Calibration and Validation of Measurement System

Wave Dragon, Nissum Bredning

Project:

Sea Testing and Optimization of Power Production on a Scale 1:4.5 Test Rig of the Offshore Wave Energy Converter Wave Dragon

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March, 2004
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by

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1. Introduction

This report deals with the calibration of the measuring equipment on board the Wave Dragon, Nissum Bredning (WD-NB) prototype.

The report covers the following instruments on board WD-NB:

- Pressure transducers.
- Force transducers.
- Accelerometers.
- Displacement sensors.
- Strain gauges.
- Inclinometers.

All of these instruments are connected to the HBM MGC+ amplifier and data acquisition unit. In the following the calibration will be dealt with individually.

Furthermore, a preliminary calibration of the siphon and dummy turbines has been carried out and this is also described in the following.
2. List of transducers

Below all transducers connected to the MGC+ is listed, see Table 2.1. In the following chapters the transducers are called by the tags given in this table. The table also gives the make and model of the individual transducers as well as what board in the MGC+ they are connected to. Also the location of the individual transducers are given in the table.

<table>
<thead>
<tr>
<th>No.</th>
<th>Transducer Name</th>
<th>Plane No.</th>
<th>Tag Code</th>
<th>Description</th>
<th>Make</th>
<th>Model</th>
<th>Board for SG</th>
<th>Board for ML-801</th>
<th>Connection</th>
<th>Processing Module</th>
</tr>
</thead>
<tbody>
<tr>
<td>103</td>
<td>SG_MBP3</td>
<td>SG</td>
<td>3</td>
<td>rosette 3 in rosette 1 inside main beam, on wall parallel with and close to CL, on vertical line at EU Cons. item 3 WP</td>
<td>1.5 HBM 13.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>107</td>
<td>SG_MBP7</td>
<td>SG</td>
<td>1</td>
<td>rosette 1 in rosette 3 inside main beam, on wall parallel with and close to CL, on vertical line EU Cons. item 3 WP</td>
<td>1.5 HBM 14.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>110</td>
<td>SG_MBP10</td>
<td>SG</td>
<td>1</td>
<td>rosette 1 in rosette 4 inside main beam, on wall parallel with and close to CL, on vertical line EU Cons. item 3 WP</td>
<td>1.5 HBM 14.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>111</td>
<td>SG_MBP11</td>
<td>SG</td>
<td>2</td>
<td>rosette 2 in rosette 4 inside main beam, on wall parallel with and close to CL, on vertical line EU Cons. item 3 WP</td>
<td>1.5 HBM 14.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>112</td>
<td>SG_MBP12</td>
<td>SG</td>
<td>3</td>
<td>rosette 3 in rosette 4 inside main beam, on wall parallel with and close to CL, on vertical line EU Cons. item 3 WP</td>
<td>1.5 HBM 14.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>123</td>
<td>SG_RM11</td>
<td>SG</td>
<td>1</td>
<td>rosette 1 in rosette 2 inside main beam, on wall parallel with and close to CL, on vertical line EU Cons. item 3 WP</td>
<td>1.5 HBM 14.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>124</td>
<td>SG_RM12</td>
<td>SG</td>
<td>3</td>
<td>rosette 3 in rosette 2 inside main beam, on wall parallel with and close to CL, on vertical line EU Cons. item 3 WP</td>
<td>1.5 HBM 14.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2.1. List of transducers connected to the MGC+.
3. Pressure transducers

A total 14 pressure transducers are currently deployed at WD-NB. The transducers are calibrated from manufacturer, see Figure 3.1, and the calibration constants have been checked before deployment.

![Calibration Certificate](image)

Figure 3.1 Example of calibration report from manufacturer for pressure transducer.

