Computers and Structures xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Computers and Structures

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

Optimization of a cylindrical shell housing a belt-conveyor bridge

Luis M.C. Simões [a,*], József Farkas [b], Károly Jármai [b]

[a] University of Coimbra, Coimbra, Portugal
[b] University of Miskolc, Miskolc, Hungary

ARTICLE INFO

Article history:
Accepted 29 September 2014
Available online xxxx

Keywords:
Structural optimization
Buckling
Welded joints
Costs
Reliability-based design

ABSTRACT

A belt-conveyor bridge is built inside a ring-stiffened cylindrical shell, the belt-conveyor supports being independent of the stiffeners. Reliability-based and deterministic optimization results are compared. The design variables are the shell thickness as well as the thickness and the number of flat rings. Optimum solutions are evaluated for different bridge lengths in view of finding the most effective cost/span ratios. The design constraints relate to the local shell buckling strength, to the panel ring buckling and to the deflection of the bridge. The cost function includes the material and fabrication costs. A level II reliability method (FORM) is used to find the probability of failure. The overall structural reliability is obtained by using Ditlevsen method of conditional bounding. The costs of the plate designed to ensure a stipulated probability of failure will be compared with the solutions obtained for a code based method, which employs partial safety factors. A branch and bound strategy coupled with a entropy-based algorithm is used to provide discrete solutions.

1. Introduction

Stiffened shells are widely used in offshore structures, bridges, towers, etc. Rings and/or stringers can be used to strengthen the shape of cylindrical shells. Shells can be loaded by axial compression, bending, external or internal pressure or by combined load. Design rules for the shell buckling strength have been worked out in ECCS [1], API [2] and DNV [3]. The optimum design of a stiffened shell belt-conveyor bridge has been treated by Farkas et al. [4]. The buckling behaviour of stiffened cylindrical shells has been investigated by several 'authors, e.g. Harding [5], Dowling and Harding [6], Ellinas et al. [7], Frieze et al. [8], Shen et al. [9], and Tian et al. [10].

In the calculation of shell buckling strength the initial imperfections should be taken into account. These imperfections are caused by fabrication and by shrinkage of circumferential welds. A calculation method for the effect of welding has been worked out by Farkas et al. [4] and it is used in the calculation of the local shell buckling strength.

In the present study the design rules of Det Norske Veritas (DNV) are used for ring-stiffened cylindrical shells. The shape of rings is a simple flat plate, which is welded to the shell by double fillet welds. The cost function includes material and fabrication costs. In the calculation of the fabrication cost, the cost of forming the shell elements into the cylindrical shape and the cutting of the flat ring-stiffeners is also taken into account. In design and optimization problems material constants, loading, and structure geometry are usually considered as given data but in real world assumed values do not correspond with actual ones. All this is accounted by safety factors which amplify load magnitude or reduce material strength. Stresses and displacements can be computed based on the deterministic parameters of loads, geometry and material behaviour. Some structural codes specify a maximum probability of failure within a given reference period (lifetime of the structure). This probability of failure is ideally translated into partial safety factors and combination factors by which variables like strength and load have to be divided or multiplied to find the so called design values. The structure is supposed to have met the reliability requirements when the limit states are not exceeded. The advantage of the code type level I method (using partial safety factors) is that the limit states are to be checked for only a small number of combinations of variables. The safety factors are often derived for components of the structure disregarding the system behaviour. The disadvantage is lack of accuracy, but this problem can be overcome by using more sophisticated reliability methods such as level II (first order second order reliability method, FOSM [11,12]) and level III (Monte Carlo) reliability methods. In this work FOSM was used and the sensitivity information was obtained analytically. Besides stipulating maximum probabilities of failure for the individual modes, the overall probability of failure which account for the interaction by correlating the modes of failure is considered. The relevance of reliability-based design has been

* Corresponding author.

http://dx.doi.org/10.1016/j.compstruc.2014.09.015
0045-7949/© 2014 Published by Civil-Comp Ltd and Elsevier Ltd.

recognized by the industry through the development of probabilistic structural codes. A recent example is the IACS-CSR structural design codes for stiffened plates which include a limit design criterion calibrated to satisfy a predefined target safety level [13].

A branch and bound strategy coupled with a entropy-based algorithm is used to solve the reliability-based optimization [14]. The entropy-based procedure is employed to find optimum continuous design variables giving lower bounds on the decision tree and the discrete solutions are found by implicit enumeration. A branch and bound procedure is associated with this algorithm to provide a discrete solution.

The discrete optimization of a belt conveyor bridge was solved in [15] and a reliability assessment was made of the results. Here a more stringent reliability-based optimum is provided.

The shell is a supporting bridge for a belt-conveyor, simply supported with variable span length L and radius of $R = 1800$ mm (Figs. 1 and 2). The uniformly distributed vertical load consists of dead and live load. The intensity of the factored uniformly distributed vertical load is $p = 16.5$ N/mm + self-mass. Factored live load is 12 N/mm, dead load (belts, rollers, service-walkway) is 4.5 N/mm. For self-mass a safety factor of 1.35 is used, which is prescribed by Eurocode 3 (note that ECCS gives 1.3). The safety factor for variable load is 1.5. The flat plate rings are uniformly distributed along the shell. Note that the belt-conveyor supports are independent of the ring stiffeners, and can be realized by using local plate elements. The dynamic loading caused by the belt movement must be damped and the type of supports used for isolation limit further stiffening of the structure provided by the plate elements, thus effect of belt-conveyor on the structural stiffness is neglected.

