NECKARWELLE: A RIVER SURFING WAVE FACILITY IN THE HEART OF THE CITY OF STUTTGART

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Experiencing the joy and excitement of riding perfect waves is the dream of many surfers living far from the sea. In Stuttgart, this dream could soon become reality with the installation of a stationary wave in the River Neckar. To find the optimal hydraulic conditions, the flow of the river is replicated both experimentally and through numerical simulations. The results of these investigations will be key elements in the design of the perfect river wave.

Figure 1. Rendering of prospective Neckarwelle

Why river surfing?

Today, the pleasure of riding waves and the thrill of feeling the powers of nature has made surfing one of the most popular and fastest growing sports. Meanwhile, there are millions of 'land-locked' surfers in continental regions, relying on flights, or long trips to coastal areas. At the same time, the best spots become increasingly crowded and visitors often struggle to compete against highly skilled local surfers. The lack of surfing opportunities has initiated artificial 'wave' projects in water parks [1], indoor leisure sites [2], wave pools [3] or even barreling wave machines of the size of a football stadium [4]. A more economic and environmentally friendly approach is to use the natural power of rivers to create a stationary wave. A well-known example is the Eisbach River in Munich, Germany, which attracts thousands of tourists every year.

In Stuttgart, Germany, a group of surfers and scientists are investigating the opportunity of installing a surfable wave in the Neckar River. The prospective Neckarwelle ('Neckar wave') will be situated in the vibrant area of Untertürkheim in Stuttgart. The scenery around the proposed wave area is beautiful and the wave would fit naturally to this spot, where swimming, rowing and kayaking is already offered [Figure 1]. A map of the location is shown in Figure 2. The wave is not in the main channel of the Neckar River itself but in a diverted side channel, which carries the majority of the flow. A hydraulic power plant is located upstream of the wave and represents an important aspect of the design of the wave facility. This side channel is advantageous as it is not used for navigation and it offers protection for the wave facility from extreme flows and

Figure 2. Map of Neckarwelle location

floating debris. The difference between the headwater and tailwater level at the power plant is 3.6 m with approximately 1 m of head being required to operate the wave.

The science behind river waves

In ocean surfing, the surfer moves along with a propagating shallow water wave until it breaks. In contrast to this, river waves are created by a hydraulic jump. The working principle is sketched in Figure 3. To carry the weight of the rider, the surfboard requires a sufficiently high flow velocity and a certain gradient of the water surface. The required velocity is achieved by impounding the water level upstream of the wave and then guiding the flow in the streamwise direction down a ramp with a short deflector at its end. Physically speaking, potential energy is accumulated by increasing the level of headwater and then converted into kinetic energy at the location of the wave. The velocity at the wave trough is in the order of 3.5 m/s, yielding Froude numbers in a range of 1.5 to 3. A hydraulic jump forms closely downstream of the wave, where the supercritical flow conditions are transformed into subcritical flow conditions. A result of the pressure increase due to the hydraulic jump is the formation of a recirculation zone with a rotating vortex below the layer of supercritical flow. This recirculation zone has a significant impact on the formation of the wave and on the safety of the surfer [5]. At constant inflow conditions, this phenomenon is stationary and the result is a standing wave [6]. However, only the maximum wave, a specific type of hydraulic jump, can be surfed. The maximum wave features a smooth surface and leads to both the greatest wave height and major inclination [7]. The maximum wave only forms under specific conditions and is highly sensitive to any variations in these conditions. For instance, a 5 % reduction of the tailwater height reduces the total wave height by 50 % [5]. Previous studies investigated the physical mechanisms for the wave formation process [6,5,8]. However, given the restricting simplifications made in the different experimental set-ups, the results of these studies are not transferable to the Neckar River.

