EAN 2018
56th conference on experimental stress analysis

FEM Calculation, Measuring and Testing of Flood Protection Barriers

ŠEVČÍK Ladislav[1,a] and LUFINKA Aleš[1,b]

[1]Technical University of Liberec, Studentská 2, 46117 Liberec 1, Czech Republic

[a]ladislav.sevcik@tul.cz, [b]ales.lufinka@tul.cz

Keywords: flood protection barrier, FEM, testing, properties measuring.

Abstract. A new type of flood barrier to protect doors or windows has been developed as part of the research project VI20152018005 of the Ministry of the Interior of the Czech republic. Designing, finite element modeling and testing of the barrier prototype real properties are described in this paper.

Introduction

The newly designed flood barrier will be used to protect doors or windows against water ingress. This barrier is supposed to replace the sandbags so far used. Its advantage is quick and easy assembly and reusability. Its principle and real prototype are shown in the Fig. 1.

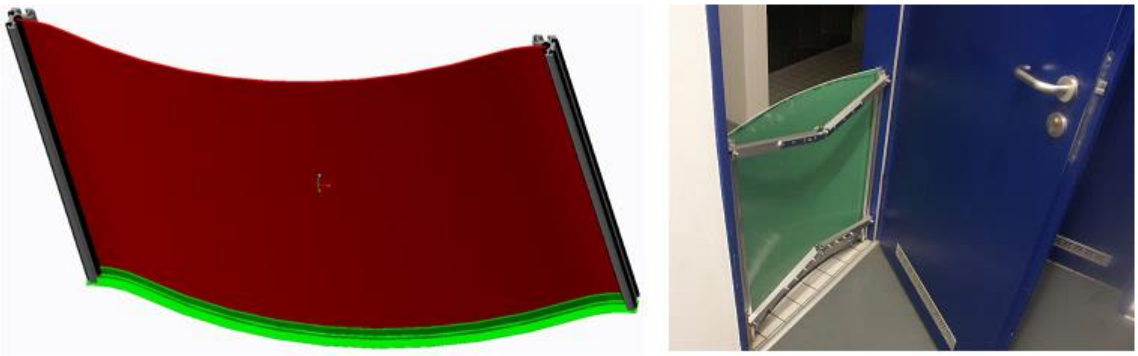


Fig.1 The flood protection barrier principle (left) and its real prototype (right)

The barrier is made up of a flexible composite plate, which is anchored on the vertical sides in the sidewalls with a rubber seal, which is also on the underside of the composite plate. The sidewalls are joined by flexible pulls. By pushing the pulls the plate is bent and the barrier can be inserted into the door frame. After loosening the bars, the bending of the plate causes a force that makes the barrier firmly anchored in the door frame. When the barrier is flooded, the hydrostatic pressure acting on the curved plate further increases the compressive force. The barrier is anchored in the door frame without any mounting. The bent shape of the board further eliminates certain inaccuracies in the width of the door frames.

CAD modeling and FEM Calculation

Composite plate properties are subject to contradictory requirements. The board must be flexible enough to be bent only by human force without the use of tools during its inserting to the door. The opposing requirement is that the bending of the plate must cause sufficient compressive force to anchor the barrier sidewalls in the door frame. The plate must also withstand the hydrostatic pressure from the retained water, and it must not collapse. The sidewalls profiles must allow the plate to be bent while ensuring watertightness. The barrier design including the seal was created using 3D CAD modelling and the parameters were optimized using FEM calculations [1, 2].

The basic problem was the decision how to solve computationally this case, whether to apply the bending theory of thin composite plates or the theory of buckling of thin composite boards for the calculation of expansion forces. The decision was mainly to place the board (boundary conditions) and the method of assembly (preload) and operation of the plate (hydrostatic pressure). Installation of flood protection is done in several steps. These steps affect to the calculation process. The assembly procedure is as follows: aluminum profiles are fitted with a rubber ring seal. Seal has the slot for the composite board (see Fig. 2).