The calibration constants have been found to be correct. The calibration constants for the individual transducers are quoted in the table below.
<table>
<thead>
<tr>
<th>#</th>
<th>Tag</th>
<th>MGC+ ch. no.</th>
<th>Serial no.</th>
<th>Calib.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PRES_U1</td>
<td>1.1</td>
<td>6155-6-122</td>
<td>72.969 mV/BAR VG</td>
</tr>
<tr>
<td>2</td>
<td>PRES_U2</td>
<td>1.2</td>
<td>6155-6-124</td>
<td>72.380 mV/BAR VG</td>
</tr>
<tr>
<td>3</td>
<td>PRES_U3</td>
<td>1.3</td>
<td>6155-6-125</td>
<td>72.760 mV/BAR VG</td>
</tr>
<tr>
<td>4</td>
<td>PRES_U4</td>
<td>1.4</td>
<td>6155-6-126</td>
<td>74.470 mV/BAR VG</td>
</tr>
<tr>
<td>5</td>
<td>PRES_R1</td>
<td>1.5</td>
<td>6155-6-127</td>
<td>71.530 mV/BAR VG</td>
</tr>
<tr>
<td>6</td>
<td>PRES_R2</td>
<td>1.6</td>
<td>6155-6-128</td>
<td>72.489 mV/BAR VG</td>
</tr>
<tr>
<td>7</td>
<td>PRES_R3</td>
<td>1.7</td>
<td>6155-6-129</td>
<td>74.340 mV/BAR VG</td>
</tr>
<tr>
<td>8</td>
<td>PRES_P</td>
<td>1.8</td>
<td>6155-6-132</td>
<td>73.170 mV/BAR VG</td>
</tr>
<tr>
<td>9</td>
<td>PRES_AC1</td>
<td>2.1</td>
<td>6155-6-133</td>
<td>72.360 mV/BAR VG</td>
</tr>
<tr>
<td>10</td>
<td>PRES_AC2</td>
<td>2.2</td>
<td>6155-6-134</td>
<td>74.119 mV/BAR VG</td>
</tr>
<tr>
<td>11</td>
<td>PRES_AC3</td>
<td>2.3</td>
<td>6155-6-135</td>
<td>73.150 mV/BAR VG</td>
</tr>
<tr>
<td>12</td>
<td>PRES_AC4</td>
<td>2.4</td>
<td>6155-6-136</td>
<td>72.599 mV/BAR VG</td>
</tr>
<tr>
<td>13</td>
<td>PRES_AC5</td>
<td>2.5</td>
<td>6155-6-137</td>
<td>74.569 mV/BAR VG</td>
</tr>
<tr>
<td>14</td>
<td>PRES_FL</td>
<td>2.6</td>
<td>6155-6-117</td>
<td>75.070 mV/BAR VG</td>
</tr>
</tbody>
</table>

Table 3.1. Calibration constants for pressure transducers.

Some drift in the offset for the individual transducers has been observed – especially for the transducers PRES_U1-4 (placed underneath the structure) used for measuring the floating level, heel and trim of the reservoir part of the device. This is most probably due to marine growth on the transducers. Subsequently, an extra retractable pressure transducer (PRES_FL) and the two inclinometers have been installed. Thus, PRES_U1-4 are no longer needed and currently only used for reference.

The operation of the pressure transducer at the pile PRES_P, used for measuring the wave conditions, has been influenced by the fact that the signal cable to the pile has been damaged on more than one occasion. Currently the cable has been temporarily fixed, but a replacement of the current cable is highly needed in order to insure continuous measurements from PRES_P.
4. Force transducers

A total of two force transducers have been deployed at WD-NB. The transducers have been calibrated by the manufacturer, and the calibration has been verified prior to installation. The calibration constants for the individual transducers are quoted in the table below.

<table>
<thead>
<tr>
<th>#</th>
<th>Tag</th>
<th>MGC+ ch. no.</th>
<th>Serial no.</th>
<th>Calib.</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>FORCE_M</td>
<td>3.1</td>
<td>J57384</td>
<td>-1.9996 mV/V</td>
</tr>
<tr>
<td>18</td>
<td>FORCE_C</td>
<td>3.2</td>
<td>J74671</td>
<td>-2.0005 mV/V</td>
</tr>
<tr>
<td>19</td>
<td></td>
<td>3.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
<td>3.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td></td>
<td>3.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td></td>
<td>3.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td></td>
<td>3.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td></td>
<td>3.8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4.1. Calibration constants for force transducers.

The performance of FORCE_M measuring the mooring forces in the main mooring line attaching WD-NB to the pile, has been influenced by the fact that the signal cable to the pile has been damaged on more than one occasion. Currently the cable has been temporarily fixed, but a replacement of the current cable is highly needed in order to insure continuous measurements from FORCE_M.

