Applied Ocean Research 69 (2017) 38–52

Contents lists available at ScienceDirect

Applied Ocean Research

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

Experimental studies on performances of flexible floating oil booms in coupled wave-current flow

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ARTICLE INFO

Article history:
Received 19 February 2017
Received in revised form 5 July 2017
Accepted 6 October 2017

Keywords:
Flexible floating oil boom
Hydrodynamic performance
Boom effectiveness

ABSTRACT

Floating oil booms are commonly-adopted facility to collect spilled oil on sea surface, or to protect specific areas against oil slick spreading. In this study, 931 runs of laboratory test were carried out under wave-current coupling conditions to investigate hydrodynamic performances of the flexible floating oil boom. The tests first conducted a comparison on motion responses between the flexible floating boom and the rigid one to indicate the necessity of taking the flexibility of boom into consideration. Then a comprehensive analysis was carried out to investigate the effects of the ambient currents, waves and the boom characteristics of material stiffness, diameter of floater, length of skirt, and *B*/*W* (Buoyancy/Weight) ratio on the motion responses of the flexible floating booms. Finally, by taking the water blockage effect in front of the boom into consideration in the definition of boom effectiveness, the effective draft and freeboard were compared between the flexible boom and rigid one under fixed current and wave conditions. The effects of currents, waves, skirt lengths and *B*/*W* ratios on the effective draft and effective freeboard are assessed.

1. Introduction

Floating oil boom is widely used in collecting spilled oil and preventing oil from spreading [1]. Its performances and ability of retaining oil depend not only on the external dynamic environment, e.g. the ambient currents, waves or combination, but also on the characteristics of the floating boom itself, e.g. the floater diameter, the skirt length and the buoyancy/counterweight (*B*/*W*) ratio [2]. Failure modes of oil containment, such as splash-over, submergence and overturning [3,4] are directly related with the motion responses of the floating oil boom, whereas the drainage [5–8], entrainment [9] and critical accumulation [10,11], on the other hand, are indirectly affected by its motion responses.

Despite the importance of the hydrodynamic performances of floating boom, documented research work on boom behaviors is relatively insufficient. Milgram [12] found, through theoretical analysis, that the seakeeping properties of a floating oil boom are closely related to the relative difference between the wave frequency and the inherent oscillating frequency of the oil boom in fluid. He emphasized the importance of making the boom lighter and believed that a boom with sufficient frequency difference with waves could avoid resonance. He also believed that such designed floating boom could sensitively follow up with the free surface oscillation and hence could well retain the effective freeboard. Kim et al. [2], on the other hand, investigated the seakeeping performance of a floating boom through large number of flume experiments using movable rigid floating booms but only with roll and sway in their experiments. His conclusion was that a boom of smaller *B*/*W* ratio (heavier) was more effective against the waves with longer period regardless of current velocity, whereas was incapable in resisting over-splashing under shorter waves. Castro et al. [14] conducted flume tests using movable but rigid floating booms with three degrees of freedom under wave and current conditions. They found through experiment that the influence of the initial draft on boom's efficiency was far more complex than imagined due to some unrevealed or even counterintuitive facts behind the phenomena, e.g. booms with longer skirt length could be, under certain conditions, less efficient against drainage failure than with shorter one. Moreover, Lee and Kang [4] showed that the influence of current on the performances of oil boom was closely related with the ratio of dynamic pressure exerting on the front surface of the oil boom and the counterweight. Fu et al. [13] showed that overtopping might also have considerable influences on the hydrodynamics of floating cylinder in oscillatory and steady flows. Shi et al. [15] simulated the motion of a rigid floating oil boom by using a mesh-frame N-S equation solver and found that heavier boom had good per-

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https://doi.org/10.1016/j.apor.2017.10.001
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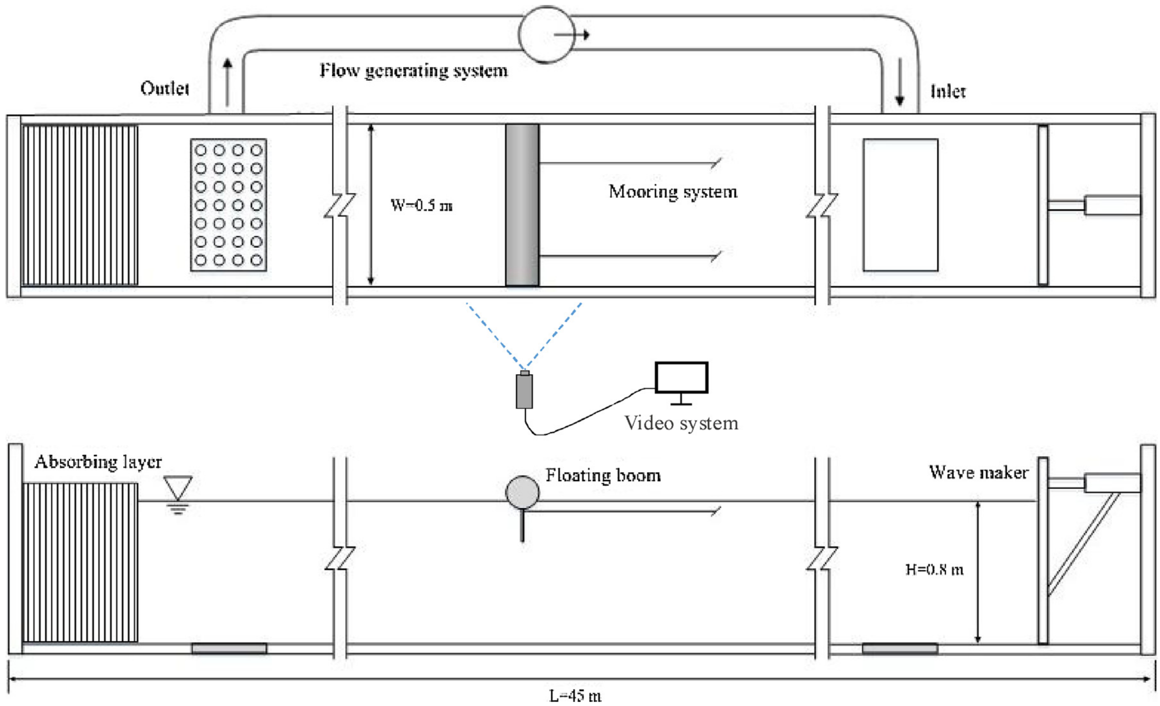

