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Fatigue repair of underwater navigation steel structures using Carbon Fiber Reinforced Polymer (CFRP)

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ABSTRACT

The nation's Steel Hydraulic Structures (SHS) have significant deterioration caused by the effects of complex phenomena including corrosion and fatigue cracking caused by mixed mode loading. Current methods of repair of SHS, adopted primarily from the bridge engineering industry, have proven ineffective because they were developed for Mode 1 loading (tension) only. Various studies have been carried out to assess the use of CFRP for the rehabilitation of the aging and deteriorated infrastructure systems in the United States, however no research has been conducted on submerged steel structures. This paper presents the evaluation and implementation of an innovative retrofit method of CFRP to repair and strengthen the strut arms of a tainter valve. The evaluation of the retrofit method required a Fitness-for-Service fatigue assessment followed by a Finite Element Analysis (FEA) of the tainter valve with and without the retrofit method. Finally, the article presents the installation procedures used to install the CFRP retrofit and describes the advantages of the innovative repair techniques resulting in two to four folds increase of fatigue life.

1. Introduction

Steel hydraulic structures (SHS) such as miter gates, spillway gates, tainter valves, and maintenance closure structures may have fabrication defects and flaws large enough to threaten the integrity of the structure [1–4]. In addition to the fabrication defects and flaws, the nation's SHS are suffering significant deterioration caused by several complex phenomena including corrosion and fatigue cracking. Effective and economical retrofit practices are essential for ensuring continuous operation and to mitigate the level of risk associated with catastrophic failure or unscheduled repairs. Current methods of repair of SHS are adopted primarily from the bridge engineering industry [5–8], but have proven ineffective. These methods are ineffective due to excessive corrosion and deterioration conditions of the SHS, as well as differences in operation and loading conditions. In addition, the cost and time associated with the implementation of conventional repair methods are significant.

Various studies have been carried out to assess the use of CFRP to rehabilitate aging and deteriorated civil structures and infrastructure systems in the United States. Deterioration is typically manifested in terms of fatigue cracking, corrosion, deterioration of the protective system (paint), and impacts and overloads [9–12]. Most previously conducted studies were aimed at investigating the use of CFRP for flexure and shear retrofitting of concrete structures [13–19]. The given studies highlighted the significant potential of CFRP application as a retrofit demonstrated by the numerous field implementations of CFRP repair of concrete structures.

Less research has been conducted on the use of CFRP in strengthening metallic structures with most studies geared towards flexure retrofitting of aluminum panels in the aviation industry [20–22]. In general, research efforts on retrofitting steel elements have examined the repair of naturally deteriorated steel girders [23–25], repair of an artificially notched girder or steel plates to simulate fatigue cracks [26–28], strengthening an intact section to increase the stiffness [29–31], increasing the composite action between the steel girder and concrete deck in bridge applications [32,33], as well as developing a design criteria for CFRP as a repair element [34]. Further research has been conducted on CFRP as a pre-stress retrofit strategy in bridges [35–40] and most recently in SHS [41–43].

Experimental and analytical studies investigating crack growth of adhesively repaired steel panels were conducted on flat steel specimens and have shown an increase in fatigue life in comparison to the unrepaired specimens [23,26,32,37,44–46]. Very few studies have been conducted on fatigue crack propagation in CFRP-repaired largescale specimens representing real structural members [18,29,40,42,43,47–49] and only one recent study conducted on

