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# Conceptual design and evaluation of the alternative construction of lightweight hall building with polygonal ground plan and canvas roofing

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**Abstract**

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The paper presents the results of a conceptual study of lightweight wooden construction hall building with polygonal ground plan, suitable for agriculture. It comprises evaluation of chosen technical and functional characteristics and possibilities for animal production. The results of the study confirm advantages (mainly lower material and costs demandingness, environmentally friendliness, light-weight construction, fast assembly operations) and disadvantages (mainly larger range of groundwork, higher demandingness on roof structure, foundation of slab constructions and anchoring of vertical bearing constructions). Values of radial tensile stress at an interval of 9.0 to 21.0 MPa and tangential tensile stress at an interval of 1.4 to 16.0 MPa were calculated on vertical load 100 kN at the top of the construction). The construction makes possible to achieve a span as far as 60 m with effective canvas strain at large radius curvature from 80 m to 100 m.

**Keywords**: farm building; lightweight construction; polygonal stable; tent roof

The introduction part of this paper contains literature review about farm buildings with emphasis on lightweight wooden structures. Wood as a construction material is today considered as an excellent building material for both its technical and its environmental qualities. Main advantages of wood are as follows: it is highly recyclable and the raw material is renewable, and its carbon storage capacity and the reduced use of fossil fuels in its production make it particularly interesting compared to other materials (Baño et al. 2011, 2013). Villar et al. (2016) stated that the optimization of structures concerns itself with finding the geometrical dimensions that are the cheapest while being capable of withstanding the forces required in the design with solutions that meet the criteria predefined in structural design standards. The particular norm considered in the present work is the European timber structures standard, CEN EN 1995-1-1:2006+A1:2010. Building layout and construction affect building costs (Pereira et al. 2003; Fernández et al. 2008). Domestic regulations, material costs, labour prices and building tradition might also influence building costs (Van Caenegem 2003). Zähner et al. (2004) stated that uninsulated or open barns have been shown to be sufficient to avoid high-yielding dairy cows overtaxing their thermoregulatory ability in a cold climate. For the use as a structural material in buildings, timber must satisfy conditions that ensure the

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durability and good performance of the structure. Structural timber, as a general rule, should not be obtained from sapwood and should also show the appropriate degree of drying at the moment of construction, considering the service class for which it is designed. Usually, solid timber can be used in sawn or round form. The use of sawn or round timber is influenced by the building system used. The timber species used determines the strength properties and affects the cross-sectional size of structural members Mariño et al. (2009). The definition of the barn layout is the basis for the search for suitable structural solutions. The layout, the structure and the building enclosure for a freestall barn depend on the economics, aesthetics and the maintenance of environmental conditions inside the building (Ikeguchi, Okushima 2001; Pereira et al. 2003; Snell et al. 2003).

The goal of the paper is a conceptual design and evaluation of chosen technical characteristics of the alternative construction of lightweight hall concept with polygonal ground plan and plastic roofing, suitable for farm buildings.

## MATERIAL AND METHODS

Evaluated model facility is constructional design of polygonal lightweight hall concept for fattening pigs on deep litter. Presented timber framework construction is technically easy and low-cost hall construction design with wide utilization in agriculture as building for barns, stocks and garages for mechanization.

The mechanical properties of materials are taken from the recent CEN EN 14080:2013 standard (Timber structures. Glued laminated timber and glued solid timber. Requirements). The analysis against the Ultimate Limit States (ULS) involves an ordered verification of the strength of the cross-sections and joints, defined by their number, type and the arrangement of the elements. Section strength is analysed according to CEN EN 1995-1-1:2006+A1:2010 (Eurocode 5: Design of timber structures-Part. 1.1 general. Common rules and rules for buildings (1)), henceforth referred to as EUROCODE. The General Model is calculated using the rigid nodes except for the intermediate members which are calculated with pinned-pinned elements, and variable loads. The General Model will be used to calculate separately the ULS stresses and the SLS deformations.

The ANSYS 5.5.3 software (ANSYS, Inc., USA) was used for a preliminary static analysis. Static model of the analysed construction consists of these defined structural elements:

– Space loaded elastic beam with sectional area 300 mm$^2$.
– Space loaded element – canvas from plastic technical textile with thickness 0.5 mm.
– Nonlinear supporting element for simulation of border conditions at polygonal construction perimeter.

The pre-stress load case with different values of total tensile force in the top of the construction was analysed. The border conditions are defined as tension in corners of the top polygon and horizontal drift in corners of the polygonal envelope (200 mm from outside of polygon in radial direction). Calculation of direct stress and deformation was performed repeatedly for total load at the top polygonal steel ring by tension force (50 kN, 100 kN and 200 kN) with constant volume of border deformation.

