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Summary Report on the Research Project

Thermally Activated Sandwich Floating System for Building on Water

(Reference number: II 3-F20-11-1-067/ SWD – 10.08.18.7 – 13.18)

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1 Motivation

The global population growth and the raising sea level lead, among other things, to shortage of building space for future expansion. This shortage can be countered by construction of buildings on water. Moreover, application of floating structures can be interesting for the tourist industry as well, as it can create new economic opportunities in sparsely-industrialised regions.

2 Conduction of the research project

2.1 State of the art and functionality of floating structures

Currently, floating buildings in Germany are constructed on pontoons, which serve to provide buoyancy solely and do not allow any utilisation of interior spaces. The pontoons consist of steel boxes or foamed reinforced concrete bells. Floating pontoons with functional interior space out of in-situ concrete in WU-system are currently produced in Holland. The demand on heating and cooling of living interior spaces is covered usually by a flexible tube systems connected with mainland. Self-sufficient supply of heating and cooling energy for floating buildings can be achieved with photovoltaic panels and/or solar collectors possible only. Those systems, however, are cost-intensive. Surrounding water offers an inexhaustible energy reservoir, which can be used for heating or cooling. The energy reservoir is surrounded by thermally activated façade wythes. In this case the thermally activated façade wythe is thermally insulated from the interior space by a core layer. The inner load-carrying layer of sandwich cross-section carries all loads acting on a floating structure.

2.2 Loads on floating structures

In order to design a floating basement storey structure, constructed out of sandwich panels, actions on a structure and their combinations have to be determined. Besides usual actions on a structure a constant water pressure, a dynamic load of waves and thermal ice pressure due to closed ice cover need to be considered. The ice pressure on a structure is significantly decreased by heat exchange through the thermally activated façade wythe. The thermal ice pressure caused by a breakdown of the thermally activated façade wythe is classified as an accidental action.

A temperature loads are of a particular importance in case of sandwich cross-section of a member. The difference of temperatures between façade and load-carrying wythe results in elongation differential, which has to be carried by connectors between the façade and load-carrying wythe. In case of floating structures the façade wythe is partially below and partially above water, what causes an additional temperature load case. An non-linear temperature profile occurs over the height of the façade wythe. An extensive calculations showed an increase of shear deformations of a façade wythe by 20%. The connectors between façade and load-carrying wythe need to have corresponding spare capacity. According to the Archimedean principle a body floats if its weight force is cancelled by buoyancy force.

The buoyancy force is calculated as a volume of water displaced by immersed floating structure multiplied by water density. The displaced volume of water is crucial for the design of a floating structure since the density of water remains constant. Furthermore the stable position in water needs to be taken into consideration. If the centre of gravity lies under the centre of buoyancy of a floating basement storey, its position is stable. Therefore an open on the top tub with heavy bottom plate offers advantages in terms of buoyant stability.

2.3 Water impermeability

Building components made out of water impermeable concrete are needed when interior spaces of floating structures shall be utilised. In the DafStb guidance for water impermeable buildings ‚Richtlinie Wasserundurchlässige Bauwerke‘ [6] there are rules stated for application of normal strength concrete. There are, however, none guidance provided for high-performance concrete. In the investigation programme normal strength concrete as well as high-performance concrete were checked in terms of water impermeability according to DIN EN 12390-8 [7] under various storage conditions.

The weak points of a façade wythe created in the manufacturing process by puncturing of GFRP – connectors and working of high-strength glue were also tested for water impermeability in the uncracked state. The test results show a negligible water penetration depth in case of the specimens of high-performance concrete. The weak points caused by GFRP – connectors are crucial for both concretes. In case of high-performance concrete a maximal water penetration depth of 3 cm occurred. Furthermore the self-sealing effect reaches the end in the duration time of the test for normal strength and high-performance concretes. This effect is created by relocation of water from capillary pores into gel pores of the concrete matrix. Due to the lower proportion of capillary pores in high-performance concrete the self-sealing effect is more pronounced. As a result lower member’s thickness is possible to apply for building members in direct contact with water.

2.4 Self-healing of concrete

The performance of high-performance concrete in the cracked state remains unexplained. In case of normal-strength concrete the maximal crack width is permissible, because of the self-healing effect cracks with calculated width up to 0,2 mm close up after certain time under the pressure gradient of a < 10 m water column. For a high-performance concrete there are none test results available. The reasons of self-healing effect are divided into physical, chemical and mechanical processes. Due to lower content of water/fine aggregate in a high-performance concrete it can be assumed, that hydration of member can have stronger effects and self-healing process can be faster or wider crack openings can be closed up under the same pressure gradient. The self-healing effect of high-performance concrete should be more investigated in order to establish permissible crack widths. As a result of that the structures with continuous contact with water could be designed less conservatively.