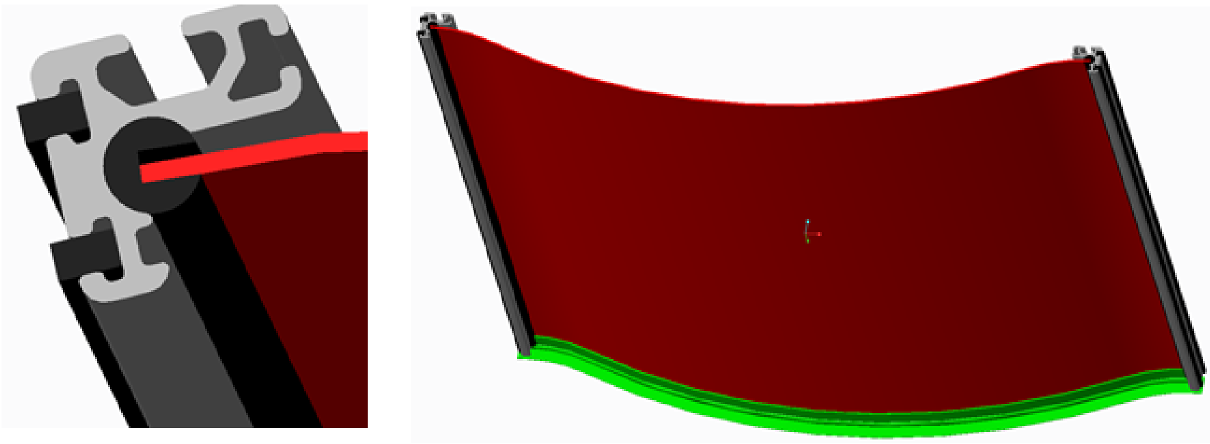


Fig. 2 Detail of the aluminium profile with rubber ring seal and composite plate (left) and the flood protection barrier (right)

The right and left aluminum profiles are connected by two jointed spacers. These spacers have joints at the junction with the profiles in the middle. The distance between the profiles maintains the spacers. Pressing the spacers together will decrease the distance of the profiles. The locations of forces are indicated by an arrow (see Fig. 3).

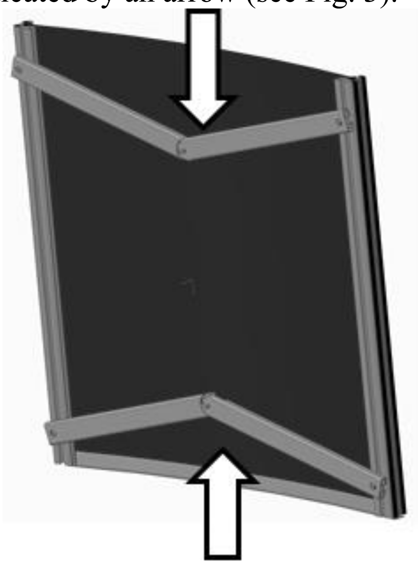


Fig.3 System of spacers with direction of pressing forces

In free states the composite plate is slightly longer than the pitch of the profiles including the grooves in the rubber. The board is inserted with preload force given by operator, during assembly. The plate deflects to shape near arc. The barrier holds together by action of the preloading force. This pressures force of buckling cause the frictional forces between the plate, sealing and the profile. These forces prevent the individual components of the barrier from ejecting. This folded barrier is inserted into the construction hole. The hole must be smaller than the size of assembled barrier. By computing and measuring the size of this dimension has to be verified. By pushing the spacer, the profiles are approached and the complete barrier is inserted into the door or window frame.

When the spacer's aren´t press, the plate is expanded and fixed in the hole. The prepared plate is waiting for the torrent water. This water loaded plate by hydrostatic and somewhere hydrodynamic pressure. Press of water acts against plate swelling. To some extent, this can increases the expansion force. This depends especially on the size of the construction hole and on the stiffness (thickness) of the composite board. In the case of a thin composite board, the hydrostatic pressure of the water causes its instability and thus the plate to break out. The results is that the plate has 1.5 waves in the loaded area. This wave loses its distance from the water level.