The force transducer meant for measuring the forces in the cross mooring line between the reflectors FORCE_C was damaged during the first reflector accidents (described in Kofoed & O’Donovan, 2003). Especially the cable to the transducer was damaged. The transducer has been brought to the workshop for repair and is currently back in place. However, the reflector accidents experienced have also damaged the signal cables going to the port reflector, and the correct functioning of FORCE_C is currently awaiting the re-establishing of these cables.
5. Accelerometers

A total of six accelerometers are to be deployed at WD-NB. The two of these meant for placement on the port reflector has not yet been put in place, due to the accidents experienced with the reflectors. This awaits the re-installation of the signal cables to the port reflector. The two accelerometers placed on the starboard and port shoulder on the platform was initially installed and tested before deployment of WD at test site 1. However, due to damage done to the signal cabling to the shoulder they have not yet been in action. The two accelerometers placed in the equipment container have been delivering data continuously since deployment of WD at test site 1.

All accelerometers are rented from The Structural Research Laboratory, Aalborg University, who also provided the amplifier box and calibration constants for the instruments, see Figure 5.1.

The functioning of the instruments and the calibration were checked prior to installation on board WD-NB, see Figure 5.2.
<table>
<thead>
<tr>
<th>#</th>
<th>Tag</th>
<th>MGC+ ch. no</th>
<th>Serial no</th>
<th>Calib.</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>ACC_P1</td>
<td>4.1</td>
<td>11246</td>
<td>1.961 (m/s^2)/V</td>
</tr>
<tr>
<td>26</td>
<td>ACC_P2</td>
<td>4.2</td>
<td>11243</td>
<td>0.981 (m/s^2)/V</td>
</tr>
<tr>
<td>27</td>
<td>ACC_P3</td>
<td>4.3</td>
<td>11244</td>
<td>0.981 (m/s^2)/V</td>
</tr>
<tr>
<td>28</td>
<td>ACC_P4</td>
<td>4.4</td>
<td>11360</td>
<td>0.981 (m/s^2)/V</td>
</tr>
<tr>
<td>29</td>
<td>ACC_R1</td>
<td>4.5</td>
<td>11361</td>
<td>1.963 (m/s^2)/V</td>
</tr>
<tr>
<td>30</td>
<td>ACC_R2</td>
<td>4.6</td>
<td>11362</td>
<td>1.962 (m/s^2)/V</td>
</tr>
</tbody>
</table>

Table 5.1. Calibration constants for accelerometers.

Figure 5.2. Example of check of the calibration and functioning of the accelerometers (applied amplitude of oscillation was 0.146 m, indicated with the horizontal line in the lowest graph).
6. **Displacement sensors**

The displacement sensors meant for measuring the relative movements in the port shoulder junction have not yet been installed. This is due to the accidents experienced with the reflectors.

The sensors are calibrated by manufacturer and will be checked once installed.
7. Strain gauges

All 84 strain gauges, mounted as rosettes of three, were installed prior to the deployment of WD. All rosettes were of the same type and with the same characteristics which has been given by the manufacturer HBM, see scan hereof in Figure 7.1.

![Figure 7.1. Characteristics of rosette strain gauges used on board WD-NB.](image)

All rosettes were tested after application. However, due to the reflector accidents and the following problems with signal cable to port reflector and shoulder, the strain gauges in this part of the structure has not been tested or utilized so far. The strain gauges placed in the central part of the platform seems to working, but due to time constraints no detailed measurements with these have been conducted so far.
8. Inclinometers

Due to problems with the pressure transducers placed underneath the platform, two inclinometers have been installed in order to obtain direct measurements of heel and trim of the platform. The inclinometers have a calibration constant of 60 mV/°.

The inclinometers are giving more reliable readings of the heel and trim than was obtained using the pressure transducers. However, some minor changes in the offset of especially the trim readings occasionally occur. The reason for this is yet to be found.
9. Siphon turbine

A preliminary calibration of the siphon turbine was carried out by Kofoed & O’Donovan, 2003 as given below.