2.5 Thermally activated façade wythe

The thermally activated façade wythe absorbs and gives off heat through a tube register. The thermally activated building system is assessed according to its specific performance, defined as giving off heat or absorbing cold. The performance of a thermally activated building component depends on following parameters:

- tube pattern,
- concrete cover of the tubes,
- thermal conductivity of the tube material,
- thermal conductivity of the load-carring wythe,
- volumetric flow of the heating as well as cooling medium and
- temperature differential between the supply and the ambient temperature.

An efficient test body was designed by means of parameter study.

The test body for thermally activated façade wythe was tested under realistic conditions in Partwitzer Lake (Brandenburg). The supply and the return temperature directly at the test body, the volumetric flow as well as the temperature of the surrounding water around the test body should be recorded in order to determine the specific efficiency of the test body. A numeric model was developed in ANSYS Fluent software. The results of the simulation are in very good agreement with the results obtained during the test. In the future efficiency of a heat exchanger will not have to be determined by use of expensive experimental investigation.

2.6 The large-scale demonstrator

The results of theoretical and practical investigation along the research programme were implemented into the large-scale demonstrator. The manufacturability, sealing concept and ensuring of ice-free condition of the thermally activated façade wythe were tested under realistic conditions. The large-scale demonstrator consists of sandwich concrete pre-cast panels with thermally activated façade wythes. The pre-cast concrete panels are rigidly connected by use of steel connectors in the load-carring wythes, working against tensile as well as compressive forces, creating a rigid tub. The application of the elastic sealing material along the outer joints between façade wythes is absolutely necessary. A rigid sealing material cannot compensate the temperature-induced shear deformations. Continuous measurement was conducted at the lake in order to assess the realistic performance of the thermally activated sandwich floating system (see Abbildung 5). The supply and return flow temperatures and volumetric flow of water were introduced and permanently saved in pipe register inside of the large-scale demonstrator. Additionally, temperature and air humidity were recorded by use of internal and external sensors. Measurement and pumping equipment are provided with energy solely by photovoltaic panels and energy storage device. The continuous measurement of the thermally activated façade wythe provides information about energy potential, which can be gained from the surrounding water. Also ensuring of ice-free conditions was documented on the large-scale demonstrator. The presented results make a structural design of a floating structure with utilisation of interior spaces possible and give essential information for construction of such structures.

