Construction and Building Materials 154 (2017) 1–9

Contents lists available at ScienceDirect

Construction and Building Materials

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

Experimental study on effectiveness of retrofitting via normal strength concrete filling on damaged circular steel tubes subjected to axial and horizontal loads

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HIGHLIGHTS

- A damaged steel tube is retrofitted by filling it with normal strength concrete.
- Concrete filling improves load-carrying capacity of a damaged steel tubes.
- The progression of local buckling deformation is suppressed by infilled concrete.
- Concrete filling is an effective retrofitting for a damaged steel tube.

ARTICLE INFO

Article history:
Received 22 July 2016
Received in revised form 22 July 2017
Accepted 23 July 2017
Available online 17 August 2017

Keywords:
Retrofitting
Steel tube
Concrete filling
Damage
Buckling

ABSTRACT

Following an idea derived from the concrete-filled steel tube (CFT), this research aims to enhance the structural responses of a damaged hollow steel tube by filling it with concrete. A series of experiments are conducted to investigate the effectiveness of this technique, simulating repair but more importantly retrofitting after the tube is damaged by accidental loads such as earthquakes. To this end, loading tests are performed on the modeled specimens. The level of damage induced on the steel tube by loading is one of the parameters investigated. Concrete filling is found to improve the load-carrying capacity as well as the stiffness and ductility of a damaged hollow steel tube even with severe local buckling. The load-carrying capacity of the retrofitted steel tube is more than 1.5 times that of a hollow steel tube and was 72–89% of that of a traditional concrete-filled steel tube calculated using the design codes presented by Japan Society of Civil Engineers. From these experimental results, concrete filling promises to be an effective means of enhancing the structural response of a damaged hollow steel tube.

1. Introduction

Following the experiences of the 2011 off the Pacific coast of Tohoku Earthquake, it has been strongly recognized that port facilities are vital for urgent restoration of disaster-affected areas [1]. This is because they can be used as a base for transportation of urgently needed materials and rescue activities.

In current designs for port facilities in Japan, performance-based design was introduced [2]. Safety, serviceability or restorability should satisfy the required performance level during the service life. Restorability is defined as the performance that the facilities can recover their required functions within a reasonable period of time by repairs in a range which is technically possible and economically appropriate. This requires engineers to quickly assess whether damaged steel members subjected to accidental loads satisfy the required performance specifications and judge whether repairs are necessary. When severe aftershocks are also a serious risk, retrofitting works may also be necessary. This illustrates the necessity of quick and easy repair and/or retrofitting of damaged steel members in order to limit the extent of possible damage. Methods for repair and/or retrofitting of some structural members damaged by seismic actions have been investigated [3–6]. However, there are few methods for the repair or retrofitting of damaged steel members, especially when such members are embedded in the ground.

Following the 2011 off the Pacific coast of Tohoku Earthquake, several steel piles serving as a coupled raking-pile anchorage for

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http://dx.doi.org/10.1016/j.conbuildmat.2017.07.173
0950-0618/

Nomenclature

N_y	axial load-carrying capacity
P_H	horizontal load
P_V	axial load
$P_{h\text{-}max}$	the maximum horizontal load
δ_H	horizontal displacement

a quay wall with steel sheet piles for a mooring facility critically failed. After being subjected to the mainshock (11/03/2011) and a considerable number of aftershocks, the amount of tilt for the coupled-pile anchorage was measured (Fig. 1, measurement was performed on 29/11/2012). It was found that the top of the coupled-pile anchorage was deformed by approximately 1 m toward the sea, starting at a depth of 12 m. After this measurement, the interiors of the steel tubes were observed through video camera monitoring. This observation clarified that the steel pile in compression at a depth of 12 m had been severely damaged by local buckling. The cause of this damage was attributed to large earth pressure due to lateral displacement of backfill. The use of a steel tube with a diameter–thickness ratio (D/t) of 100 also would have led to premature local buckling. For such damaged steel tubes, however, there was no method for repair or retrofitting. Consequently, additional steel tubes were driven in as part of restoration work in the years after the earthquake.

There are scant data available for the effectiveness of repair and retrofitting methods for damaged steel tubes. It is not practical to carry out restoration work from the exterior of a tube for damaged steel tubes embedded in the ground. However, one possible method is to fill the steel tube with concrete, an idea derived from concrete-filled steel tubes (CFT): the difference is with or without damage of the steel tubes. CFTs are widely used as structural members to ensure a higher load-carrying capacity and a higher ductility than a hollow steel tube [7–9]. Therefore, concrete filling might be a solution to the repair but more importantly retrofitting of damaged steel members.

