

# Welded cellular shell structure for a belt-conveyor bridge

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**ABSTRACT:** The cellular shell consists of two circular cylindrical shells and a longitudinal stiffening welded between them. Halved circular hollow section (CHS) stiffeners are used to ease the welding of outer shell elements. Advantages of cellular shells are as follows: thinner structural parts can be used, which decreases the welding cost, large bending and torsional stiffness can be achieved with small diameter. In the present study a simple supported tubular beam is strengthened in the middle part of the span by cellular shell, which enables to fulfil the strict deflection constraint and the limiting of the shell diameter. The single tube version has too large thickness unsuitable for fabrication and the structural volume is larger than the cellular shell one. The shell thicknesses, dimensions of stiffeners and the length of the stiffening are optimized for minimum cost. The cost function contains the cost of material, welding and painting.

## 1 INTRODUCTION

The economy of welded structures can be achieved by the design of stiffened thin-walled structures instead of unstiffened thick-walled ones. A very efficient structural type is the cellular plate, which consists of two plates and stiffening welded between them (Farkas 1976, 1984) (Farkas & Jármai 1997). Similarly, a cellular shell consists of two circular cylindrical shells and stiffening welded between them. For stiffening longitudinal halved circular hollow section (CHS) stiffeners (EN 10219-2: 2006) are used, which enables the welding of outer shell parts (Figure 2).

Cellular shells are economic in cases of strict constraints on displacements and dimensional constraints. Such a case has been treated in our previous study (Farkas & Jármai 2016).

In the present study the cellular shell is applied for a simply supported tubular beam loaded by bending and shear, the maximum deflection and the outer shell diameter are limited.

*Given data:* beam span length  $L = 84$  m. Factored live load is 10 N/m (safety factor 1.5), factored dead load (belts, rollers, service-walkway) is 3 N/m (safety factor 1.35). Yield stress of steel  $f_y = 355$  MPa, for thicknesses  $16 < t < 40$  mm the allowable stress is  $\sigma_{allow} = 314$  MPa, elastic modulus  $E = 2.1 \times 10^5$  MPa. In the calculation of displacement the factored loads are divided by safety factors, i.e. the intensity of the uniformly distributed load for deflection is  $p = 10/1.5 + 3/1.35 = 8.89$  N/m.

*Constraints:* limitation of the maximum deflection:  $w_{max} = L/\phi, \phi = 1000$  and limitation of the outer shell diameter:  $D = 2R = 2800$  mm.

## 2 THE BEAM CONSTRUCTED FROM A SINGLE CIRCULAR CYLINDRICAL SHELL

The required shell thickness is

$$t \geq \frac{5pL^3\phi}{384E\pi R^3} = 37.9 \text{ mm}, \quad (1)$$

which is unsuitable for fabrication.

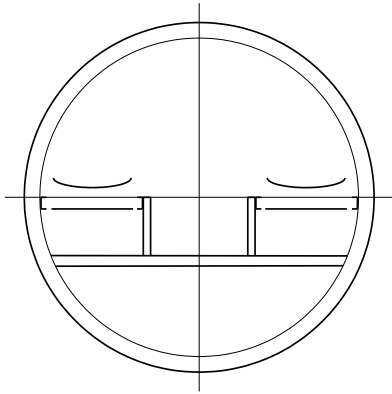


Figure 1. Cross-section of the belt-conveyor bridge with two belt-conveyors and a service walkway in the middle

## 3 THE TUBULAR BEAM PARTIALLY OR TOTALLY STRENGTHENED BY CELLULAR SHELL

### 3.1 Geometric characteristics

The cross-sectional area of a half CHS is (Fig.2)

$$A_s = \pi R_s t_s, \quad R_s = \frac{D_s - t_s}{2} \quad (2)$$

the distance of its gravity centre is (Fig.3)

$$y_G = \frac{2R_s}{\pi} \quad (3)$$

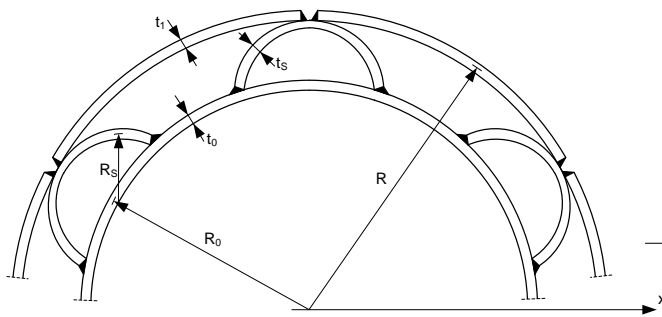


Figure 2. Dimensions of cellular shell

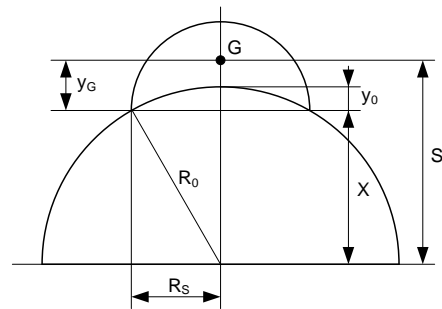


Figure 3. Geometry of cellular shell

and its moment of inertia

$$I_s = \frac{R_s^3 \pi}{2} \left( 1 - \frac{8}{\pi^2} \right) \quad (4)$$

The distance  $X$

$$X = \sqrt{\left( R_0 + \frac{t_0}{2} \right)^2 - R_s^2} \quad (5)$$

The radius of the inner shell  $R_0$  can be calculated from the following equation

