

UDC 004.94

Numerical simulation of the movement behavior of floating structures

The sea level is rising, and floods threaten the infrastructure all over the world; therefore, we should identify the risks for envelopes of buildings and settlements. The risks arise due to the new boundary conditions and a direct contact between the water flows in motion. A floating construction site requires a manifold adaptation of structures. The paper demonstrates the effect of water waves on floating houses built on abandoned open pit mines. Pictures of destroyed accessways to such properties have proven the need to study the effect of water waves on floating houses. In order to minimize the time and spending on experimental activities, some of the field studies should be replaced by numerical simulations using modern computing equipment and ANSYS FLUENT, ANSYS MECHANICAL FSI, and ANSYS AQWA software. The results can be validated using a hydraulic testing channel (15 x 5 m), a floating platform near the harbor of Lake Gro r schener See and floating houses in the Lusatian Lakeland. The results demonstrate the wave forces acting on the structures of the pontoons. New connection elements, adapted versions of materials and structures have been developed, water waves are damped, and options for the wave energy use have been analyzed.

Keywords: water attacks, floating houses, numerical simulation, Lusatian Lakeland

1. INTRODUCTION

1.1. WHY, WHAT, HOW

There are two reasons why this topic must be dealt with. On the one hand, it is a search for alternative energy sources, i.e., the conversion of the kinetic energy of water waves into useful energy, and the simultaneous damping of destructive forces. At the same time, it is important to store energy, for example, thermal energy in a pontoon [1]. On the other hand, it is necessary to study these forces and develop appropriate structural solutions in order to limit the damage in the long term. Fig. 1 and 2 demonstrate floating houses recently destroyed by the storms in the Lusatian Lakeland near the university of Cottbus (both lakes can be seen in Fig. 3). Besides a testing site on



Fig. 1. A damaged accessway to a floating house in the marina of Geerswalde

the university campus and inhabited floating houses, the institute of floating houses and settlements has a testing site at the Großräschen Lake, where results of numerical simulations can be validated.

2. THE BASIS FOR THE VALIDATION OF NUMERICAL RESULTS

2.1. FLOATING HOUSES IN THE LUSATIAN LAKELAND

Floating structures are built on the four lakes of the Lusatian Lakeland; their designs can be seen in



Fig. 2. A damaged accessway to the floating houses on Lake Partwitzer

Fig. 4, 5. Each of them has measuring instruments installed pursuant to the contracts made with their owners. Water parameters, indoor climate and material properties are measured there [2, 3].

2.2. LAKE GROßRÄESCHEN AS A TERRITORY FOR EXPERIMENTS

This testing site is located 35 kilometers from the university, and it uses the infrastructure of the newly built Großräschen Süd port. The IfSB testing site, designated for floating structures, has two dolphins, two pontoons and a small bridge needed to access the floating platform. The pontoons were manufactured at the IfSB institute, and they are made of glulam wood that has several layers of coating applied.



Fig. 3. Lusatian Lakeland; eleven lakes are connected by canals, that have so-called locks, or water gates to compensate for the height differences

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Fig. 4. Left photo: a floating wooden structure on Lake Partwitzer; right photo: a floating diving school and a guest house on Lake Gräbendorf

Fig. 6 and 7 show the initial stage of the construction work at the testing site on Lake Großräschener See.

2.2. LAKE GROßRÄSCHEN AS A TERRITORY FOR EXPERIMENTS

Fig. 8 shows the canal used to investigate floating pontoons and other facilities. It is analyzed in chapter 4 “Experimental work”.

2.3. A WIDE CANAL ON CAMPUS

Fig. 8 shows the canal used to investigate floating pontoons and other facilities. It is analyzed in chapter 4 “Experimental work”.



Fig. 5. Left photo: a floating house of the “Arche” type on Lake Geierswald; five houses were built in the marina so far, including a guest house, and two houses were built on the land in the same architectural style. Right photo: “Freilichthaus” on Lake Bergheider

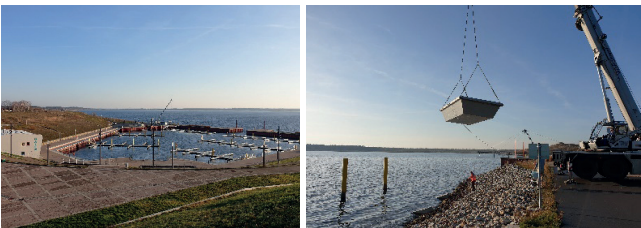


Fig. 6. Left photo: two freely available dolphins, brought in before the open pit mine was flooded; their length is 10 m; right photo: the view of Großräschchen Süd, a new port, a crane can be seen in the background



Fig. 7. The left photo: the assembly of the two pontoons; the right photo: using an assembly crane to make an accessway



Fig. 8. Using the crane to lift the shock absorber

3. RESULTS OF NUMERICAL SIMULATIONS

In the following sections, some examples of numerical simulation results are presented. They deal with the kinematics of pontoons and effects of forces caused by water waves. Software programmes are ANSYS-Fluent and ANSYS-AQWA.

