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Investigation on the evolution and propagation of waves in highly concentrated fluid

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1 Introduction

In the framework of an industry-funded research project in the Dead Sea, Israel, the evolution and propagation of waves in a fluid with high density (brine) was investigated. In general, the density as well as the viscosity of water is neglected in wave theories and run-up formulas due to the fact that fresh water at 20 °C exhibits a density of 1 t/m³ and a dynamic viscosity of 1x10^{-3} kg/(m s). Yet, it is unknown how significant changes of these parameters influence the sensitivity of wave propagation and wave run-up on sloping beaches. Hence, this project follows the scientific approach to study the behaviour of a fluid, i.e. brine, stemming from the Dead Sea (Israel) with a density of 1.23 t/m³ and a dynamic viscosity at 20 °C of 3.4x10^{-3} kg/(m s). In a newly constructed wave (twin) flume with two separated channels (see pictures in Fig. 1) wave kinematics and run-up of brine have been compared directly with fresh water wave kinematics and run-up.

Fig. 1: Wave flume construction as a twin flume with one wave paddle

In general, internal friction due to viscosity as well as energy dissipation due to wave breaking and bottom friction changes when brine is considered instead of fresh or regular sea water. The density and viscosity of brine yet differ by magnitudes from liquid properties of fresh or sea water. Most of the formulas at hand given e.g. in EurOtop (2007) base on an empirical fit of experimental results obtained for fresh or sea water. Here, the results of brine wave heights in contrast with fresh water wave heights are shown and finally brine wave run-up will be compared with formulas of Hunt (1959) and EurOtop (2007).

2 Physical model description

Fig. 2 shows the model set-up in the twin flume. Both channels have a width of 2 m, a length of 28 m and a maximum water depth of 1 m. Waves in both channels are generated by only one wave paddle operated in piston-type mode. One channel has been filled with brine and the parallel channel with fresh water. A smooth, impermeable slope of 1:20 was installed to investigate wave run-up. Wave heights have been measured with six wired wave gauges in the fresh water and with ultra sonic sensors in the brine.

Orbital velocities were measured by means of 3D velocity sensor in front of the slope and currents due to wave run-up were recorded by 2D velocity sensor mounted on the slope. The run-up height of waves was documented with image records and the thickness of the run-up tongue was measured with pressure sensors installed in the slope. In the beginning of the experimental phase, 24 reference tests with regular waves with fresh water have been performed in order to calibrate and verify equivalent test conditions in both channels of the flume.