The optimization of the design is to design the thickness of the laminate plate to suit the given width of the opening and the desired level of the torque wave. Available theories are mainly solved by composite boards loaded onto buckling. In order to take into account all buckling modes (global, local and their interaction), the plate two-dimensional theory has been adopted to model the structures under analysis. Basic assumptions for thin plates were given by Kirchhoff law for the linear classical thin plate theory (CPT) and by von Kármán and Marquerre for the nonlinear CPT.

They made their assumptions for isotropic materials. In nowadays the knowledges have extended those assumptions for orthotropic or even for composite multilayer thin plates. The assumptions are as follows:

- The plate is homogeneous (for example, orthotropic homogenization is made for a fiber composite—resin matrix and fiber-reinforcement).
- The plate is thin—other dimensions (length and width) are at least 10 times higher than the plate thickness.
- The material of the plate is deformable and it is subjected to Hooke's law.
- The plane stress state is considered for the plate—the stress acting in the plate plane dominates the plate behaviour, stresses acting in the direction normal to the plate plane are assumed to be zero.
- All strains (normal and shear) in the plate plane are low compared to unity and they are linear.
- The strains normal to the plate mid-surface are neglected (the plate thickness does not change after deformation)—this assumption is made according to Kirchhoff-Love; normal to the mid-surface after deformation.
- There are no interactions in the normal direction between layers parallel to the middle surface;
- Deflections of the plate can be considered in terms of nonlinear geometrical relations.

Additionally, it is assumed that the principal axes of orthotropy do not need to be parallel to the edges of analyzed structures.

Examples of FEM modelling results are shown in the Fig. 4 and the Tab.1.

Tab.1 3-axis forces and torques of the bent plate

	Compression 20mm		Compression 40mm	
Direction	Force [N]	Torque [Nm]	Force [N]	Torque [Nm]
X	1212	1.5	1274	4.2
Y	9	52.3	52	96
Z	46	5.1	148	4.4

