View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by Hydraulic Engineering Repository

HENRY
Hydraulic Engineering Repository

Ein Service der Bundesanstalt für Wasserbau

Conference Paper, Published Version

Shevchuk, Ivan; Böttner, Carl-Uwe; Kornev, Nikolai

Numerical Investigation of Scale Effects on Squat in Extremey Shallow Water

Verfügbar unter/Available at: https://hdl.handle.net/20.500.11970/107204

Vorgeschlagene Zitierweise/Suggested citation:
Shevchuk, Ivan; Böttner, Carl-Uwe; Kornev, Nikolai (2019): Numerical Investigation of Scale Effects on Squat in Extremey Shallow Water. In: Maxim Candries, Evert Lataire, Katrien Eloot, Guillaume Delefortrie (Hg.): Proceedings of the 5th International Conference on Ship Manoeuvring in Shallow and Confined Water (MASHCON), 19 – 23 May 2019, Ostend, Belgium. Ostend: Knowledge Centre Manoeuvring in Shallow and Confined Water (Maritime Technology Division, Ghent University and Flanders Hydraulics Research). S. 390-402. https://mashcon2019.ugent.be/EN/mashcon2019_proceedings_EN.htm.

Standardnutzungsbedingungen/Terms of Use:

Die Dokumente in HENRY stehen unter der Creative Commons Lizenz CC BY 4.0, sofern keine abweichenden Nutzungsbedingungen getroffen wurden. Damit ist sowohl die kommerzielle Nutzung als auch das Teilen, die Weiterbearbeitung und Speicherung erlaubt. Das Verwenden und das Bearbeiten stehen unter der Bedingung der Namensnennung. Im Einzelfall kann eine restriktivere Lizenz gelten; dann gelten abweichend von den obigen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Documents in HENRY are made available under the Creative Commons License CC BY 4.0, if no other license is applicable. Under CC BY 4.0 commercial use and sharing, remixing, transforming, and building upon the material of the work is permitted. In some cases a different, more restrictive license may apply; if applicable the terms of the restrictive license will be binding.

NUMERICAL INVESTIGATION OF SCALE EFFECTS ON SQUAT IN SHALLOW WATER

Ivan Shevchuk, Technical University Hamburg, Germany
Carl-Uwe Böttner, Federal Waterways Engineering and Research Institute, Germany
Nikolai Kornev, University of Rostock, Germany

SUMMARY

This paper is aimed at clarifying, to what extent the scale factor influences the squat phenomenon. In order to do that, a series of squat computations for three containerships (one Panamax and two Post-Panamax) were conducted in three scales: 1:1, 1:6, 1:40, and a range of depth to draft (*h/T*) ratios from 2.0 to 1.15. Also, a range of hull roughness values was considered by different diameters of Nikuradses equivalent sand roughness k_s.
It was found out that for the two of the three considered ships, the scaling error for squat grows as the *h/T* ratio is reduced. At the same time, the increase of the sand roughness leads to a better agreement between the full scale and the model scale results. For most of the considered cases the maximum scaling error was estimated to be 15cm (in full scale) or 10%, which is quite moderate and does not necessary require a correction. The dependence of scale effects on the Froude number, the *h/T* ratio and the roughness height is not the same among the considered ships. Therefore, one of the conclusions is that a development of a generally valid correction would be a challenging task.

NOMENCLATURE

h	Fairway depth (m)
T	Ship draft (m)
λ	Scale factor (-)
k_s	Nikuradse's sand roughness (m)
k_s^+	Dimensionless sand roughness (-)
θ	Trim angle (deg)
$\delta\theta$	Trim angle scaling error (deg)
S_M	Sinkage at midship (m)
S_B	Sinkage at the bow (m)
S_H	Kinematic viscosity (m)
$\delta S_{M,B,H}$	Scaling error for sinkage at midship, at the bow and at the stern respectively (m)
U	Uncertainty of the computed quantity
$\|E\|\%D$	Discrepancy between the experimental and the computed values
U_V	Validation uncertainty

1 INTRODUCTION

Nowadays, the results of the model tests for squat are converted to full scale by direct multiplication with the scale factor. By doing so one assumes, that the difference of Reynolds number between the model and the ship cannot considerably influence the squat phenomenon. However, in extremely shallow water even a small change of the effective gap between the ship and the fairway bottom may have noticeable consequences for ship behavior. Therefore, the difference between the relative boundary layer thickness in the model and the full scale caused by the difference in Reynolds number may indeed play a significant role in this case. In order to clarify the role of the scale effects on squat, a research project, named ReSquat was conducted at the University of Rostock in collaboration with the Federal Waterways Engineering and Research Institute (BAW). The aim of the project was to estimate the order of magnitude of the direct scaling error for the squat between the model and the ship using CFD.
Prediction of squat effect has nowadays become a routine task for CFD, at least in model scale and for moderate h/T ratios. Multiple papers describe the successful application of CFD codes for this purpose. (Jachowski, 2008) conducted squat simulations using commercial CFD code for a range of Froude numbers and h/T ratios and obtained good agreement with the average result of empirical methods. Drastic intensification of squat was observed for the smallest h/T. (Linde et al., 2015) developed a quasi-steady simulation procedure to speed up the squat computations and obtained fair agreement with experimental data. (Tezdogan et al., 2016) conducted a thorough CFD investigation of squat and resistance for a DTC hull moving in a canal. The discrepancy with experimental results was found to be smaller than the uncertainty of the experimental data.
In the context of the present paper, the work of (von Graefe et al., 2011) is especially important to mention. Authors compared the performance of a commercial CFD solver with potential methods for prediction of squat in restricted waterways. The CFD computations showed best agreement with the full scale measurements. Comparing the results between the computations at full scale and the model scale authors concluded that squat in full scale is larger than in model scale. However, no systematic information on this effect was presented. Moreover, the information on the hull roughness used in full scale computations was not present in the paper.
Even though the studies on scale effects for ship resistance, viscous wake and wave making are presented in literature, see e.g. (Raven, 2008), to the authors' best knowledge systematic studies of scale effects on squat have not been published yet. The present paper is an attempt to fill this gap.

2 CONSIDERED HULL FORMS

Three hull forms were considered in the present study: two Post-Panamax-container ships (PPM52, PPM55) and one Panamax-container ship (PM32). The hull forms of the mentioned ships are shown in Figures 1 and 2, whereas the main ship dimensions are given in Table 1. The hull forms were specifically selected in such a way, that PM32 has a C_B lying between the C_B values of PPM52 and PPM55. This way, the dependence of the studied phenomena on the block coefficient could be analyzed.

3 CONSIDERED CONDITIONS

Following parameters were varied in the framework of the study for each of the hull forms: the scale factor λ, the depth-to-draft ratio h/T, the Froude number Fr and the equivalent sand roughness k_s. Three scale factors were considered: full scale (λ = 1), model scale (λ = 40) and the intermediate scale (λ = 6). The depth-to-draft ratio was varied in the range h/T = 2.0, 1.5, 1.4, 1.25, 1.15 whereas the range of the Froude numbers was Fr = 0.07, 0.09, 0.11, 0.13. The Reynolds numbers for the model scale vary in the range from $6 \cdot 10^6$ to $\cdot 10^7$, whereas for the full scale from $1.4 \cdot 10^9$ -to $2.7 \cdot 10^9$, which is at least two orders of magnitude larger, than for the model. Next important parameter is the hull surface roughness. Four roughness diameters were considered k_s = 0.15mm (ITTC recommended, (ITTC, 2017)), 0.5mm, 1mm, 2mm. In total 720 computations were conducted (3 ships x 4 roughness heights x 5 depths x 3 scale factors x 4 Froude numbers). The conduction of a large number of RANS computations in a relatively short period of time was possible due to the development of a quasi-steady-state free-surface flow solver, which is briefly described in the next section.