3.1. THE EFFECT OF CONNECTIONS BETWEEN THE PONTOON

Here the effect of various platform connections on the stability of a structure as a whole and the forces arising inside it, in particular, are studied.

Initially, the immersion depth of the platform is 45.58 cm above the base, and it coincides with the zero point of the Z-axis. The attachment point of the joints is exactly in the middle of the platform. The attachment points of the cables are located in the upper part of the platform, they are equidistant from each other (1.7 m), and the distance from the Y-axis is 0.85. Fixed cable attachment points are in the same plane as the points on the platform, and it is located at the distance of 5 m from them.

It is also noteworthy that all cables, that keep the platforms together, are metal and linearly elastic; hence, tension is proportional to extension, and the constant of proportionality is called stiffness. As extension may vary in the course of the analysis, structures, to which the cable is attached, will experience a force of varying intensity and direction. The value of this force, which is equal to cable tension, is calculated using the formula: Force = Stiffness x Cable Extension. Stiffness as a universal value for a metal cable is set as 10 MN/m. Parameters of waves are presented in Table 1.

All calculations were performed at the time step of 0.01 s and the time interval of 50 s. Different initial conditions were considered for each type of attachment.

ANSYS AQWA allows for the analysis of various connections, including the so-called joints. A joint connection does not allow for any

Table 1. Wave parameters

	Lake	Test installation
Depth, in m	10	1.1
Water density, in kg/m ³	1,000	1,000
Wave amplitude, in m	0.5	0.15
Wave period, in s	2,118	1.4
Wave frequency, in Hz	0.472	0.714
Wave length, in m	7.0	3.0
Wave direction	0.0°	0.0°

relative translation of the two structures, but it allows for the relative rotational movement in a number of ways that can be defined by the user. Simulation results obtained for the platforms, using a universal joint, are presented first. Its design is shown in Fig. 9.

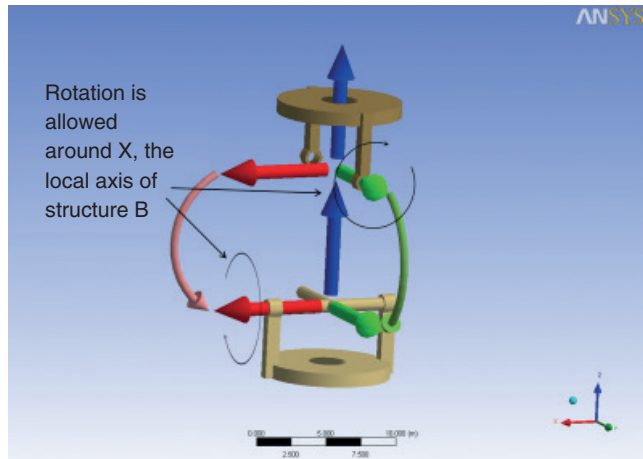


Fig. 9. Construction of a universal joint

The structure can freely rotate around the two axes, transmitting a moment around the third axis. In our case, it restricts the rotation along the X- and Z-axes and allows rotation along the Y-axis.

The illustration is available in Fig. 10 and 11 below.

To limit the rotation of the rear platform around the Z-axis, metal cables that are 0.2 m long were stretched between the platforms. Numerical simulation results are presented in Table 2 for comparison purposes.

Below are the diagrams of forces arising in the joints and tensions arising in the cables between the platforms in the case of mooring with the help of two (Fig. 12) and four (Fig. 13) steel cables.

It should be noted that the largest portion of the loading is accepted by the joint, while cables serve to stabilize the platform and increase its resistance to fluctuating wave loads. In the case of

