Physics of the Interaction Between a Crab and a Seismic Test Pulse- Stage 4: continued development of mathematical model and testing of model via simulation

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Chapter 1

Summary

We have continued a theoretical study of the likelihood that crabs could suffer physical damage from exposure to the intense sound that occurs during a seismic shoot. This phase of the study was primarily intended to assess the importance of various approximations that have been made up to this point and to try to remove one or more of these approximations. We have succeeded in removing one of these approximations – neglecting sound damping in the tissues. We have found that this approximation makes very little difference. Thus, it is a reasonable approximation; future studies can continue to make this approximation, making calculations somewhat simpler.

As part of this effort we wished to compare our analytical calculations with results from a computer program developed by Defense Research and Development Canada (DRDC). In the process of doing this we found that the software package, which DRDC had hoped was capable of carrying out this work, does not appear to do this kind of scattering calculation correctly. We have, as a result, carried out some significant testing of the DRDC software package and this is helping DRDC to improve the package.

We have also improved our own software which we use in carrying out our analytical calculations. These improvements have included developing a simple user interface so that the software should be more usable to researchers without specific knowledge of the program that we have used to develop our package.

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Chapter 2

Introduction

The impacts of offshore seismic surveys on ecosystems and fisheries is not well understood. While considerable work has been done exploring the effects on marine mammals (e.g. [2, Goold, 1998]), somewhat less work has been done to understand the effects on fish and very little has been done to determine the effects on marine invertebrates. A good survey of work done prior to the current OEER studies is contained in [7, Moriyasu, 2004]. The current research into this area funded by OEER was largely sparked by the inconclusive nature of a study that is reported in [1, Chadwick, 2004]. The current study is part of an ongoing research program launched by OEER. The overall goals of this program are summarized in [9, Walmsley, 2007].

Chapter 3

Discussion of Objectives, Methodology and Results

The original objectives, as laid out in the proposal for this project, were:

- Attempt to remove one or more approximations that are currently made in the theory
- Evaluate how large the effects are of one or more of the approximations currently made
- Continue development of the Maple sheets that we use for our calculations and start making them more user friendly so that they are more useful to other users

As discussed in earlier reports (e.g. [5, Lee-Dadswell,2008]), the model used in this work to date involve the following approximations:

1. The crab is treated as a sphere
2. Internal structure, such as organs, in the crab is neglected
3. Viscous damping in the tissues and carapace of the crab is neglected
4. The seabottom is not included in the model
5. The incoming sound is treated as a plane wave (except in [6, Lee-Dadswell,2010])
6. The responses of all materials in the system are treated as linear

A number of these approximations make an enormous difference in the complexity of the calculations. This means that relaxing them would be extremely difficult. It was hoped, therefore, that the relative importance of the approximations could be assessed by computer simulation, and that the simulations could be used to guide the analytical calculations. Towards this end, we had agreement from researchers at Defense Research and Development Canada (DRDC) that we could use their finite element analysis program, MAVART, to carry out these simulations. MAVART was developed mainly for simulation of sound sources such as sonar. It has been demonstrated that it does this task very well. The present research involves scattering calculations, and it was hoped by researchers at DRDC that MAVART's scattering packages, which have not been extensively tested, would be up to this task. However, initial testing of MAVART showed that it was unable to reproduce a number of well known results that are in the literature. This led DRDC, over the fall and winter of 2010/2011, to carry out a major recoding of their scattering packages. Over the summer of 2011 we have tested these recoded packages. Unfortunately, they still seem to be unable to reproduce results from the literature.

Early in the present study, after it became clear that MAVART might not be able to carry out the calculations we needed it to do, it was decided that we should focus our attention on approximations 3 and 4. The reasons are as follows.

In [6, Lee-Dadswell,2010] this research group examined the effects of relaxing approximation 5. While the detailed examination carried out in that study led us to a re-evaluation of maximum sound levels near the bottom during a seismic shoot, it also showed that approximating the incoming sound as a plane wave is a very good approximation. Thus, we use that approximation throughout the present study.

Approximation 6. is expected to be a good approximation. As shown in [5, Lee-Dadswell, 2008] and in [6, Lee-Dadswell,2010], sound intensities inside the crab are not expected to approach the levels where the tissues would be near their elastic limits. So the tissues should still be well within their linear response regimes, where Hooke's law holds. Thus, it is probably not worth the considerable difficulty of relaxing this approximation.

Relaxing approximation 2. could only be done by intensive numerical calculations. There is virtually no hope that an analytical model could be used to fully model a crab with internal organs. Similarly, relaxing approximation 1 would make the analytical calculations extremely difficult. Thus, it would only be worth doing if it was expected to significantly change the results. Several existing studies are useful for assessing whether this is likely. In particular [8, Stanton,1988] shows many comparisons of scattering by spherical and spheroidal shells. The trend appears to be there is rather little qualitative difference. The exception is that for intermediate frequencies, thin spherical shells seem to couple to the sound better than thin spheroidal shells. So, approximating crabs as spherical might somewhat exagerate the danger posed by seismic shoots. Since the studies to date seem to suggest that there is little danger of direct physical damage, relaxing approximations that cause an overestimate of the danger seems less productive than relaxing approximations that might be causing us to underestimate the danger.