Table 1. Main dimensions of the considered hull forms

	PPM52	PPM55	PM32
L_{pp}	347	355.8	281.6
B	52	55	32.3
T	16	16	11.8
C_B	0.668	0.689	0.679

4 NUMERICAL METHOD

The simulations in the present study were conducted using a quasi-steady-state volume-of-fluid solver, developed by the authors in collaboration with the research group of the University of Zagreb. This solver uses the ghost-fluid method (also known as embedded free-surface) to account for the presence of the air/water interface in the computational domain (Vukcevic, 2016). The momentum equations are solved in a steady-state manner, whereas the transport equations for the volume fraction are solved in an unsteady formulation with high Courant numbers. This way the convergence of the wave pattern and the forces acting on the ship can be attained already after a few thousand iterations, analogous to the single-phase steady-state solvers. The discretisation of the governing equations was done using the finite volume method with the schemes of nominally second order accuracy for all terms. The Menter's $k - \omega$ SST model was used for the turbulence modelling.

In order to account for the influence of the propeller on the flow in the stern and by these means increase the accuracy of trim and sinkage prediction an actuator disc (AD) model proposed in (Hoekstra, 2006) was used. This model was extended with the ability to predict the propeller rps, based on the propeller K_T and K_Q curves, provided by the user. The values of V_A and J are estimated based on local flow quantities. The adaptation of rps was done in an iterative manner.

The effect of the roughness on the flow was accounted for by the application of the wall functions. In order to properly apply the wall functions, the y^+ value of the first wall-adjacent computational node had to be larger than k_s^+, which in some cases led to the y^+ values of up to 700. In order to avoid the influence of the switch between different wall functions, the same roughness-based wall functions were used for all scales, but the sand roughness was scaled accordingly.

It is known, that the application of wall functions for flows with separations/strong pressure gradients (which is the case for the considered task) can be problematic. However, the wall-resolved simulations could not be used for two reasons. First, the use of wall resolved meshes for full scale would drastically increase the computational costs. Second, even if the wall-resolved meshes were used, this would require the modification of k and omega equations, introducing the influence of roughness into the turbulence model. Such models to authors' knowledge are neither widely used, nor well established and would definitely lead to some influence on separation behavior too.

The experimental observations as well as computational results (Shevchuk et al., 2016) indicate, that the flow at the ship stern in very shallow water is considerably unsteady, which raises a concern, to what extent RANS models are applicable for such cases. However, application of RANS/LES for this task resulted in just 5% change of the mean sinkage at the stern compared to RANS results. Therefore, authors believe, that application of RANS would not pose a significant problem for the accuracy of the results even for the smallest h/T considered.

5 VERIFICATION AND VALIDATION OF THE TRIM AND SINKAGE PREDICTION

The verification and validation (V&V) of the computational method, described in the previous section, was only possible for the model scale, since the experimental values for trim and sinkage for other scales were not available. The determination of the numerical uncertainty was on the other hand conducted for all scales. Three meshes for each scale were generated using snappyHexMesh generator: from 0.9M to 3.1M of cells for a half of ship hull. Due to the symmetry about the middle line plane only the left half of the flow was simulated. The special step-by-step meshing procedure allowed for the 99.6% coverage of the ship surface with prism layers. Examples of the mesh structure (slice at the stern) are shown in Figure 3.

Table 2. V&V study for the PPM52 hull at model scale, Fr=0.12. Res – result. CONV-convergence, DIV-divergence. Val. –was the validation achieved?

Mesh	θ [˚]	ε	S_M [m]	ε
C	0.063	-	-0.028	-
M	0.066	2.59E-03	-0.028	4.30E-05
F	0.067	1.17E-03	-0.028	9.94E-05
Res	CONV		DIV	
U [%]	4.37		1.53	
|E| % D	10.88		7.31	
U_v %	15.48		7.63	
Val. ?	Yes		Yes	

Table 3. Uncertainty estimation for PPM52, h/T=1.25, scale 1:1

Mesh	θ [˚]	ε	S_M [m]	ε
C	0.053		-1.194	-
M	0.055	1.74E-03	-1.168	2.61E-02
F	0.054	-4.57E-04	-1.162	5.45E-03
Res	OCONV	-	CONV	-
U[%]	1.991	-	0.370	-

Table 4: Uncertainty estimation for PPM52, h/T=1.25, scale 1:6

Mesh	θ [˚]	ε	S_M [m]	ε
C	0.055		-0.198	-
M	0.067	1.22E-02	-0.201	-2.71E-03
F	0.067	-9.27E-05	-0.199	1.87E-03
Res	OCONV	-	CONV	-
U[%]	1.991	-	0.370	-

Only one hull form (PPM52) was considered in V&V studies, since the other hull forms are considered similar from the point of view of the numerical method. Only the results for the depth-by-draft ratio of 1.25 and the Froude number of 0.12 are shown in the present paper for the sake of brevity. The V&V procedure as recommended by the ITTC was used (ITTC, 2008).

In Table 2 one can see the results of the V&V study for the model scale. The values of the experimental uncertainties were chosen based on the results presented by the ITTC in 2011 on the facility biases for the trim and sinkage measurements (ITTC, 2011). One can notice, that the values of the trim angle show monotone grid convergence (CONV), whereas the values of squat at the midship formally show grid divergence (DIV), which strictly speaking means that no uncertainty estimation can be done. However, the difference in the results between the coarsest and the finest grid are obviously negligibly small and therefore it seems reasonable to assume that the solution is converged. The uncertainty estimation in this case was done using the formula $U = (\Phi_{max} - \Phi_{min}) \cdot F_s$, where Φ_{max}, Φ_{min} are the maximum and minimum values of the quantity and $F_s = 3$ - safety factor. Using this formula validation both for trim and sinkage could be attained.

Tables 3 and 4 contain information on the uncertainty estimation for the scales 1:1 and 1:6 respectively. In most cases either the monotone or the oscillatory convergence were observed. The estimated values of the uncertainty are quite small: for the sinkage it lies below 0.8%, whereas for the trim angle the value is much higher - up to 11%.

Table 5. Comparison of the rps obtained from the actuator disc model with the experimental data, PPM52, model scale, h/T=1.25

Fr	rps, CFD	rps, Exp	Discr. [%]
0.07	3.93	4.05	0.03
0.09	4.99	5.07	0.02
0.11	6.13	6.18	0.01
0.13	7.42	7.36	-0.01

All the previously described verification and validation results were obtained using an actuator disc model. However, the version of AD model, without the determination of the rps was used. In order to make sure, that the values of the rps are predicted accurately, the flow computations for the model of PPM52 at depth-by-draft ratio (1.25) were conducted for a range of Froude numbers. The values of the rps were compared to the self-propulsion tests, conducted by SVA-P (Anschau, 2016). Results of the comparison can be seen in Table 5 and were considered satisfactory. No grid convergence study was conducted for this quantity.

6 ANALYSIS OF THE SCALING ERROR FOR THE SQUAT EFFECT

In order to analyze the scaling error for squat, one can compare two pairs of quantities between the model and the ship scale: either the sinkage at midship and the trim angle (S_M, θ) or the sinkage at the bow and at the stern (S_B, S_H). The former two quantities seem to be more suitable for the explanation of the physical phenomena, because sinkage depends just on the vertical force, whereas the trim angle on the trimming moment. At the same time S_B, S_H are more practically important, because they allow for evaluation of the effective differences in the under-keel clearance between the model and the full scale. In our opinion, both the practical and the physical aspects of the studied phenomena are important, therefore the analysis for both sets of variables (S_M, θ and S_B, S_H) will be presented.

In the following only the results for $\lambda = 40$ and $\lambda = 1$ are going to be compared. The results for $\lambda = 6$ almost in all cases showed oscillatory dependence of the scaling error on the scale factor. For example, in some cases the scaling errors between $\lambda = 1$ and $\lambda = 6$ surprisingly turned out to be higher, than between $\lambda = 1$ and $\lambda = 40$. Because of this behavior of the numerical model it was decided to neglect the results for λ = 6, until the reasons are clarified.

6.1 SCALING ERROR FOR S_M AND θ

In Figures 4, 5 and 6 one can see the scaling error for sinkage at midship (δS_M). The value of δS_M was calculated according to the following formula:

$$\delta S_M = S_M^{ship} - S_M^{model}\lambda, \quad (1)$$

where S_M^{ship}, S_M^{model} are the sinkages calculated at the full scale and model scale and λ - scale factor. S_M is the change of the vertical coordinate of the ship's center of gravity, which is negative for squat. This means, that if δS_M is negative, then the center of gravity of the ship is lower, than for the model and vice versa.