Turbine calibration data (screen-dump from SCADA system, see Figure 9.1) comprising time plots of Turbine Rotational Speed (N), Turbine Power (P), Relative Basin Level (RBL) and Floating Level (FL) have been established for various values of Basin Work Span (BWS).

![Figure 9.1. Turbine calibration plot](image)

This plot was used to estimate the specific speed for the siphon turbine in use on WD by carrying out the following steps:

- Divide the plots into 20 second intervals, noting the values for N, P, RBL & FL at each interval.
- Calculate the Reservoir Area from the accompanying CAD drawing.
- Calculate the Basin Level (BL) = Crest Height – ((1-RBL)x BWS)
- Calculate Flowrate (Q) = (Reservoir Area x Change in BL)/Time Interval
- Calculate Head (H) = Average Floating Level – [(1-Average RBL) x BWS]
- Specific speed, NS = $\frac{N \sqrt{Q}}{H^{0.75}}$
- Crest Height = Vertical Distance from floor (turbine level) to the crest.

From such data a specific speed of 340.6 resulted. Primarily due to corrosion of a vital part of the shaft, the oil lubricated bearing in the siphon turbine has been damaged. This entails that the turbine has been taken out of service.
10. Dummy turbines

In order to use the dummy turbines for measuring the discharge, these have been calibrated by filling up the reservoir and emptying it while measuring the falling water level in the reservoir and the position of the reservoir. The performed calibrations are described below.

10.1 Introduction

The aim of the measurements was to determine a function for the discharge of the dummy turbines depending on the head between basin level and sea level. Significant differences in the behaviour of the three valves should also be identified. These differences can arise from the asymmetric arrangement of the valves, which causes unequal flow conditions. The measurements should furthermore detect any interaction between the dummy turbines.

The arrangement of the dummy valves and the pressure transducers is the following:

![Diagram of valve arrangement](image)

**Figure 10.1. Arrangement of valves and pressure transducers.**

The pressure transducers R1, R2, R3 are used to determine the water level in the basin, they are mounted 35 mm above deck level.

There are three steel plates situated between the dummy valves, each of them with a height of 300 mm above deck level. Their purpose is to guide the flow to the valves and to prevent interaction between the valves. As the work span of the water level in the basin is between 300 mm and 600 mm above deck level, the water level should never be lower than the upper edge of the steel plates.

10.2 Measuring and data interpretation

The measurements were all made at the same crest height of the Wave Dragon, which means that the air mass in the chambers below the Wave Dragon was never changed. A variation of the crest height was not possible due to the weather conditions and the necessary time span for the compensation of the movements after changing the level.

Before each measurement the basin was filled completely by pumping water into it. After the water surface had calmed down, the dummy turbines were opened manually from the SCADA control system and closed after the surface had reached the minimum basin level $h_{bas,min} = 300$ mm. The raw data of seven pressure transducers (three for the basin level on deck: R1, R2, R3; four for the
vertical position of the Wave Dragon on the bottom of the device: U1, U2, U3, U4) including a time
stamp were recorded. The possibility to transfer the calibrated data directly out of the SCADA
system was not yet implemented.

For the data interpretation the raw data taken on the Wave Dragon first had to be calibrated. There
was no secure information how to use the given calibration constants. The results could only be
validated by comparison with screen shots from the SCADA system. During the measuring there
were small waves which influenced the quality of the measuring data.

Due to the influence of the waves and the uncertainty concerning the calibration constants, the data
interpretation and the results have to be considered as preliminary.

10.3 Results

Discharge, calculated from the basin level

Figure 10.2 to Figure 10.4 show the discharge calculated from the basin level $h_{bas}$ (measured by R1,
R2, R3). The discharge is obtained by comparing the water volume in the basin with the time scale.
The corresponding head is calculated from the basin level in combination with the Wave Dragon's
crest height (measured by U1, U2, U3, U4).

The dashed curve is a manual fit calculated from

$$Q = kA \sqrt{2gH} ,$$

where $A = \pi/4*D^2 = 0.147 \ m^2$ is the dummy turbine cross section.

