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Load capacity and stiffness of angular cross section reinforced concrete beams under torsion

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The paper presents the results of tests, numerical analyses and theoretical analyses of reinforced concrete beams loaded with a torsional moment as well as a shearing force and a bending moment, carried out in the Research Laboratory of the Institute of Building Engineering at Wrocław University of Technology. The research focused on the load capacity and stiffness of such elements. Beams angular (in the shape of the inverted letter L) and rectangular in cross section were investigated. The tests were carried out in two series. In the first test series the elements were loaded with solely a torsional moment. In the second test series the beams were subjected to the combined load of a torsional moment, a shearing force and a bending moment. The behaviour of the beams with the different cross sectional shapes was compared. The experimental results and the ones yielded by numerical analyses were compared with theoretical and standard results.

Keywords: *beam, crack, experimental research, L-beam, load capacity, reinforced concrete, stiffness, torsion*

1. Introduction

A torsional moment in building structures always arises when the resultant force acts eccentrically relative to the longitudinal axis of an element. Although this happens quite often, in most cases the torsional moment is slight and has a smaller effect (in comparison with the other types of loading) on the ultimate limit state. Torsion usually occurs together with a bending moment and a shearing force. Generally, it is the bending moment which is decisive. In building engineering the loading of an element with a torsional moment alone (pure torsion) is a wholly theoretical case. In most cases, the reinforced concrete elements under torsion are simultaneously loaded with a bending moment and a shearing force (sometimes also with a longitudinal force, as in prestressed reinforced concrete elements). Examples of reinforced concrete elements often loaded with a torsional moment are: edge floor joists, balcony slab ring beams, spatial frames, spiral stairs and reinforced concrete arches loaded perpendicularly to their plane (Figure 1).

Structural components have been the subject of extensive research for over a hundred years of the history of reinforced concrete. Most of the experimental research has been on beams rectangular or circular in cross section (the latter were investigated mainly at the beginning of the 20th century). Simultaneously, theories describing the behaviour of reinforced concrete elements under torsional loads have been developed.

Two main theoretical models describing the behaviour of cracked reinforced concrete elements under torsional moment, i.e. the Rausch space truss model (1929) [18] and the Lessig spatial cross section model (1959) [13], were created. Since then the models have been modified and refined in order to bring them closer to reality. The most comprehensive monograph on torsion was written by T.T.C. Hsu [4].

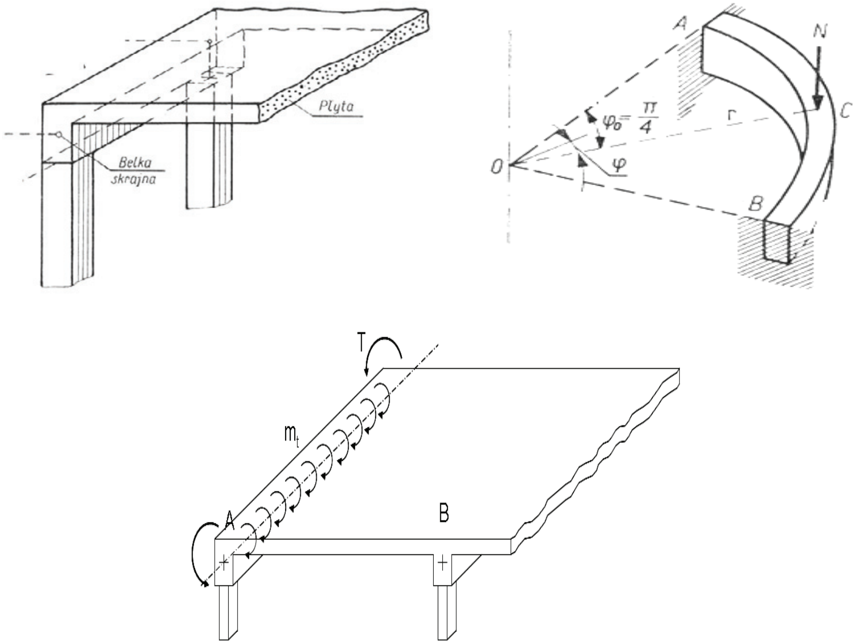

Fig. 1. Examples of reinforced concrete elements in which torsion occurs

Selected conclusions emerging from the experimental studies and theoretical analyses found in the literature on the subject are presented below:

- the cracking moment for elements with and without reinforcement is basically the same (the cracking moment is mainly determined by the strength of the concrete, the influence of the reinforcement being almost imperceptible);
- the longitudinal reinforcement and the lateral reinforcement of elements subjected to pure torsion should have a similar "strength" (for strength and economic reasons spiral reinforcement with the spiral direction consistent with that of element torsion under same-sign torsional moment is most preferable);
- after cracking the stiffness and the load-bearing capacity are determined mainly by the amount and type of reinforcement, not by the strength of the concrete;
- spiral reinforcement is better utilized (but it has many drawbacks, such as workmanship defects and possible errors in laying the spiral consistently with the direction of the twist);