In pioneering research, Suzuki et al. [10–12] reported on “repair” methods for locally buckled circular steel tubes and demonstrated their effectiveness for seismic resistance through cyclic loading tests. They concluded that the concrete filling method can potentially recover the load-carrying capacity and stiffness of a buckled tube. In their experiment, the applied load on a damaged steel tube was released during repair works. On the contrary, the damaged tubular steel pile was restrained by ground pressure even after the earthquake. It is thus important to investigate the effects of repair using concrete filling in such situations. In addition, retrofitting to enhance the structural response of steel tubes will be also important. However, the effects of retrofitting by filling normal strength concrete into a damaged steel tube are not yet clear.

On this basis, in this paper, experimental models are constructed to evaluate the structural response of a steel tube retrofitted using normal strength concrete filling at various damage levels. It should be noted that the balance of the structural members connected each other should be taken into account when retrofitting the damaged steel tube, in order to avoid the unexpected failure mode of the structure. Although the main objective of this study is to investigate the potential retrofitting ability of concrete filling for damaged steel tubes, this viewpoint should be discussed after establishing the retrofitting method using concrete filling.

2. Experimental details

2.1. Specimens and experimental setup

A total of six specimens, shown in Fig. 2, were tested in this study. The diameter and length of the steel tube were 600 mm and 2800 mm, respectively. The thickness of the steel tube was 6.0 mm. The diameter–thickness ratio (D/t) was set to be 100, so as to be the same as the actually damaged steel tube described earlier. It should be noted that the pile head of the raking-pile anchorage, at which the moment is the critical at this point, is of interest so that the pile head is partly modeled in this study. Therefore, the bottom end of the specimen was simply modeled as a pile head.

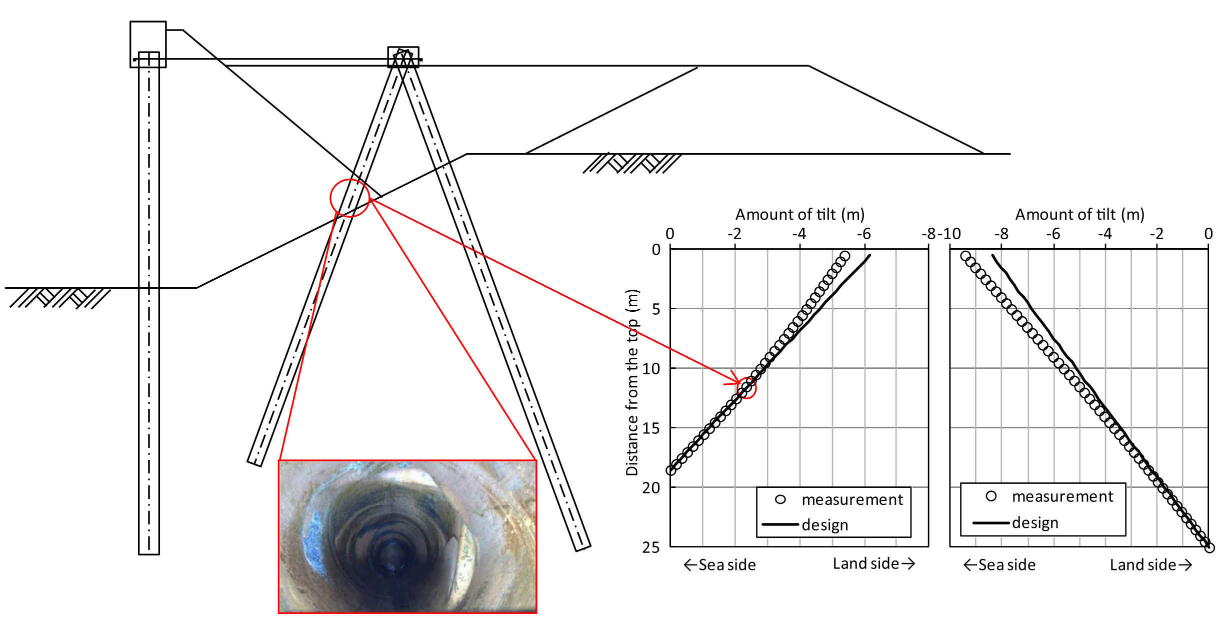

Fig. 1. Tilt of coupled-pile anchor measured after the 2011 off the Pacific coast of Tohoku Earthquake with comparison to designed one.