$$R = X + R_s + \frac{t_1 + t_s}{2} \quad (6)$$

( $t_1$  is the thickness of the outer shell)

$$R_0 = \sqrt{\left( R - R_s - \frac{t_1 + t_s}{2} \right)^2 + R_s^2} - \frac{t_0}{2} \quad (7)$$

The moment of inertia of  $n_s$  stiffeners about the centre of the shell

$$I_{xs} = \left( I_s + A_s s^2 \right) \sum_{i=1}^{n_s} \cos^2 \left( \frac{2\pi i}{n_s} \right) + \left( \frac{\pi R_s^3 t_s}{2} \right) \sum_{i=1}^{n_s} \sin^2 \left( \frac{2\pi i}{n_s} \right) \quad (8)$$

The moment of inertia of the whole cellular shell (Fig.3)

$$I_x = \pi R_0^3 t_0 + \pi R^3 t_1 + I_{xs} \quad (9)$$

Fabrication constraint to enable the welding of the half CHS stiffeners to the inner shell:

from

$$\frac{2R_0 \pi}{n_s} - 2R_s \geq 2t_s \quad (10)$$

the maximum allowable number of half CHS stiffeners

$$n_{s,\max} = \frac{\pi R_0}{R_s + t_s} \quad (11)$$

### 3.2 Constraint on panel shell buckling of the outer shell parts between stiffeners

The Det Norske Veritas (2002) design rules are used.

In the case of such a very strict displacement constraint the panel buckling constraint is not active.  $\sigma_{\max}$  is so small that the effective shell width is equal to the whole width  $s_0$ . Calculations show that this constraint is passive.

### 3.3 The deflection constraint

$$w_{\max} \leq w_{\text{allow}} = \frac{L}{\phi}, \phi = 1000 \quad (12)$$

$I_1, I_2$  are the moments of inertia of the beam parts, respectively.

The stress constraint of the beam cross section at the distance  $L_1$  is also passive.

### 3.4 The cost function

The cost is calculated according to the fabrication sequence (Farkas & Jármai 2008, 2013).

The beam is divided into 7 units (84 = 7x12 m). Two types of units are constructed as follows:

- (a)  $n_1 = \frac{L_1}{L_0}$  units of simple shell, the length of a unit is  $L_0 = 12\text{m}$ ,  $L_1 = 12,24,36\text{ m}$ ,  
 (b)  $n_2 = \frac{L-2L_1}{L_0}$  units of cellular shell.

Two end plates are welded to each unit and the units are connected with bolted joints using these end plates. The cost of bolted connections is not treated.

### 3.4.1 Total cost of the whole beam

$$K = 2n_1K_1 + n_2K_2 \quad (13)$$

Total volume

$$V = 2n_1V_1 + n_2V_5 \quad (14)$$

### 3.5 Optimization and results

In the optimum design procedure the optimal values of variables ( $D_s, t_s, n_s, t_0, t_1, L_1$ ) are determined by a systematic search using a MathCAD algorithm to minimize the structural cost.

Table 1 shows the search results.

Table 1 Optimization results. Dimensions in mm, volume in  $\text{mm}^3$ , cost in \$. Optimum is marked by bold letters. It can be seen that in the case of  $L_1 = 36\text{ m}$  the required thicknesses  $t_0$  and  $t_1$  are not suitable for fabrication, this solution is marked by italics. The deflection is limited to 84 mm

$D_s$	$t_s$	$t_0$	$t_1$	$L_1$	$w_{max}$	$10^{-10}V$	$10^{-6}K$
101.6	6	21	20	0	82.5	4.281	1.170
<b>114.3</b>	<b>6</b>	<b>22</b>	<b>21</b>	<b>12000</b>	<b>82.3</b>	<b>4.484</b>	<b>1.131</b>
114.3	10	26	27	24000	83.5	5.551	1.470
<i>114.3</i>	<i>10</i>	<i>39</i>	<i>38</i>	<i>36000</i>	<i>83.1</i>	<i>7.968</i>	<i>2.087</i>

It can be seen that the optimum solution uses suitable thicknesses.

### ACKNOWLEDGEMENTS

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