

Vorwort (Hrsg.)

Die Küstengebiete der Erde sind die bevorzugten Siedlungsräume der Menschheit. Die Siedlungsdichte ist hier besonders hoch, aber auch die Infrastruktur und die landwirtschaftliche Nutzung konzentrieren sich besonders in den flachen Niederungszonen der Küstengebiete. Gleichzeitig unterliegen fast alle Lockergesteinsküsten einer zunehmenden Erosion, die zum großen Teil ursächlich auf den steigenden Meeresspiegel zurückzuführen ist. Aber auch bauliche Eingriffe in den Flussregionen und Küstenschutzmaßnahmen stellen häufig eine Ursache für eine regionale Veränderung der Sedimentverfrachtung dar. Was an einer Stelle dem Küstenschutz dient kann an anderer Stelle negative Folgen mit sich bringen, so dass Küstenschutzmaßnahmen wissenschaftlich und ingenieurtechnisch mit besonderer Weitsicht begründet sein müssen.

Die Bevölkerungszunahme, die Verstädterung und die Konzentration von Werten in diesen Regionen rücken in Kombination mit einem wahrscheinlich weiter beschleunigt ansteigenden Meeresspiegel die konkurrierenden Nutzungsansprüche stärker in das Bewusstsein und wecken ein steigendes Bedürfnis nach Schutzeinrichtungen. Die Deltas der großen Flüsse stellen dabei die am meisten vom Meeresspiegelanstieg betroffenen Regionen dar. Dies gilt insbesondere auch für das Nildelta. Aus dieser Sicht heraus sind möglichst einfache, kostengünstige und umweltverträgliche Schutzmaßnahmen gefragt, die bei der Verteidigung der Küstenlinie helfen können. Langfristig sind solche Maßnahmen in ein integriertes KüstenZonenManagement einzubinden. Ägypten ist gerade dabei sich auch von der wissenschaftlichen Seite her mit diesen Problemen und möglichen Lösungsansätzen zu beschäftigen. Die vorliegende Dissertation soll hierzu einen Beitrag leisten.

Wuppertal, Dezember 2011

Andreas Schlenkhoff



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WAVE INTERACTION WITH VERTICAL SLOTTED WALLS
AS A PERMEABLE BREAKWATER

Vom Fachbereich D (Abteilung Bauingenieurwesen)
der Bergischen Universität Wuppertal

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M. Sc. Hany Gomaa Ibrahim Ahmed
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Erster Gutachter: Univ.-Prof. Dr.-Ing. Andreas SCHLENKHOFF
LuFG Wasserwirtschaft und Wasserbau
Bergische Universität Wuppertal

Zweiter Gutachter: Univ.-Prof. Dr.-Ing. habil. Torsten SCHLURMANN
Franzius-Institut für Wasserbau und Küsteningenieurwesen
Leibniz Universität Hannover

Vorsitzender: Univ.-Prof. Dr.-Ing. Matthias PULSFORT
LuFG Geotechnik
Bergische Universität Wuppertal

Weitere Mitglieder: Univ.-Prof. Dr.-Ing. habil. Wolfhard ZAHLTEN
LuG Baumechanik und numerische Methoden
Bergische Universität Wuppertal
Obering. Dr.-Ing. Mario OERTEL
LuFG Wasserwirtschaft und Wasserbau
Bergische Universität Wuppertal

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Hany Ahmed

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Abstract

The development of coastal areas depends on shore protection against waves and currents. Solid breakwaters are commonly used along shorelines, but they are often unsuitable due to environmental impacts. Permeable breakwaters like rows of piles have been suggested as a more environmentally friendly alternative, but the performance of piles alone has been proven as too weak. Breakwaters with impermeable skirts in combination with piles are assumed to perform better. However, wave-structure-interaction and flow behavior of this type are more complicated, but have to be analyzed before designing.

