Ocean Engineering 125 (2016) 82–89

Contents lists available at ScienceDirect

Ocean Engineering

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

Lifting forces required to salvage a sunken vessel and caisson and their response to bottom friction, buoyancy release, surface tension, water capture and water release☆

Chan-Soo Lee[a], Han-Sam Yoon[b], Dongha Kim[c], Won-Bae Na[c,*]

[a] La Mer Solution, Busan 612-031, Republic of Korea
[b] Department of Ecological Engineering, Pukyong National University, Busan 48513, Republic of Korea
[c] Department of Ocean Engineering, Pukyong National University, Busan 48513, Republic of Korea

ARTICLE INFO

Article history:
Received 29 January 2016
Received in revised form
3 August 2016
Accepted 3 August 2016
Available online 10 August 2016

Keywords:
Lifting force
Salvage
Sunken caisson
Sunken vessel

ABSTRACT

Two field tests were carried out to measure the lifting forces required to salvage a sunken vessel and caisson, and force histories were obtained to assess their response to bottom friction (BF), surface tension (ST), buoyancy release (BR), water capture (WC) and water release (W*R*). The test results for the two fully sunken objects showed rather different force profiles. The effect of BF on the caisson, at 1.27 MN, is much larger than that (0.086 MN) on the vessel due to the greater weight of the caisson, whereas the effect indices are almost identical. During separation from the surface water, the vessel was affected by the WC within the vessel as well as by BR and ST. Once fully salvaged, the lifting force of the vessel gradually reduced to 0.71 MN from the maximum of 1.38 MN, owing to W*R*. The maximum lifting forces of the vessel and the caisson correspond to two and one times the initial lifting forces of 0.69 MN and 9.41 MN, respectively. It was found that the salvage process of the vessel resulted in a more complicated lifting force history than that of the caisson, primarily because the vessel structure allowed WC and release.

1. Introduction

Vessels are capsized or sunken following a loss of stability initiated by weather damage, collision, intentional flooding, man-made carelessness, or other causes (Bartholomew, 1992). A tragic accident that occurred in South Korea – the sinking of the MV Sewol in April 2014 – is illustrative; the accident rescue operations took over 3 months and resulted in the death of 304 passengers. The sinking of the MV Sewol occurred due to human error. Once it was known that bodies were trapped in the sinking vessel, salvage of the vessel was necessary. Unfortunately, initial trials for the salvage of the MV Sewol failed.

Although it is technically possible to recover vessels from great depths, the cost is usually prohibitive. The difficulty and cost of salvage are critically dependent on depth. Accordingly, the salvage of sunken ships or other large objects whose decks or tops are submersed in over 30 m of water is considered uneconomical, although justification can be made for valuable or sensitive cargo (Bartholomew, 1992). Recently, removal of wrecked ships by the relevant coastal authority has increased, especially where the wreck presents a hazard to shipping, or the cargo or fuel threatens to damage the environment (Ellis, 1988; Herbert, 2013; Henkel et al., 2014). Significant environmental impacts have previously been experienced following major historical accidents (Rogowska et al., 2010), such as the sinking of the nuclear submarine Komsomolets (Høibråten et al., 1997), and with respect to World War II, shipwrecks in the Pacific and East Asia (Monfils, et al., 2006).

Unlike the salvage of stranded vessels (Nguyen et al., 2011), salvage of sunken vessels is not time-critical. Unless severe storms develop, a sunken vessel is unlikely to deteriorate in deep water because disturbing surface water conditions are absent. As such, salvage efforts can occur in a timely manner. However, a vessel or large object partially sunk or exposed on the coast should be treated as vessel stranding, in which the condition of the casualty will deteriorate over time. On this basis, the fact that the rescue operation for the fully sunk MV Sewol took more than 3 months can be defended, despite the negative social and political reaction within South Korea and the criticism directed toward the captain, most of the crew, the ferry operator and regulators, the government, and the media (who downplayed government culpability) (The New York Times, 2014). A review of representative cases suggests that human factors are the root cause of more than 75% of vessel casualties and therefore many wrecks (King, 1995;

☆The English in this document has been checked by at least two professional editors, both native speakers of English. For a certificate, please see: http://www.textcheck.com/certificate/hl4pCD.

* Corresponding author.
E-mail addresses: wna@pknu.ac.kr, arizcat@gmail.com (W.-B. Na).

http://dx.doi.org/10.1016/j.oceaneng.2016.08.008
0029-8018/

Rothblum, 2000). Human factors include fatigue, poor communication, lack of technical knowledge, inadequate knowledge of a ship's systems, poor ship handling, and poor maintenance.

Process-based models for wreck site formation were introduced by Harpster, (2009), Muckelroy, (1978) and Ward et al. (1999). They presented flowcharts showing the evolution of a wreck, highlighting the main processes that affect wreck disintegration, caused by the wreck itself and the sedimentary and hydrodynamic environment. However, these approaches were based on maritime archeology; hence, the engineering details of salvage operations were limited. An overall conception of salvage engineering is required because all marine salvage work is a combination of seamanship and engineering (Bartholomew, 1992; Gray, 2013; Shi et al., 2014). Typically, the salvage engineer has four principal tasks: predicting the behavior of sunken and capsized vessels based on the principles of buoyancy and stability; determining the required lifting and/or righting forces; assessing the effects of environmental forces with respect to causality and salvage systems; and devising methods of applying force to right or lift the casualty in a controlled manner (Bartholomew, 1992; US Navy, 2013; Domeh et al., 2015).

When using one or multiple methods for marine salvage, it is necessary to determine the required lifting and/or righting forces. This determination should be based on the geometry of the sunken ship, as well as the seabed conditions, flow pattern, water depth, and other factors as necessary.

