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Review PhD thesis Duje Veic

Dear Colleague.

Enclosed please find my review on the PhD thesis of Duje Veic. Sorry for the delayed delivery, this was a result of a misunderstanding and a work-overload end of last year and early this year.

Sincerely,

Prof. Dr.-Ing. Peter Fröhle

Hamburg, 20.02.20202

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Review and Opinion

About the doctoral dissertation of Mgr inz. Duje Veic on "Effect of the Breaking Wave Shape on the Temporal and Spatial Pressure Distribution around a Monopile Support Structure"

1. Preliminary remarks and work composition

The review was prepared on the basis of contract KB/153/2019 between the Institute of Hydro-Engineering, IBW PAN and myself.

The thesis presented for review consists of 115 pages including 89 figures, 5 tables, 2 appendices and 64 cited publications. The thesis is into 4 chapters, where chapter 1 contains the introduction, chapter 2 the theoretical model, chapter 3 the experimental work and chapter 4 the conclusions.

In the introduction the doctoral candidate discusses the background of the research work and discusses advantages and shortcomings of the two methodologies used within the research work, namely, physical model tests and numerical model tests. In addition, the thesis scope and objectives are defined in the introduction. The second chapter is the main chapter of the thesis and provides basic information about the theoretical work of the research, namely, i) the wave breaking characteristics, ii) the analytical approach, iii) the numerical model, iv) the thickness of air-water interface, v) the results of the numerical modelling and vi) a first summary. Chapter 3 contains i) the experimental work performed within the research, ii) the validation of the numerical approach and iii) the results of the experiments as well as iv) a second short summary. Chapter 4 contains the conclusions and chapter 5 two short appendices.

The main research work described in the thesis of Duje Veic is to investigate the effects of the shape of breaking waves on the load distribution arising from the breaking wave impact on a monopile structure.

The prediction of wave loads on maritime structures is of fundamental importance for coastal and offshore engineering. For slender cylindrical structures, the loads resulting from breaking wave are often the dominating design forces. Even if many theoretical, numerical and laboratory studies have been conducted to describe the interactions between waves and slender cylindrical structures, the uncertainties and variabilities of the results are still high and certain effects as for example the compressibility of entrapped air or the form of the breaking wave are quite often neglected or simplified.

From the methodological point of view the candidate uses a hydrodynamic-numerical (HN) model based on incompressible Navier-Stokes-Volume of Fluid (NS-VOF) equations and a numerical model which includes the effects of air compressibility (compressible numerical model). The investigations have been performed with a temporal resolution, which is high enough to resolve the important physical processes. In addition, the results of a physical-hydraulic (PH) model are used in comparison to the results of the numerical models for validation.

2. Critical discussion of individual elements of the dissertation

2.1 Introduction

The analysis of wave forces resulting on slender cylinders using theoretical approaches, physical laboratory experiment and/or numerical models is the subject of many research projects and research works at least since 1950 where Morison, et al. (Morison, J. R., Johnson, J. W., & Schaaf, S. A. (1950, May 1). The Force Exerted by Surface Waves on Piles. Society of Petroleum Engineers. doi:10.2118/950149-G) published one of the first complete theoretical approaches for the determination of wave forces on slender cylinders. Nevertheless, many open questions related to the aforementioned question are still unsolved and the doctoral candidate addresses some of them, namely:

- the influence of the sampling rates of experimental set-ups on maximum forces measured in physical model tests
- the spatial limitations of physical model tests to describe the vertical distribution of the wave induce forces and also the distribution of the wave induced forces around the cylinder
- the influence of air compressibility and water bubbles in hydrodynamic-numerical models and when scaling the results of physical-hydraulic model tests
- the influence of shape of breaking waves on the characteristics of the impact loads

Based on these open questions the main objective of the research was to investigate the effect of the breaking wave shape on the impact wave loads on a monopile structure by means of a two numerical model set-ups: one model set-up using incompressible NS-VOF and one set up using a compressible numerical model together with result from physical-hydraulic model tests.

