Composite Structures 134 (2015) 72–81

Contents lists available at ScienceDirect

Composite Structures

journal homepage: www.elsevier.com/locate/compstruct

Design of composite tank covers

Agnieszka Bondyra [a,*], Marian Klasztorny [b], Aleksander Muc [a]

[a] Department of Machine Design, Faculty of Mechanical Engineering, Krakow University of Technology, Al. Jana Pawla II 37, PL-31864 Krakow, Poland
[b] Department of Mechanics and Applied Computer Science, Faculty of Mechanical Engineering, Military University of Technology, ul. gen. S. Kaliskiego 2, PL-00908 Warsaw, Poland

ARTICLE INFO

Article history:
Available online 27 July 2015

Keywords:
Composite covers
Composite joints
Finite element method
Static analysis
Failure

ABSTRACT

The problem of design and failure analysis of composite tank covers is discussed in the paper. Covering systems consist of segmental parts of tanks, independently on tank structure. Composite covers have several advantages connected with structure, transport and assembly. Additionally, the construction divided into several sections enables repair and inspection improving. However, on the one hand, failure of the tank covers, which are occurred sometimes, and on the other hand new applications, make it necessary to develop design, analysis and optimization of these structures. In this study, the main advantages of the GRP covers are shown against other covers and roofs systems. The construction of the representative rectangular composite tank cover, segments and joints are described. Failure analysis of the covering segment under combined loading is presented. The exemplary cover was built in the sewage treatment plant in Poland. The cover is built of repetitive two-wave segments with flanges overlapping one another. The segments are made of mixed glass-fiber reinforced plastic laminates. The cover is subjected to the following static loads: dead load, technological vacuum, snow and ice and local load (workers with tools). Static analysis of the exemplary cover was conducted using the finite element code MSC.Marc. The considerations include shell geometry of the cover, structural GRP laminates with specified ply sequences, segment connections of rivet nut–bolt and anchor–nut types, friction at the interface between flanges and between flanges and tank walls. Safety coefficients have been analyzed for the different elements of the exemplary composite cover.

1. Introduction

Roofs and covering systems are well-known solutions in typical building constructions such as houses, gyms, stores etc. There is a wide range of original applications to cover the engineering construction, e.g. on the one hand steel and steel–concrete composite shell roofs and on the other hand the composite covering systems. Self-supported metallic roof shells can perform a double function: the arch beam and the building cover [1,2]. Another interesting solution design, steel–concrete composite shell roofs (Comshell roofs), are formed by pouring concrete on a thin stiffened steel base shell (the permanent formwork with the tensile steel reinforcement). It is constructed by bolting together open-topped modular units consisting of a base plate with surrounding edge plates to form with thin stiffeners in both directions [3]. Concrete [4,5], steel [6,7] tank dome roofs are widely described in literature. Concrete tanks constructions have sometimes construction errors caused by the location of the reinforcement layers, which can be discovered as a consequence of the failure. Natural hazards are possible to additionally hasten construction collapse [5].

The shape of above-ground tank covers is one of the classify criterion of the tank types, due to the fact that general dimensions of the tanks and covers result from the design. There are several standardized steel tank roofs: fixed (domes or spherical caps), conical (a vertical axis of symmetry, the flat bottom, shallow cone top), umbrella (self-supporting structure, partial construction), dome (flatter than umbrella). A special type of a tank roof is a floating cover, which has a form of an external or internal structure in order to reduce the area of a liquid, that is exposed to the atmosphere influence. Design requirements for steel tank roofs are included in calculation under combinations of loading: fluid and internal pressure, hydrostatic test, wind and internal pressure, gravity and seismic loads [8].

Steel or concrete roofs are used to cover silos, liquid tanks, warehouses, exhibition halls etc. They are made of segments, rings, cover plates and additional elements. Finite element analysis (FEA) allowed improvement of existing roof systems, design of such structures and analysis of these systems under various loading

* Corresponding author. Tel.: +48 12 3743409.
E-mail addresses: abondyra@wp.pl (A. Bondyra), m.klasztorny@gmail.com (M. Klasztorny), olekmuc@mech.pk.edu.pl (A. Muc).

http://dx.doi.org/10.1016/j.compstruct.2015.07.008
0263-8223/

combination. Methodologies of covering systems calculations presented in the literature demonstrate the necessity of taking into account joints between composite segments [9].

There is a variety of covering systems applications: for tanks with and without a central support or walkway, for different tanks shapes, etc. Currently, this type of constructions has been widely used in the applications such as water reservoirs, sewage treatment plants, above-ground tanks for liquids, channels, spiral pump stations, special design tanks [10]. These constructions required the additional features such as, e.g. encapsulation or lightweight, what results in an increased use of GRP (glass reinforced plastics). Development of composite materials applications allowed design of modern tank covers. GRP composites and their advantages were well known: high tensile and compressive strength, low weight, chemical resistance, good color ability and UV resistance, maximum options for shaping and also extreme resistance to weathering and ageing – GRP covers, which were assembled more than thirty years ago, are still in use. The main disadvantage of composites, used for covers constructions, is the low transverse shear strength of composites (delamination) [11].