The unknown variables are as follows: shell thickness t, stiffener thickness t_r and number of stiffeners n. To ensure a stable cylindrical shape, a certain number of ring-stiffeners should be used. In the present study we consider a range of ring numbers $n = 6$–30. Those results for which the place of stiffeners coincides with the circumferential welds of the shell segments ($n = 9$, 19) are not applicable for fabrication reasons. The range of thicknesses t and t_r is taken as 4–20 mm, rounded to 1 mm. The design constraints relate to the local shell buckling strength, to the panel ring buckling and to the deflection of the simply supported bridge.

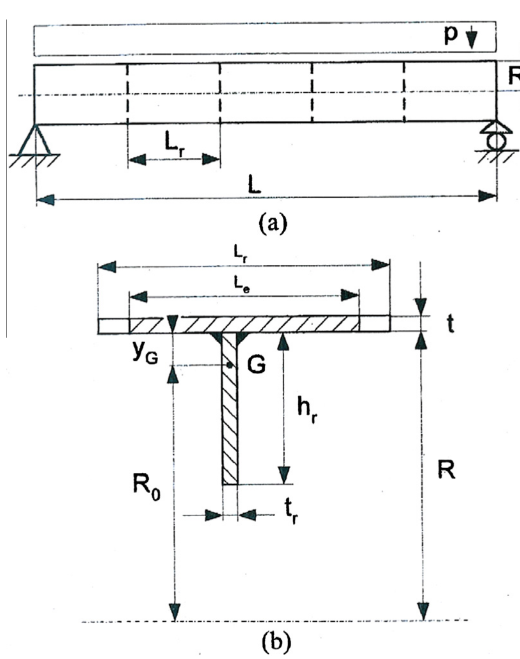

Fig. 1. (a) Simply supported belt conveyor bridge constructed as a ring stiffened cylindrical shell. (b) Cross-section of a ring stiffener including the effective width of the shell.

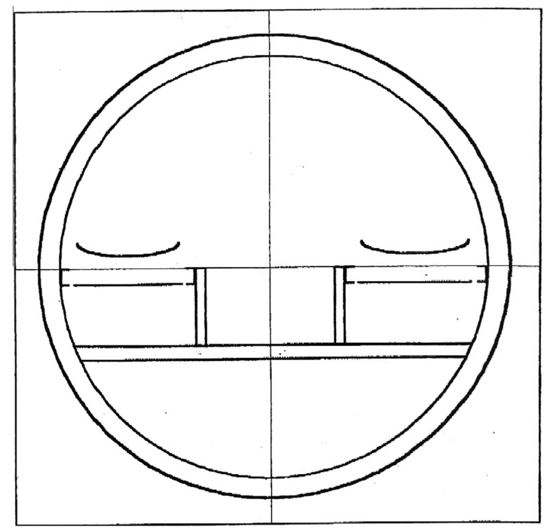

Fig. 2. Cross-section of a belt conveyor bridge with two belt conveyors and a service walkway in the middle.

2. Design constraints

2.1. Local buckling of the flat ring-stiffeners (Fig. 1)

According to DNV,

$$\frac{h_r}{t_r} \leqslant 0.4\sqrt{\frac{E}{f_y}} \tag{1}$$

Considering this constraint as active, for $E = 2.1 \times 10^5$ MPa and yield stress $f_y = 355$ MPa, one obtains $h_r = 9t_r$.

2.2. Constraint on local shell buckling (as unstiffened) (Fig. 3)

$$\begin{aligned} p &= 16.5 + 1.35\rho(2R\pi t + nA_r); \quad \rho \\ &= 7.85 \times 10^{-6}\ \text{kg/mm}^3; \quad A_r = h_r t_r \end{aligned} \tag{2}$$

$$M_{\max} = \frac{pL^2}{8}; \quad \sigma_{\max} = \frac{M_{\max}}{\pi R^2 t} \leqslant \sigma_{cr} = \frac{f_y}{\sqrt{1+\lambda^4}} \tag{3}$$

$$\lambda^2 = \frac{f_y}{\sigma_E}, \quad \sigma_E = (1.5 - 50\beta)C\frac{\pi^2 E}{10.92}\left(\frac{t}{L_r}\right)^2; \quad L_r = \frac{L}{n+1} \tag{4}$$

The factor (1.5–50β) expresses the effect of the initial radial shell deformation caused by the shrinkage of circumferential welds [16]. Introducing the reduction factor of β for which

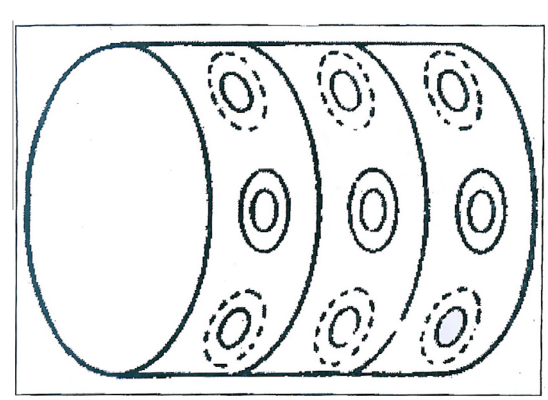

Fig. 3. Top-view of the shell with local buckling.

Please cite this article in press as: Simões LMC et al. Optimization of a cylindrical shell housing a belt-conveyor bridge. Comput Struct (2014), http://dx.doi.org/10.1016/j.compstruc.2014.09.015