Chapter 6

Calculating the response of a ship

How does a ship react to the continuously wave action? MARIN asked the study group to find a way to calculate the response from the ship from a bulk of measurements. They found a solution, but was it more clever than what MARIN was doing?

Maritime Research Institute Netherlands (MARIN) is a familiar face around the study group. The previous years they brought problems about extreme rolling of vessels in head waves, thruster allocation and maneuvering behavior of ships. Naturally, their 2012 question was also about ships: this time floating production, storage and offloading units (abbreviated as FPSO's). Offshore companies use these vessels for storing and processing oil and gas. Most of these ships are moored at a fixed position at the sea. They are huge. The study group used data from a FPSO that is 230 meters long. For comparison: the Dom Tower, the tallest Dutch church tower, is a measly 113 meters high.

A FPSO typically has a lifespan of twenty to thirty years. Cyclic loading from waves slowly degrades the structure. How can you determine this consumed fatigue life time? Over time the draft of the ship is recorded, a buoy around it measures wave elevation and angle, and strain gauges continuously monitor the strains in the structure. These measurements can be related to design limits to predict when the structure will fail, or even better: to prevent the structure from failing.

There is a small problem: the amount of data is overwhelming. For instance, one buoy provides twice an hour the incoming waves in 91 angles, for 64 frequencies each. After two years this adds up to more than two hundred million data points. The question for the study group was to find a new mathematical way to compute the response of the structure from this giant heap of data. The main goal was to determine the response amplitude operators, or more informally, the response of the structure to the incoming waves.

Ingo Drummen, project manager at MARIN, knew this was a though problem: “We had spent a lot of time on it and I mainly wanted to get a fresh perspective. Could the mathematicians come up with something more clever than what we were doing?” It was Drummen’s first personal experience with the study group and he was amazed how much time it took to communicate the problem: “I have been in this field for many years and it was hard to go back to the basics. It surprised me that people didn’t know what the draft of a ship is.” Just to be sure: the draft of a ship is the vertical distance between the waterline and the bottom of the hull.

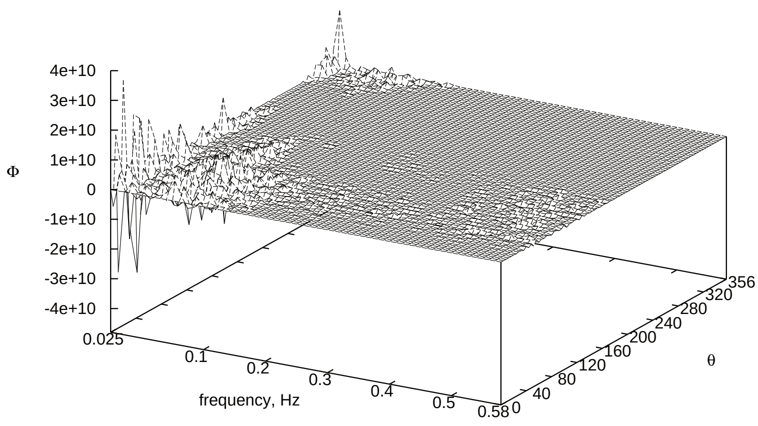
Cherry-picking

Iason Zisis from Technical University Eindhoven chose this problem because he liked the engineering and mathematics behind it: “It is about doing something smart with the data” He and his colleagues soon decided that they should limit themselves to the mathematical part of the problem and not advice MARIN about the ship: “We truncated the problem to pure data-analysis.”

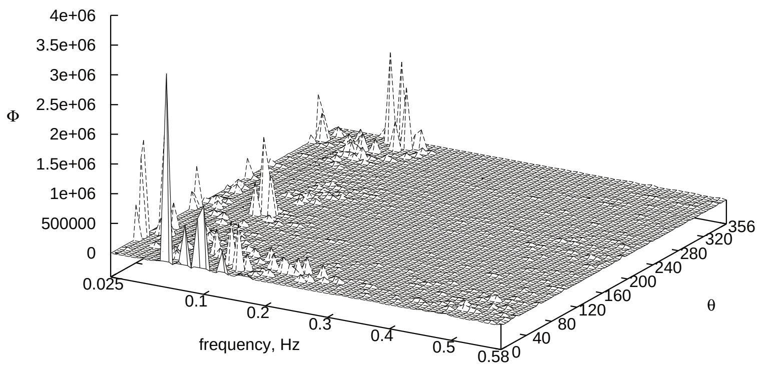
It was not easy to handle the data. During their presentation the mathematicians joked that in their normal work there was too little data: “But here we had more than enough. It was hard to figure out what to do with it.” They decided to only use a small part of the data. Firstly they picked just one draft range of the ship and just used the measurements in which the draft was between 12.5 and 13 meters. This left “only” 1176 measurements for each wave frequency. The system was still overdetermined, because for each frequency there were 91 unknowns, one for each of the angles. But not every measurement is good. For instance, when a ship passes the measuring buoy, this will affect the local measurements, but not the reaction of the vessel. To exclude such erroneous measurements the mathematicians selected for each frequency only the data point with the highest response of the ship.

Least squares

Even after cherry-picking the data the system was overdetermined, there were still many possible solutions. So they needed a way to choose the best solution. A standard solution for such overdetermined problems is fitting the data with a least squares approximation. This method finds the solution for which the sum of the squared errors is minimal.



At the first try the least squares method found a solution with negative values. This might theoretically be the best solution for the given data, but in reality the response of the ship cannot be negative. Therefore a constrained least Squares method was used that only returns positive solutions.



The resulting solution was very, very spiky. For a small change in the frequency or angle of the incoming wave, there would suddenly be a very strong reaction from the vessel. But the actual relation has to be smooth; changing the waves a bit should only change the reaction of the ship a bit.

More assumptions

The study group decided to further limit the allowed solutions. They assumed that the reaction of the ship was a periodic function in terms of the direction of the waves. To be more precise; they assumed that it could be written as a truncated Fourier series using cosines of the wave direction. Zisis: “In reality waves come from the front or the side. The ship shows a big response in one direction and a small one on the other side. Therefore it makes sense to use cosines.”

This approach yielded a reasonable solution, but for some small frequencies the approximation error was still very high. In their report the mathematicians note that this is probably caused by measurement errors. They conclude that you need at least 500 data points to make a reasonable approximation. They also observe that if the number of free parameters in the Fourier function increases, the solution becomes bad.

Ingo Drummen from MARIN: “I deliberately did not tell the study group what the solution should look like, because I wanted to give them as much freedom in modeling as possible. But during their presentation I noticed that their solution became worse when it had too many free parameters. In such cases you start explaining errors of measurement with physics. This was the biggest eye-opener for me. A few weeks later with another project I was in the exact same situation, trying to find the balance between keeping the system as free as possible and avoiding that too much freedom produces nonsense."

The study group did not come with something more clever than MARIN was already doing. Drummen: "Their methods are as good as ours. This was both a disappointment and a relief. A disappointment, because it would have been nice to have a better solution. But also a relief, because this showed that MARIN had not overlooked something easy."

MARIN continues working on this problem with people from Technical University Eindhoven. Ingo Drummen hopes to come back to the study group next year: "It is good to have a week of intense contact and then work together in the long run for more depth."

Team MARIN

Giovanni A. Bonaschi, Olena Filatova, Carlo Mercuri, Adrian Muntean, Mark A. Peletier, Volha Shchetnikava and Iason Zisis (all from Eindhoven University of Technology) Ingo Drummen (MARIN) and Eric Siero (Leiden University)