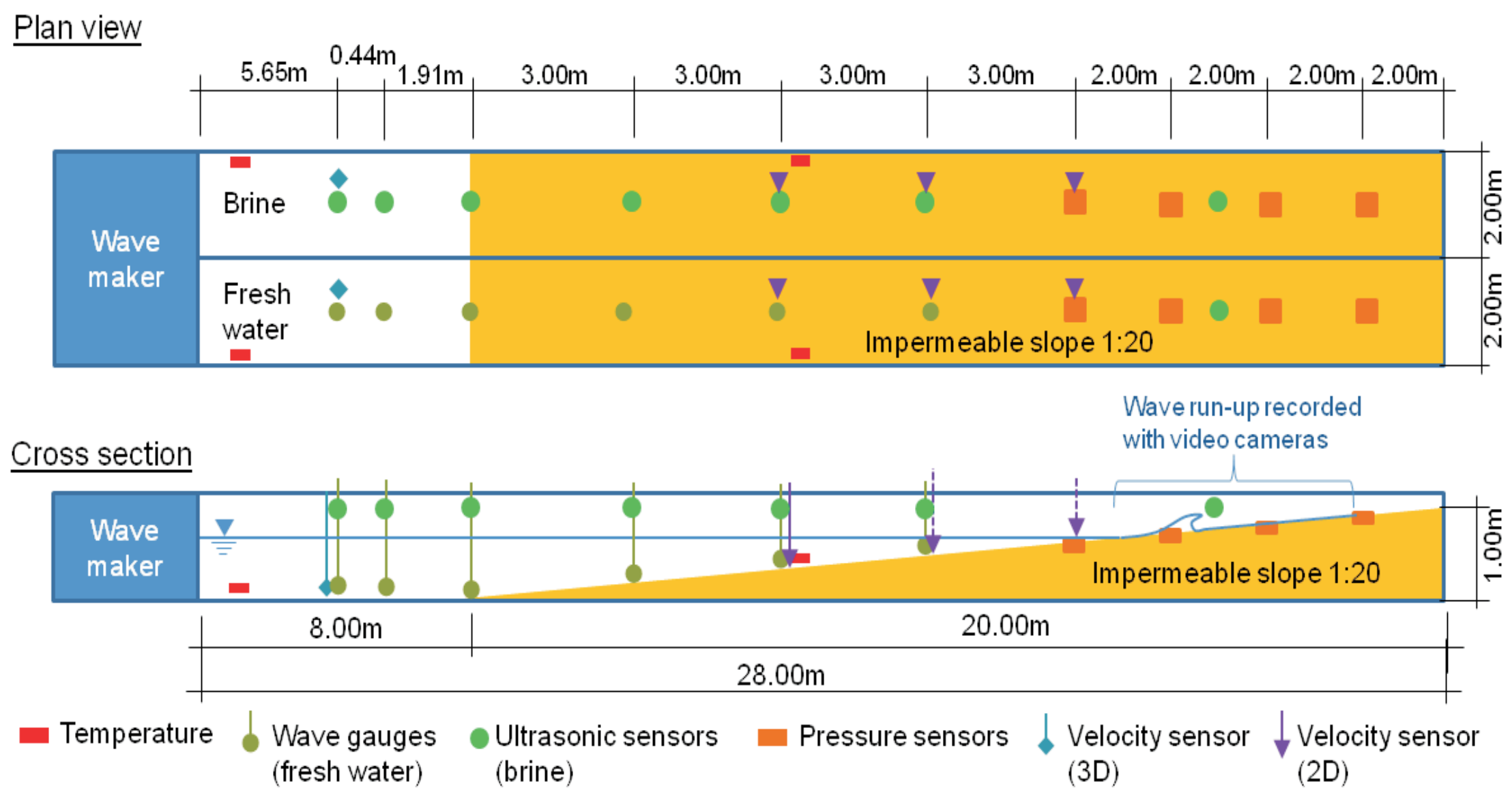

Fig. 2: Plan view (top) and cross section (bottom) of the physical model

Due to constructional limitations of the flume, the accuracy of the concrete slope construction as well as due to the accuracy of the measurement devices a relative deviation between run-up of left to right channel has been determined to 6.3%. Therefore, the run-up results of brine has been reduced with this percentage deviation.

After the preliminary tests, regular waves have been generated to obtain closer insight of the physical effects and processes. In the test matrix, wave heights varied from 0.1 to 0.3 m and wave periods from 0.8 to 3.2 s. With these conditions, the surf similarity parameter for the regular waves ranges between 0.16 and 0.63.

Therefore, that the viscosity depends on the temperature the whole test matrix was repeated for different temperatures at 18, 25, 30 and 35°C. Additionally, selected tests of the test matrix were also repeated in order to prove reproducibility. Altogether, 1116 tests for regular waves have been performed.

3 Test results

The correlation of the fresh water wave heights measured at the toe of the slope in the right channel (x-axis) and brine wave heights in the left channel (y-axis) in Fig. 3a shows that small wave heights of brine and freshwater generated in the flume are similar. In case of larger amplitudes, wave heights in brine seem to be higher in relation to fresh water. Analyzing the corresponding wave steepness as given in Fig. 3b fresh water and brine waves correlate and no clear tendency towards brine waves can be seen.