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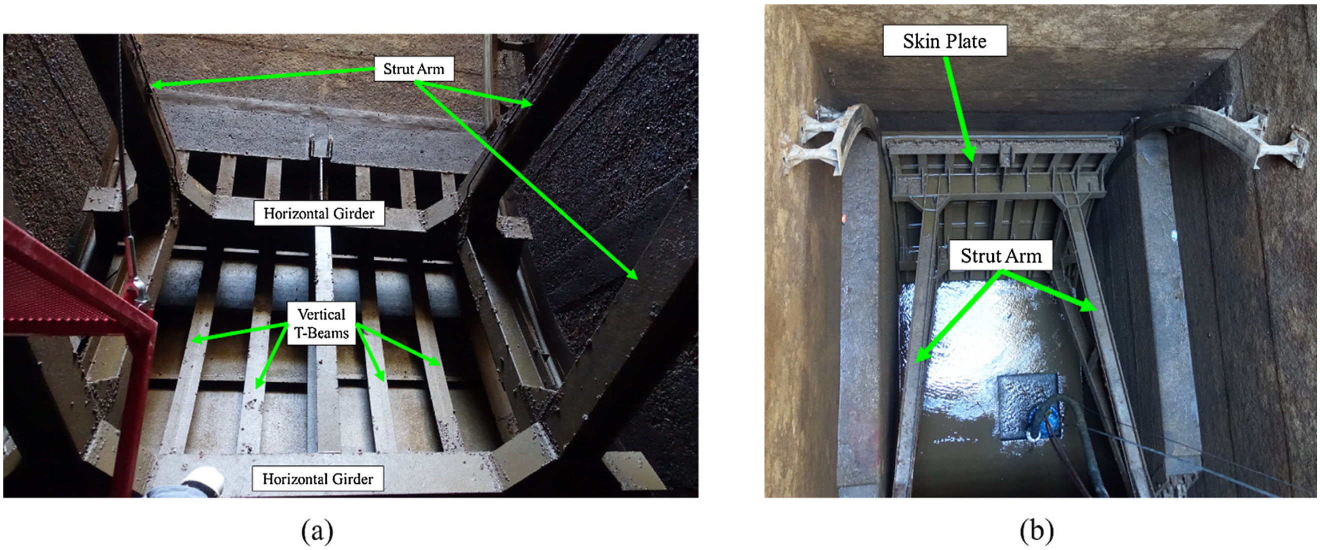

Fig. 1. Pickwick Lock and Dam Vertical Framed Tainter Valve: (a) Front view of the valve and (b) top view of the valve.

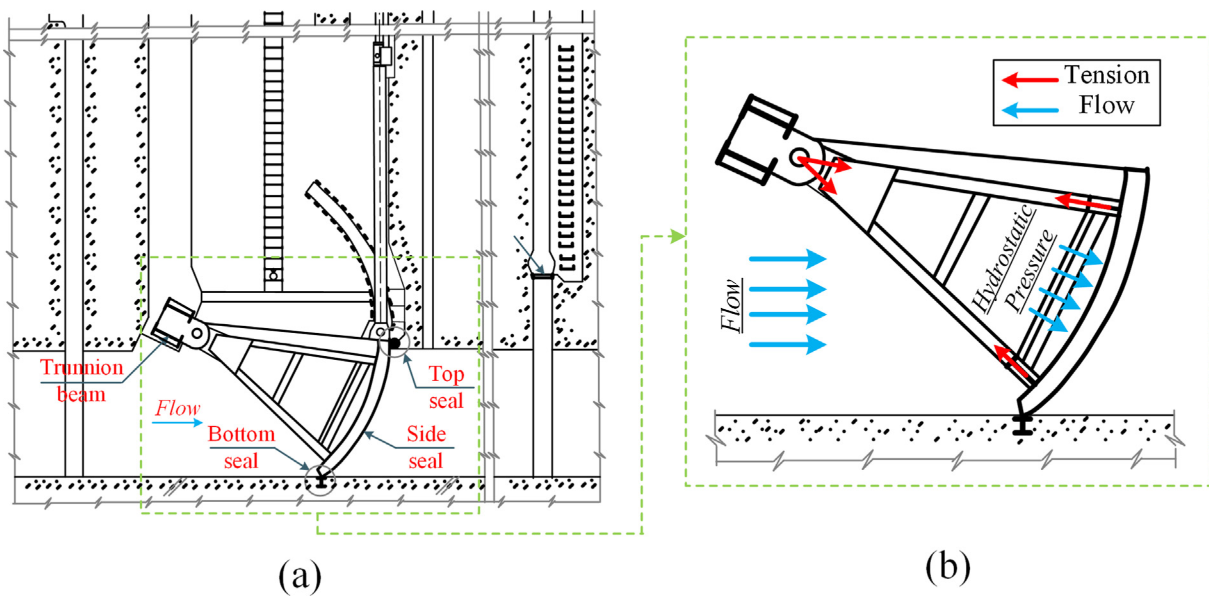

Fig. 2. (a) Side view of Tainter Valve operation and (b) free body diagram of Tainter Valve: after [51,52].

Fig. 3. Typical crack in the I-shaped strut arm (a) flange and (b) flange and web.