The analysis of the mentioned plots allows to notice the following trends. First of all, one can see, that the most plots for $h/T = 1.15$ do not correspond very well to the ones for higher h/T. Only for PPM52 the curve $h/T = 1.15$ follows the overall trends and seems reasonable, whereas for PPM55 and PM32 the results for h/T=1.15 do not agree at all with other depths. Therefore, one can conclude, that the numerical solution at h/T=1.15 obviously has a higher numerical uncertainty, than that for h/T=1.25. Because of this, the results for h/T could not be considered reliable. However, the behavior of the solution for PPM52 points to the fact, that the absolute value of the scaling error increases, when the depth-by-draft ratio diminishes and at h/T = 1.15 there is rapid growth compared to h/T = 1.25 (see Fig. 5). Second of all, in most cases the scaling error for S_M is negative. This means, that the ship vertical position is lower than that of the model ($S_M^{ship} < S_M^{model}\lambda$). This agrees well with the observations made in (von Graefe, 2011). However, in all considered cases the absolute value of the error is smaller than 15 cm (the evaluation in percent will be shown for δS_B, δS_H in the next subsection (see Figs. 10, 11 and 12). Third of all, the increase of the roughness height obviously results in the reduction of δS_M and in some cases not only the absolute value, but also the sign of the scaling error changes (see e.g. Fig. 4).

Unfortunately, it does not seem possible, to determine general trends in the behavior of δS_M: for each ship the dependence of the scaling error on h/T, Fr and k_s looks differently, e.g. for PPM52 one can see a monotone trend, for PPM55 the data contains a jump between Fr = 0.11 and 0.13, whereas for PM32 the scaling error turned out to be almost independent of the mentioned parameters.

Therefore, one can draw a conclusion, that the derivation of a generally valid correction for the scaling error cannot be undertaken, at least with the available database.

The scaling error for the trim angle was calculated according to the following formula:

$$\delta\theta = \theta^{ship} - \theta^{model}, \quad (1)$$

where θ^{ship}, θ^{model} are the values computed for the ship and the model respectively. If $\delta\theta$ is positive, the ship is trimmed more to the bow, than the model, and vice versa. The curves for $\delta\theta$ can be seen in Figures 7, 8 and 9. Exactly as it was noticed for S_M, the plots for h/T = 1.15 do not agree well with the plot for other h/T, even though in case of $\delta\theta$ the situation is a bit better. The scaling error of θ obviously strongly depends on the roughness height, used for the full scale simulations, which is an expected result, since the roughness affects the viscous forces under the hull and the pressure drop. However, the trends vary between the ships. For PPM55 the dependence is oscillatory, whereas for PPM52 and PM32 the error is positive at small k_s ($\theta^{ship} > \theta^{model}$), but starting from k_s = 1mm it changes the sign. In computations of (von Graefe, 2011) the error in trim angle was positive as well, i.e. the ship trimmed more to the bow. However, the values of the roughness used in the computations were not reported in that work.

The $\delta\theta$ increases, when h/T is reduced and when Fr grows. Generally, the values of $\delta\theta$ are quite small (< 0.02°), but significantly different for all hull forms.

6.2 SCALING ERROR FOR THE MAXIMUM SINKAGE

As it has already been mentioned, analysis the differences in maximum sinkage between the model scale and the full scale can be undertaken using the plots for δS_B and δS_H. Whether the sinkage at the bow or at the stern is larger, depends on the sign of the trim angle. If the sign is positive, then the sinkage at the bow is larger, than at the stern and vice versa. The containerships PPM55 and PM32 are trimmed to the stern, but PPM52 - to the bow. Therefore, in this section the quantity S_H is analyzed for PPM55 and PM32, whereas for PPM52 - δS_B. Formulae for δS_B and δS_H are similar to the one used for δS_M.From the plots shown in Figures 10, 11, 12, 13, 14 and 15 one can draw the following conclusions. In most cases (h/T = 1.25 - 2.0), the scaling error of maximum sinkage is under 10%. The only exception is the case h/T =1.15, where the relative deviation can reach 12-15%. However, one has to keep in mind that the results for h/T = 1.15 have higher uncertainty. The maximum absolute discrepancy in the maximum sinkage between the model and the ship is 19cm (PPM52, h/T=1.15, k_s=0.15mm). The values of δS_B, δS_H are obviously very sensitive to the roughness height. The larger the value of k_s is, the better is the agreement between the ship and the model squat estimations. For example, the scaling error of S_B has maximum value of 15% for PPM52 at k_s = 0.15mm, but at k_s=2mm its value diminishes to 5%. In the majority of the considered cases the scaling error is negative (squat effect is more pronounced for the ship, that for the model), which has to be taken into account in practice.

Similarly to the previously analyzed quantities, the trends for the scaling error of maximum sinkage vary strongly among the ships and therefore a generally valid correction seems hard to derive. One has to mention the interesting results observed for PM32, where the scaling error is in general much smaller than for other two ships and is almost independent of the sand roughness or the Froude number.

7 CONCLUSION

The conducted numerical analysis of the scale effects on squat for the range of depth-by-draft ratio h/T = 1.25 - 2.0 has shown, that the conversion of the data from the model to the full scale using linear scaling leads to an error of about 10% (15cm) percent of the maximum sinkage. Under very shallow water conditions (h/T =1.15) this error can reach up to 15% (19cm). The squat effect in model scale is normally less intense, than at full scale. This means, that for a ship the values of the sinkage can be from $7-10\%$ (at $h/T \geq 1.25$) to 15% (h/T = 1.15) larger, than that observed in model tests. Other authors drew similar conclusions on this matter (von Graefe, 2011). As the h/T is reduced, the conversion error grows, because of the increasing importance of the viscous effects. The reliability of the results for the lowest h/T considered in the present work (1.15) unfortunately remains an open question. Since at smaller values of h/T the physics of the flow becomes more complex and the numerical solution of the task is more challenging, additional study is needed, to determine the source of the errors. The authors consider this to be an important task, since at h/T = 1.15 a dramatic increase of the scaling error was observed and one has to make sure, that this phenomenon is accurately captured.

The parameters of the ship hull roughness have a significant influence on the studied phenomenon due to the influence on the boundary layer thickness. Up to some particular point the increase of k_s leads to a reduction of the scaling error, but at high values of k_s the error changes its sign and its absolute values start growing again.

The initial idea of the conducted research was to derive scaling laws, which would help to decrease the error of linear scaling for the values of sinkage from model scale to full scale. However, as it was shown the δS_M, $\delta\theta$, δS_B, δS_H as the functions for h/T, k_s, Fr behave themselves completely differently for each ship, even though the considered ships have similar hull forms and block coefficients and thus it is hard to propose a generally valid correction even for one class of ships. The derivation of the correction for one ship would lead to increase of the error for the other hull forms. But keeping in mind, that the overall maximum scaling error observed in numerical analysis was 8% of the UKC (19cm in full scale), the necessity of a correction is questionable.

8 ACKNOWLEDGEMENTS

The authors gratefully acknowledge the help of the research group of the Faculty of Mechanical Engineering and Naval Architecture of the University of Zagreb (H. Jasak, V. Vukcevic, I. Gatin) with the development of the computational method, used in the present study. The computational resources were provided by the Deutsche Forschungsgemeinschaft (German Research Foundation) under the grant INST 264/113-1 FUGG.

9 REFERENCES

Anschau, P., 2016. LDV-Messungen an einem Containerschiffsmodell im Flachwasser. Report 349/4447 of Potsdam model basin (SVATech), Schiffbau-Versuchsanstalt, 2016.

Hoekstra, M., 2006. A RANS-based analysis tool for ducted propeller systems in open water condition. International Shipbuilding Progress, 53(3)

Jachowski, J. Assessment of ship squat in shallow water using CFD, Archives of Civil and Mechanical Engineering, Volume 8, Issue 1, 2008

ITTC, 2008. Recommended Procedures and Guidelines , Uncertainty Analysis in CFD Verification and Validation Methodology and Procedures, 7.5-0.3-01-01. http://ittc.info/media/4184/75-03-01-01.pdf.

ITTC, The ITTC Resistance Committee, 2011. Final report and recommendation to the 26th ITTC, volume I of Proceedings of 26th ITTC.