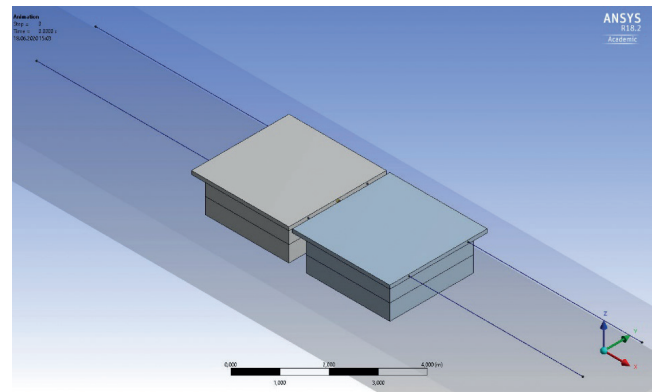


Fig. 10. The overall view of the system having a universal joint

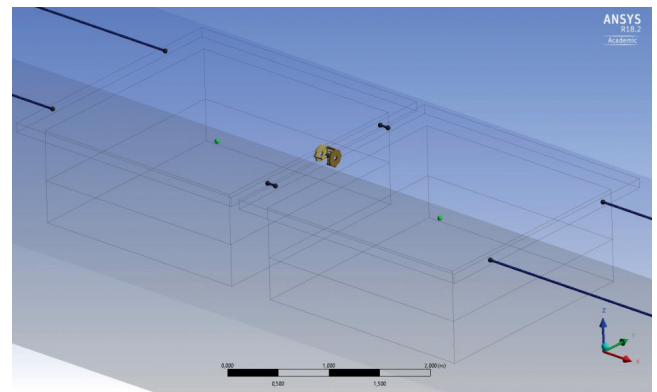


Fig. 11. A connection system having a universal joint

four-cable mooring, inner cables are not strained at all, since there is no need to limit the additional rotation resulting from the turning of the structure by waves.

A simulated platform-to-platform connection by the metal cables is shown below (Fig. 14). To increase the resistance to loads, outer cables are pre-stretched by 1 cm.

Table 2. Numerical simulation results

	Lake			Test Installation		
	2 metal cables	4 metal cables	4 PP cables	2 metal cables	4 metal cables	4 PP cables
	A universal joint in combination with a cable connection					
Max. tension in Cable 5 in N	—	483	5,261	9,763	453	1,087
Max. tension in Cable 6 in N	—	499	5,150	10,316	386	1,082
Max. force in Joint X in N	—	227,518	28,857	8,074	56,306	5,180
Max. Platform 1 shift along Z axis in cm	—	21.7	35.4	3.1	2.7	2.6
Max. Platform 2 shift along the Z axis in cm	—	20.6	40.3	2.2	2.0	2.3
	A cable connection					
	2 metal cables	4 metal cables	4 PP cables	2 metal cables	4 metal cables	4 PP cables
	A universal joint in combination with a cable connection					
Max. tension in Cable 5 in N	—					
Max. tension in Cable 6 in N	—	136,195	27,581	29,903	148,927	27,726
Max. Platform 1 shift along Z axis in cm	—	136,195	27,581	33,842	148,924	27,726
Max. Platform 2 shift along the Z axis in cm	—	34.5	19.2	3.9	37.0	7.4

