basic changes which can occur in a steel bridge due to corrosion: loss of material, reduction of section parameters, and buildup of corrosion products, are reported by R. Kayser and S. Nowak [3].

Loss of material will cause smaller net sections. This may increase the stress level for a given load or the stress range due to cyclic loading. When corrosion is localized, as in pitting, stress concentrations can occur, further increasing the stress level. A reduction in section area will decrease the geometric properties, such as moment of inertia or radius of gyration. This change may occur in a nonlinear manner because the geometric properties are related to the square or cube of the dimensions. Buckling capacity of members can be critically affected by the reduction in metal thickness.

The buildup of corrosion products can also adversely affect steel bridges. Rust formation may exert pressure on adjacent elements.

Missing structural elements has been not widely discussed in many documents for years; while this issue has always been an extremely serious and frequently reported in Vietnam by Hai *et al*. [1]. It is confirmed that this issue almost derives from burglaries. Illegal thieves have targeted many bridge elements built from valuable metals as many burglaries were confirmed from site observation. Common missing items are anchors, bolts, nameplates, drain gulleys. Moreover, under the impact of traffic vibrations, etc., bridges have lost their stiffness and solidity. Small elements therefore can be easily taken away from the main structures. Besides, the investigation has also recorded the phenomenon of elements damaged by people who are troublemakers and lack awareness of the severe action that they have done.

3.1.3. Functional Obsolescence

The most common and effective way to protect steel constructions is to maintain a protective coating system. For steel bridges, fatigue cracks and coating failure are two primary types of deterioration. The performance of the corrosion protective system is a critical factor. Durability of corrosion protection is an important issue to consider when designing and detailing steel bridges. Nowadays coatings have reach 20 to 25 years of lifetimes to the first major maintenance. The basis for choice and verification of materials and surface corrosion treatments long-term exposed to atmospheric environment is degree of corrosivity. General provisions are given to prevent the effects of corrosion during the lifetime of metal structures was not required at that time.

Corrosion is even accelerated on areas where construction details provide pockets or crevices to retain moisture and deposition (scuppers, downspout, bottom inside flange of girders, horizontal surfaces under the edge of bridge decks and expansion dams). Problems may occur for the structural metal fixings such as bolts, rivets, screws and pins. Rust detected around their heads may indicate corrosion along the entire length of them causing reduced structural integrity.

Database from HCMC Department of Transport and site inspection show that load-carrying capacity, speed design, space clearance of many bridges cannot satisfy the current demand which have been constantly increasing.

Due to the economic boom in Vietnam since the 1990s, traffic demands have increased several folds in terms of the number of vehicles and their weights. This has therefore imposed overloads which will make steel bridges functionally obsolete sooner or later.

4 Results of Data Analysis

4.1. Analysis results

TABLE 2
EVALUATION THE LEVEL OF FREQUENCY OF POPULAR DEFICIENCIES IN STEEL BRIDGES IN HCMC

Conditions	Quantity of Steel bridges	Ratio (%)	Level of Frequency
Coating damage – Steel corrosion	20	100	Frequent
Missing structural elements	4	20	Sometimes
Functional obsolescence	13	65	Frequent
Reclaiming old steel girders	2	10	Rare

TABLE 3
CURRENT WORKING STATUS OF STEEL BRIDGES CORRE-SPOND TO EACH DEFICIENCIES

Conditions	Quantity of Steel bridges	Working condition		
		Working normally	Maintenance – improvement required	Replacement required
Coating damage - Steel corrosion	20	11	1	8
Missing structural elements	4	4		
Functional obsolescence	13	4	1	8
Reclaiming old steel girders	2	2		

4.2. Main causes

- Beside many common factors that were carefully discussed in [2], [4], [5], [6], some typical factors are detected in steel bridges in HCMC are listed in Table 3:

+ Inner factors

- Inadequacy of the design, construction. There are many unsynchronized bridges appeared due to traffic volume whose load capacity and speed allowance are very different. This is because of the difference in construction time, design standard, materials used, etc;
- Quality of the materials;
- Aging.
- Corrosion is even accelerated on areas where construction details provide pockets or crevices to retain moisture and deposition (scuppers, downspout,

bottom inside flange of girders, horizontal surfaces under the edge of bridge decks and expansion dams). Problems may occur for the structural metal fixings such as bolts, rivets, screws and pins. Rust detected around their heads may indicate corrosion along the entire length of them causing reduced structural integrity. The corrosion rate is significantly higher at crevices than on flat, open surfaces.