## RESULTS AND DISCUSSION

The model shed is specified as a pig fattening facility for 100 heads. Hall construction has the medium-scale span of 14 m and mostly round timber pole height of 2.6 m. Materials and construction design of hall meet requirements according to the technical standards and legislation.

Technological conception of the stable is group-housing at deep bedding composted with using of bio-activators. Disposal of composted manure is after every fattening cycle with using of simple mechanization (skid-steer loader) and final hand-made cleaning. Bedding consists of mixture of straw and wooden saw-dust (week addition from 0.5 to 1.0 kg per head). Feeding system is made with disc-type feeders and dry feeding mixture. Transport of the mixture is ensured using a piped conveyor from exterior silos. Pig drinkers are of jet type with protection against freezing by electric tempering. The scheme of the technological conception is presented in Fig. 1.

The construction system of the polygonal hall is suitable for roofing of canvas made of technical water-proof plastic textile. The presented barn has polygonal ground plan with 13.3 m circumradius and side length of 2.6 m. The barn is symmetri-

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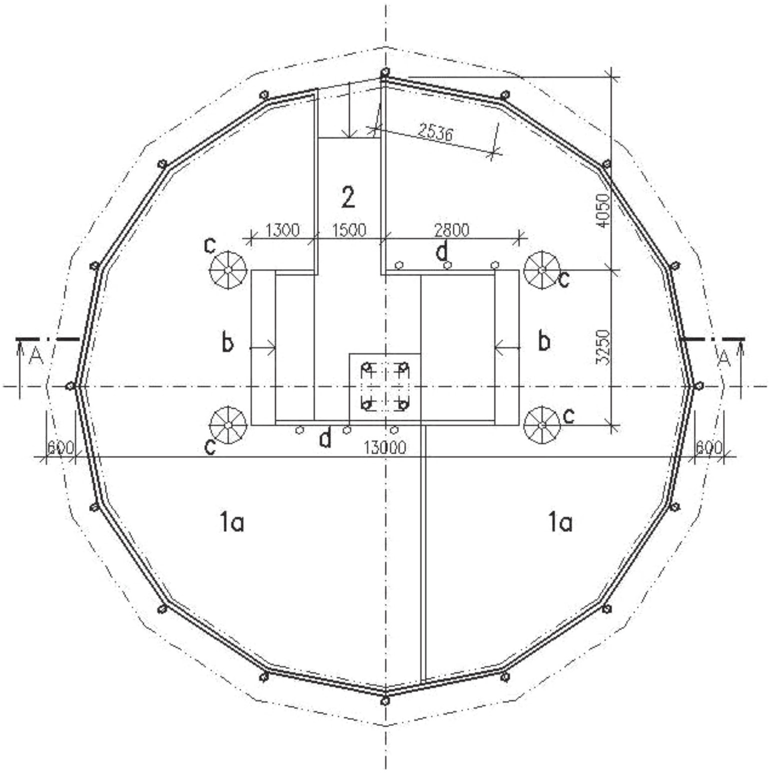


Fig. 1. Ground plan scheme of the polygonal hall construction
1 – pen for 50 heads; 2 – operating aisle; a – deep litter; b – feeding place; c - disc-type feeders; d – drinkers

cally divided into two semi-circular sections for 50 heads. The sections consist of a resting area with deep litter and an elevated feeding area. A central hallway makes possible handling with animals and provides access to the feeding area. The main bearing construction consists of a timber trussed pole with steel base anchored to the concrete foundation slab. Next part of the construction is a steel polygonal ring for gripping of canvas roofing on the top of the central pole. Gripping and tensing of the canvas is provided by force of four pulley drapes with nylon ropes. The polygonal steel ring has circumradius of 1.5 m and serves also as an air vent of a self-ventilation system. There is a circumflex mark with diameter of 2.0 m from transparent polycarbonate above the air vent. Vertical bearing timber poles for supporting roof structure are situated in the corners of the polygonal envelope. These bearing poles co-operate with the framed structure of the polygonal envelope which tensing external border of canvas and supply roof linkage for capture of horizontal force reactions. Roof structure is pre-stressed canvas tent type construction with roofing from plastic technical textile (PES