Physical Experiments

A scaled model of the planned design was constructed in a laboratory flume at the Hydraulic Laboratory of the Institute for Modelling Hydraulic and Environmental Systems, University of Stuttgart, Germany. A novel aspect of this work is the combination of all relevant hydraulic and geometrical

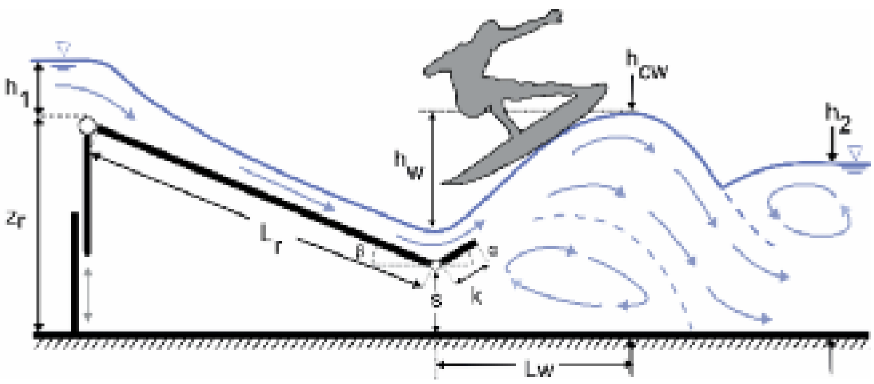

Figure 3. Schematic sketch of working principle and experimental set-up


Dominik K. Puckert graduated in Aerospace Engineering and currently works as a Ph.D. student at the Institute of Aerodynamics and Gas Dynamics, University of Stuttgart. His research subject is on experimental boundary layer instabilities and his passion for surfing made him member of the management board of Neckarwelle e.V.


Benedikt Mester, as part of his master thesis, conducts the physical 'Neckarwelle' experiments at the University of Stuttgart. His research interest focuses on PIV, CFD and hydromorphological processes.


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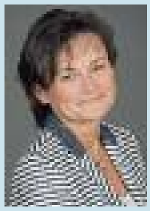
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parameters in one physical experiment. The upstream boundary conditions are determined by the power plant operation as well as by the natural fluctuations of the flow rate whereas the downstream boundary conditions are determined by the water level of the Neckar River. Investigations into the influence of the different parameters will lead to a deeper understanding of the wave formation mechanisms, which is vital to adapt the prospective wave to naturally fluctuating boundary conditions.

The experimental setup comprises a height-adjustable ramp to impound water in order to gain potential energy and to accelerate the flow towards the wave. At the end of the ramp, a deflector is attached for the fine-tuning of the wave s face. Both the deflector and the ramp are variable in length and angle to examine whether the step height beneath the deflector or the inclination of the ramp is more important for the wave formation. In addition, other aspects of the design, such as the influence of the ramp's length, have not been addressed in the literature to the authors' knowledge. It is noted that different studies on surfing facilities do not show good agreement on whether a deflector only balances the tailwater fluctuations, or if it can actually increase the wave height [5, 8].

Numerical simulations

The experimental work is supported by numerical simulations performed at the Institute of Aerodynamics and Gas Dynamics at the University of Stuttgart. The open-source code OpenFOAM is used to simulate the wave using the finite volume method. Two approaches are used to simulate the interfaces of air and water, namely the volume-of-fluids method and the isoAdvector method. The simulations are first verified with a simple geometry against the experimental data and will then be extended to more complex geometries at a later stage of the project.

Future work

The results of the experimental and numerical studies will provide information for the conceptual design of a hydraulic structure that produces surfing waves for the varying boundary conditions at the Neckar River. Many additional investigations of non-technical aspects of the planned Neckarwelle are currently ongoing such as looking at water quality, ecological aspects, safety, legal issues and financing. This work is performed in close cooperation with the City of Stuttgart, Neckar River authorities, the hydropower company and residents. The social impact of the surfing wave facility on Stuttgart will be immense. The goal of the team of surfers and scientists working on this project is to bring together all groups of different ages and social backgrounds interested in this exciting sport.