ITTC, 2017. Recommended Procedures and Guidelines, 1978 ITTC Performance Prediction Method,7.5–02-03–01.4

Linde, F., Ouashine, A., Huybrechts, N., Sergent, P., 2015. Numerical prediction of ship resistance and squat in confined waters. Proceedings of VI International Conference on Computational Methods for Coupled Problems in Science and Engineering.

Raven, H.C., Ploeg, A., Starke, A. R., 2008. Towards a CFD-based prediction of ship performance - Progress in predicting full-scale resistance and scale effects. RINA - International Conference - Marine CFD 2008 - Papers.

Shevchuk, I., Böttner C.-U., Kornev, N., 2016. Numerical analysis of the flow in the gap between the ship hull and the fairway bottom in extremely shallow water, Proceedings of the 4th MASHCON.

von Graefe A., el Moctar O., Shigunov V., Söding H., Zorn T., 2011. Squat Computations for Containerships in Restricted Waterways, Proceedings of the 2nd MASHCON

Vukcevic, V., 2016. Numerical Modelling of Coupled Potential and Viscous Flow for Marine Applications. PhD thesis, University of Zagreb, 2016.

10 AUTHORS' BIOGRAPHY

Ivan Shevchuk works at Hamburg University of Technology as a research engineer on the field of hydrodynamics and computational fluid dynamics. He holds a diploma and a PhD degree in Naval Architecture

Carl-Uwe Böttner currently works as a research engineer with the Federal Waterways Engineering and Research Institute (BAW) in Hamburg on the fields of ship dynamics and ship handling simulation. He is responsible for consulting the authorities in terms of ship handling simulation.

Nikolai Kornev is the head of the chair of modelling and simulation at the University of Rostock.

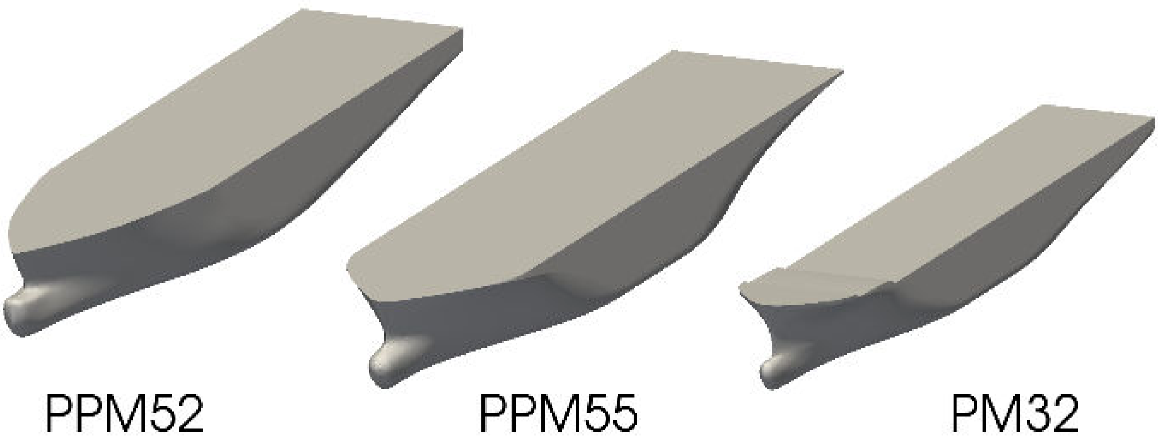

Figure 1. Considered hull forms, I

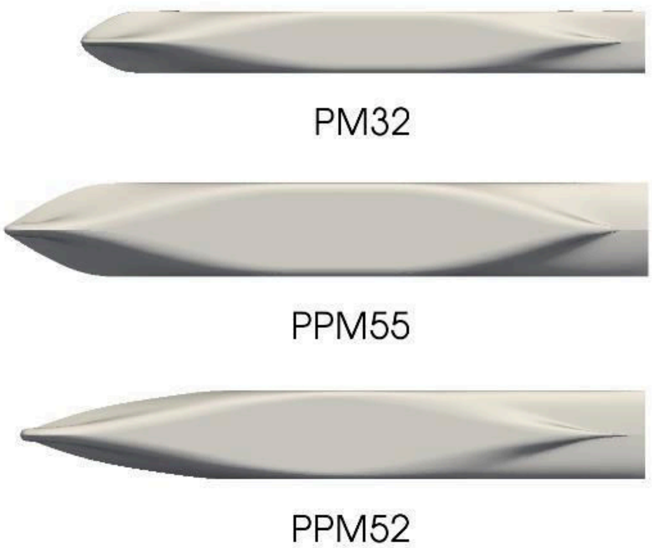

Figure 2. Considered hull forms, II

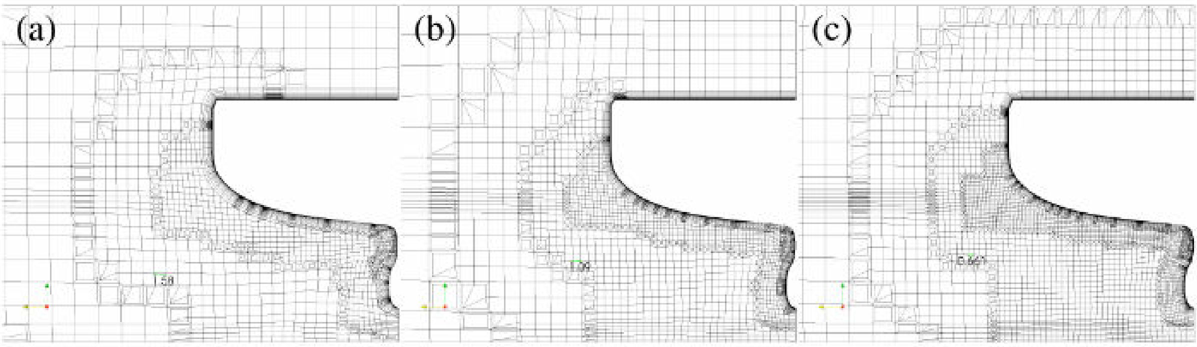

Figure 3. Slices of the computational mesh at the ship stern (a) –coarse, (b) –medium, (c) - fine