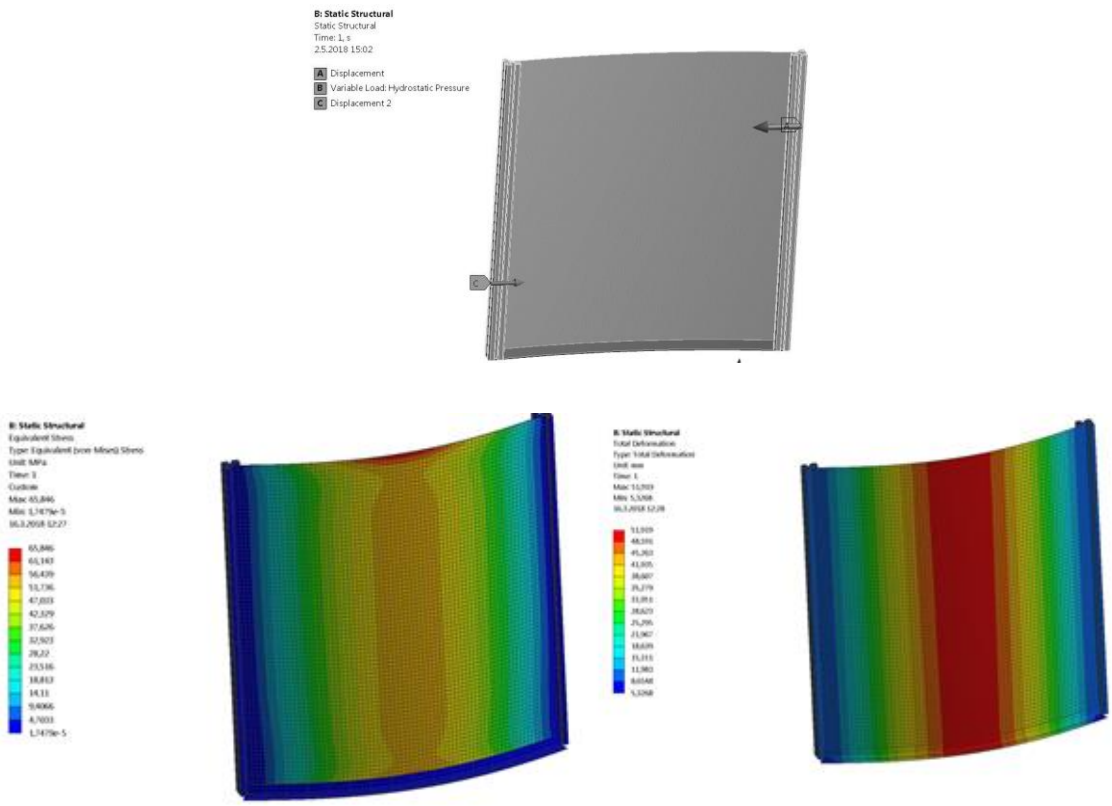
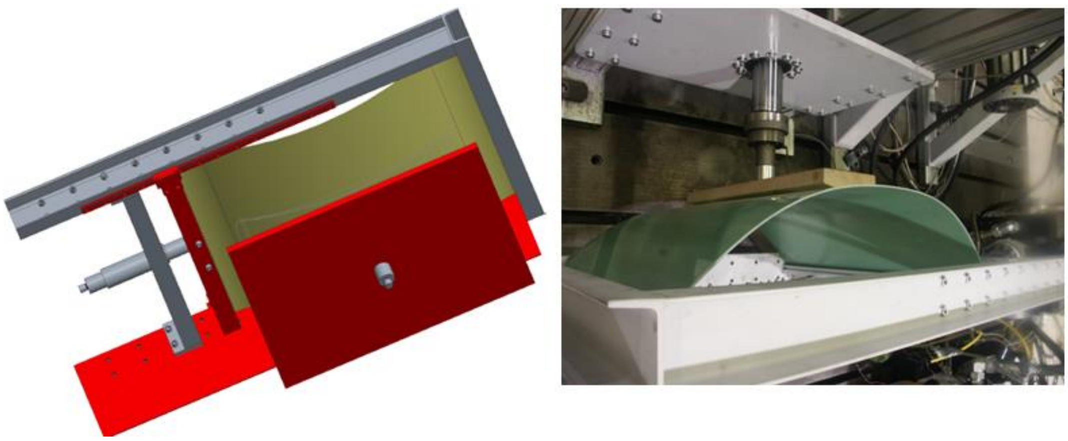


Fig. 4 Boundary condition for deformation 20 and 40 mm (up) and results of HMH stress for deformation left 20, right 40 mm

Real prototype measuring

The special test device was built to validate modelling results. It allows to set different door frame widths and to simulate the load of the barrier by hydrostatic pressure. The hydrostatic pressure of flood water is simulated using a plate driven by the linear hydraulic engine. The test device CAD design model and real test device configuration are shown in the Fig. 5.



Fid. 5 Testing device and its CAD model

The real properties of the various composite plates were measured using this device. The barrier was inserted into the test device and hydrostatic pressure was simulated using the hydraulic engine (see Fig.6 up). The force acting to the barrier, its deflection and side force from the barrier to the door frame were measured. Measured results were then compared with FEM calculations (see Fig. 6 down).

