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Predicting Underwater Radiated Noise From Offshore Impact Pile Driving

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Predicting underwater radiated noise from offshore impact pile driving

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Contents

1. Progress statement

Introduction

Offshore wind turbines have been installed throughout Europe and are expected to be built in the United States water shortly. Offshore wind is an attractive option because 53% of the nation's population lives in coastal area where energy cost and demands are high. Offshore winds tend to blow harder and more uniformly than on land [1]. However, structure borne noise and vibration generated by offshore impact pile driving radiate into and propagate through the air, water, and sediment media. The objective of this project is quantitatively predicting noise level around the piling location at sea to estimate the effects of the noise and vibration on marine life. Ultimately, it is necessary to mitigate noise impact on animals living in the coastal area even if people construct renewable energy resources.

Results

To predict transient structure borne noise due to offshore impact pile driving, one of the commercial FE (Finite Element) code Abaqus 6.11 Implicit Dynamic Analysis has been used. The transient pressure impact loading provided by Reinhall and Dahl's previous work [2] applied on top of the pile and the steel pile structure is tied to water and sediment acoustic medium to simulate acoustic-structure interaction phenomenon. A compressional wave in the pile caused by the hammer strike produces an associated radial displacement motion due to the Poisson effect. The radial displacement propagates downwards. Since the speed of sound in the steel pile is higher than in water, the rapidly downward propagating wave produces an acoustic field in the shape of an axisymmetric cone which is called Mach wavefront. The cone's apex travels concurrently with the pile deformation wavefront. When the wavefront reaches the pile's terminal end, it is reflected upward. The field output in each time step (3, 6, 9, 12 milliseconds) represents this phenomenon shown in Figure 1. The FE model has been verified with measured data using the VLA in Reinhall and Dahl's published paper [2] and is presented at the conferences [3, 4].

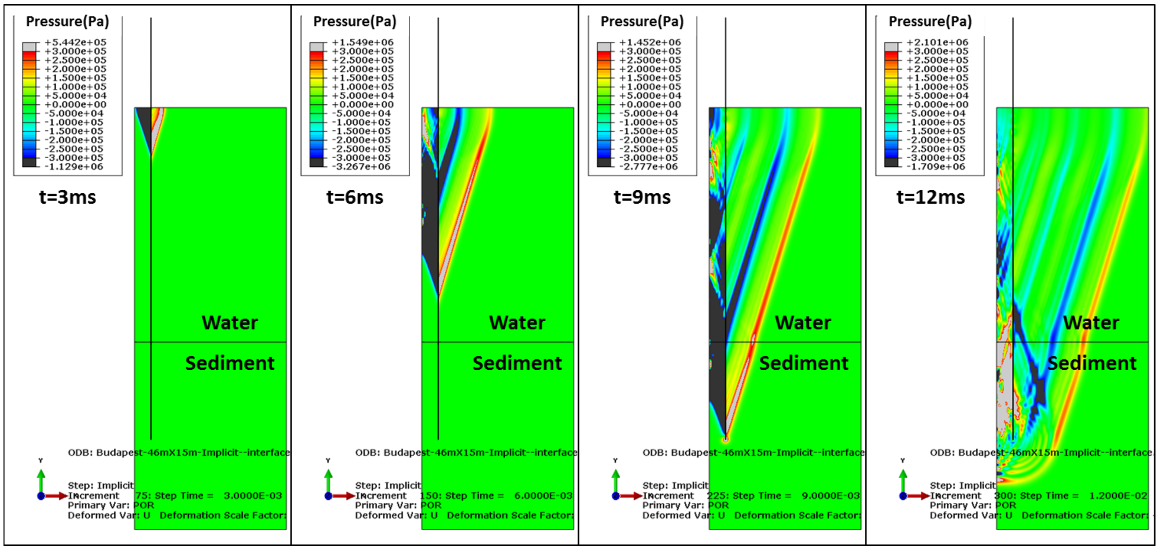

Figure 1. Mach wave generated by the pile hammer impact. The four panels show the evolution of the waves at time t=3, 6, 9, 12milliseconds.

This project extended the prediction of offshore impact pile driving noise in the far field by coupling the FE steady state dynamic analysis outputs to the Standard MMPE (Monterey-Miami Parabolic Equation) model as the MMPE model's starting field. The Figure 2 is showing the concept of the coupled FE-MMPE model. Briefly, the FE steady state dynamic analysis calculates harmonic response of the complex acoustic pressure on the surface of the pile at each frequency (1st panel in Figure 2). The complex acoustic pressure amplitudes along the pile is fitted into the long range propagation model MMPE's starting field (2ndpanel in Figure 2). Then the MMPE model calculates the SSP (Sound Speed Profile) and bathymetry dependent complex acoustic pressure field by accepting the associated starting field at the specific frequency (3rd panel in Figure 2).

