DIBt-Research Project ZP 52-5-13.161-1092/04

„Load capacity and design of glulam beams with round holes“

- safety relevant modification of the design methods in Eurocode 5 and DIN 1052 -

Short title: Design of glulam beams with holes

here: Abstract

Round holes in massive glulam beams represent a frequent architectural and use-bound necessity especially for enabling the penetration of pipes. The design of holes in glulam members is handled pronouncedly different in German and European design standards and respective design drafts. The European pre-standard DIN V ENV 1995-1-1:1994 and the present version of Eurocode 5, EN 1995-1-1:2004, contain no design rule for holes. The design rules in DIN 1052-1:1988, prEN1995-1-1:2003 and in DIN 1052:2004 differ considerably with respect to the underlying mechanical models and forward pronouncedly divergent calculation results. The finished research project aimed at two goals: i) creation of a consistent data basis of tests results with structural sized specimens for a validated calibration of a design model; ii) development of a modified design concept overcoming the methodology based deficits of the presently used approaches.

The experimental investigations comprised in total 68 homogeneously built-up glulam members of strength class B16 resp. GL 32 h with round holes placed symmetrically with respect to the beam axis. The cross-sectional width was constantly 120 mm. In the frame of 13 test series the following four parameters were varied: i) beam depth (h = 450 and 900 mm); ii) relative hole size (d/h = 0,2; 0,3 and 0,4; d = hole diameter); iii) ratio of section forces M/V at the hole and iv) beam shape (straight or slightly curved). In case of all test specimens the total damage evolution was recorded in detail, comprising the development of the first crack at the periphery of the hole, followed by the full cross-sectional crack and finally ultimate load. The first crack occurs always at mid-width of the cross-section as a consequence of the cylindrical anisotropy of the material in case of the usual sawing pattern of the boards with curved annual ring configuration. After occurrence of the full cross-sectional crack a quantity of 30 % of the beams failed immediately by unstable crack growth without any further load increase. In case of 70 % of the specimens a differently pronounced stable crack growth was encountered until sudden occurrence of ultimate load. In average of all specimens the first crack occurred at 70 % of the full cross-sectional crack load and at 59 % of ultimate load. The pronouncedly varying ratio of full cross-sectioned crack load vs. ultimate load was in average (± standard deviation) 0,86 ± 0,14. At 50 % of the tests the ratio of full cross-sectional crack load vs. ultimate load was ≥ 0,9; the lowest respective ratio was 0,5.

The most important result of the experimental investigations consists in the confirmation and quantification of the supposed pronounced influence of the size of geometrically similar structures on the load capacity (size effect). The load capacities of the beams with large cross-sectional depth (h = 900 mm) evolved at the levels of the full cross-sectional cracking load and ultimate load, respectively, to be only 1,31 and 1,54

times higher as compared to the respective capacities of the 2times less deep beams (h = 450 mm). The load levels of full cross-sectional cracking and ultimate failure decrease significantly with increasing hole size (d/h – ratio); the obtained capacity reductions were well comparable for both, full cross-sectional crack load and ultimate load. An increasing section force ratio M/V results in a verifiable load capacity reduction. It is essential to note that very small beam curvatures forward significant decreases of the load capacity as compared to straight beams.

The theoretical investigations comprised the development of a Weibull theory based design procedure whereby tension stress perpendicular to fiber direction was considered being decisive for the load capacity. The Weibull approach has been chosen as this theory is provenly apt for brittle materials / material properties with stochastically distributed defects and for the simple incorporation of very inhomogeneous stress distributions in differently sized volumes. As the Weibull theory is already used at the European (EC 5) and German (DIN 1052:2004) level for the design of tension stresses perpendicular to fiber direction in curved and pitched cambered glulam beams, the choice of the specific design concept reflects a consequent extension of a recognized model perception for glulam. The design concept comprises all parameters which revealed relevancy for both, the full cross-sectional crack load and ultimate load in the experiments, being: the section forces V and M, the hole ratio d/h, the relative beam curvature h/r_m and the size of the building component.

For fitting of the calculated resistance of the building component in the design concept to the entity of test results, a scalar parameter has been introduced, which is calculated by minimization of the error squares between computational and experimental results of all test series. The determination of the calibration factor can be performed with almost equal fitting quality with regard to the characteristic values of the full cross-sectional crack load and the ultimate load. However, for design of beams with long-term structural integrity and fitness for use only the adoption of the calibration factor based on full cross-sectional cracking load is sensible. This results from the encountered principal damage evolution and the avoidance of conceptually accepted large sized cracks. The developed design concept forwards for small and medium sized beam depths up to about 0,5 m comparable results as DIN 1052:2004, which agree well with the test results for both approaches. At large beam depths the approach of DIN 1052:2004, not incorporating a size effect which was proven experimentally, forwards pronouncedly higher load capacities than the Weibull model which represents the experimentally obtained size effect well. As there is no substantiated argument for the assumption that the obtained size effect decreases considerably for structural depths > 0,9 m, it has to be assumed that the characteristic ultimate load values are exclusively described in conservative manner by means of the Weibull approach and are considerably overestimated by DIN 1052:2004.