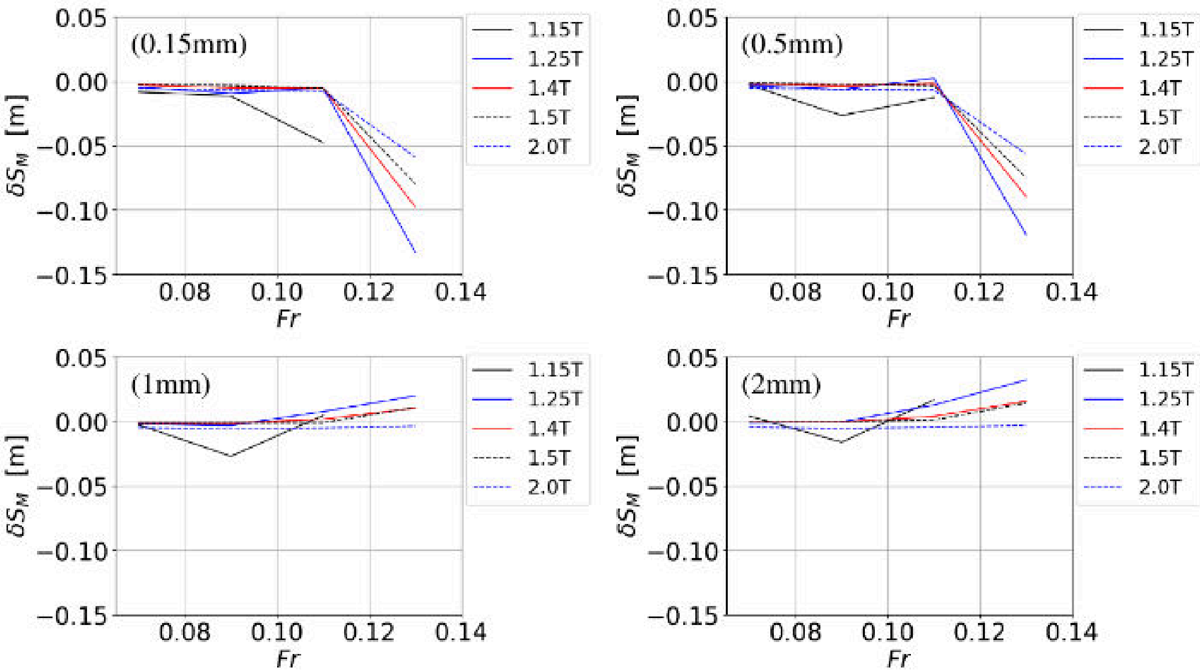

Figure 4. δS_M for different sand roughnesses, PPM55

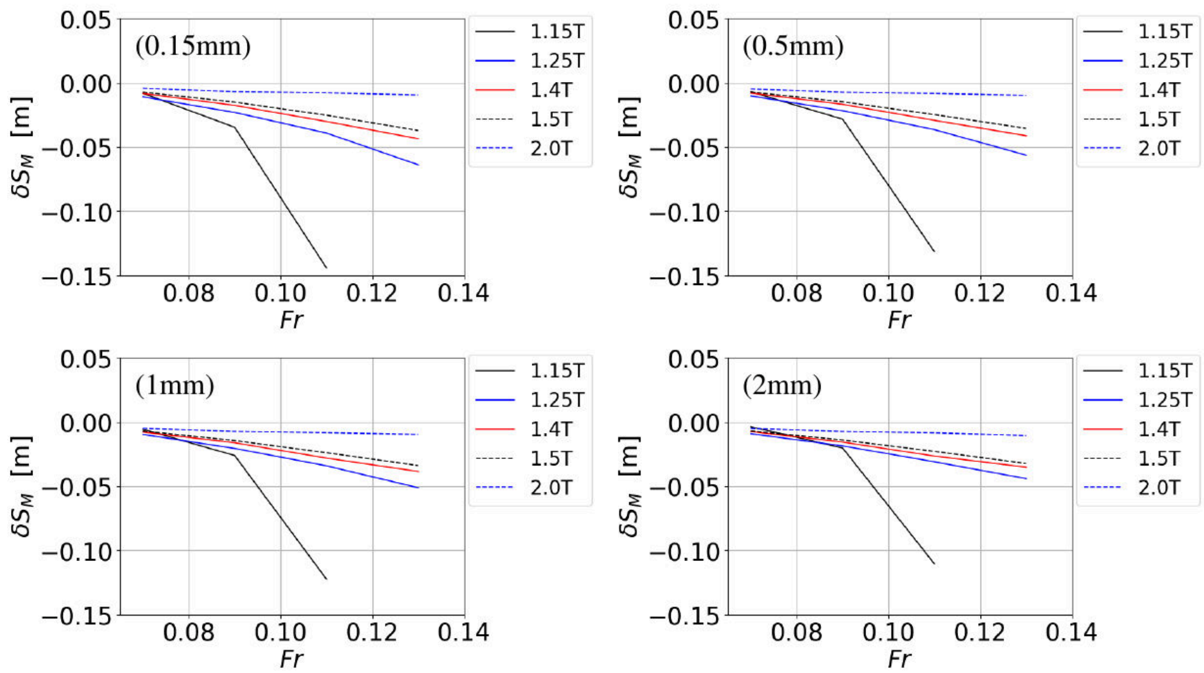

Figure 5. δS_M for different sand roughnesses, PPM52

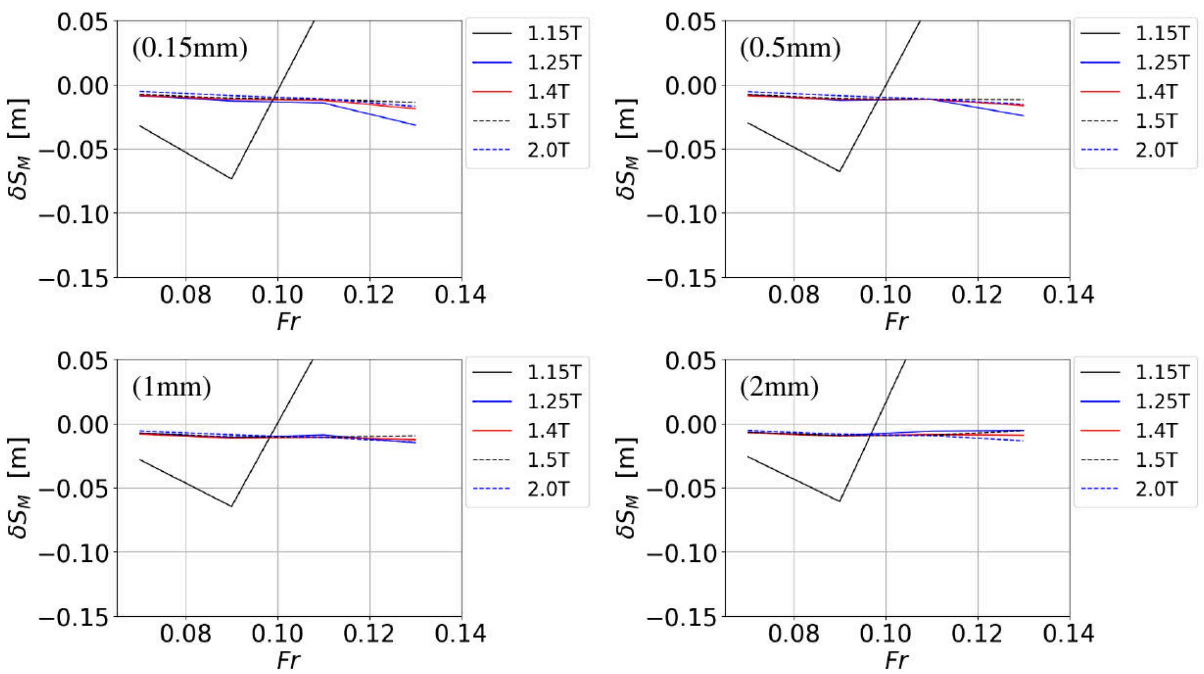

Figure 6. δS_M for different sand roughnesses, PM32

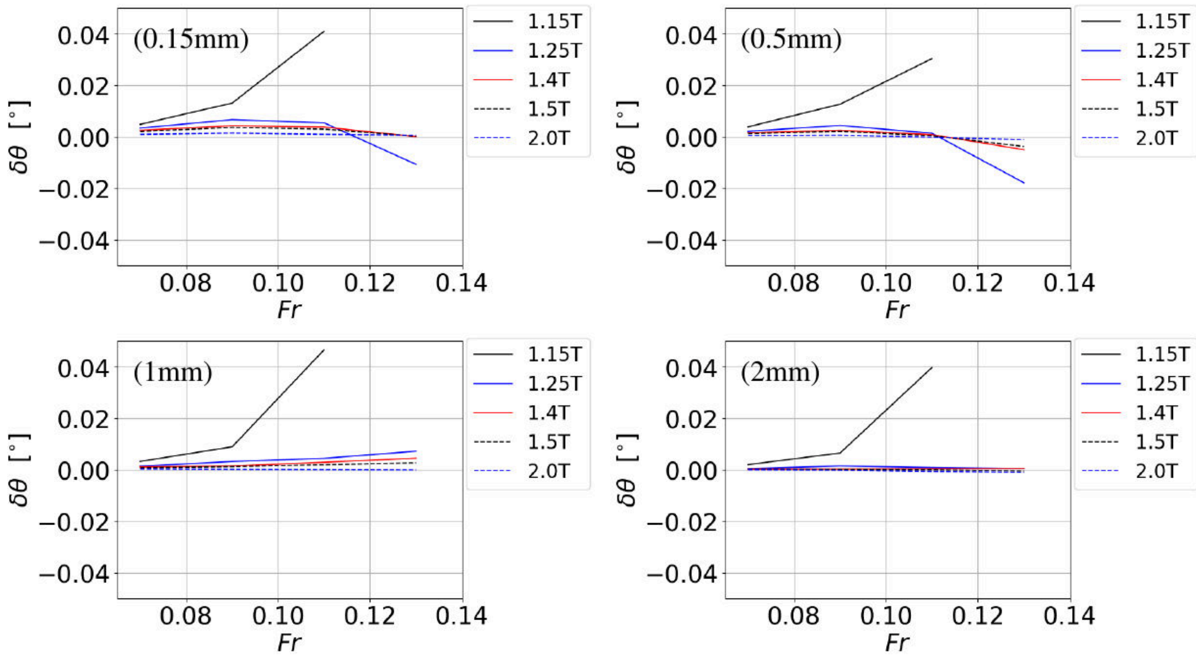

Figure 7. $\delta\theta$ **for different sand roughnesses, PPM55**