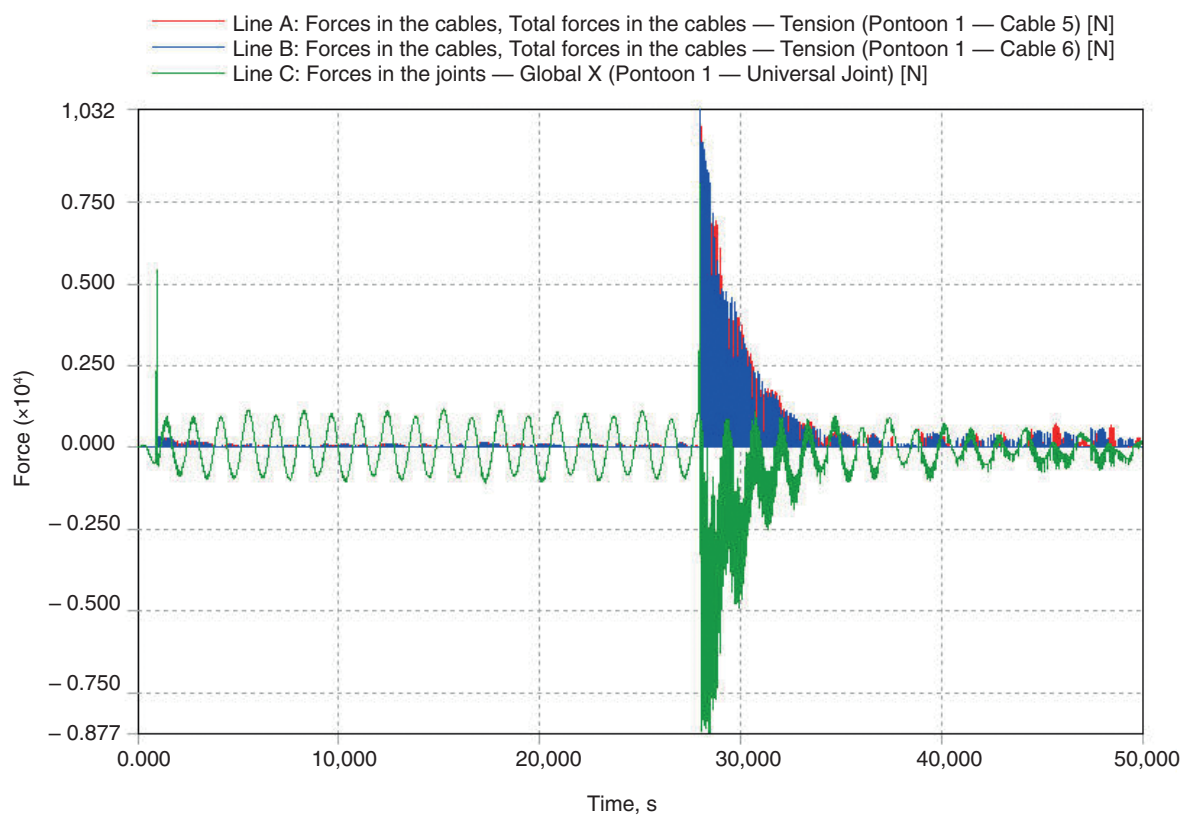


Fig. 12. Forces in the joints and forces/tensions in the cables arising between the platforms in the case of the two cable mooring

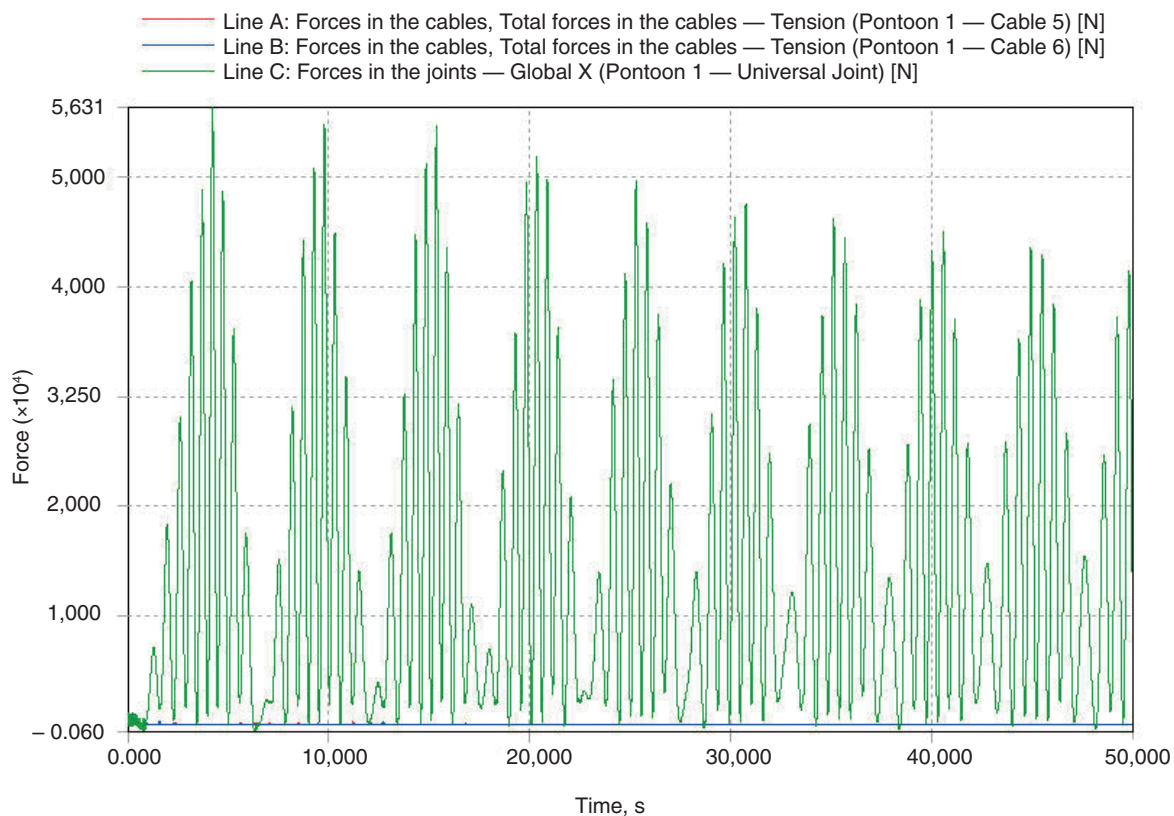


Fig. 13. Forces in the joints and forces/tensions in the cables arising between the platforms in the case of two-cable mooring

The diagram of stresses, arising in platform fastening cables in the process of their mooring by a metal cable, is presented below (Fig. 15). A shift in the platform's centres of gravity along the Z-axis is also shown in Fig. 16.

It is safe to say that after about 20 s of oscillation, the system comes to a fairly stable state with an average tension in the cables of about 67 kN and a 2...3 cm deviation of the center of gravity from its initial position. In fact, the constancy of tension in the cables shows the insignificance of the influence of forces created by the waves, and the dominance of the cable tension.