3 Key data

Short title: Sandwich floating system

Researcher / Project Responsible: F20-11-1-067

Project Managment: F20-11-1-067

Total Cost: 186.000,00 €

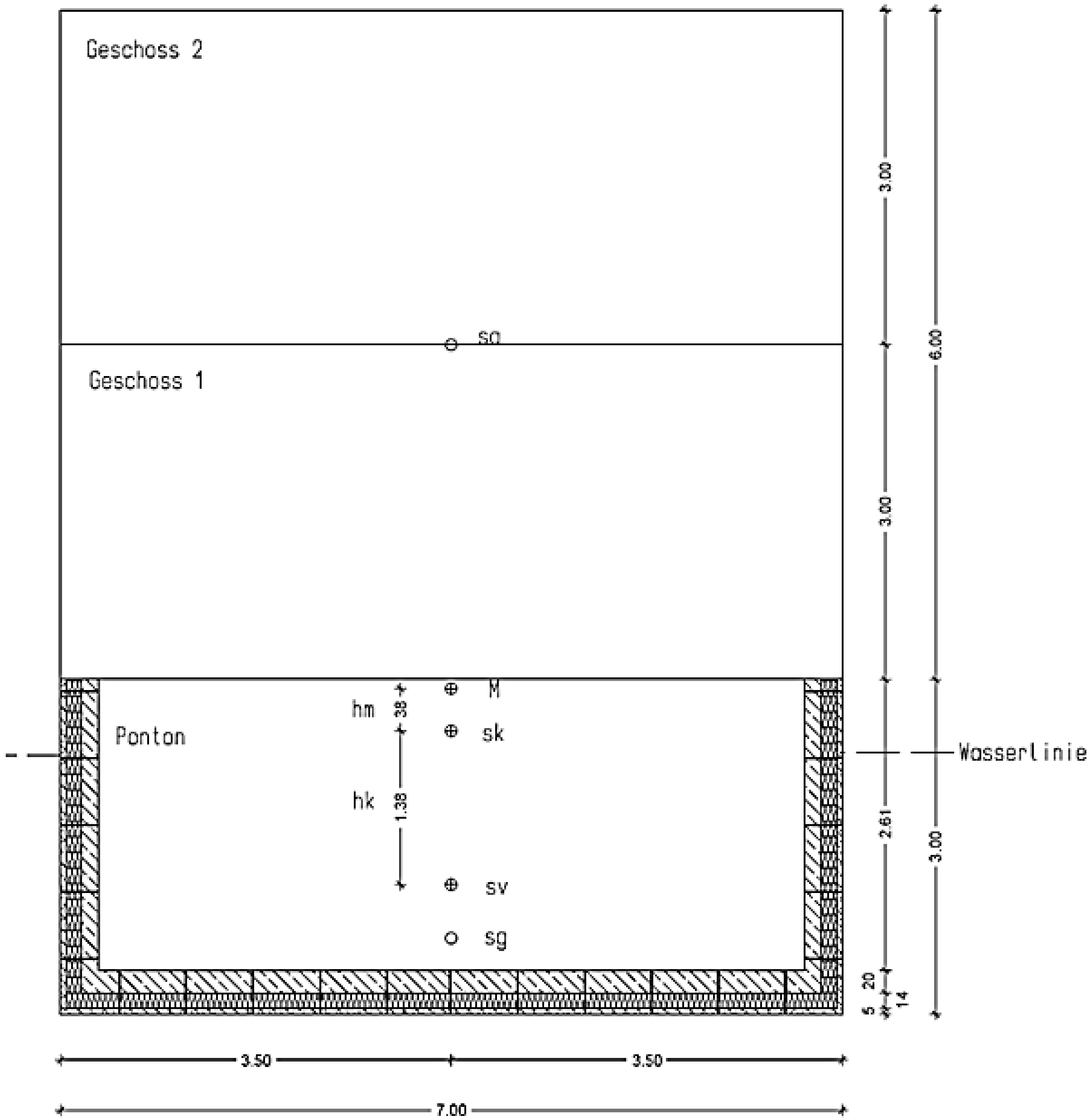
Federal Subsidy Part: 98.560,00 €

Duration of the Project: 07.2013 to 11.2015

4 References

[1] DAfStb, „DAfStb-Richtlinie Wasserundurchlässige Bauwerke aus Beton,“ Beuth, Berlin, 2003.

[2] DIN EN 12390-8, Prüfung von Festbeton – Teil 8 Wassereindringtiefe unter Druck, Berlin: Beuth Verlag, 2009.



s_a: Gewichtsschwerpunkt Aufbau

s_g: Gewichtsschwerpunkt Ponton

s_v: Auftriebsschwerpunkt

s_k: Gewichtsschwerpunkt Aufbau und Ponton

M: Metazentrum

h_k: Höhendifferenz zwischen Gewichts- und Auftriebsschwerpunkt

h_m: metazentrische Höhe

Abbildung 1: Entwurf des schwimmenden Untergeschosses. pdf

Figure: Design of the floating basement storey.