+ Traffic load factors

- It should be emphasized that the intensity and speed of the road traffic and loads of heavy vehicles have been tremendous increasing during the last few decades; Wind and vehicle speed, type of vehicle and the density of traffic all influence the amount of formed salt mist and how far it is carried from roads.
- Overloading by the heavy, oversized vehicles.
- Since the actual corroded surfaces are different from each other, only experimental approach is not enough to estimate the remaining strength of corroded bridge members. It is necessary to categorize the different corrosion conditions which can be seen in actual steel structures, into few general types for better understanding of their remaining strength capacities considering their visual distinctiveness, amount of corrosion and their expected mechanical and ultimate behaviour

+ Weather and environmental factors

- Atmospheric falls containing aggressive chemicals (acid rains);
- Aggressive chemicals in rivers, canals.

- Besides, several special factors have also been significant impacts causing increasing deteriorations in many bridges that we should take into account:

+ Human impacts

Bridge clearance spaces are used generally as flea-markets or street-front shops while their abutments can be used for anchoring vessels and barges as shown in Fig.2. There are many bridges that had pedestrian lanes invaded by residential sellers and pass-over buyers. These practices have created many problems such as narrowing of traffic lanes, creating congestions, and imposing extra loads to create unsafe conditions for traffic operations.

Since steel bridges are generally located at ideal traffic locations, they provide residents with good places for running businesses or storage spaces. This, together with the lack of protection from the Vietnamese authorities, made existing bridges in an easy target for illegal intruders. The time-history is moreover complicated as many bridges were now located inside animated business areas, where their boundaries can not be clearly identified. Bridge authorities are therefore in a difficult situation to impose strong actions against invaders and have to sometimes accept the nature of the problem.

Fig. 2. Human activities under Long Giang Xay and Ha Thanh bridge.

+ Poor management and maintenance

Up to present, there has still been no effective data management method as well as software applied, resulting in undigitized bridges data, that makes establishment of maintenance program more difficult and complicated. In addition, negligently coping with incurred bridge deficiencies without any proactive preparedness to potential risks has also added fuel to the fire.

The poor-quality coating deteriorates through porous coating layers that left water, oxygen, and soluble salts may go through layer and reach the steel before signs of coating degradation are visible. When a protective coating has deteriorated beyond a certain level, it can lead to section loss of the steel substrate without a timely repair. The amount of time it takes a bridge to reach this condition depends on the type of paint, bridge type, and geographic location of the bridge. Generally, paint systems will last 15 to 20 years before total repainting is required, but local repainting may be necessary after few years on critical surfaces of bridge structure.

4.3. Feasibility of reclaiming old steel girders.

Fig. 3. Reuse old girders in constructing Tien Giang and Cai No bridge

The ability to reclaim old steel girders is an important advantage. This is represented clearly in case of HCMC. Fig. 3 shows the two bridges that were built of steel girders dismantled from other old steel bridges. With a limited budget for constructing new bridges, this solution really does the trick.

5 Conclution

The paper describes the current status of steel bridges in HCMC and reviewed the deficiencies occurring on steel structures. It revealed that the existing steel bridges are in a state of poor physical condition and have many deficiencies. Following the caused provided by the available literatures, and the conditions observed in the site inspections, steel corrosion, functional obsolescence, were identified as the most common and critical deficiencies. On the other hand, human actions and missing elements have been additionally detected as city-specific problems. The main causes of these problems according to the study are overloads, collisions, extreme climate, changes of future conditions, and lack of site maintenance. Additionally, the lack of management system has been considered as remarkable causes in HCMC.

Some recent methods are updated based on computer software program for high-resolution photographs of coated structures taken with digital camera. The software includes non-uniform algorithms using image processing filters that enhance slight differences in coating hues, identify areas where coating have faded of are deteriorated (flaked, blisters, delaminated, etc.).

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