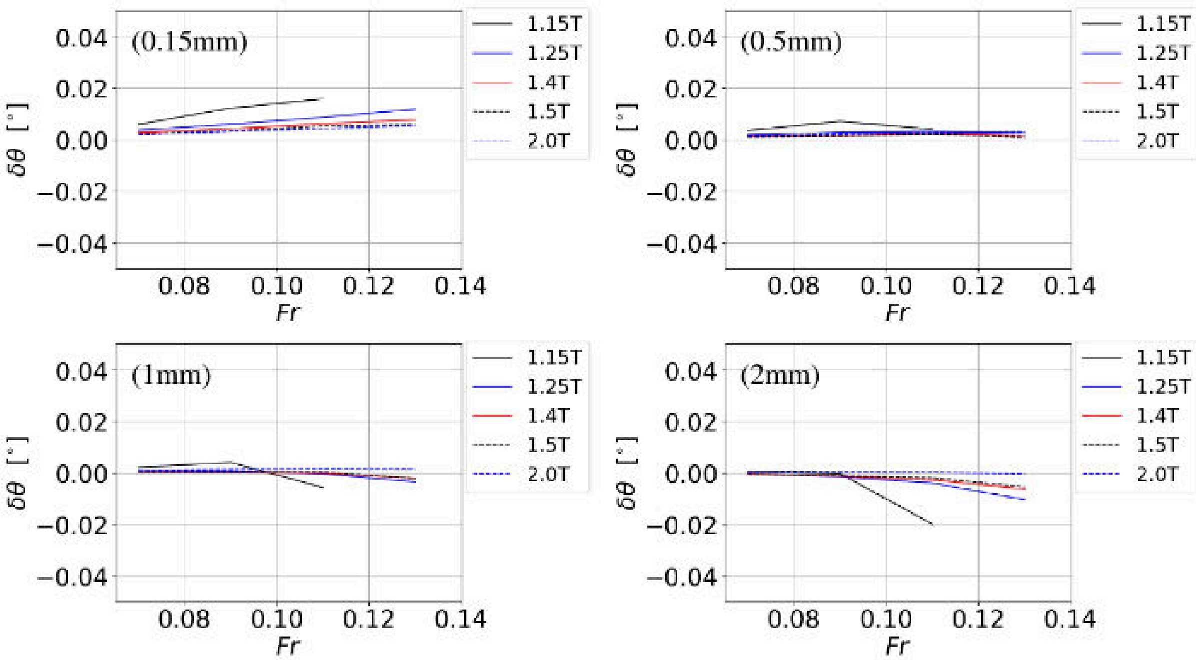

Figure 8. $\delta\theta$ **for different sand roughnesses, PPM52**

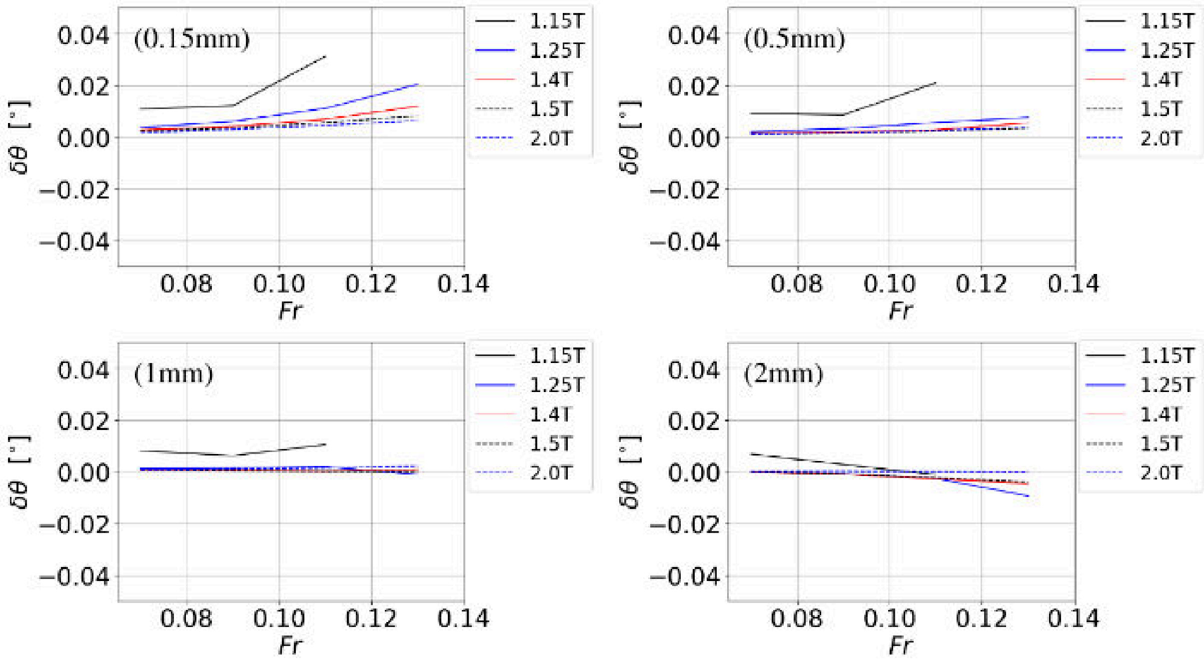

Figure 9. $\delta\theta$ **for different sand roughnesses, PM32**

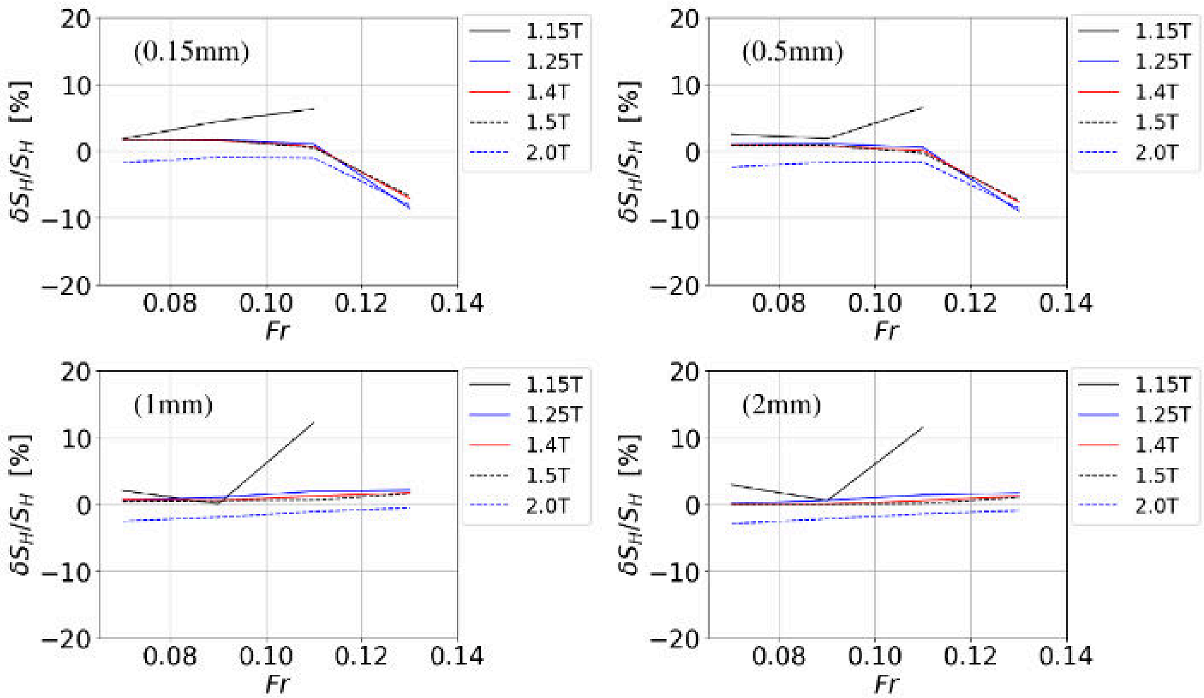

Figure 10. δS_H**(in % of** S_H^{ship}**) for different sand roughnesses, PPM55**