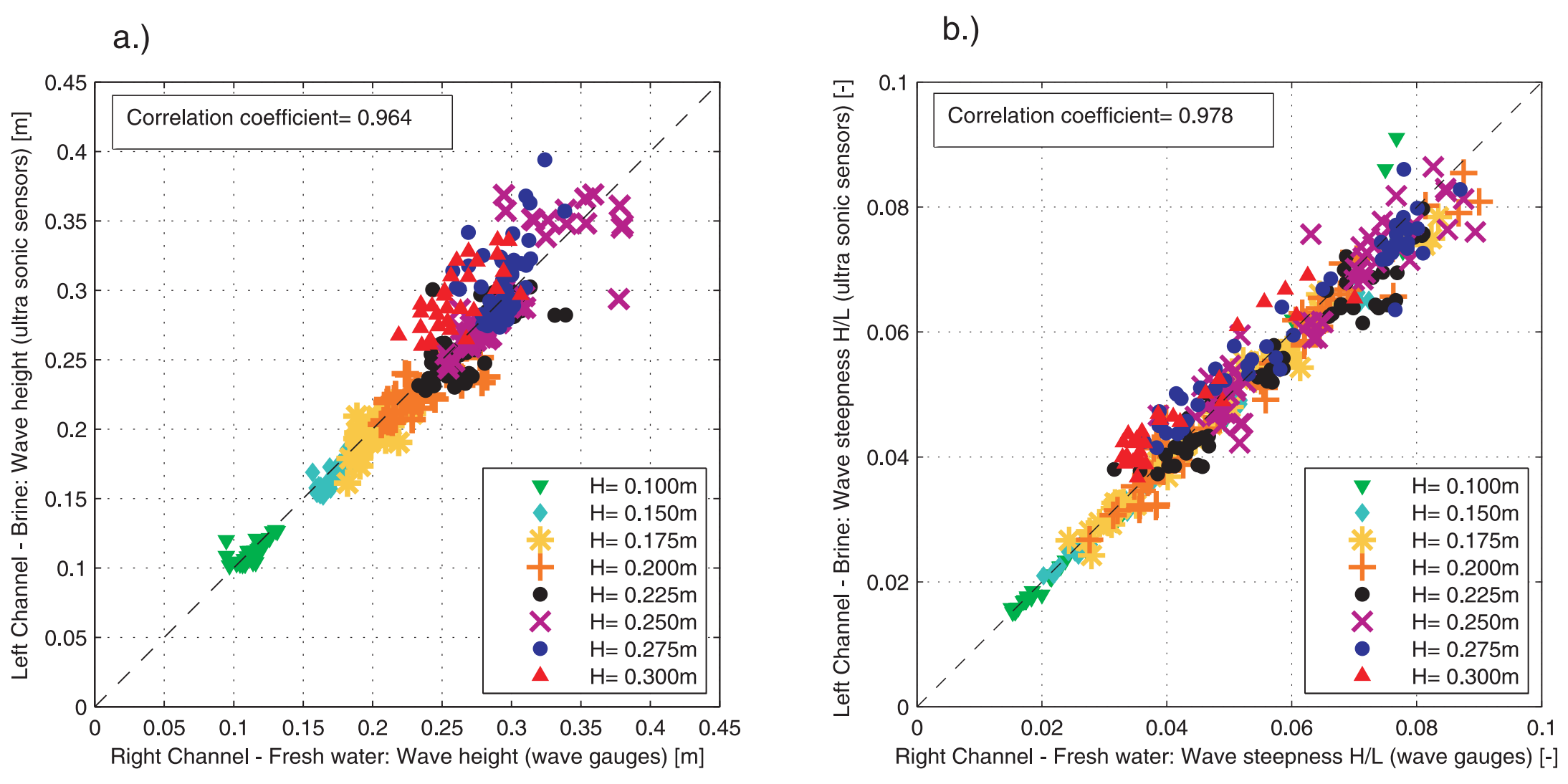

Fig. 3: Correlation of wave heights measured at the toe of the slope in the right channel (fresh water) and in the left channel (brine) (a.) and correlation of wave steepness of measured wave heights (b.)

In Fig. 4, results of maximum diagonal run-up $R_{d,max}$ of the total number of tests are given. It can be seen that the scattered data cloud shifts towards fresh water run-up for wave heights higher than 0.2m due to increasing ratio of H/d and increasing bottom influence.

