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Synergies Between VLFS Hydroelasticity and Sea Ice Research

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A conspicuous overlap exists between publications that describe how sea ice responds to an ocean wave field and those that relate to a very large floating structure (VLFS) experiencing comparable forcing. Contemporary hydroelastic theory has been developed concurrently yet independently despite the similarity of the topics being studied and the methods being applied. While sea ice is a natural heterogeneous material that shows variability on all spatial scales, e.g. it may contain cracks, open and refrozen leads, pressure ridges, or gradual or abrupt changes of thickness or property, VLFS can also be nonuniform—particularly when they are manufactured from several interconnected parts with differing material moduli or shapes. In this work the basic mathematical theory and physics are developed that characterize hydroelasticity, drawing from both corpora and calling attention to connexions and interpretations that could benefit both spheres of research. Particular attention is given to explaining apparently unrelated analyses where an underlying relationship exists that is not necessarily plainly evident.

INTRODUCTION

Jules Verne, the 19th century French novelist and one of the fathers of science fiction, wrote in 1895 what is probably the first account of a VLFS (very large floating structure) in his book *L'île à hélice* (Verne, 1896—front cover shown in Fig. 1). There Verne describes how a French string quartet is diverted to Standard Island while travelling from San Francisco to San Diego. Standard Island is an immense artificial island designed to travel the waters of the Pacific Ocean that is eventually annihilated by the forces of nature in the zone of the tornadoes. I leave it to the reader to pursue all the gory details. In 1927, Edward Robert Armstrong (1876–1955), a Canadian-born engineer and inventor, proposed a project to establish floating islands in the open ocean at conveniently spaced intervals. Aeroplanes would land and refuel at these "seadromes" (Armstrong, 1927) during transatlantic flights. The last time he made the proposal was in 1943 during World War II, but by that time long-range aircraft had already been designed for the war effort and aircraft carriers were in use. Almost contemporaneously, at the height of World War II in Canada, an ambitious plan to build a VLFS from ice was proposed to Winston Churchill by Lord Mountbatten and the overtly eccentric scientist Geoffrey Pyke. Initially known as Project Habbakuk, after an Admiralty clerk's misspelling of the biblical name Habakkuk that was corrected later, the British proposed to construct a 2000 × 300 × 200-foot aircraft carrier with 40-ft-thick walls and a displacement of 2 million tons or more from 280,000 blocks of ice. This was to be used against German U-boats in the mid-Atlantic. The building material was changed subsequently to a mixture of ice and approximately 14% sawdust (or, less frequently, wood pulp) known as pykrete, which was later studied by the Nobel Laureate Max Ferdinand Perutz (Perutz, 1948). A 1:50 scale model was actually constructed in Patricia Lake, Alberta, which engineers managed to keep frozen during the entire summer of 1943. Because of its enormous cost, Project Habakkuk was eventually scrapped. It is ironic, given the historical concert of glaciology and engineering that underpinned this ludicrous scheme, that I now find myself presenting a paper about floating bodies that aspires to reconcile 2 constituents of hydroelastic thinking that have disaffiliated. (Hydroelastic describes the branch of science concerned with the motion and distortion of deformable bodies responding to environmental excitations in the sea—Chen et al., 2006.)

Immense theoretical progress made in the last decade or so has considerably advanced our understanding of how floating compliant sheets and plates are affected by ocean wave activity. To some degree this has been inspired by the current debate on global climate change, which has recognized that ocean wave trains are destined to become more severe more frequently and will therefore carry a far greater destructive payload as they engage with less compact fields of pack ice that have already been weakened by elevated temperatures. The review of Squire et al. (1995) was recently updated to take account of this extraordinary surge of activity on topics in the general area of ocean wave/sea ice interactions, especially in relation to modelling and the application of a powerful new set of mathematical techniques to this important geophysical theme. (See Squire, 2007, and papers cited there.) Invariably adopting a so-called direct approach (Eatock Taylor, 2003), models have become a good deal more sophisticated, with the most recent ones allowing the sea ice to be heterogeneous and have nonzero draft and the ocean to have variable depth. Pressure ridges, cracks, open and refrozen leads, and gradual or abrupt changes of material property can all be accommodated, and inhomogeneous marginal ice zones can also be modelled effectively.

In reviewing this corpus of work it became clear to me that there was a strong synergy between the Arctic and Antarctic marine geophysics being reported and a complementary library in the offshore engineering literature concerned with hydroelasticity. (See Andrianov, 2005; Andrianov and Hermans, 2003a,b, 2004, 2005a,b, 2006; Banichuk et al., 2002; Bishop and Price, 1979; Bishop et al., 1986; Chen et al., 2003, 2006a,b; Eatock Taylor, 2003, 2007; Eatock Taylor and Ohkusu, 2000; Hermans, 2000, 2001, 2003a,b, 2007; Kashiwagi, 1998; Khabakhpasheva, 2003; Khabakhpasheva and Korobkin, 2002a,b; Kim and Ertekin, 1998; Korobkin and Khabakhpasheva, 2007; Kyoung et al., 2005; Maeda et al., 2001; Murai et al., 1999; Newman, 1994; Ohkusu and Namba, 2004; Ohmatsu, 2005; Takagi and Nagayasu, 2007;

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