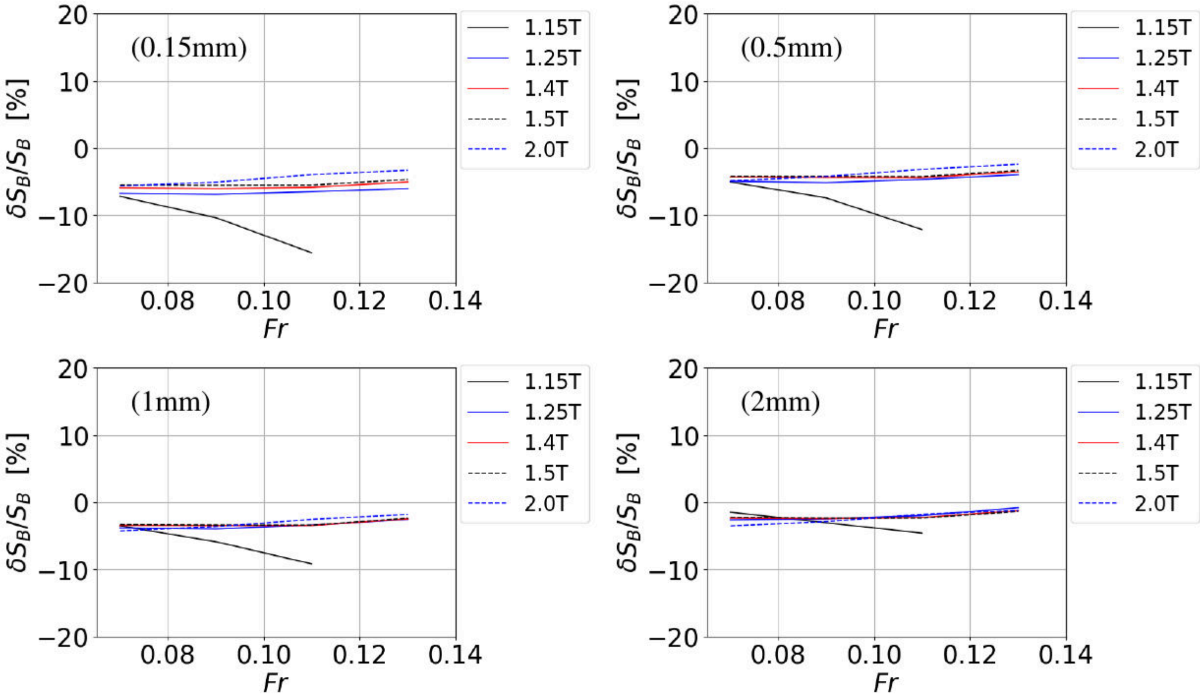

Figure 11. δS_B**(in % of** S_B^{ship}**) for different sand roughnesses, PPM52**