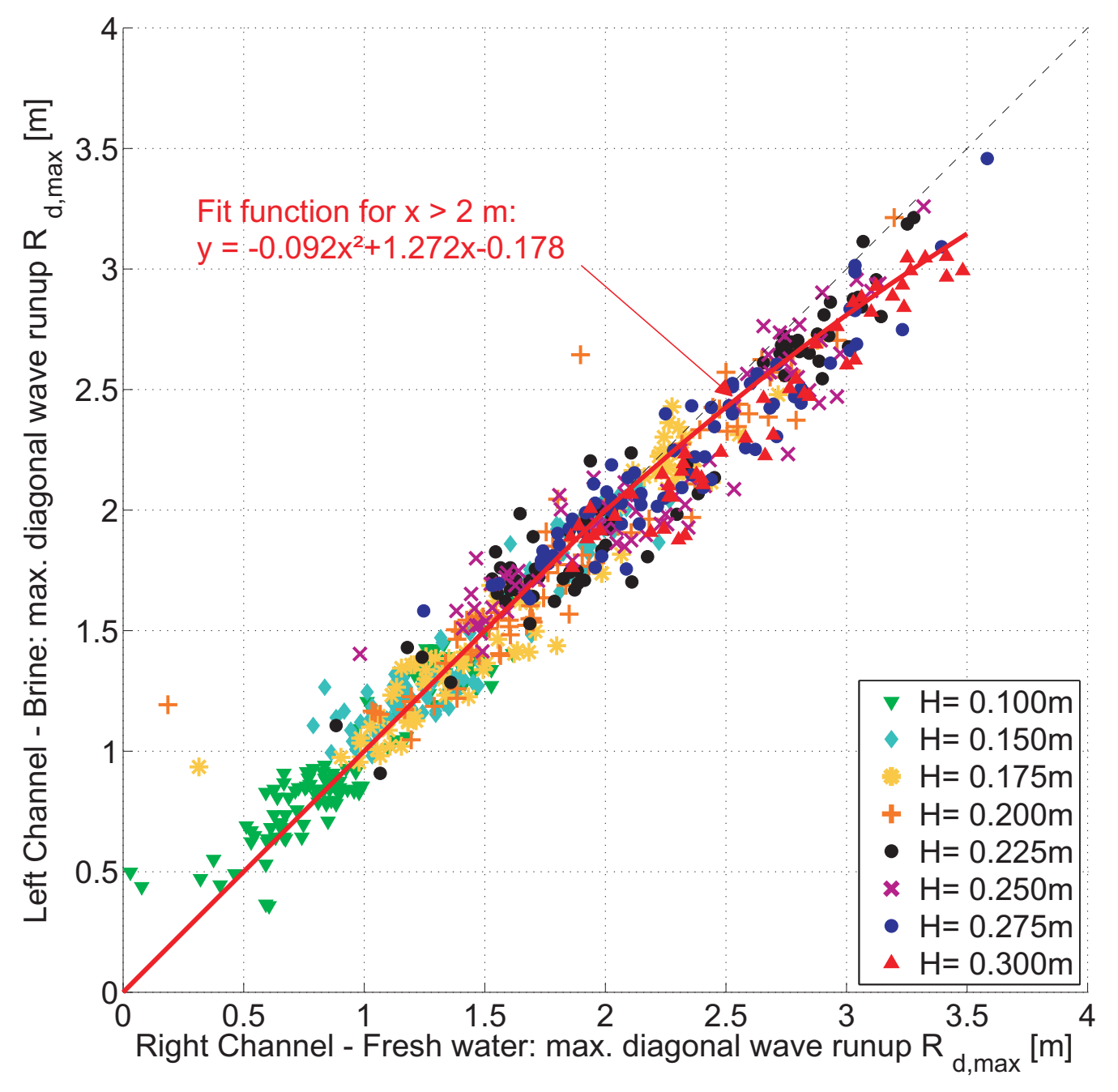

Fig. 4: Correlation of maximum fresh water wave run-up R_{max} in the right channel and brine wave run-up R_{max} in the left channel of the flume

From this figure, the conclusion can be drawn that on the basis of concise experimental means and under the consideration of its physical model uncertainties nearly no clear difference in brine and fresh water wave run-up could be determined for small wave heights (i.e. H < 0.2m) and a linear relationship can be adopted.

In case of higher wave heights (i.e. H > 0.2m) the relationship between brine and fresh water run-up can be described by a fit function:

$$y = -0.092x^2 + 1.272x - 0.178 \quad ; \quad x > 2m \qquad \text{[Eq. 1]}$$

Considering the increasing bottom influence in case of larger wave heights, Fig. 5 shows the results for the multiplication of maximum diagonal run-up $R_{d,max}$ with H/d which gives a linear relationship between brine and fresh water wave run-up.

