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Time domain analysis of a coupled system with trawler and trawl gear using a numerical method

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Introduction

Trawling is one of the most important methods used in the fishing industry. While towing a large trawl gear, the trawler is subjected to changes in course, speed, and wave action, and its mobility is restricted. In addition, the gear towed by a trawler undergoes changes in shape and behavior according to the behavior of the trawler, especially in cases when the trawl is operated under harsh sea conditions. However, no previous study has yet carried out a time domain analysis of a coupled system composed of a trawler and its gear, even though fishing vessels and fishing gear separately have each been the subject of much research [1-3].

This study presents an interaction model using a coupled system comprising both the vessel and the gear to reflect the influence of oceanic factors such as currents and waves. The model can be analyzed in a time domain. This allows the mutual interference between the stern of the trawler and the trawl doors to be analyzed, taking into account the amplitude of vertical oscillations under different conditions of wave height, wave length, and wave periods. The results will help understand the behavior of fishing gear from the point of view of gear handling and the safety of the vessel.

Materials and methods

The trawler and trawl gear

The selected trawlers simulated in this study were a 139-ton class offshore large trawler (L: 42.63 m, B: 7.15 m, T: 3.604 m, D: 3.536 m) and a 2,000-ton class deep-sea trawler (L: 84.5 m, B: 12.8 m, T: 8.15 m, D: 4.684 m). Both kinds of trawlers were divided into sections for modeling as shown in Fig. 1. The specifications for the selected representative trawl gear are described in Table 1.

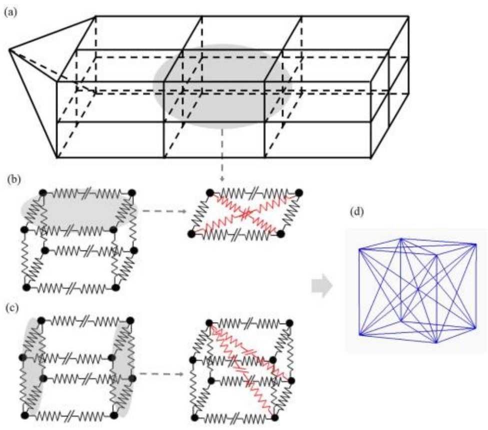

Fig. 1. Modeling a trawler with a mass-spring model: (**a**) the trawler, (**b**) mass point connections within the same plane, (**c**) mass point connections to another plane, (**d**) one modeled section.

Table 1. Specifications for the selected gear

Item	Offshore large trawl	Deep-sea trawl
Warp (m)	250	500
Sweep line (m)	100	94/47
Upper bridle (m)	100	97
Lower bridle (m)	105	103
Float line (m)	91.55	76.4
Ground rope (m)	91.55	76.4
Front weight (kg)	350	1,000
Buoyancy (kgf)	570	800
Sinking force (kgf)	460	320
Area of trawl door (m^2)	5.21	9.16
Weight of trawl door in water (kg)	1,170	2,654

A mathematical model for a coupled system

A trawl system is constructed as a coupled system, with the fishing vessel as an elastic structure and the fishing gear as a flexible structure. In general, theoretical models consider the system to be a physical system in which each structural element is divided into a finite number of mass points connected by flexible lines. The elements of such a structure can be modeled using a mass-spring model [4-7]. In this study, the trawler and trawl gear had 37 and 167 mass points, respectively.

Calculation methods

After substituting the internal and external forces into the model, the governing equation was transformed into a non-linear, second-order differential equation in the time domain.

Wave conditions

The numerical simulations were carried out using various wave conditions. In each case, the direction of the wave was heading towards the bow of the trawler. Three different wave conditions were applied to the offshore large trawl system and two to the deep-sea trawl system. The detailed wave conditions are described in Table 2.

Table 2. Wave conditions

Type	Case	Wave condition		
		Height (m)	Length (m)	Period (sec)
Offshore large trawl	1	2	250	10
	2	3		
	3	4		
Deep-sea trawl	1	4		
	2	6		

Results and discussion

Mutual interference between the trawler and the gear

The amplitudes of vertical oscillations of the stern of the trawler and the trawl doors were analyzed under the different wave conditions of Table 2 to investigate mutual interference within the coupled system.

For the offshore large trawl system under the different wave conditions, the amplitudes ranged from 4.13 to 5.85 m at the stern of the trawler and from 3.87 to 5.56 m at the trawl doors. The difference between the amplitude at the stern of trawler and at the trawl doors ranged from 5 to 7.3%.

In the case of the deep-sea trawl system, the amplitudes of vertical oscillations ranged from 4.75 to 5.72 m at the stern of the trawler and from 4.16 to 5 m at the trawl doors, for a difference of 12.4 to 12.6% as shown in Table 3.

In the cases where the same wave condition was simulated on both systems, the amplitudes of the vertical oscillations of the offshore large trawl system were higher at the stern and trawl doors than the corresponding amplitudes of the deep-sea trawl system. This can be attributed to the different sizes of the trawlers.

Table 3. Mutual interference between the stern of the trawler and the trawl doors

Type	Case	Amplitude of vertical oscillations (m)		Difference (%)
		The stern of trawler	Trawl doors	
Offshore large trawl	1	4.13	3.87	6.3
	2	5.24	4.86	7.3
	3	5.85	5.56	5
Deep-sea trawl	1	4.75	4.16	12.4
	2	5.72	5.00	12.6

Tension on the warp

In addition, the tension on the warp was analyzed for both the 139-ton class trawl system and the 2,000-ton class trawl system.

The tension on the warp varied periodically from 5,835 to 10,215 kgf for the 139-ton case and from 11,241 to 20,036 kgf for the 2,000-ton case. The tension for the 2,000-ton case was higher than that of the 139-ton case because the heavier mass of the deep-sea trawl system generated a much higher inertial force than the offshore large trawl system.

Conclusions

We modeled a coupled system consisting of a trawler and trawl gear using a numerical method in the time domain. Furthermore, we investigated the mutual interference between the stern of the trawler and the trawl doors by analyzing the vertical oscillations and the tension on the warp. The results of this study can contribute towards better gear-handling efficiency and vessel safety.

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