One of the calculations in [4, Lee-Dadswell,2008] estimated the amount of sound damping that occurs in the crab's tissues during a seismic shoot. The conclusion of that report was that the effects of viscous damping are extremely small. Nevertheless, it is relatively easy to remove approximation 3; an undergraduate research assistant was able to carry out the calculations in a matter of a few days. The result is in agreement with the assessments in [4, Lee-Dadswell,2008]. Viscous damping is completely negligible in these studies.

Finally, approximation 4 presents a very interesting case. Various studies have been done of scattering by spheres near boundaries. A good example is [3, Huang,1997]. This paper shows some comparisons of scattering by elastic shells with and without boundaries near them. Somewhat as expected, the boundary causes an enhancement of the scattering in a fairly narrow band of frequencies. As the space between the sphere and the boundary is made smaller this enhancement moves to higher frequencies. This is of possible interest. For a crab the distance between the bottom of its carapace and the surface underneath it is normally smaller than the thickness of the crab. It is possible that the enhanced coupling would fall in a frequency band where the crab's own body experiences many resonances. This seems like the approximation most in need of examination. A reasonable target would be to analyze a spherical model crab near an elastic surface. This would involve going considerably beyond results that have been reported in the literature. While an analytical approach might be possible, it would likely be more reasonable to investigate this with MAVART in future if the DRDC researchers can make sufficient progress in fixing MAVART's scattering packages.

Chapter 4

Dissemination and Technology Transfer

Two of us (G. L-D. and J. T.) attended the Nova Scotia Research and Development Forum in 2010. We were mostly presenting the results from the Phase 2 and 3 projects, but did discuss the Phase 4 project with a number of people.

Testing of MAVART

We carried out detailed testing of the scattering packages in MAVART. In particular we examined far field scattering and near field particle displacements for rigid and elastic solid spheres in water. These are well studied with a wealth of results reported in the literature, including classic results which appear in acoustics textbooks. Our Maple sheets are able to reproduce the results reported in the literature. We have carried out the same calculations in MAVART. Unfortunately we find that MAVART does not reproduce the expected far field scattering or near field displacements. This has seriously limited the progress we have been able to make in improving our model. On the other hand we have done considerable testing of MAVART. This will help DRDC continue to improve MAVART's capabilities.

Improvement of Maple Sheets

We now have a working Maple sheet which will solve the acoustic scattering problem for a sphere with any number of layers of different materials. The materials can be any combination of elastic solids or fluids. We have made a simple user interface so that users who are not familiar with Maple can still easily make some use of it. However, it would still be most useful to a researcher who knows how to use Maple and who knows some acoustic scattering theory. The Maple sheet will be provided with this report. It was written in Maple version 12. We will maintain this Maple sheet and provide it free of charge to any researcher or educator who wishes to use it.

Chapter 5

Conclusions and Recommendations

The most significant outcome of this project was probably the testing that was carried out on MAVART, which should help DRDC to improve its scattering packages. An assessment of the literature, and some calculations that we have carried out show that of the approximations currently used in our analytical models, the only one that is likely to be worth investigating further is including the seabottom in the model. This will make the calculations considerably more difficult and should not be attempted without the assistance of working simulations. Our work on our Maple sheets has yielded a sheet which could be moderately useful to others doing acoustic scattering related research.

The physical theory of the interaction of seismic sound with a snow crab appears to have been pushed as far as is reasonable at this time. We feel that until there is a corresponding experimental effort it would not be productive to continue development of the theory. Furthermore, any further development of the theory will require support by simulations. It is hoped that DRDC can get the scattering packages in MAVART working to allow this.

We strongly recommend that some preliminary experimental work be done to validate this theory. These should initially be done in an acoustically “clean” setting, building up to carefully controlled experiments which simulate a real crab on the bottom during a seismic shoot. An experiment on spheres suspended well above the bottom would be a good starting point. These should be compared with follow up experiments on spheres near a surface and with experiments carried out on real crabs. The most direct experiments would measure displacements within the targets. However, the internal displacements could be infered from scattering experiments.

These acoustic experiments would need to be supplemented by some relatively simple experiments to measure the elastic limits of various tissues from crabs. It is expected, based on these theoretical investigations, that the internal displacements seen in the acoustic experiments will be well below the elastic limits of the crab tissues.

Chapter 6

Publications

None at this time. A paper related to this work is in preparation which will be submitted to the Journal of the Acoustical Society of America Express Letters. It is expected that this paper will be completed by Dec. 2011.

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