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Research
Marine Structures—Perspective

Marine Structures: Future Trends and the Role of Universities

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ABSTRACT This paper emphasizes some of the challenges and trends associated with the future development of marine structures. Its main focus is on ways to improve the efficiency of energy-consuming ships, and on design challenges related to energy-producing offshore structures. This paper also discusses the analysis tools that are most needed to enable sustainable designs for future ships and offshore structures. The last section of the paper contains thoughts on the role of universities in education, research, and innovation regarding marine structures. It discusses curriculum requirements for maritime-technology education, basic research activities, and international cooperation.

KEYWORDS marine structures, ships, offshore structures, curriculum, research activities

1 Introduction

Seventy percent of the surface of planet Earth is water, with a mean depth of 3800 m. The oceans are of immense importance in maintaining a reasonable standard of living for an ever-increasing global population, for these reasons:

- The oceans are enormously important in the global exchange of goods; current global trade could not take place without the use of oceans as a transportation medium.
- The oceans and the ocean floors contain large reservoirs of raw materials such as hydrocarbons.
- The oceans have a large potential for exploration and for the future cultivation of living resources in the form of fish and plankton.
- The oceans receive 70% of our primary sustainable energy source: radiation from the sun. This energy can be harvested in the form of thermal gradients, wind, current or wave energy, salt gradients, and so on.

Marine structures are necessary in order to exploit these possibilities. Since marine structures such as ships and offshore structures are massive, capital-intensive, and complicated structures placed in a special unfriendly environment, their design and development require research and skilled engineers. For any country wishing to participate in industrial development within this area, therefore, education and university research are essential.

2 Ship structures

Without commercial shipping, the rapid development in the global standard of living over the past 50 years would not have occurred. Over the last 200 years, ships have been by far the largest and most complex mobile structures built by humankind. In the period between 1800 and 1900, ship structures underwent a revolution. The main driver for this development was a technology push: Building materials changed from wood to iron, and then to steel; power sources changed from sail to steam, and thereafter to diesel engines; and propulsion means changed from paddlewheels to propellers. As a result, in 1912 the first ocean-going diesel motor ship, *MS Selandia*, was put into service between Asia and Europe. This ship possessed most of the main characteristics of a modern ship (Figure 1).

Since *MS Selandia*, ship development has evolved from empirical building rules to design by first principles. Continued optimization occurs, as the size and main dimensions of a ship are determined by

Figure 1. *MS Selandia*. The first ocean-going diesel motor ship, carrying 6800 DWT, built by B&W in 1912 and assigned to the EAC. (http://selandia100.dk/diesel-2, 12 February 2015)

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its mission. In addition to the basic functional considerations that are influenced by cargoes and routes, requirements include low resistance, high propulsive efficiency, stability, and navigational limitations on draft and beam, all of which influence the choice of dimensions and layout. This continued optimization has led to the development of highly optimized structures. For example, the mass of the hull plus machinery of a modern tanker or bulk carrier is now less than 15% of the mass of the carried deadweight.

Today, about 90% of the world trade in raw materials and finished goods are transported by ship. The resulting CO_2 emissions are approximately 4% of the global total. As a result, the main driver for current development in ship structures is a society pull. Public focus is primarily on the reduction of emissions per transported unit, and on shipping accidents. This focus has resulted in more severe international [1] and regional requirements, and has caused non-environmentally friendly ships and operations to be punished by port and coastal states. In addition, the public has increased expectations for green supply chains.

The response from the shipping industry has been to improve efficiency. Although large two-stroke diesel engines have a very high thermal efficiency (around 50%), it is still possible to gain further fuel efficiency. One possibility is to install a waste-heat recovery system that utilizes exhaust heat to generate power for a shaft generator.

Research on propellers has led to new optimized propeller shapes, devices for recovering rotational losses from the propeller stream, and improvements in the water flow to the propeller. Researchers are also using computational fluid dynamics (CFD) to explore alternatives to propeller propulsion, such as fin propulsion.

By using CFD in combination with model-tank testing, researchers have made progress in hull-shape optimization, resulting in reduced calm-water propulsion resistance.

However, what really matters is size and speed. As shown in Figure 2, energy efficiency, and thereby emission reduction ($g\ CO_2 \cdot (t \cdot mile)^{-1}$), strongly improves with speed reduction as well as with vessel size. The capital cost and the manning cost per deadweight ton are also strongly reduced with larger vessel sizes.

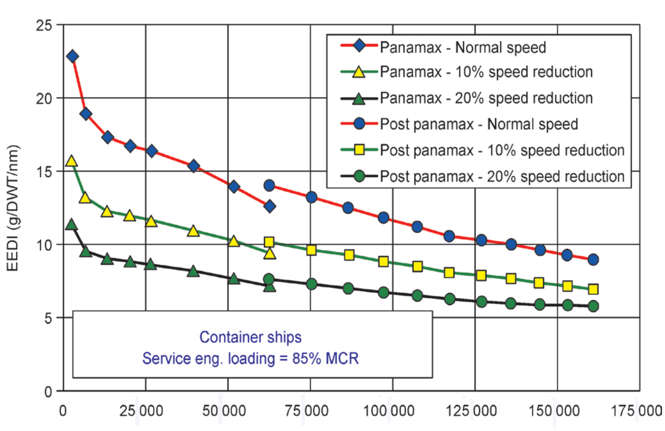

Figure 2. EEDI (energy-efficiency design index) in g $CO_2 \cdot (t \cdot mile)^{-1}$ as a function of size for different speeds [2].

These benefits have been major drivers in a development towards larger and larger ships. Container ships are a good example of this development. The first specially designed container ship was put into use in 1960, and could carry 610 TEU (twenty-foot equivalent units). In 1988, as the size of containerships increased to about 4500 TEU, it became necessary to design vessels that exceeded the existing maximum breadth (Panamax) of the Panama Canal.

Figure 3. The *Triple E*. An example of the new generation of large containerships; it is 400 m long and 59 m wide, has a speed of 19 kn and carries 165 000 DWT. (http://www.maersk.com/en/search?q=Tripple%20e&t=images, 12 February 2015)

This development has continued exponentially, so that the new generation of large containerships, which have scantling deadweights of about 195 000 DWT and relatively low speed, can carry around 20 000 twenty-foot containers (Figure 3). Use of these ships has resulted in a 50% reduction in CO_2 per transported unit, compared to the industry average for Asia-Europe trade.

2.1 Research needed for ship structures

The drive towards larger ships has not stopped. However, the structural design of such large vessels poses a number of technical challenges. The increase in size has been so rapid that there has been no feedback from service experience. That is, these ultra-large steel structures have to be designed by direct calculations. They have large bow flare and therefore highly non-linear wave-induced loading. When ships increase in size, and if materials with higher strength are used, hull flexibility plays an important role in the response of the vessel. For ultra-large container ships, the lowest hull-girder natural frequencies are as low as 0.40 Hz (or 2.5 s in natural period). The hull-girder vibration natural frequencies become so small for these ships that in order to calculate the wave-induced loads, it is not sufficient to consider the ship hull as a rigid body (Figure 4). Slamming-induced *whipping vibrations* of the hull girder determine the maximum hull-girder loads, and therefore the ultimate limit state. Full-scale measurements show that the higher frequency whipping stresses can be as large as the direct wave-frequency part of the stresses in high sea-states, as shown in Figure 5.

Another serious wave-induced effect on the fatigue strength of flexible ship hulls is *springing*, that is, a continuous excitation of the lowest hull-girder natural frequencies, due to the high-frequency components in the wave spectrum