Acknowledgements

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References

[1] McLaughlin Whitewater Design Group. https://mclaughlinwhitewater.com/contact, accessed: April 10, 2018.
[2] Jochen Schweizer Arena. Erlebniswelt München Betriebsgesellschaft mbH. https://www.jochen-schweizer-arena.de, accessed: April 10, 2018.
[3] Wasserski Langenfeld GmbH. https://www.surf-langenfeld.de accessed: April 10, 2018.
[4] Kelly Slater Wave Company. http://www.kswaveco.com, accessed: April 10, 2018.
[5] Koch, Christof. "Einfluss einer Klappe auf die Surfbarkeit stehender Wellen". Master Thesis at ETH Zürich. 2016.
[6] Trachsel, Jürg. "Surfbare Wellen." Project Report at ETH Zürich. 2013.
[7] Ohtsu, Iwao & Yasuda, Youichi. "Transition from supercritical to subcritical flow at an abrupt drop." Journal of Hydraulic Research, VOL 29:3, pp. 309-328. 1991.
[8] von Wyl, Rafael. "Einfluss einer Klappe auf die Surfbarkeit stehender Wellen." Master Thesis at ETH Zürich. 2015.

Pavel Novak (1918-2018)

Professor Pavel (Paul) Novak passed away on the 24th of February 2018 at the age of 99. He was born on the 7th of September 1918 in Stribro, now located in the Czech Republic. He lost family to the Holocaust and first came to England during WW2, studying engineering at the University of London, and making a contribution to the war effort by interrogating German POWs and as a member of the Home Guard. He met his future wife Elizabeth (Eli) in 1943 while staying in Nottingham. After the war he returned to Czechoslovakia, was from 1950 to 1955 Deputy Director of the Water Research Institute in Prague and later Director of the Institute of Hydrodynamics, the Czechoslovak Academy of Sciences. In 1968, when the Soviet army invaded Czechoslovakia, he returned to Britain where he was offered a position at Newcastle University.

Prof. Novak was an internationally leading hydraulic engineer, and wrote several noteworthy books on the subject. He was Professor of Civil and Hydraulic Engineering in the Department of Civil Engineering from 1970-1983 and was Head of Department 1981-83. Pavel retired then and was accorded the title of Emeritus Professor. By then, the Water Resources Group was the largest such postgraduate group in the UK. His contribution to Newcastle was immense and he continued until recent times as an author and mentor. He held the University and city in his greatest affection as a place where he found freedom from the difficulties in central Europe in his earlier life. This affection is reciprocated.

Prof. Novak was the first official Editor of the Journal of Hydraulic Research (JHR) from 1983, following Johannes T. Thijsse (1893-1984), who had done this job as IAHR Executive Director from JHR foundation in 1963. Pavel has taken this position for 8 years until 1991, from when JHR Editors serve for 5 years. Pavel must be credited for having made JHR an internationally accepted journal, one of the few then published in Europe. In parallel, Pavel was a successful book author. Of note is his book Models in hydraulic engineering (1981) written jointly with Jaroslav Cabelka (1906-1989), his Hydraulic Structures (2001) and his Hydraulic Modelling (2010). In addition, he was the editor of the book series Developments in Hydraulic Engineering. He also authored more than 100 journal and congress papers. Pavel Novak was an Honorary IAHR Member and awarded the ASCE Hydraulic Structures Medal, among others. He was awarded in 2008 the highest honorary medal 'De Scientia et Humanitate optime Meritis' of the Academy of Sciences of the Czech Republic.

In his retirement, Paul painted landscapes with great enthusiasm and continued to write text books. He travelled widely and enjoyed many years of activity, only giving up skiing in his 70s.

Following the death of Eli after 70 years of marriage, he spent his last years in The Philip Cussins House in Gosforth he communicating from there with family, friends and colleagues often via email. Those, who were present at the 2017 ICE Seniors Annual Lunch will recall how he spoke, still with clarity and strength.

Pavel is survived by his son Michal, daughter Zuzana, and over 50 grandchildren and great grandchildren. He will be greatly missed by all who knew him.

Eric Valentine and Willi H. Hager