

Stress Oriented Rigid Foldings as an Optimized Lightweight System

J. Musto, M. Trautz

Keywords: rigid foldings, stress oriented foldings, stress trajectories,

Abstract

Rigid foldings made of thin materials are an appropriate and efficient structural principle for lightweight load-bearing systems. In architecture, they are mainly limited to parallel longitudinal foldings with uniaxial load-bearing, e.g. trapezoidal sheets, or occasionally represented constructions with periodic folding patterns such as polyhedron based domes or tunnel vaults with rhomboidal elements. This paper shows that the efficiency may be increased, if the supporting structure is built in the direction of the load transfer in a structure by adapting the folding pattern based on the stresses.

Current approaches in steel construction for the stress oriented structures are more based on numerical optimization of support structures. Construction parameters such as height, distance and thickness are achieved via interactive algorithms with the aim to minimize the material consumption. The target of this paper is to orient the supporting structure to the direction of load transfer.

In the framework of this paper the potential of stress oriented foldings influencing an increase in efficiency will be examined. In contrast to a folding pattern based on a regular tessellation, the fold edges are aligned to the principle stress trajectories (Figure 1). This leads inevitably to an irregular tessellation, in unfavorable case to different folded entities without even a topological relationship. With the application of innovative transformation techniques like the incremental sheet forming (ISF), complex structures with unequal facets can also be produced economically (Herkrath & Trautz, 2011).

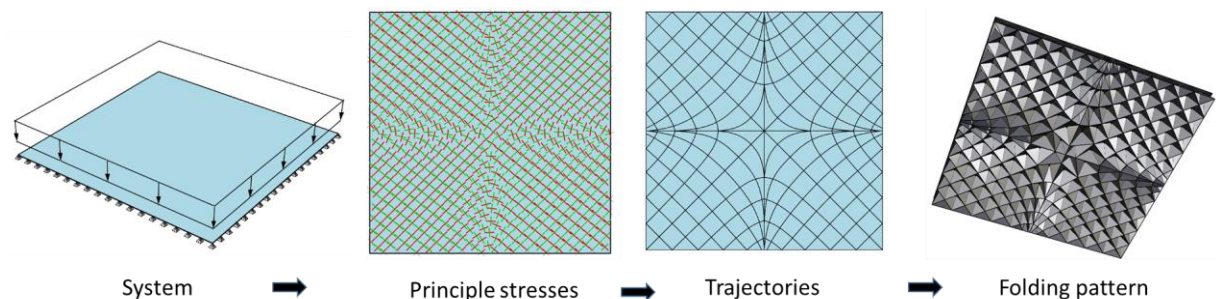


Figure 1: Folding pattern based on stress trajectories on an example of a simple supported square plate

The primary task of this investigation was to determine the shape of the construction. The first part deals with the concept of stress orientation. For this purpose, the stress states, principal

stresses and principal stress directions of a body are described. Based on this, the trajectories are presented as a visualization of the main stress directions, which form the basis for the folding orientation (Figure 1). Different definitions of load paths are discussed and compared to achieve the most efficient utilization of the structure as well as material.

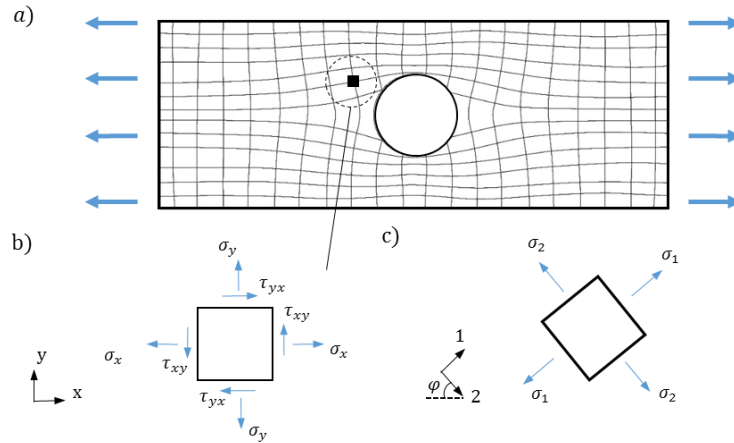


Figure 2: stress trajectories of a tension element with circular cut out b) section with random orientation c) section in main normal stress direction

The design of stress-oriented folding was done in the following steps: Starting from a flat surface representing the underside of the planned geometry, the principal stresses and their directions for the relevant load case were calculated. An algorithm was programmed to generate the associated main stress trajectories. Based on this net of trajectories, a folding design is generated (Figure 3). The trajectories are used to tessellate the plane surface into subareas which represent the bases of the point folds. Through extrusion of the centers of these partial surfaces, pyramidal point folds results whose base edges are aligned along the main stress trajectories. The completion of folding plates builds the top plate, connected to the pyramid tops.

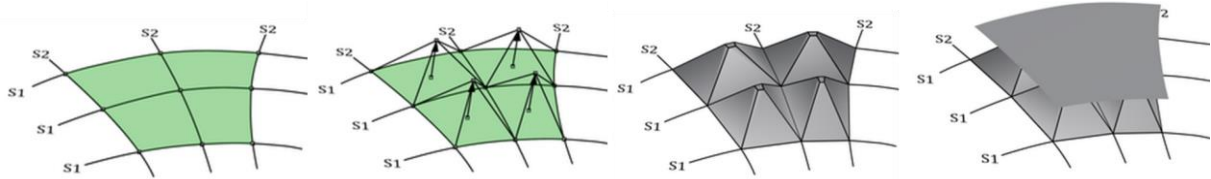


Figure 3: Process of folding

The research was carried out with plane, spatially curved and free form geometries subjected to various loads (e.g. single and surface loads and different support situations). All cases were developed with both regular and stress oriented foldings and were subjected to a structural analysis.

The ratio of the total load capacity to the construction weight was used as a criterion of efficiency for the evaluation. A parameter study, in which the system variables, folding density, construction height and sheet thickness are defined as parameters, was used to calculate the

maximum efficiency for the both systems. The study shows an increase in efficiency of up to 40 percent for the stress oriented folding in comparison to the regular foldings.

References

- Della Puppa, G., & Trautz, M. (2016). *Effizienz von Faltleichtbauplatten*. Aachen: Shaker Verlag.
- Herkath, R., & Trautz, M. (2011). Starre Faltungen als Leichtbauprinzip im Bauwesen. *Bautechnik*, 88(2), S. 80-85.
- Musto, J., & Trautz, M. (2017). Stress Oriented Foldings as an Optimized Lightweight System. *International Association for Shell and Spatial Structures (IASS)*. Hamburg.