The objective of the present dissertation thesis is to describe the flow behavior and the hydraulic performance of this kind of permeable breakwaters. A numerical model has been developed based on an Eigen function expansion method for wave interaction with a single and a double vertical slotted wall. Experimental tests have been conducted on a model scale of 1 to 25 to validate the numerical model and to assess the performance characteristics of the reflection (CR), transmission (CT) and energy losses (CE). Additional, experimental tests have been conducted to measure and analyze the velocity distribution in front and behind of the vertical slotted wall and to understand the pattern that dissipates wave energy.

To fulfill the above-mentioned objectives, this thesis is divided into the following Chapters: Chapter 1 gives an introduction into the problem. Chapter 2 is dealing with the state of the art and an extensive literature review. A numerical model based on Eigen function expansion is described in Chapter 3. The numerical model is suitable to determine the wave interaction with single or double vertical slotted wall breakwaters. Furthermore, Stokes second-order wave theory has been compared to the linear wave theory assumption. In Chapter 4, a series of experimental tests are shown, which have been conducted in the wave flume of the University of Wuppertal. The set-up and the measurement devices are explained. Additional, attention has been given to the measurement of the velocities via PIV. The results have been discussed and analyzed with emphasis on the interaction of waves with the

vertical slotted walls. In Chapter 5, the results of the numerical model are compared with previous studies and the experimental work of this study. Chapter 6 closes with a summary, concluding remarks, recommendations and suggestions for future studies. The major results from this study are the following:

- The numerical model has been validated by comparisons with previous studies and experimental results of this study. The agreement is generally satisfying.
- The degree of target protection can be achieved through a combination of permeability area and its location.
- The coefficient of friction f and the coefficient of porosity ε have significant influence on CR , CT and CE of the permeable breakwaters, while the influence of added mass coefficient cm is low and can be neglected for this configuration.
- For the case of double walls, the second wall should be constructed at a distance of an uneven multiple of a quarter of the wavelength ($0.25 L$, $0.75 L$ and $1.25 L$). This position can increase the dissipation of the energy up to 40 % than a single wall.
- PIV measurements can be used in the laboratory for measuring the co-existing and transmitted waves and to visualize the wave interaction with a permeable breakwater. The achievable accuracy of PIV measurement within this set-up is a function of the relative time increment $\delta t/T$.

Finally, it is recommended to use vertical slotted walls as breakwaters for the protection against waves, whenever it is possible. The progressively decreasing depth of the permeability part of the wall can be used to minimize the transmission of wave energy. For double rows of vertical slotted walls, the spacing between rows should be an uneven multiple of a quarter of the wavelength.

Deutsche Zusammenfassung

Die weitere Entwicklung von Küstenregionen steht in engem Zusammenhang mit den Möglichkeiten, geeignete Schutzmaßnahmen gegen Wellen und Strömung zu schaffen. Üblicherweise werden für diesen Zweck massive, undurchlässige Bauwerksstrukturen gebaut, die aber wegen gerade dieser Eigenschaften erhebliche negative Nebeneffekte für die Umwelt mit sich bringen. Durchlässige Wellenbrecher, wie zum Beispiel auf Lücke gesetzte Pfahlreihen, werden zwar als umweltfreundlicher eingestuft, erreichen aber häufig nicht die gewünschte Schutzwirkung. Solche Wellenbrecher können allerdings in Kombination mit undurchlässigen Schürzen eine wesentlich bessere Wirkung entfalten. Die hydrodynamischen Verhältnisse der Um- und Durchströmung sowie die Energieumwandlung durch die Interaktion zwischen Wellen und Bauwerk werden sehr komplex, müssen aber für die angemessene Dimensionierung des Bauwerks bekannt sein.