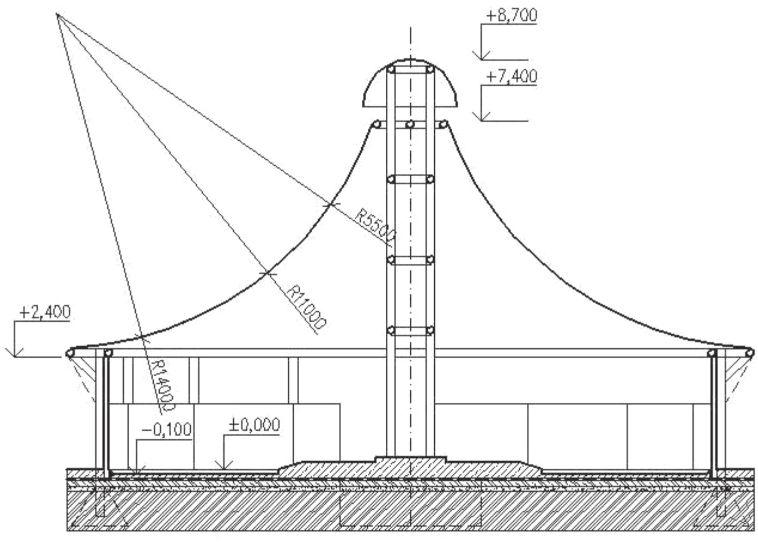


Fig. 2. Sectional drawing scheme of the polygonal hall construction

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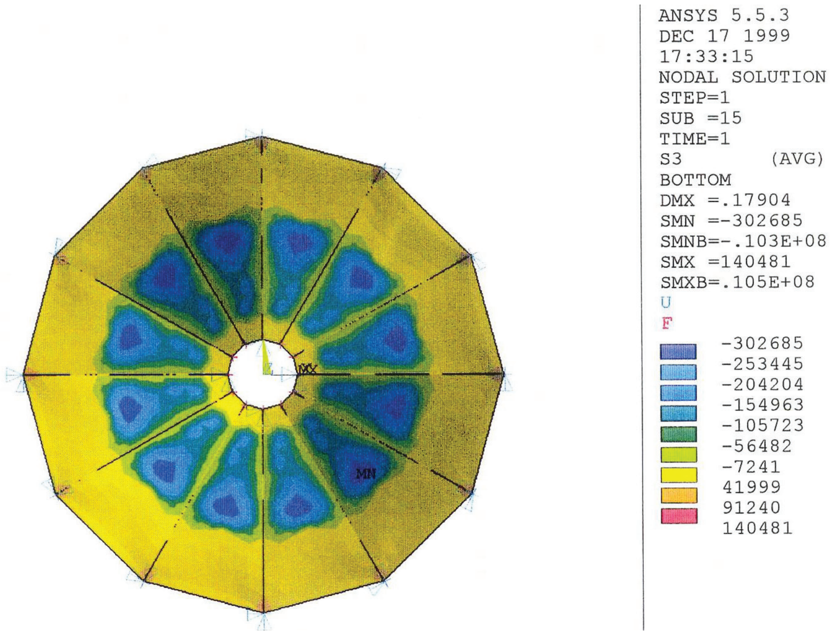


Fig. 3. Diagram of tension and deformation course at 100 kN load (tangential stress (Pa))

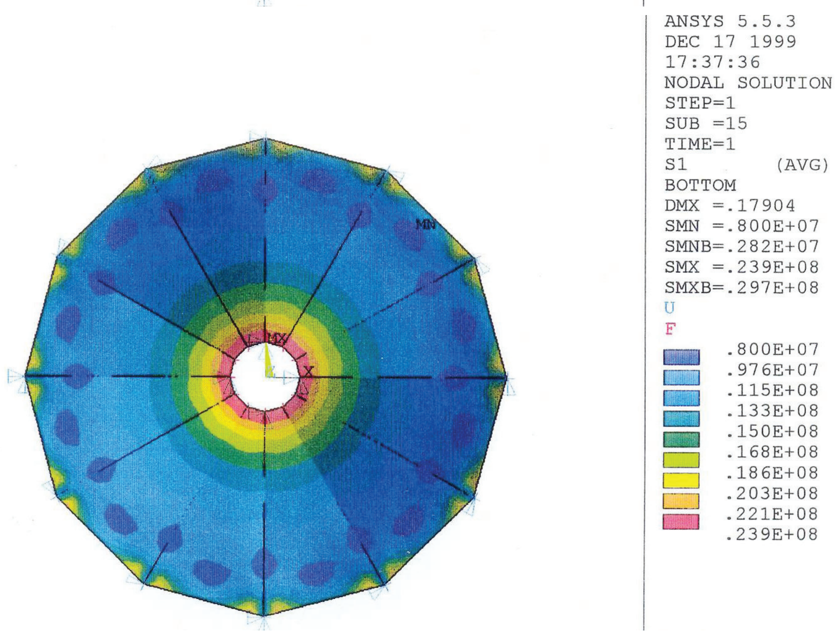


Fig. 4. Diagram of tension and deformation course at 100 kN load (radial stress (Pa))