The table of summarized results has maximum tensions, arising in the cables and joints fastening the platforms, and shifts in the centers of gravity of platforms 1 and 2 from the center of buoyancy along the Z-axis under different initial conditions.

To sum up this section, it's important to emphasize that the connection of floating platforms is a fairly complex issue in terms of both mathematical modeling and interpretation of the results.

In the future, more types of connections will be studied to ensure greater system stability and feasibility of the universal application of connections. Subsequently, one of the objectives is to conduct an experiment to check the stability of systems having different connections using the wave generator installed at BTU Cottbus-Senftenberg Campus Sachsendorf. The results of this experiment will be used to validate the models and to ensure their universal application.

3.2. VERTICAL FLOATING PIPE PONTON

The movement behavior of a pontoon consisting of four rigidly connected pipes is shown in Fig. 17 and 18. The pipes are only opened in the water. The enclosed air damps the motion.

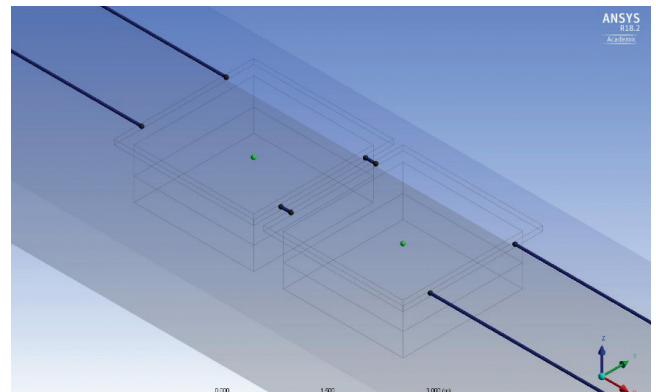


Fig. 14. The system that has two platforms connected by two steel cables

3.3. INTERACTIONS BETWEEN WATER WAVES AND THE STRUCTURE OF THE PONTOON

In this case, a tested pontoon, being a floating subject, was made of the so-called fiber concrete manufactured by TU Dresden and a company in Thuringia (Germany). Fig. 19 and 20 demonstrate the numerical simulation of its behaviour.

3.4. CONSIDERING AND USING DIFFRACTION AND SUPERPOSITION OF WATER WAVES

A very interesting topic is the effect of diffraction of water waves caused by gaps between floating pontoons. Floating houses, placed behind the "wall", could be protected from water wave attacks by such a floating chain of pontoons. Fig. 21 shows a