5 Figures

Abbildung 2: P-WE_VM1_C2530_Lagerung A, jpeg

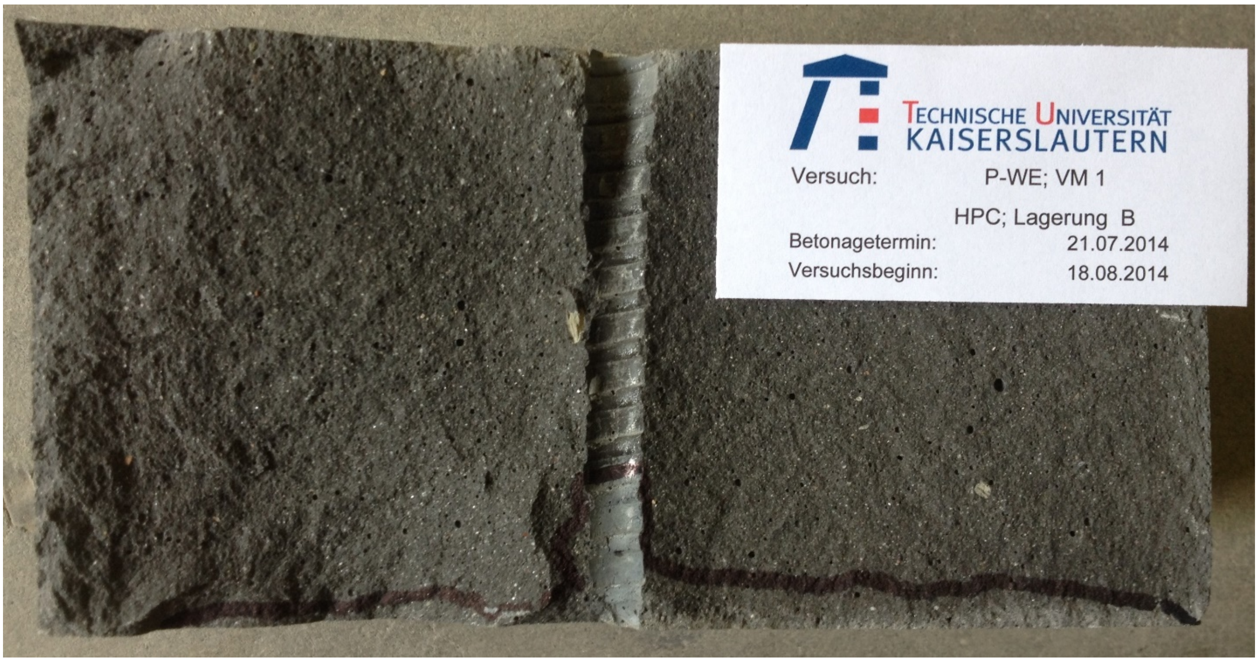


Abbildung 3: P-WE_VM1_C2530_Lagerung A, jpeg

Figure: P-WE; VM1; C2530; Storage A

Figure: P-WE; VM 1; C25/30; Storage A

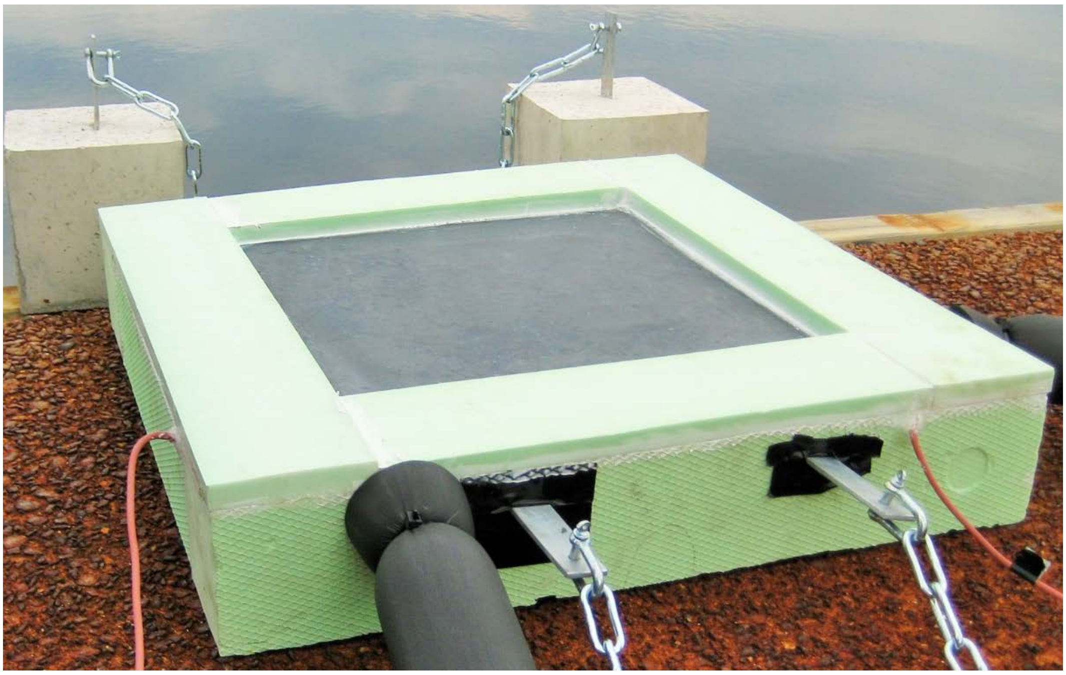


Abbildung 4: Wärmetauscher in Vorbereitung. jpeg

Figure: Preparation of the heat exchanger

Abbildung 5: endgültige Schwimmlage, jpeg

Figure: Ultimate afloat position

Abbildung 6: Schwimmkörper Endprodukt, jpeg

Figure: Floating structure as a final product