$\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure102.png}
\caption{Discharge of dummy turbine No. 8.}
\end{figure}$

$\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure103.png}
\caption{Discharge of dummy turbine No. 9.}
\end{figure}$
Especially the discharge curve of dummy turbine No. 8 shows a big discrepancy to the manual fit for $h_{bas} < 0.40 \, m$, the discharge seems to increase with lower heads. Furthermore, there is noise in the curves although the discharge $Q$ is averaged twice (see section below). The following chapter gives an explanation for these phenomena.

Row 1 in Table 10.1 displays the values of $k$ which have been determined by measuring the discharge in different valve opening situations. The second row shows the average value of $k$ calculated from the single values in columns 8, 9 and 10. The discrepancies between row 2 and row 3 are smaller than 2.7 %, there seems to be no significant interaction between the valves.

### Table 10.1. Values of $k$, determined from the calculations of the basin level.

<table>
<thead>
<tr>
<th>Valve No.</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>8+9</th>
<th>8+10</th>
<th>9+10</th>
<th>8+9+10</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k$</td>
<td>1.07</td>
<td>1.05</td>
<td>1.09</td>
<td>1.08</td>
<td>1.09</td>
<td>1.07</td>
<td>1.10</td>
</tr>
<tr>
<td>$k_{av}$</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.06</td>
<td>1.08</td>
<td>1.07</td>
<td>1.07</td>
</tr>
<tr>
<td>$(k-k_{av})/k$</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.9%</td>
<td>0.9%</td>
<td>0.0%</td>
<td>2.7%</td>
</tr>
</tbody>
</table>

### Reasons for the discharge discrepancies

**a) Waves in the basin**

The values needed to calculate the discharge curves in Figure 10.2 to Figure 10.4, namely $h_{bas}$ and $H$, are averaged over ten seconds, the discharge $Q$ itself is then again averaged over ten seconds, but the discharge curve $Q(H)$ is still unsteady. The combination of the water surface movements in the basin and the sea waves is responsible for the quality of the discharge curves.

**b) Non-planar water surface**

During the discharge the water surface in the basin is not strictly planar. Especially at lower basin levels a depression in the middle of the basin was observed. The pressure transducers R1, R2, R3 used to calculate the basin level and the discharge in Figure 10.2 to Figure 10.4 are situated in this depression. Thus, the measured level decreases faster than the real average level, hence the calculated discharge is larger than the real one.

According to Figure 10.2 to Figure 10.4 it is possible to specify minimum basin levels above which the water surface seems to be planar:

### Table 10.2. Minimum basin levels with planar water surface.

<table>
<thead>
<tr>
<th>Valve No.</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>8+9</th>
<th>8+10</th>
<th>9+10</th>
<th>8+9+10</th>
</tr>
</thead>
<tbody>
<tr>
<td>$h_{bas} , [m]$</td>
<td>&gt;0.40</td>
<td>&gt;0.35</td>
<td>&gt;0.35</td>
<td>&gt;0.40</td>
<td>&gt;0.45</td>
<td>&gt;0.35</td>
<td>&gt;0.47</td>
</tr>
</tbody>
</table>

The following figure shows the influence of the non-planar surface for different valve combinations:
Influence of non-planar surface

The more valves are opened, the larger is the discrepancy between measured and real average head \( H \). The closing point of the valves can be identified in the curves of valve No. 8 and valve No. 10: The water level is levelling out, the curves meet again the "normal" immersion curve which is defined by an immersion coefficient of "\( ic = 0.73 \)".

The reasons for the formation of a non-planar water surface in the basin are:

- The swash plates, which are placed on the Wave Dragon in order to keep ballast water on deck are restricting the water from flowing towards the middle of the basin.
- The dynamic pressure, which increases significantly in the region of the dummy turbines is lowering the static pressure height especially at lower basin levels.