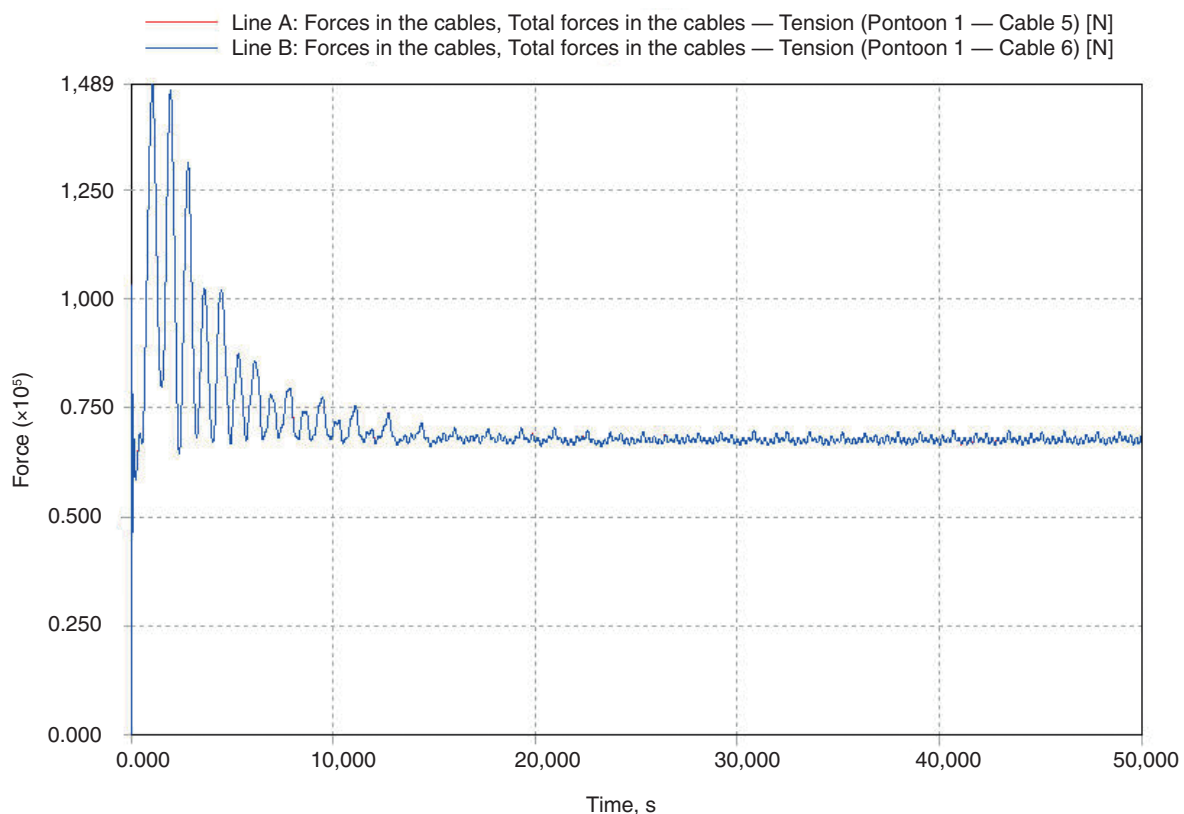


Fig. 15. Total tensions in the cables between the platforms if the connection has no joints

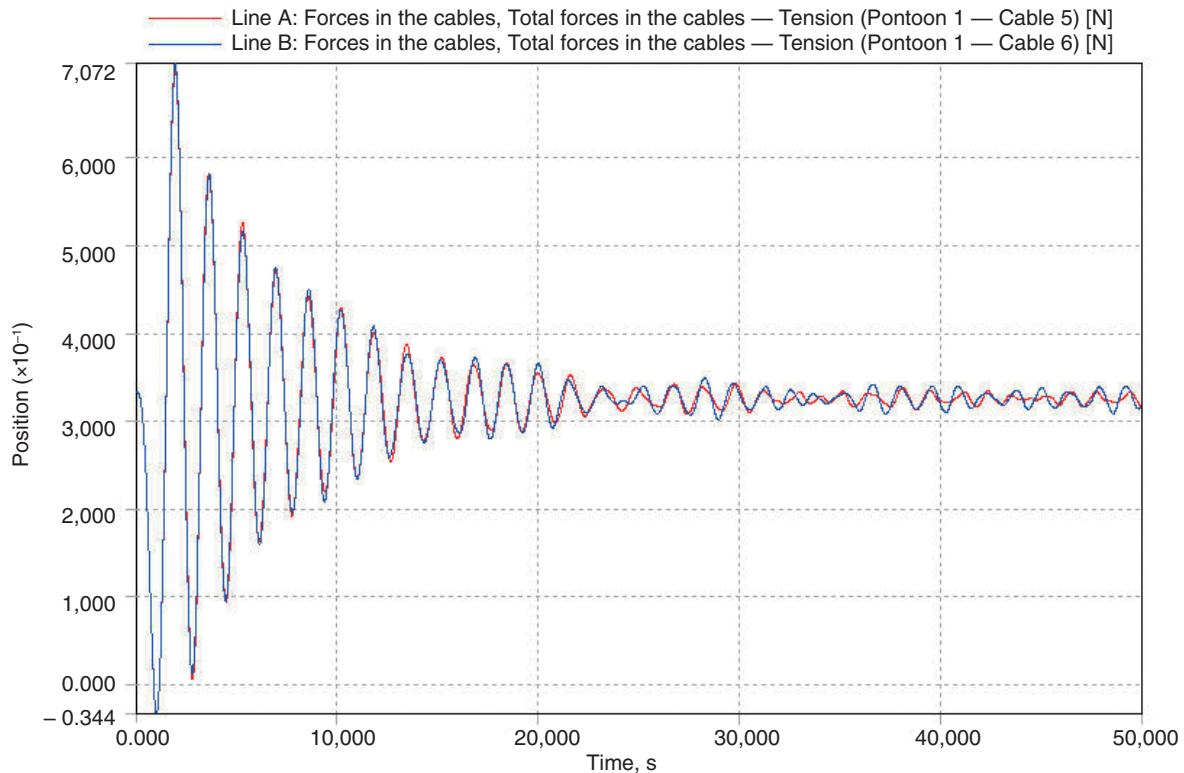
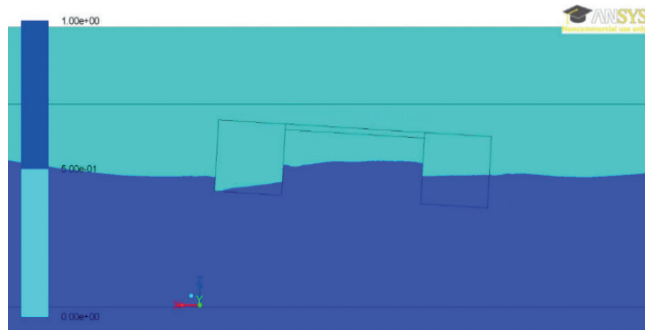


Fig. 16. A shift in the platform's gravity centers along the Z-axis



Contours of the Volume fraction (water) (Time = 1,4000e+01) Jan 03, 2017
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Fig. 17. A snapshot of the platform section. Motion parameters are available in Fig. 18

principal sketch simulated by the software. The result is shown in Fig. 22.