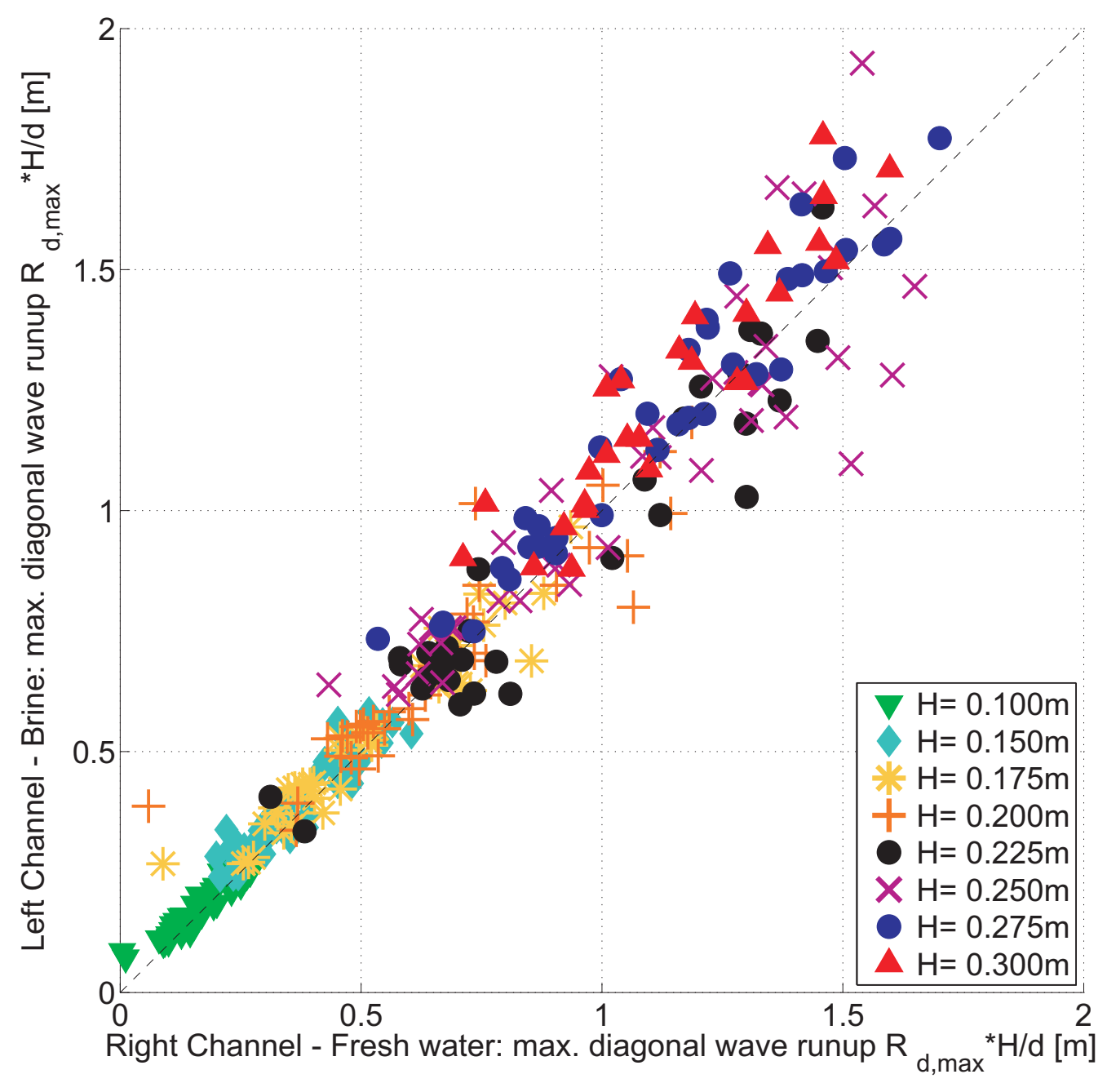

Fig. 5: Correlation of maximum wave run-up R_{max} multiplied with H/d for fresh water (Right channel) and brine (Left channel)

The results of maximum vertical run-up height R_{max} of brine for all testing temperatures 18°C to 35°C are given in Fig. 6 together with the formula for regular wave run-up (Eq. 2) developed by Hunt (1959) and EurOtop formula (2007) for wave spectra (Eq. 3):

$$\frac{R}{H_0} = \frac{\tan\beta}{\sqrt{H_0/L_0}} = \xi \quad ; \quad for\ 0.1 < \xi < 2.3 \qquad \text{[Eq. 2]}$$

$$\frac{R_{u2\%}}{H_{m0}} = 1.65 \cdot \gamma_b \cdot \gamma_f \cdot \gamma_\beta \cdot \xi_{m-1,0} \quad ; \quad for\ 0.5 < \gamma_\beta \cdot \xi_{m-1,0} < 8\ to\ 10 \qquad \text{[Eq. 3]}$$

where H_0 and L_0 are the deepwater wave height and wave length, β is the beach slope, ξ is the surf similarity parameter, γ_b, γ_f, γ_β are factors for berm, slope roughness and oblique wave attack.