Figure 10.6 shows the dimension of \( p_{\text{dyn}} \) with valve No. 8 opened, calculated at the position of the valve nearest pressure transducer R1. The dynamic pressure depending on the basin level is obtained by calculating the following quantities:

- the head \( H \) from \( h_{\text{bas}} \) with the immersion coefficient \( ic \) and a starting point \( h_{\text{bas}} = 0.60 \, m, \) \( Rc0 = 0.25 \, m \) resp. \( 0.90 \, m \)
- the discharge \( Q(h_{\text{bas}}) \) from \( Q = k \cdot A \sqrt{2gH(h_{\text{bas}})} = 1.05 \cdot 0.147m^2 \sqrt{2gH(h_{\text{bas}})} \)
- the flow area, using half of a cylinder with a radius of \( r = 1.45 \, m \) around valve No. 8 touching the pressure transducer R1
- the average flow velocity \( c \) and with it the dynamic pressure \( p_{\text{dyn}} = \rho/2 \cdot c^2 \)

At lower crest heights the dynamic pressure can be neglected. However, it should be noted that at a crest height of \( Rc0 = 0.90 \, m \) the proportion of the dynamic pressure can rise to 3.5% of the total pressure, thus leading to a further depression of the surface near the pressure transducers.
Discharge, calculated from Wave Dragon crest height

Another possibility to calculate the discharge is to determine the water volume in the basin from the crest height, taking the immersion coefficient into account. The advantage of this method is that the total mass of the water in the reservoir is determined by measuring the immersion, thus avoiding the aforementioned problems in measuring the reservoir level. Starting with a filled basin \((h_{bas} = 0.60 \text{ m})\) at a certain crest height \(Rc0\), the basin level can be evaluated from

\[
\Delta h_{bas} = -\frac{\Delta Rc}{ic},
\]

where \(ic\) is the immersion coefficient. The crest height is measured using the pressure transducers U1, U2, U3, U4.

Due to the irregular structure of the hull, the immersion coefficient \(ic\) is a complex function of the crest height and the volume of the compressible air enclosed in the ballast tanks. This function has not yet been determined. As a simplifying assumption a constant immersion coefficient \(ic = 0.73\) has been used. The discharge characteristic thus derived is shown in Figure 10.7.

![Diagram](image)

**Figure 10.7. Discharge of dummy turbine No. 9.**

The calculated curve contains oscillations resulting from sea waves, but it can be fitted with the function \(Q = kA\sqrt{2gH}\) quite well (see the curve "Q_man.fit" in the figure).

Table 10.3 refers to the above calculations from the immersion coefficient and corresponds to Table 10.1. The values of \(k\) are larger than those given in Table 10.1. A possible reason is the use of a constant immersion coefficient, which is not a perfectly realistic assumption.

<table>
<thead>
<tr>
<th>Valve No.</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>8+9</th>
<th>8+10</th>
<th>9+10</th>
<th>8+9+10</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A[m^2])</td>
<td>0.147</td>
<td>0.147</td>
<td>0.147</td>
<td>0.294</td>
<td>0.294</td>
<td>0.294</td>
<td>0.441</td>
</tr>
<tr>
<td>(k)</td>
<td>1.17</td>
<td>1.17</td>
<td>1.20</td>
<td>1.20</td>
<td>1.20</td>
<td>1.20</td>
<td>1.17</td>
</tr>
</tbody>
</table>

**Table 10.3. Values of \(k\), determined from the measured crest height.**

### 10.4 Conclusions

Given the difficulty of determining the exact function \(ic (Rc, h_{bas})\), it seems advisable to use the pressure transducers R1, R2, R3 in the basin for the calculation of the discharge rather than using the crest height. The results of the calculations are listed below: Row 2 shows the values of \(k\), row 3 compares these values with the siphon turbine model test results in the laboratory, taking the different cross-sectional areas into account. It can be concluded that the discharge of each dummy turbine is approx. 2.3 times the one of the siphon turbine.
Table 10.4. Test results and comparison with the siphon turbine.

The results of the measurements have to be considered as preliminary due to the following reasons:

- no data acquisition possible for siphon turbine.
- only raw data of dummy turbine measurements available, no secure information about how to calibrate the data.
- no ideal weather conditions.

For further measurements the following requirements have to be fulfilled:

- complete functioning data acquisition for siphon turbine (quantities $R_c$, $h_{bas}$, $n_{tur}$, $P_{tur}$).
- secure information about the calibration of the raw data from the pressure transducers.
- calm sea, no overtopping at $R_c \theta = 0.2$ m.
- known correlation between the immersion coefficient and $R_c \theta$ at a certain air chamber setting.
11. Literature