Ein Ziel der vorgelegten Dissertation ist die Beschreibung der Strömungseigenschaften und der Wellen-Bauwerk-Interaktion. Dafür wird ein numerisches Modell genutzt, welches die Methode der Entwicklung nach Eigenfunktionen verwendet. Als eine typische Bauwerkskonfiguration wird eine bzw. mehrere hintereinander liegende, geschlitzte Wände mit Schürzen gewählt. Die Validierung des Modellansatzes wird mithilfe von Literaturdaten und physikalischen Modellversuchen geführt. Die eigenen Versuche werden in einem Maßstab 1 zu 25 in der Wellenrinne der Bergischen Universität Wuppertal gefahren. Ziel der Versuche ist die Bestimmung der hydrodynamischen Parameter wie Reflektion, Transmission und Energiedissipation. Weiterhin wird das Geschwindigkeitsfeld vor und hinter dem Bauwerk mittels PIV untersucht und anhand der Wirbelstrukturen beschrieben.

Die Dissertation gliedert sich wie folgt: Kapitel 1 gibt eine Einführung in die allgemeine Problematik. Kapitel 2 spiegelt den Stand des Wissens wider und gibt eine ausführliche Literaturübersicht. Das numerische Modell, basierend auf der Entwicklung von Eigenfunktionen, wird in Kapitel 3 beschrieben. Ziele des

numerischen Modells sind die Bestimmung der hydrodynamischen Parameter und die Beschreibung der Welleninteraktion mit dem Bauwerk. Weiterhin wird das zunächst entwickelte Modell, welches sich auf die lineare Wellentheorie stützt, nach der Stoke'schen Second Order Theorie erweitert, um auch im Grenzbereich längerer Wellen noch Aussagen treffen zu können. In Kapitel 4 werden die Versuchsreihen, die in der Wellenrinne der Bergischen Universität Wuppertal durchgeführt wurden, beschrieben. Dabei werden der gewählte Versuchsaufbau und die eingesetzte Messtechnik erläutert. Zusätzlich werden die Geschwindigkeitsmessungen, die mit einem PIV System durchgeführt worden sind, hinsichtlich der Messgenauigkeit optimiert. Die Messtechnik und die daraus ableitbaren Ergebnisse werden diskutiert. In Kapitel 5 werden die Ergebnisse der numerischen Simulation den Ergebnissen der Versuchsreihen und zusätzlich den Ergebnissen von verfügbaren Untersuchungen aus der Literatur gegenübergestellt, diskutiert und bewertet. Die wichtigsten Ergebnisse der Dissertation werden in Kapitel 6 noch einmal zusammengefasst und zusammen mit Empfehlungen und einem Ausblick bewertet.

Die wichtigsten Ergebnisse dieser Dissertation sind:

- Das entwickelte numerische Modell ist gut geeignet, die hydrodynamische Wirkungsweise des untersuchten Bauwerkstyps zu beschreiben.
- Das untersuchte Bauwerk, bestehend aus einer Kombination von einer oder mehreren Pfahlreihen und undurchlässigen Schürzen, kann die gewünschte Wirkung durch eine geeignete Wahl und Anordnung der durchlässigen Bauwerksteile erreichen.
- Bei der numerischen Simulation haben der Reibungskoeffizient und die Porosität den bestimmenden Einfluss auf die Bauwerkswirkung und damit auf die Reflektion, die Transmission und die Energiedissipation. Die sogenannte zusätzlich zu beschleunigende Masse (added mass), die im numerischen Modell ebenfalls berücksichtigt wird, hat hingegen nur einen unbedeutenden Einfluss.
- Für die Bauwerkskonfiguration mit zwei hintereinander liegenden geschlitzten Wänden zeigt sich, dass der Abstand der Wände im Verhältnis zur Wellenlänge einen erheblichen Einfluss auf die Gesamtwirkung ausübt.

Eine maximale Energiedissipation kann erwartet werden, wenn der Abstand zwischen den beiden Wänden ein ungerades Vielfaches einer viertel Wellenlänge beträgt ($0.25 L$, $0.75 L$, $1.25 L$). Diese Anordnung erhöht die Energiedissipation um bis zu 40 %.