Manufacturers [10] make covering systems from glass fiber components in the form of mats, fabrics and non-woven, with strict adherence to the structural analysis and with appropriate safety margins. Stainless steel is used for joints and additional elements. Cut edges and drilled holes are carefully sealed for dependable prevention of moisture penetration into the laminate. Structural analyses are carried out for all of the variants of their modular system, with special consideration into the dimensions relating to the specific case and perhaps specific loads, such as high wind or snow loads [11].

There are two main approaches in the composite covers design: a column beam and in-fill stables arrangement (rectangular and small cylindrical tanks) and self-support construction, built from modular sections in a conical or domed shape (large circular tanks).

The laminated composite covers are preferred to engineers, in comparison to steel and concrete, constructions due to several advantages, such as:

- light weight,
- corrosion resistance,
- access and removal of sections of the covers,
- architectural consideration,
- cost effectiveness and flexibility in design (simplicity of modification),
- reliable structural analysis,
- inexpensive production precisely matching the specification,
- easy transport and assembly,
- offer flexibility to optimize the stiffness and strength properties.

Industrial structures present a large variety of geometries, stacking sequences, constraints and types of loadings. Such variety requires adequate meshing techniques, types of analysis and material models to be adopted at the different stages of design and development.

For composites structures, there is an additional need to account for failure and damage, as these may initiate at relatively low stress levels. It is therefore important to understand how damage modeling approaches are affected by the many factors listed above.

The present contribution focuses on the modeling techniques for failure in structures made of unidirectional glass reinforced polymers.

Static calculation and design methods of a rectangular tank composite cover are in the early stages of research and development [10,12,13], however, in the literature, another types of composite tank covering cases are described in more details.

Composite covers are made of segments, for example in a fluted shape. In tanks with a smaller diameter, it is possible to minimize costs of constructions by using flat sandwich panels. The considered, in the literature, circular covers were under loading by: live load (loaded in the small area of about 1/3 up to the whole length of a spans), body load (gravity), central load (in the central of cover) and thermal load (60 °C, which is ignored in analysis because of a small influence to deflection). All factors are applied as close to natural hazard in order to get realistic results. The simple models with using the symmetry planes and limited to one or several segments are shown in literature. Bolt spacing is also under considerations. Design constraints are limited to maximum deflection of 30 mm [14].

The covers are mainly constructed in order to reduce the contact of the liquid in the tank with the atmosphere. Segments are jointed with bolts. Polyurethane is used to seal the flanges connections. Clearances in holes are designed to allow thermal displacements of composite segments [15].

Estimation of the critical loading, causing covers damages, should also consider the interaction between segments of the covering system to obtain proper values, such in the steel roofs [16,17]. However, full specification of composite tanks covers design includes several main steps:

1. Definition of the tank shape, the tolerances, the stated dimensions.
2. Concentration of the additional equipment such as bridges, pipework etc.
3. Definition access hatches for inspection/cleaning etc.
4. Design loading conditions: wind, snow/sand, dead loading (staff): occasional access (cleaning), frequent access (inspection) and areas and walkways.

In the present work, rectangular composite covers are considered, whereas additional equipment and access hatches are omitted. Design rules for loading conditions of composite tank covers are discussed and verified with the use finite element method (FEM).

2. Composite cover joints modeling

Joints between segments with flanges and between whole covers and a tank wall (concrete) are an important aspect of the covers assembly. In the literature review, mainly bolt joints were used to connect the covers parts [9,10,14,15,18]. However, tank covers segments are sometimes connected with each other by a rivet nut–bolt single lap joint and an anchor–nut joint with the construction clearance between segments. In order to encapsulate the tank, rubber gaskets are frequently placed in rivet nut joints. The cover is connected to the walls of tanks with anchor–nut joints with the construction clearance. Experimental and numerical results in reference to joints are carried out in Refs. [19,20].

Classic bolt joints of laminates were analyzed by several authors. McCarthy et al. [21] developed a 3D model of single bolt joints at the elastic range. A validated model from Ref. [21] was used in Ref. [22] to test an influence of a micro clearance hole with a nominal diameter of 8 mm on the distribution of stress and strain, rigidity of joints and initiation of damage. The model of the bolt joints of composites was developed by Gray and McCarthy [23]. Experiments and simulations are related only to the elastic range. Analytical approach to modeling composites load distribution on the combined number of screw connectors have been developed in Ref. [24], where joints and laminates are represented by a group of springs and masses.