Fig. 1. Sketch of experimental setup. Top: plan view; Bottom: side view.

formance in resisting waves and currents since it was apt to gain a larger effective draft, and also found that the effective draft was significantly affected by both the skirt length and the floater diameter, whereas the freeboard was affected only by the skirt length.

The situation could be more complex than having been revealed because the coupling effect of the boom deflection and motion has not yet been addressed simultaneously up till now. Actually, most booms used in site spilled oil recovery are longitudinally and vertically flexible, and have flexible floater-skirt joint as well. Through numerical simulation, Amini and Mahzari [16] have indicated that the flexibility of skirt can significantly influence the ability of oil containment due to changes of water pressure exerting on the surface of the boom skirt. Amini and Schleiss [17] further indicated through series of flume tests that motion responses of flexible booms would become more sensitive to the presence of waves than a rigid one because of skirt deflecting. Although flexible boom was adopted in their tests, only roll responses of floating boom were considered. Such limitation on the heave and sway movement of the floating boom undoubtedly reduces the practical value of their results.

The present paper will present comprehensive understandings on the relations between motion responses of various boom models and various combination of material stiffness, floater diameter, skirt length and B/W ratio through a series of experiment tests. The experiments not only take heave, sway and roll motions of the floating boom into consideration, but also are conducted under different wave-current coupling conditions. Based on the analysis and understandings on the effectiveness of the floating boom, guidelines for optimization of the boom performances are also yielded.

2. Experiment setup

The experiments were carried out in a wave-current flume of Tianjin Research Institute for Water Transport Engineering (TIWTE), Ministry of Transportation of China. The flume was 45 m long and 0.5 m wide. A piston-type wave maker was installed at the right-hand end of the flume and a wave absorber was mounted at the opposite end (Fig. 1). A pump was employed to generate a steady current through a circulation system. In the experiment, a floating boom that consisted of a cylindrical floater, a skirt and a balance weight (Fig. 2) was placed in the middle of the flume and was restrained by two horizontal parallel plastic mooring lines, which were attached to the floater-skirt joint. The floating boom was permitted to move with three degrees of freedom, namely heave, sway and roll.

A video system (Model DS-2CD3T45D-I5 from HIKVISION, Inc.) with resolution of 2048 × 1536 pixels and frame rate of 25fps was employed to capture the real-time digital images for monitoring the motion of the floating boom and the water surface of the ambient flow. The camera was fixed on one side of the flume at about 6.0 m away from the flume sidewall with its mounting height being aligned with the water level. The camera was forced to focus on the floater-centered square area sized by 0.9 m × 0.9 m. Its optical axis was adjusted to be aiming at the boom floater centroid with a normal angle to reduce the optical distortion and the refraction of the lens. A mackintosh with length of 10 cm, was stuck on the inner side of the tank wall to serve as a fixed length reference object. For the rigid boom, monitoring was performed only at point P_1 and P_2 on the floater (Fig. 3), whereas for a flexible one, as the floater and the skirt in certain extent move separately, the positions of the floater-skirt joint and the bottom tip of the skirt, denoted respectively by P_3 and P_4 in Fig. 3, were also monitored at the same time. The monitored series of images were then processed by the lens correction filter of Adobe PhotoShop to further reduce the collateral effect. The optical refraction effect of the glass wall is neglected because the glass is thin. The time sequences of pixel information for the monitored points was then obtained using a post-processing algorithm based on the monitored images. The pixel information was subsequently transferred to real position coordinates via the fixed length reference object.

Green cellophane was glued on the inner side of the opposite lateral glass wall of the flume to enhance the contrast vision effect of the air-water interface and to reduce the light reflection from the sidewall of flume. For given resolution of the camera, one pixel