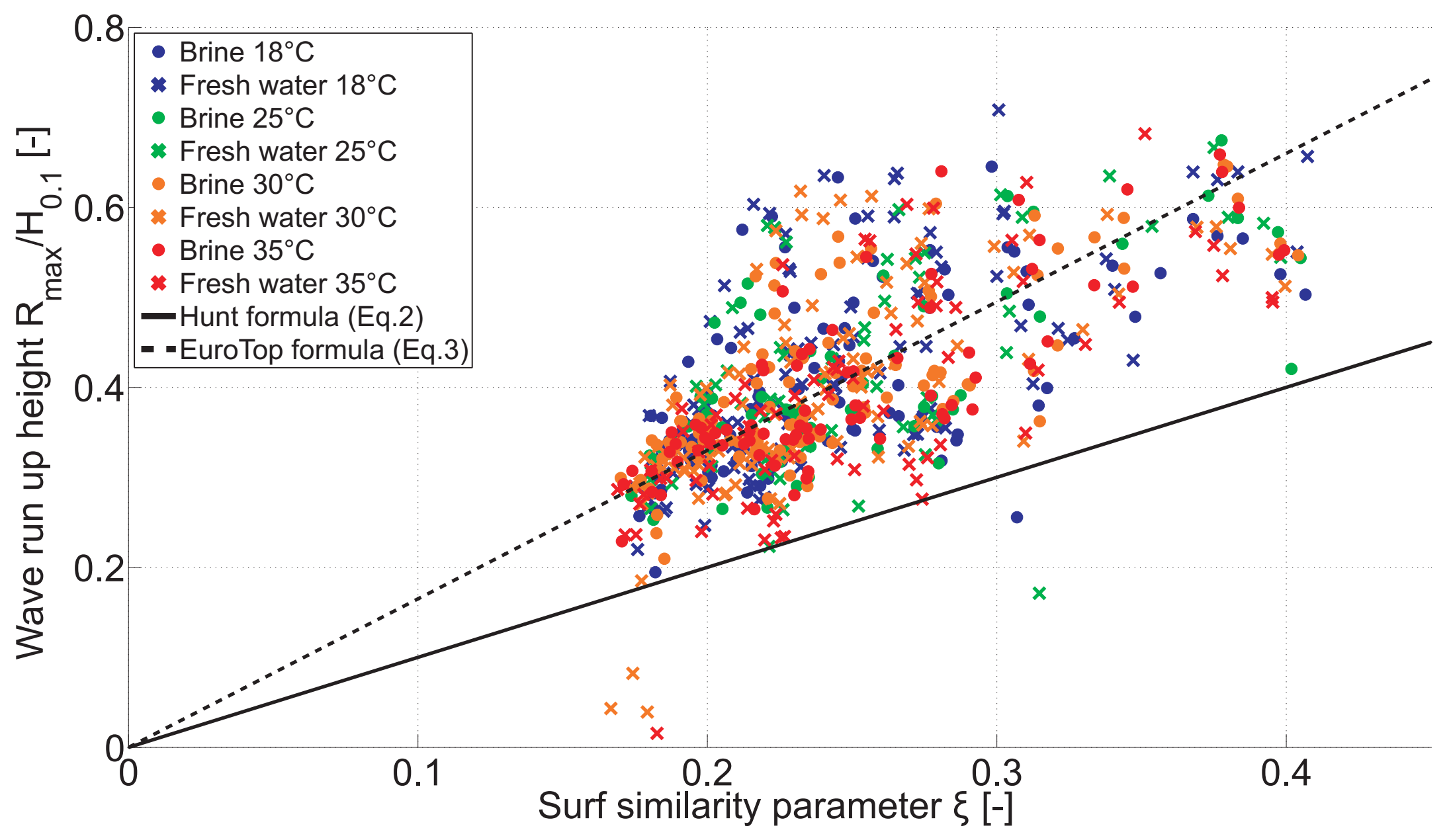

Fig. 6: Normalized max. wave run-up height $R_{max}/H_{0.1}$ of brine (dots) and fresh water (crosses) depending on the surf similarity parameter ξ for different testing temperatures

From these results in Fig. 6, brine and fresh water run-up differ only slightly for all testing temperatures. It can be seen that the Hunt formula (Eq. 2) underestimates both brine and fresh water run-up. EurOtop formula (Eq. 3) seems to be a linear fit for the brine run-up. With these results, the conclusion can be drawn that the application of EurOtop formula (Eq. 3) is suitable for brine with the given density and viscosity and for the tested wave parameter.

4 Outlook

In the next research steps, the slope in the twin flume will be increased and the run-up results will be compared with the results presented in this poster. Furthermore, a detailed analysis considering energy transport and losses due to the high density and viscosity as well as an analysis of wave kinematics and wave propagation, shoaling effect and wave breaking will be done.

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