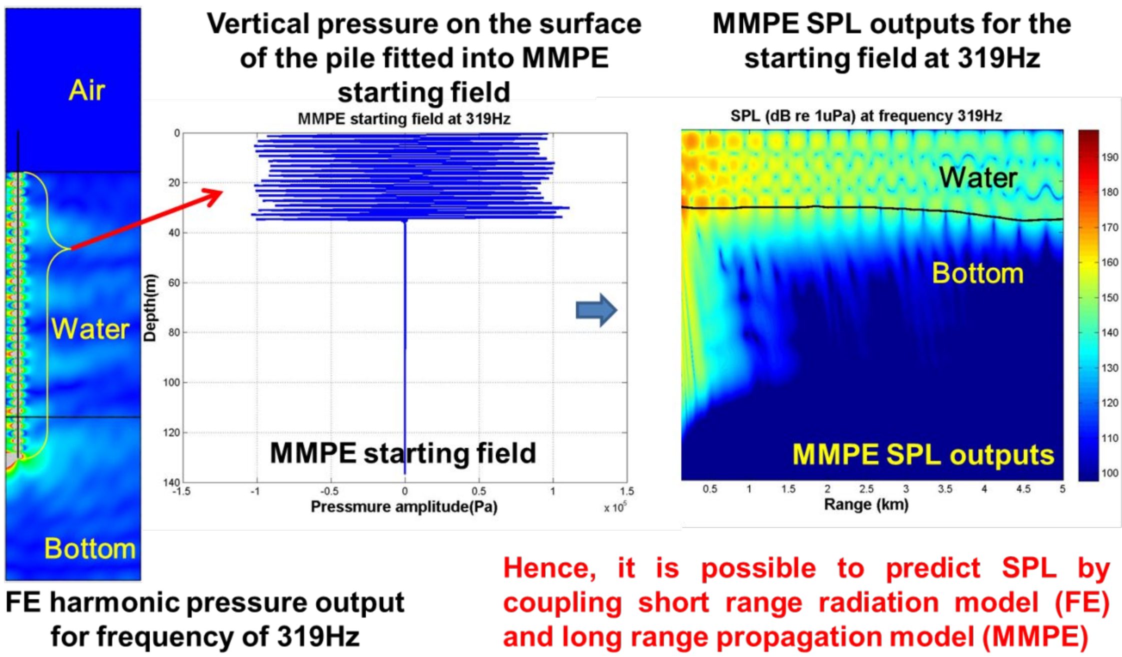

Figure 2. Concept of coupled FE-MMPE model showing the example of FE harmonic pressure output for frequency of 319 Hz (1st panel) and the real part of acoustic pressure on the surface of the pile fitted into the MMPE starting field at 319 Hz (2nd panel) and the associated range dependent MMPE SPL (Sound Pressure Level) in dB re 1 μPa field output at the frequency 319 Hz.

In addition, the project tried to calculate the range dependent peak SPL and SEL (Sound Exposure Level) which required a broadband calculation for the frequency band of interest. The peak SPL has been calculated by taking maximum of the magnitude of IFFT (Inverse Fourier Transform) for the MMPE complex acoustic pressure. The SEL has been calculated by summing the magnitude of the MMPE complex acoustic pressure for the frequency band 100 Hz ~ 1024 Hz. This work is focusing on acoustic pressure and particle velocity response along the water-sediment interface. The 1st panel in Figure 3 shows the Peak SPL and the SEL as function of range. The peak SPL is higher than 200 $\mathrm{dB\ re\ }1\mu Pa$ within 200 meters range. The range dependent SEL enables to predict RWI (Response Weighted Index) with an input of the number of strikes of piling [5]. The RWI ranges from 1 (mild trauma) to 3 (moderate injury) to 5 (mortal injury, dead within an hour) and higher. The 2nd panel in Figure 3 shows the RWI predicted as a function of range from the pile installation for 960 and 1920 pile strikes. The RWI is shown assuming

960 and 1920 pile strikes. These quantities were used in the Halvorsen et al. work [6]. The range to the mortality RWI is about 250 m at the sea floor for 960 pile strikes [7].