The open questions addressed in the research are clearly defined. This methodological approach is sound but as an approach nothing new.

2.2 Chapter 2

<u>Wave breaking</u>

In this section the physical processes leading to wave breaking and the resulting water surface form are described briefly based on existing studies. Based on the brief analysis of wave breaking five different stages of wave breaking, identified by Wienke et al. (2001) are presented. In my opinion a very short (too short) chapter on the state of the technical knowledge on wave breaking and the respective parameterization of wave characteristics.

<u>Analytical approach</u>

In this section analytical approaches for the determination of wave forces on slender cylinders are summarized, starting with the Morison approach (see above) for slightly non-linear waves and ending with results of a study of Wienke and Oumeraci (2005). A very short chapter on existing approaches where a few representative approaches have been selected. The results form the basis for the later performed comparison with numerical model results.

Comment: equation 2.6 is partly not readable.

Numerical Model

In this section, the numerical modelling approach is described, where at the end existing numerical model approaches (OceanWave3D and OpenFOAM) are used. Both models are coupled in one-way (OceanWave3D generates input for OpenFOAM) using an existing coupler. In addition, the theoretical background of the numerical approaches are given in this section.

Comment: eqs: 2.23, 2.24, 2.25 are partly not readable

Thickness of the air-water interface in VOF model

The spatial resolution of the numerical approach has an important influence on the quality and resolution of the model results. In this section, the factors influencing the model quality is analyzed by means of a theoretical approach and by means of a sensitivity analysis. Figure 2.15, 2.16 and 2.17 show clearly the influences of grid refinement on the results of the numerical model. From these theoretical considerations and sensitivity analysis the grid resolution of the numerical model is derived. The temporal resolution is also discussed, where the Courant-Friedrichs-Lewy criterion is taken as the basis. In addition and in order to save computational resources for modelling, the finally applied "simplified" computational procedure is discussed and justified in this section.

Numerical results - incompressible model

Wave breaking in nature and hence, also in numerical and physical models is strongly influenced by the bathymetry influenced transformation of the wave trains in front of the breaking area. In this section, the different analyzed bathymetries are described in detail where the resulting breaking wave profiles are shown in Figure 2.27. In addition, it is shown that the classical definition of wave breaking "the celerity of the individual water particles in a wave is higher than the wave propagation celerity" are at least in general also modelled using the numerical approach selected for the research (Figures 2.31 and 2.32). Table 2.3 shows the range of the wave parameters applied in the numerical model.

The results of the numerical modelling approach (non-impact forces) are compared with results derived from classical Morison approach in combination with wave trains derived from stream function wave theory. As expected, the results differ a lot both, with respect to the wave train and also with respect to the resulting forces, since the selected cases are not represented by the assumption made by the original approach of Morison et al..

The comparison of the impact forces with the approach described by Wienke (2001) and with the DNV (2010 and 2014) approach show that in some cases the values of the Wienke approach are reached for some layouts but that the Wienke approach normally gives higher values than the computational approach derived by Veic. The results of the DNV approach are differing less from the model results than the result obtained with the Wienke approach.

The candidate states that "The presented results show that the application of the simplified approaches for the calculation of the impact forces on the cylindrical structures, which are based on rectangular load distribution, provide unreliable results." In my opinion, this statement can not be derived from the comparisons. The simplified approaches are derived to determine design values and not meant to represent the physical properties of the processes in detail. Also the reverse conclusion that the numerical approach gives more reliable results can not be drawn from the comparisons. The results are simply differing.

The results presented in the chapters 2.5.3 and 2.5.4 impressively show the possibilities of high temporal and high spatial resolved numerical model approaches where (physical) details of the impact of breaking waves are analysed over time and over the cylinder as well as over the vertical axis. It is also impressive to see that the local loads are more than 20 times higher than loads derived with the classical stagnation approach. In addition, it is quite interesting to see that the vertical distribution of the resulting loads (impact forces) look at least qualitatively quite similar to the load distribution of the Minikin approach. In addition the candidate developed a "simplified" procedure to determine the loads over time which shows discrepancies of approx. 30% (Figure 2.58), only.