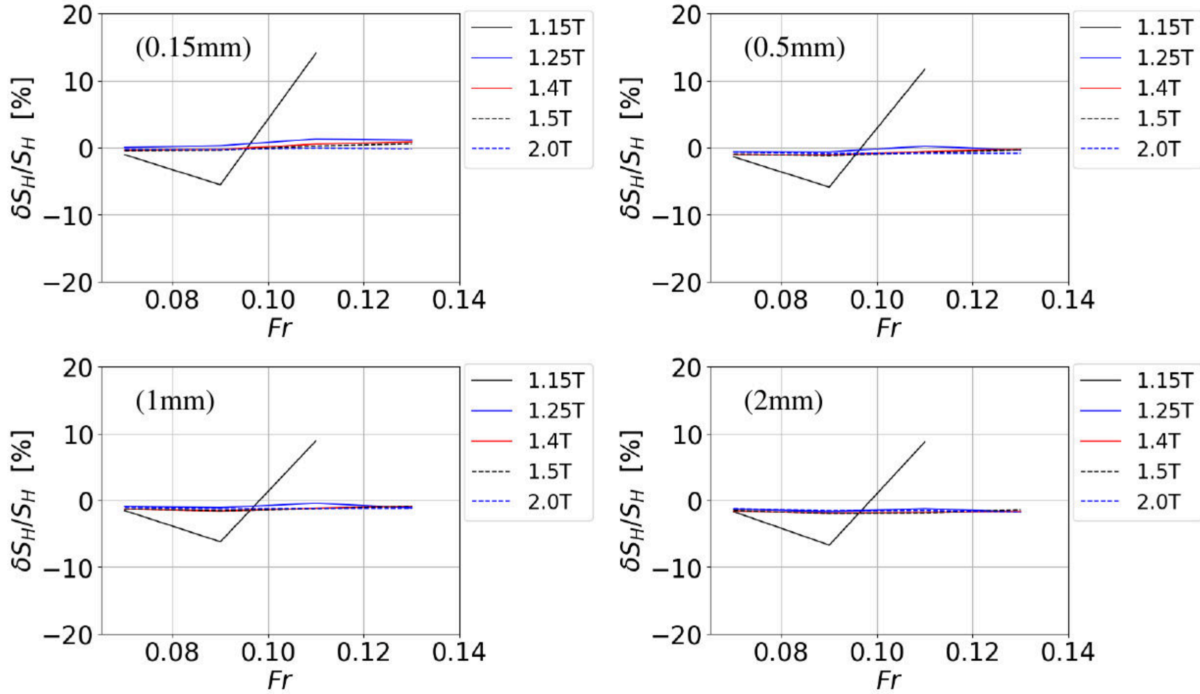

Figure 12. δS_H**(in % of** S_H^{ship}**) for different sand roughnesses, PM32**

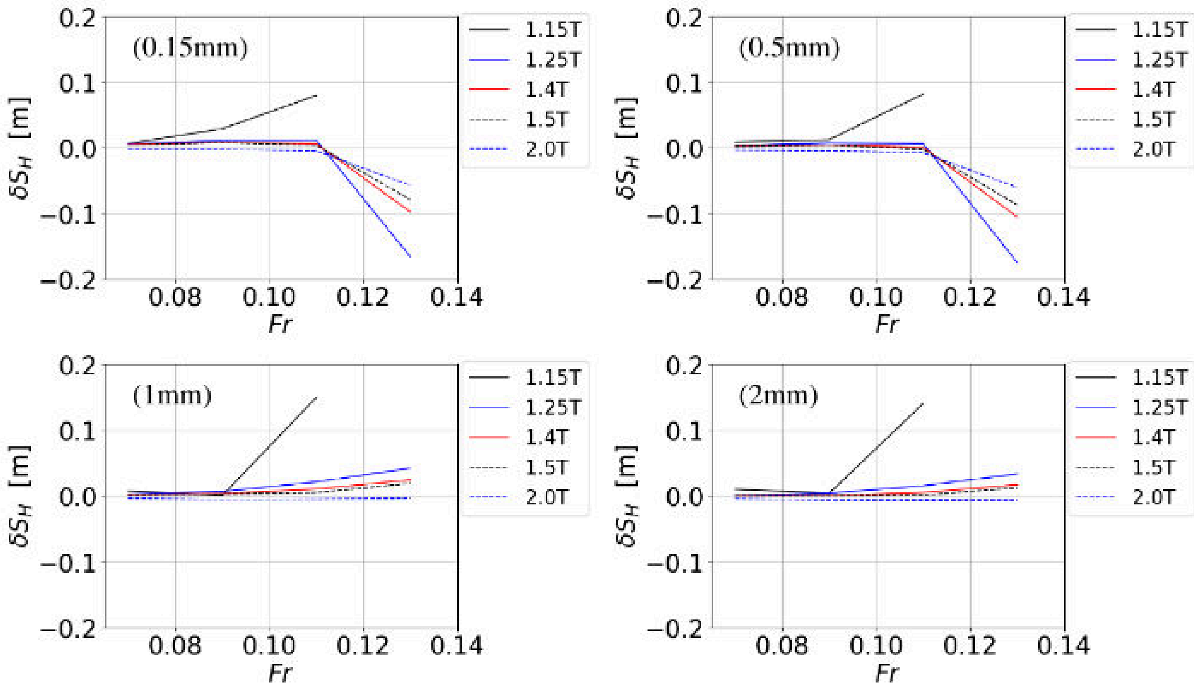

Figure 13. δS_H(in m) for different sand roughnesses, PPM55

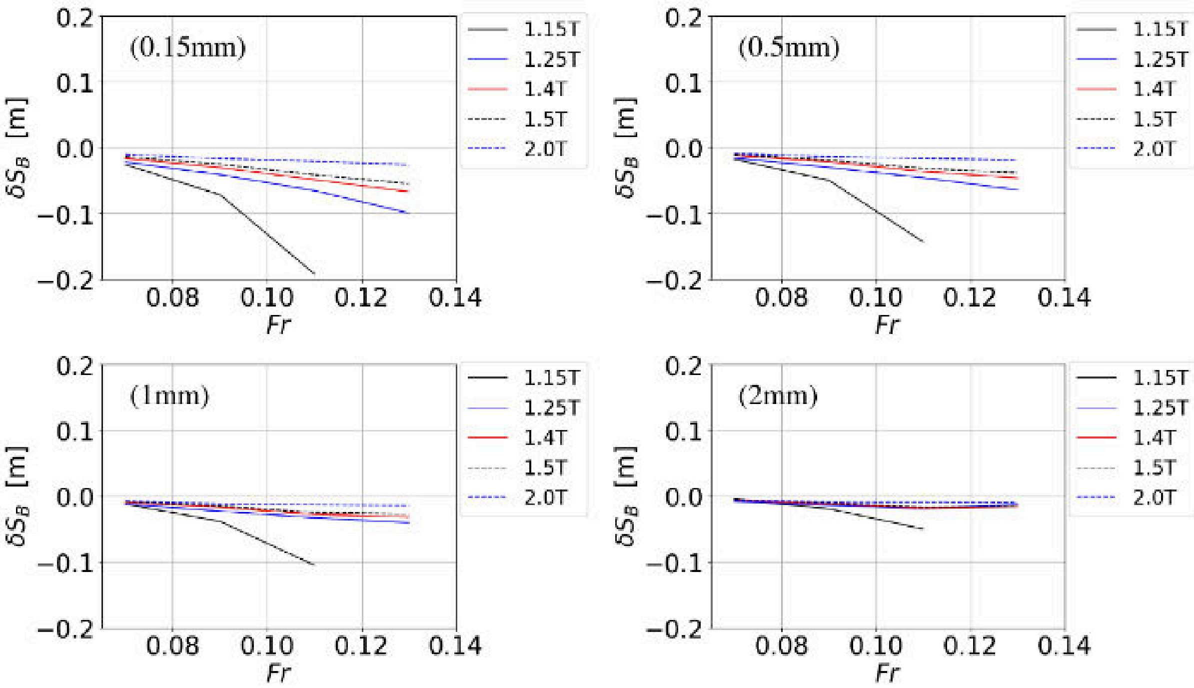

Figure 14. δS_B(in m) for different sand roughnesses, PPM52

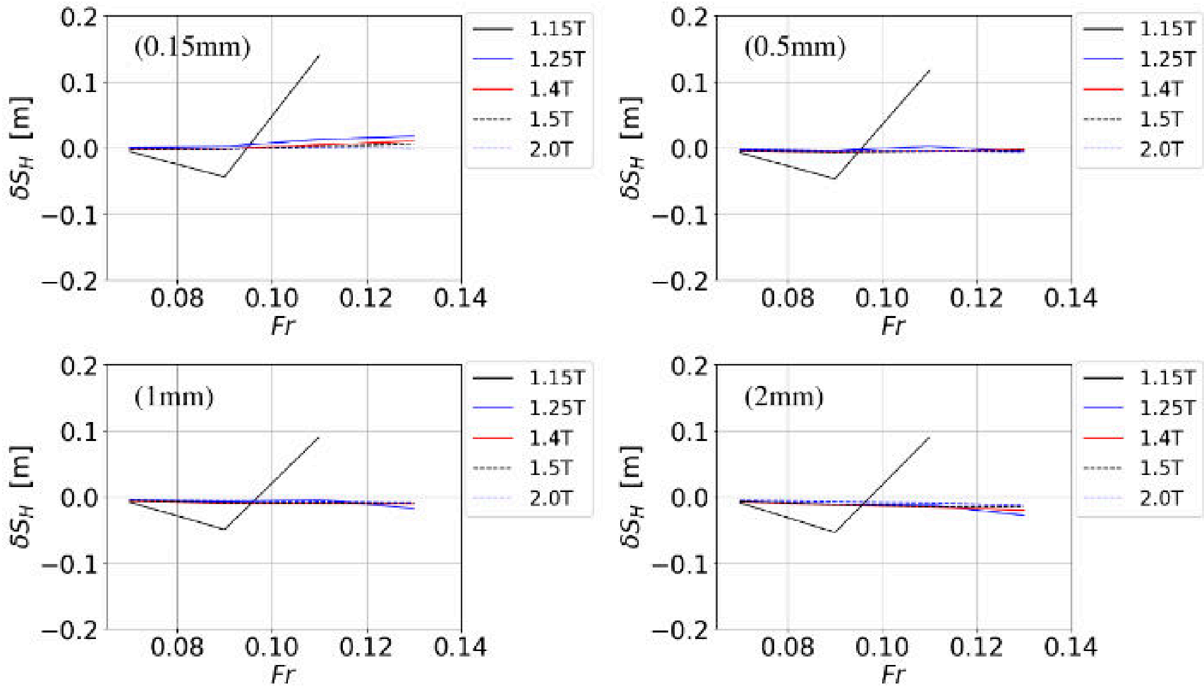

Figure 15. δS_H**(in m) for different sand roughnesses, PM32**

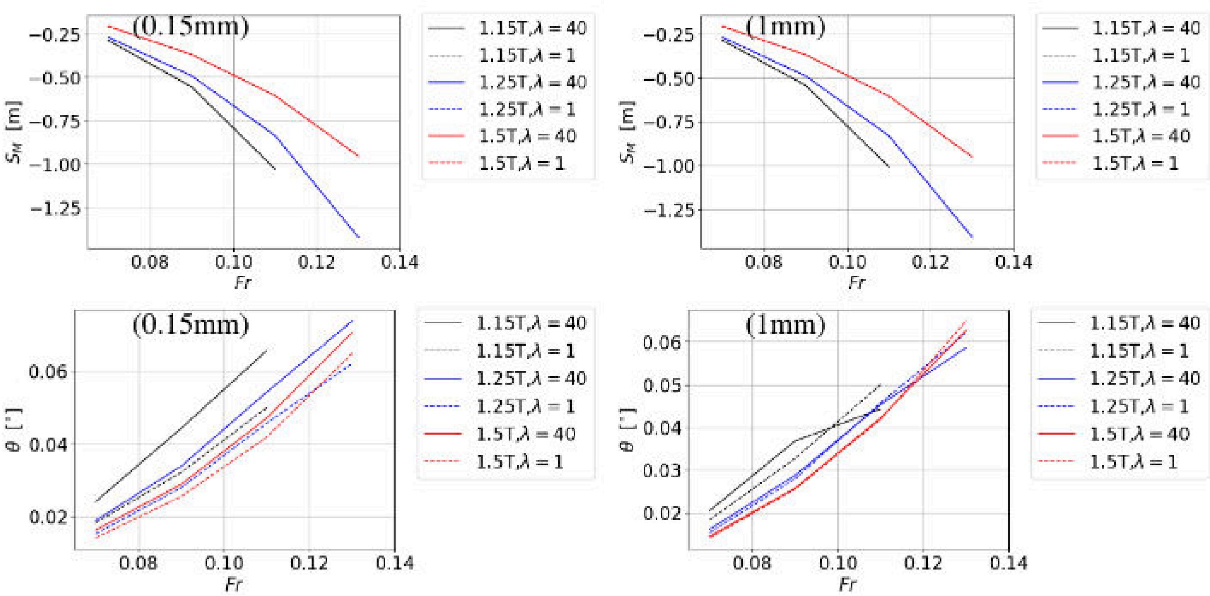

Figure 16. Comparison of the sinkage at midship and trim angle between the model scale and the full scale for two values of the sand roughness, PPM52