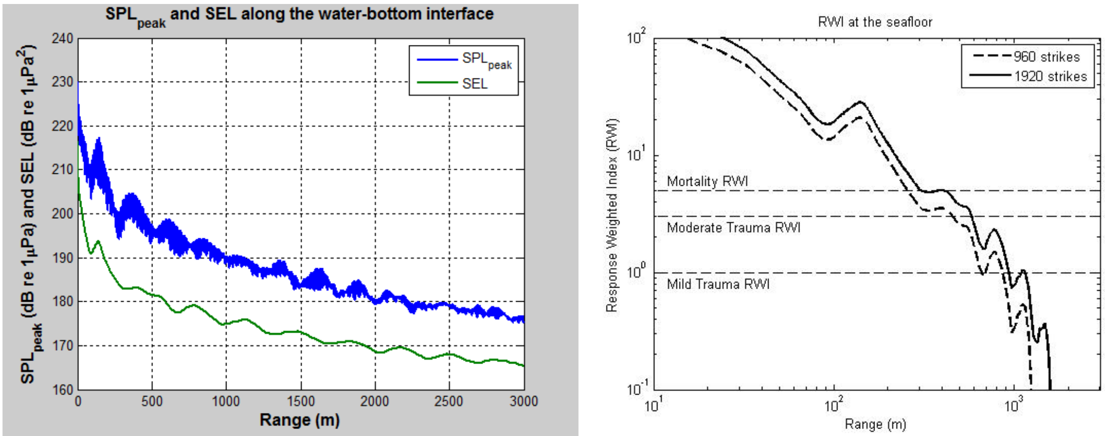

Figure 3. Broadband peak SPL and SEL as function of range (1st panel) and RWI along the water – bottom interface with 960 and 1920 pile strikes (2nd panel).

Significance and impact

This project successfully coupled a FE model to the MMPE model by incorporating the starting field from the FE model's harmonic response into the MMPE model. The coupled FE-MMPE model developed for this project is advantageous because the FE and the MMPE models compliment their strength. The FE model is ideal for short range calculations of acoustic pressure from a complex structure, but the FE model computationally unsustainable when the size of model is increased due to the mesh size requirement for long ranges. In contrast, the MMPE model is ideal for long range propagation, once a starting field can be adequately defined. The codes developed for coupling two numerical models, the FE and the MMPE, are significant contribution because long range broadband calculation for acoustic pressure and particle velocity from space and frequency dependent structure born noise source has been successfully achieved. This project makes it possible to quantitatively predict structure borne noise and vibration due to offshore impact pile driving in the ocean up to several kilometer ranges.

Where might this lead?

The coupled FE-MMPE model approach predicting long range propagation of noise and vibration due to offshore impact pile driving can be useful for the classification societies such as DNV, Lloyd's Register which establish and maintain technical standards for the construction and operation of ships and offshore structure.

References

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3. Kim, H., et al., Long range propagation modeling of offshore wind turbine noise using finite element and parabolic equation models. The Journal of the Acoustical Society of America, 2012. **131**(4): p. 3392.

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7. Miller, J.H., G.R. Potty, and H. Kim, *Pile driving pressure and particle velocity at the seabed: Quantifying effects on crustaceans and ground fish.* The 3rd International Conference on the Effects of Noise on Aquatic Life, 2013.

2. A list of all archival journal papers or scholarly reports.

- Kim, H., J.H. Miller, and G.R. Potty, Predicting underwater radiated noise levels due to the first offshore wind turbine installation in the U.S. The Proceedings of Meetings on Acoustics, 2013. 19: p. 040067
- Kim, H., J.H. Miller, and G.R. Potty, Predicting underwater radiated noise levels due to the first offshore wind turbine installation in the United States. The Journal of the Acoustical Society of America, 2013. 133: p. 3419.
- Miller, J.H., G.R. Potty, and H. Kim, Pile driving pressure and particle velocity at the seabed: Quantifying effects on crustaceans and ground fish. The 3rd International Conference on the Effects of Noise on Aquatic Life, 2013. (Submitted)

3. A statement of how discretionary funds were spent.

Part of fellowship has been spent for hotel, registration, and transportation to Montreal, Canada presenting my recent work at the conference, ICA (International Congress of Acoustics) 2013. The remainder of fellowship was used to purchase underwater connectors (eight 4-pin connectors and two 8-pin connectors) and small supplies such as liquid/normal electric tape, water proof heat shrink connectors/tube etc.

4. How did the Fellowship make a difference?

Foreign students have difficulty studying underwater acoustics in the U.S. because most of the opportunities for funding require U.S. citizenship. However, the Link Foundation Fellowship is open to all PhD students in the U.S. and Canadian universities and no limitations are placed on citizenship. I also had difficulties getting other source of funding such as part time job because the J-1 visa restricts any paid work to that directly related to research project. The Link Foundation Fellowship was the only chance I can continue my research toward PhD without any other concerns. Being selected as one of the recipients significantly improved the life of my family including a wife and daughter.