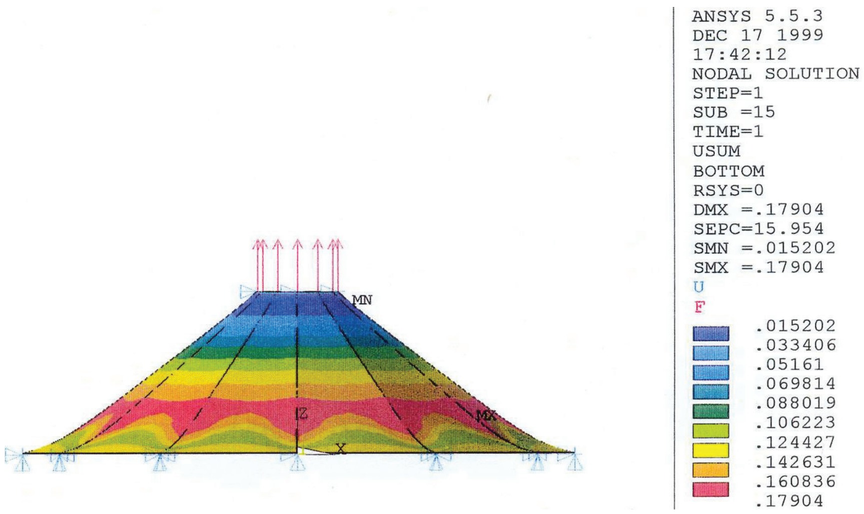


Fig. 5. Diagram of tension and deformation course at 100 kN load (deflection (m))

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with mPVC surface layer). Roof canvas has a belled figure with idealized parabolic rotary flat. The canvas has a beaded edge with a modification for dense lacer. This modification makes possible fixation of canvas. Supposed magnitude of the force necessary to sufficient tense of canvas is 75 kN (total force) and 15 kN in the polygon corners (force at the level of canvas). Supposed magnitude of the force for canvas pre-stress is ranging from 8 MPa to 14 MPa. Supposed canvas thickness is 0.5 mm and the dimension of cross-section is 300 mm$^2$. Primary engineering design of the canvas roofing is the result from technical information in Orton (1991). Critical factors for correct design of tent construction are especially wind and snow loading effect, radius of roof surface curvature and tenacity of the textile roofing. Orton (1991) stated that a span from 10 m to 18 m is typically used for tent textile constructions with bearing supports after perimeter and with an internal pole. A bigger span of the tent construction requires internal system of cable rods in radial direction. That solution makes possible to achieve span as far as 60 m with effective canvas strain at large radius curvature from 80 m to 100 m. Ground plan and sectional drawing of the hall is presented at Figs 1 and 2.

Static analysis proved relatively high differences between volumes of tensile forces in both main directions. For example on vertical load of 100 kN at the top of the construction values of radial tensile stress at an interval of 9.0 to 21.0 MPa and tangential tensile stress at an interval of 1.4 to 16.0 MPa were calculated To achieve sufficient strain of canvas and construction stability high stiffness of the polygonal envelope ring is necessary. Characteristics and magnitude of stress forces and deformation at 100 kN load are presented at Figs 3, 4 and 5.

Advantages of the polygonal shed can be defined as smaller proportion of apron surfaces, lower material (Trainer 1995) and costs (Pereira 2003) demandingness, significant share of renewable materials, light-weight construction, fast assembly operations, good level of daily illuminance, archetypal organic architecture (Abbot 1993). Disadvantages of the polygonal hall concept can be defined as a larger range of groundwork, ground shaping and worse surface utilization in the building plan, higher demand on canvas roof construction (Kadlčák, 1995), higher demand on specialized building mechanization, higher demand on foundation of slab constructions and anchoring of vertical bearing constructions, higher demand on checking and maintaining. Abbot (1993) stated that the architectonical quality of this tent barn type has an archetypal organic form with fair assumptions for integration in rural landscape.

## CONCLUSION

The assessed conceptual design of the alternative construction of lightweight hall building with polygonal ground plan and canvas roofing proved possibilities for its using in agriculture. The number of animals is restricted by tent construction span. The construction has to be free of intermediate supports, technically simple and relatively low-cost. Smaller size of this polygonal, simple and low-cost barn is fit especially for family farms. Smaller size is a disadvantage of this barn type for using in large-scale breeding. At static analysis on 100 kN vertical load at the top of the construction the values of radial tensile stress at an interval of 9.0 to 21.0 MPa and tangential tensile stress at an interval of 1.4 to 16.0 MPa were calculated. That conception study makes possible to achieve span as far as 60 m with effective canvas strain at large radius curvature from 80 m to 100 m.

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