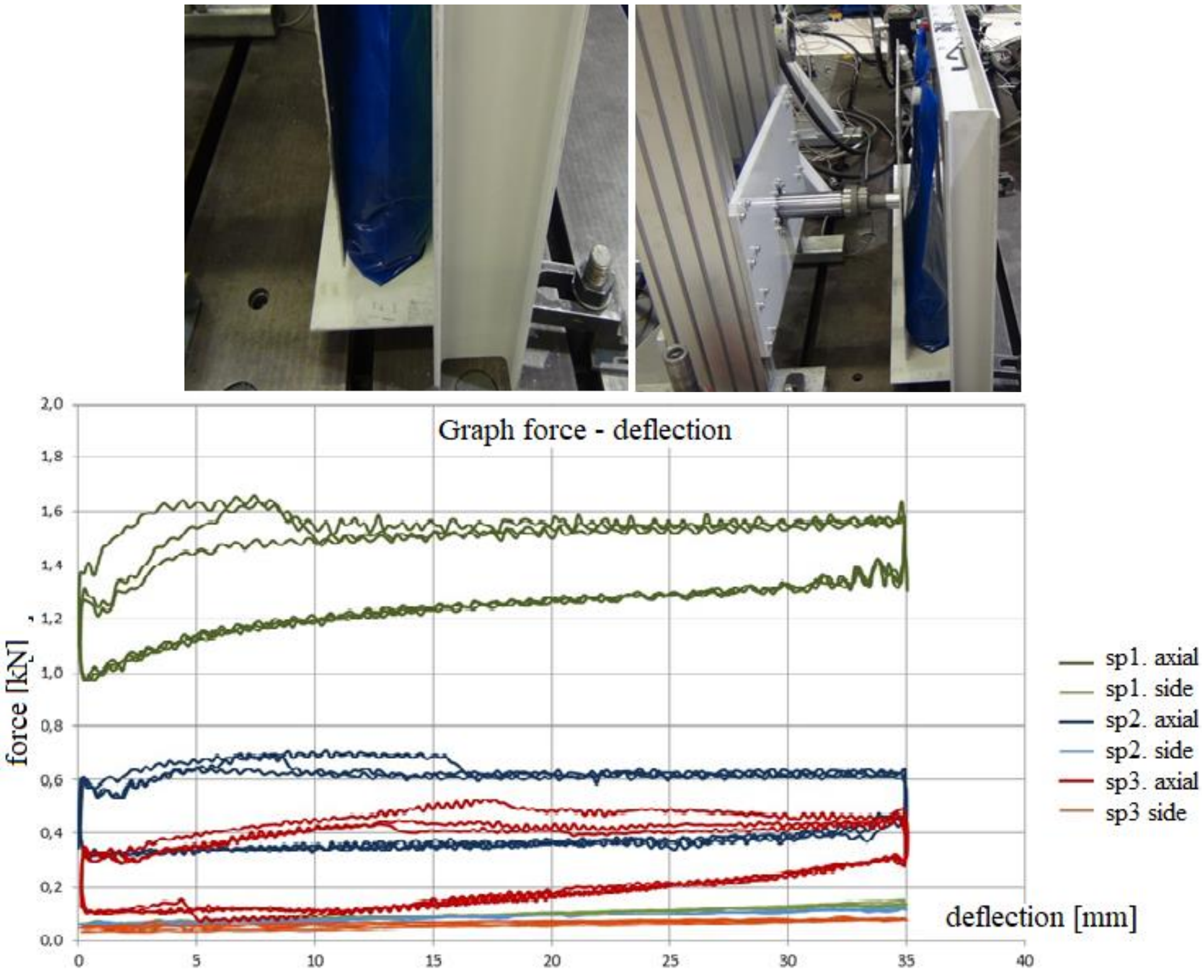


Fig. 6 Real flood barrier testing (up) and Examples of tests result(down)

Conclusions

The flood protection barrier assembly has been optimized by combining FEM modelling and measuring real properties of composite plates. The flood barrier is now ready for the final test of real water flooding. The advantage of the proposed solution is that the buckling force changes minimally in the extent of the barrier function.

The results of this project VI20152018005 were obtained with co-funding from the Ministry of the Interior of the Czech republic as part of targeted support from the project "Vývoj protipovodňových systémů pro zvýšení ochrany obyvatelstva a infrastruktury".

References

[1] Kubiak T: Static and Dynamic Buckling of Thin Walled Plate Structures, Springer 2013 ISBN 987-3-319-0D653-6,

[2] N. REDDY and A. KHDEIR. "Buckling and vibration of laminated composite plates using various plate theories", AIAA Journal, Vol. 27, No. 12 (1989), pp. 1808-1817., https://doi.org/10.2514/3.10338