4. EXPERIMENTAL WORK

The snapshots in Fig. 23 demonstrate the experimental research performed with the help of a wide hydraulic testing channel at the IfSB Institute on the campus of the BTU Cottbus-Senftenberg University. Fig. 24 shows water wave parameters, recorded using a measuring buoy on Lake Partwitzer See in the Lusatian Lakeland.

5. THE OUTLOOK FOR FURTHER WORK

In the context of the global state of affairs, it is important to develop and produce regionally adapted and affordable floating structures. Towards this end, new approaches are being

developed. Robotik will serve as an additional important forward-looking technology that will accelerate work performance and minimize costs. Student graduation projects are being drafted.

In the same way, we will investigate the use of new materials. For instance, a so-called hybrid pontoon, made of concrete and wood, is being devised. Initial trials are underway in cooperation with the partners from Vietnam and Germany.

Furthermore, the influence of the thermal effect of water waves on water-filled pontoons, used as storage areas, must be examined.

The last but not the least, we will draw more attention to damping the motion and simultaneously converting and storing energy in industrial products, e.g., pipes made of plastic or steel, Fig. 25. The final point could be also a matter of cost reduction. The major problem is a permanently rigid connection between plastic pipes and steel grating.

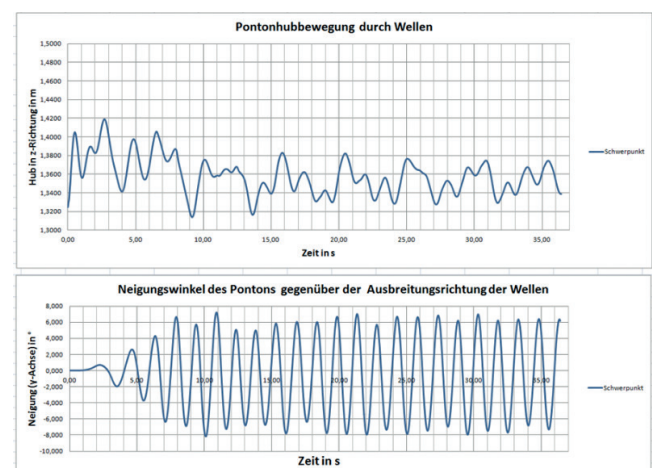


Fig. 18. The lift and the incline of the pontoon having open floating pipes on the bottom

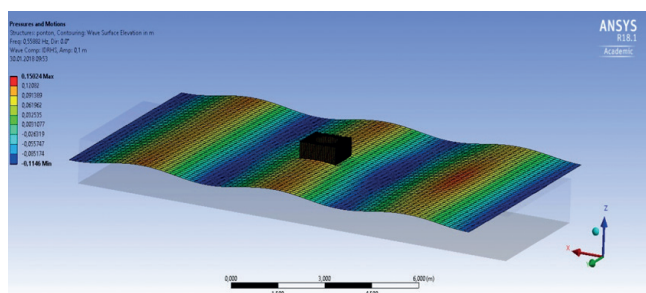


Fig. 19. The dimensions of the floating sample are $125 \times 125 \times 62.5$ cm

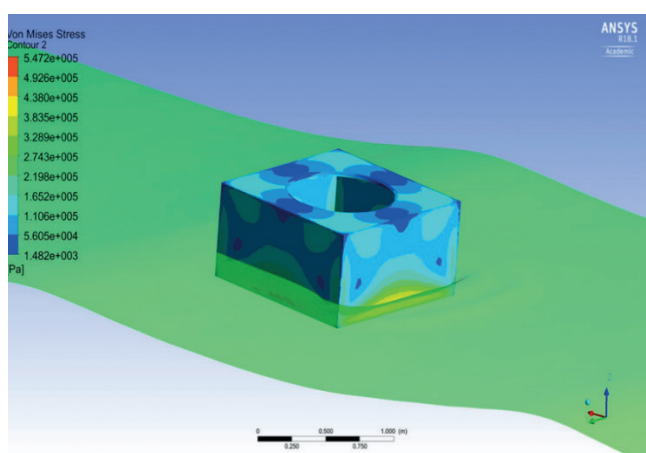


Fig. 20. The figure shows stresses caused by the wave attack on the channel

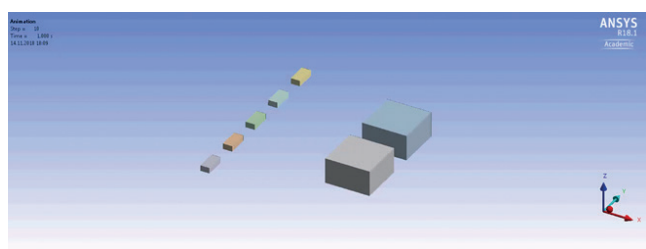


Fig. 21. The principal sketch of the two floating houses with five protecting pontoons in front, which was simulated when water waves were coming from the left