Comment: Unfortunately it is not indicated in Figure 2.58 whether the red or the black line represent the simplified approach or the model results.

<u>Numerical results - compressible model</u>

The breaking wave impact on the structure is accompanied by air entrapment (white water) and air pockets which can be formed between the overturning wave crest and the structure. This effect is not negligible, since it is observed from the results of experimental studies, that this effect may cause significant oscillations of the measured impact signal. In the research the candidate therefore is using an OpenFOAM library which includes compressibility effects. This OpenFOAM library is not finally validated and therefore the results are meant to address the importance of the air compressibility in the process.

Figrure 2.61 shows the general effect of the air compressibility and shows the typical ringing effects that are observed in physical-hydraulic model tests when air entrapment plays a role.The results are given in comparison to a scaled physical-hydraulic model. A comparison with numerical model results in full scale (Figure 2.66) shows that in full scale the ringing effect is significantly smaller. Unfortunately, these differences and physical reasons for these difference have not been discussed in the thesis.

The approach used in the thesis is described comparatively briefly and also the results obtained from the numerical experiments are basically described based on the model results. I miss a little bit the consequences for practical applications.

2.3 Chapter 3 (Experimental analysis)

For the research described in Chapter 3 results of physical-hydraulic model tests in a scale of 1:45 performed at Deltares in Delft are used. After a short description of the layout of the model tests and the analysis methods (3.1), the results are basically used to validate the numerical model approach described in Chapter 2. Breaking wave events are identified from the hydraulic model tests and compared with the model results. The experimental results are reproduced in the numerical model by applying a kinematic wavemaker boundary condition at the inlet boundary of the numerical model. The obtained numerical results are compared with experimental measurements of wave elevations, measured hydrodynamic forces and measured pressure along the front line of the monopile quantitatively and qualitatively by using high-frequency videos. Obviously, these are integrating values, since more detailed measurements are not possible in physical-hydraulic model tests. The physical model tests are basically in good agreement with the results of the numerical approach where discrepancies are explained with limitations (temporal and spatial resolution, etc.) of the physical model.

For me, the comparison section is comparatively short. Again, I miss direct statements of practical value regarding the quality of the numerical model. The results are described comparatively weak like: "The results from this section show that the presented numerical model can reproduce experimental results with sufficient accuracy." or: "in a good agreement with the laboratory measurements".

Comment: Equations 2.36 and 2.37 are not readable.

2.4 Chapter 4 (Conclusions)

In this chapter the work and the contents of the thesis are more summarized. I miss a little bit the direct conclusions which are of practical value for modellers, for designers or for the construction of monopile constructions.

3. Summary

Mr Duje Viec has provided a good dissertation, which covers important aspects numerical modelling of wave loads on monopile structures. The approaches and methods are sound. The objective of Mr. Veic was to to investigate the effect of the breaking wave shape on the impact wave loads on a monopile structure and to contribute to improve the understanding to open questions related to unresolved questions (see 2.1).

The text is well-formulated and quite easy to read and can be clearly understood. I found only a few grammatical errors and typos. Unfortunately, some equations are not readable in the printed and also in the digital version of the thesis.

The illustrations, figures and graphs are clear and help to understand the text. I have small problems with the structure of the thesis. I personally would have preferred to illustrate and discuss the results of the numerical tests with the incompressible and with the compressible model **after** the validation of the model. A structure like: introduction, model set-up, model verification, results of numerical model experiments, ... would be clearer for me.

The scientific value of the work is good. With his thesis Mr Duje Veic has proofed his ability to carry out independent scientific research.

I conclude that the doctoral dissertation of Mgr. inz Duje Veic," Effect of the Breaking Wave Shape on the Temporal and Spatial Pressure Distribution around a Monopile Support Structure" meets all the requirements of a doctoral dissertation. I recommend that the PhD-Committee should accept the dissertation and continue the promotion process.

Hamburg, 26.02.2020

Prof. Dr.-Ing. Peter Fröhle