- PIV Messungen können im Labor den Erkenntnisgewinn über die Strömungsphänomene erheblich steigern. Die Unsicherheit bei der Bestimmung der Geschwindigkeit in einem stark instationären Strömungsfeld kann durch die geeignete Wahl des relativen Zeitschrittes $\delta t / T$ minimiert werden.

Abschließend kann der untersuchte Bauwerkstyp als gut geeignet für Schutzmaßnahmen gegen Wellen eingestuft werden. Wegen der gut abstimmbaren Wirkungsweise und den geringeren Umweltbeeinträchtigungen sollten daher vorzugsweise geschlitzte Wände aus einer Kombination von Pfählen und Schürzen gewählt werden, wenn die Örtlichkeiten oder die Ansprüche an die Schutzwirkung es erlauben. Es sind allerdings weitere Untersuchungen für die Optimierung des Bauwerkstyps erforderlich.

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NOTATIONS

Symbol	Definition	Dimension
$2A$	Distance between the centers of two adjacent piles	L
$A_m, A_{im}, A_{fm}, A_{2m}, A_{3m}$ and A_{4m}	Initially unknown coefficients	-
B	Total chamber width	L
C_C	Empirical contraction coefficient	-
C_d	Coefficient of discharge	-
CE	Energy losses coefficient	-
CR	Reflection coefficient	-
CT	Transmission coefficient	-
D	Diameter of pile, $du+dm$	L
F	Frequency	Hz
F_o	Hydrodynamic forces	F
KC	Keulegan-Carpenter Number	-
L	Wave length	L
M	Maximum overturning moment	$F.L$
N	Finite number of terms	-
Re	Real part of a complex value	-
Rn	Reynolds Number	-
R_u	Run-up	L
T	Wave period	T
X, Y, Z	Three dimensional axis	L
x_{12}, x_{13}	Distance between wave probes	L
a	Gap between piles	L
a_1, a_2, a_3	Wave amplitude of co-existing wave which is measured by Sensor 1, 2, 3 respectively.	L
a_t	Wave amplitude of transmitted wave which is measured by Sensor 4.	L

b	Breakwater width	L
cm	Added mass coefficient	-
cdm	Distance from the water surface to the center of the permeability part	L
d	Water depth	L
dm	Draft of permeable intermediate part	L
du	Draft of upper impermeable part	L
dw	Draft of lower impermeable part	L
e, exp	Exponential number (2.72)	-
f	Friction coefficient	-
g	Acceleration of gravity	LT^{-2}
h_i	Incident wave height	L
h_r	Reflected wave height	L
h_t	Transmitted wave height	L
i	Imaginary number ($\sqrt{-1}$)	-
k	Incident wave number	L^{-1}
l	Length of the jet flowing through the gap between piles	L
n, m	Numbers	-
p, q	Limits of integration	-
s	Inertia coefficient	-
t	Time	T
z	Distance from the water surface to the set point	L
ϕ_i	Incident wave potential	-
ϕ_{i1}	First-Order wave potential	-
ϕ_{i2}	Second-Order wave potential	-
$\phi, \phi_1, \phi_2, \phi_3$	Velocity potential	-
θ	Phase of wave	π

α	Head loss coefficient	-
β	Energy dissipation coefficient	-
$\delta^{-}, \delta_{\sigma}^{-}, \delta_{l\;mn}^{-}$	Integration formula	-
$\delta_{z\;mn}^{-}, \delta_{0l\;mn}^{-},$ $\delta_{02\;mn}^{-}$		
η, η_1, η_2	Wave elevation	L
ε	Porosity	-
λ	Half distance of the chamber width	L
μ_m	Evanescent wave numbers	L^{-1}
μ_0	Propagating wave numbers	
ν	Kinematics viscosity	$L^2\;T^{-1}$
π	3.14	-
π_1, π_2, π_3	Name of region	-
ρ	Water density	$FL^{-4}T^2$
ω	Angular wave frequency	T^{-1}