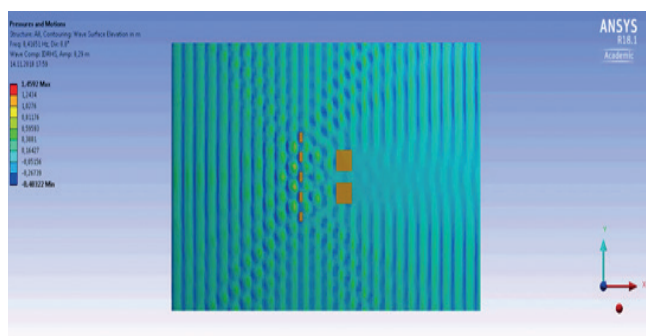


Fig. 22. The principal sketch of the two floating houses with five protecting pontoons in front, which was simulated when water waves were coming from the left



Fig. 23. Hydraulic testing channel

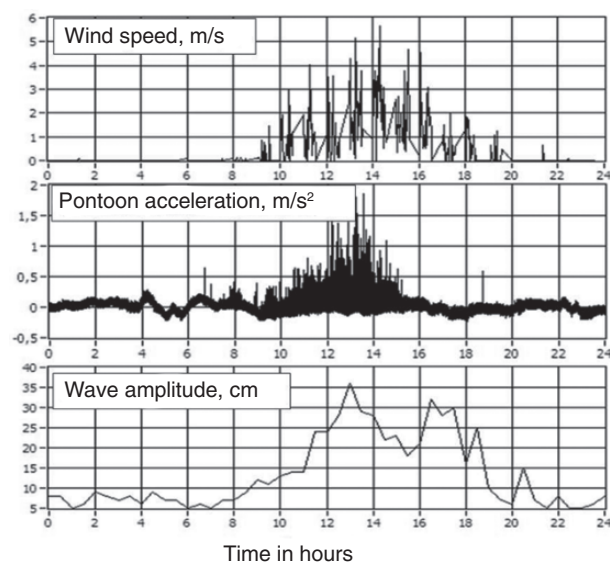


Fig. 24. The measurement protocol of a floating buoy that can be used to prognosticate the parameters of water waves in the lakes that represent former lignite mines

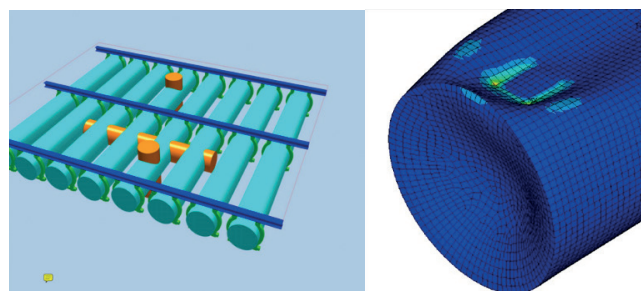


Fig. 25. The left image: a testing platform, made of prefabricated pipes. The right image: numerical simulation of the deformation behavior of plastic PE pipes exposed to mechanical loads at an immersion depth of 1.20 m (pipe diameter 1.50 m, wall thickness 60 mm)

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Численное моделирование движения плавучих конструкций

Уровень моря повышается, во всем мире наводнения угрожают инфраструктуре. Мы должны осознавать риски для ограждающих конструкций зданий и поселений, связанные с новыми граничными условиями, возникающими в результате прямого контакта с водными потоками. Для эксплуатации подвижной строительной площадки требуется адаптация конструкций во многих аспектах. В статье показано влияние волн на плавучие дома, построенные на территории бывших карьеров. Снимки разрушенных путей подхода к таким объектам подтверждают необходимость исследовать воздействие волн на плавучие дома. Чтобы сократить время и расходы на проведение экспериментов, целесообразно использовать численное моделирование, которое осуществляется с помощью современного вычислительного оборудования и программного обеспечения ANSYS FLUENT, ANSYS MECHANICAL FSI и ANSYS AQWA. Для проверки расчетных параметров использован гидравлический испытательный канал размером 15 × 5 м, плавучая платформа возле гавани озера Гросрешенер и плавучие дома в окрестностях Луижского озера в Германии. В заключение показана возможность установления параметров волновых сил, воздействующих на конструкцию понтонов. Проведена разработка новых соединительных элементов, адаптированных материалов и конструкций, осуществлено демпфирование движения воды, рассмотрены варианты использования энергии волн.

Ключевые слова: действие волн, плавучие дома, численное моделирование, Луижский озерный край

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