External lifting methods used in salvage can be categorized into buoyant lifts, tidal lifts, and mechanical lifts. Among them, mechanical lifting operations are independent of the tide or any form of induced buoyancy for obtaining their lifting forces. In facilitating mechanical lifts, the salvage units apply their lifting power to a sunken ship by heaving on wire ropes rigged around and underneath the sunken ship. Lifting capacity is obtained from vertical lift tackles rigged from A-frames, cranes or sheer legs, or from horizontal tackles rigged on deck (Tikhonov et al., 1997; US Navy, 2013). Typical combination lifts on partially or completely sunken ships are available in the US Navy Ship Salvage Manual, Volume 1 (2013).

Recent research relating to lifting analysis has focused on lifting operations in shipyards using multi-cranes (Ku and Ha, 2014), elastic boom effects on heavy lifting operations (Park et al., 2011), and lifting operations of a monopole for an offshore wind turbine (Li et al., 2014). However, these studies do not relate to the salvage of a sunken vessel but are concerned with lifting operations in a shipyard or offshore wind turbine installation. The US Navy Ship Salvage Manual, Volume 1 (2013) is the only document with relevant, detailed content; it is difficult to find any research on the variation in lifting forces over time during salvage of a sunken vessel or large object. Therefore, it is necessary to investigate the variation of forces over time, because this will provide insight into the effects of bottom friction (BF), surface tension (ST), buoyancy release (BR), and water capture (WC) operating on a vessel or large object during the salvage process.

This study presents the lifting forces applied during the salvage of a sunken vessel – and the responses – described according to the effects of BF, ST, BR, and WC. To pinpoint how the lifting force changes over the period of the salvage, a heavy concrete caisson was also considered as another target object. For the experiments, a 0.59 MN (60-ton) vessel and a 9.32 MN (950-ton) concrete caisson were submersed into water to investigate how the lifting forces vary with respect to BF. The effects of ST, BR and WC on the lifting forces during the field tests were also investigated.

The conditions of the study are presented here. First, during the field tests, the vessels and concrete caissons were wrecked using cranes; hence, launching and sinking were simulated and the salvage started after the objects had reached the bottom of the water body. The stability of the vessel and the caisson was ensured before the tests began; hence, the only concerns were recording the lifting forces and analyzing the environmental effects during the experiments. Second, prior to the tests, all fuels, chemicals, and waste products were removed; during the field tests, no hazardous materials were detected from the vessel or caisson. Third, during the tests (sites A and B), the water conditions were similar, with gentle wave heights ($H_s < 0.5$ m) and wind speeds ($s_m < 7$ m/s).

2. Materials and methods

A vessel (tug boat) of 0.59 MN (60-ton) and a caisson of 9.32 MN (950-ton) were tested in the field, as shown in Table 1 and Fig. 1. The test site (hereafter site A) of the vessel was near Narayangaj River, Bangladesh, with the coordinates N 23°34′49.97″ E 90°31′01.05″. The test site (hereafter site B) of the caisson was near Hanul nuclear power plant, South Korea, with the coordinates N 37°05′06.95″ E 129°23′45.26″. The water depths of the target sites were measured as approximately 20 m, and the currents were measured as approximately 0.51 m s − 1 (1 knot), indicating that the two sites had similar marine environmental conditions during the tests (Lee, 2014). The seabed composition was fine sand (sediment grain size d_{50}=0.25–0.125 mm) at site A and very fine sand (d_{50}=0.125–0.062 mm) at site B. These conditions were also reported by Hossain et al. (2014) and Kim et al. (2005). Owing to the similar composition, the seabed condition can be considered to have a minor effect on the BFs.

The total weight applied to the crane, including the vessel, capstone, bit, wire, chain, and hook, was 0.69 MN (70.6-ton) at site A; the total weight applied to the crane was 9.41 MN (960-ton) at site B, accounting for the weight of the caisson, wire, chain, and hook. The lifting capacity of the crane was 21.57 MN (2200-ton). In the field, the structures were launched from the barge from stationary, which allowed for free fall conditions. Once they had reached the sea floor, the salvage process commenced.

3. Test results

3.1. Lifting forces of the vessel

Fig. 2 shows the lifting forces measured during the sinking and salvage of the vessel. In Fig. 3, there are nine lifting forces (R1–R9), as recorded during the test process. At the initial stage, when the vessel was launched from the barge, a lifting force of 0.69 MN (70.6-ton) was measured (R1). The lifting force decreased rapidly during the sinking, and reached zero when the vessel stood on the sea floor and was fully sunk (R2). At R2, salvage was started; the lifting forces were applied, but the vessel remained on the sea floor because the forces did not overcome its weight and BF. Once the lifting force reached R3 (0.59 MN or 60.3-ton), the vessel started to rise, BF was released (A =0.086 MN [8.8-ton]; Fig. 2), and a constant lifting force (0.51 MN [51.5-ton]) was recorded as R4. As the vessel became partially exposed over the sea surface,

Table 1
Vessel, caisson, and crane specifications used in the field test.

Identity	Specification
Vessel	0.59 MN or 60-ton (38 m × 8.0 m × 2.5 m)
Capstone, Bit	0.049 MN or 5.0-ton
Wire, Chain, Hook	0.055 MN or 5.6-ton
Concrete caisson	9.32MN or 950-ton (7.7 m × 14.1 m × 10.0 m)
Wire, Chain, Hook	0.098MN or 10.0-ton
Crane	21.57MN or 2200-ton (110 m × 48 m × 7.5 m)