Applications of Michell's Theory in Design of High-rise Buildings, Large-scale Roofs and Long-span Bridges

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The theory of Michell's structures reveals how to optimally transmit the given external load to a given support and how to optimally transmit the given system of self-equilibrated loads. In Michell's structures bending is totally eliminated, while single members are fully stressed by tensile and compressive forces. As a result, the structure is perfectly suited to applied external loading and has minimal possible weight. Since this remarkable idea has been proposed by A.G.M. Michell in 1904 [1] many specific analytical and numerical solutions corresponding to various loads and boundary conditions have been derived [2]. These solutions did not remain only the theoretical concepts but also have inspired civil and mechanical engineers and have influenced selected contemporary designs of high-rise building, large-scale roofs and long-span bridges.

The objective of this contribution is to present and critically analyze practical applications of Michell's theory in civil engineering. The first part of the talk will present the concepts of Michell-inspired "wingy" and "bulbous" skyscrapers proposed by Polish architects Wacław Zalewski and Wojciech Zabłocki as well as selected buildings constructed by international architectural office Skidmore, Owings and Merill. Further, constructions of the large-scale coverings of two famous Polish commercial buildings, Supersam in Warsaw and Spodek in Katowice, will be analyzed in order to reveal applied by their designers combination of tensegrity principle and Michell's theory resulting in ingenious interplay of compressive and tensile forces. In the last part of the presentation, the theoretical layouts of Michell's structures created over multiple spans [3] and recent numerical solutions of topology optimization problems related to bridge design [4] will be compared against selected existing constructions of long-span cable-stayed bridges, suspension bridges and arch bridges.

References

[1] **A.G.M. Michell, 1904**, *The limits of economy of material in frame structures*, Philosophical Magazine, Vol. 8, No. 47, pp. 589–597.

[2] **T. Lewiński, T. Sokół, C. Graczykowski**, *Michell Structures*, Springer, 2019, ISBN 978-3-319-95179-9.

[3] **A.V. Pichugin, A. Tyas, M. Gilbert, L. He**, 2005, *Optimum structure for a uniform load over multiple spans*, Structural and Multidisciplinary Optimization, Vol. 52, pp. 1041–1050

[4] **H.E. Fairclough, M. Gilbert, A.V. Pichugin, A. Tyas, I. Firth**, 2018, *Theoretically optimal forms for very long-span bridges under gravity loading*, Proceedings of the Royal Society: Part A, Vol. 474: 20170726.