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APPLICATION OF BLOCKAGE CORRECTIONS TO U-BEAMS WITH POROUS RAILINGS

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Abstract: *Different models of u-beams with porous flanges were tested in wind tunnel with the use of force and moment measurements. Due to high wind tunnel blockage ratio, the wind tunnel blockage corrections were applied to the measured forces and moments. The tested model beams were manufactured in two scales, i. e. large model and small model with half dimensions of the large model in order to test Reynolds number independence. Different blockage ratio calculation methods were used on the large and small U-beam model across various wind attack angles. The Maskell blockage correction method was applied to the experimental drag coefficient data.*

Keywords: Wind tunnel, Blockage corrections, U-beam, Porous railings

1. Introduction

The size of the wind tunnel testing section imposes a limitation of the flow in contrast to the free-flow situation. The model installed in the wind tunnel presents a certain blockage to the flow, which causes the measured forces, moments and pressures to be incorrect if the blockage ratio becomes higher than a certain level. The blockage ratio is expressed as the ratio of model projected frontal area to the wind tunnel cross section area. It is usually considered, that if the blockage ratio exceeds 5%, the blockage corrections become necessary to use. The presence of the model in the wind tunnel causes the blockage effect not only the model itself (solid blockage effect), but also the wake blockage effect. The UK Standard (ESDU 80024, 1998) suggests several blockage corrections in the confined wind tunnel flow around bluff bodies and "quasi-streamlined" bodies. Bluff body flow is defined as the case, when flow separation occurs at or ahead of maximum cross-sectional area of body. On the contrary, "quasi-streamlined" flow is defined as the case, when flow separation occurs behind maximum cross-sectional area of the body. The U-beam geometry complies with the bluff body flow conditions, therefore the blockage corrections for this type of flow need to be applied.

Gu et al. (2020) used the ESDU 80024 blockage corrections for models of corrugated wind barriers on railway bridges. They calculated two blockage ratios with and without inclusion of the holes in projected area of the wind barriers. The same attitude was used in this study, so the corrections were calculated with and without the effect of flange porosity. For details see section 3.

2. Description of the experiments

Two sizes of wooden U-beam models, each with length 160 cm, were used to simulate two different blockage conditions. Both model sets include beams with U-shaped cross-sections with width-to-depth ratio 2:1. The larger U-beam model, i.e., the model with a larger U-shaped profile (LUP) has dimensions of 300 mm in breadth and 150 mm in height, while small model (SUP) is scaled down by half, with cross-section dimensions 150 x 75 mm. The holes in the railing have square shape with side dimension of 5 mm for the larger model and 2.5 mm for the smaller model, which corresponds to the hydraulic diameter ($D_h=4A_{hole}/p_{hole}$, with A_{hole} and p_{hole} respectively the area and semi-perimeter of a hole) 10 mm (larger model) and 5 mm (smaller model). The U-beam geometry is shown in Figure 1.

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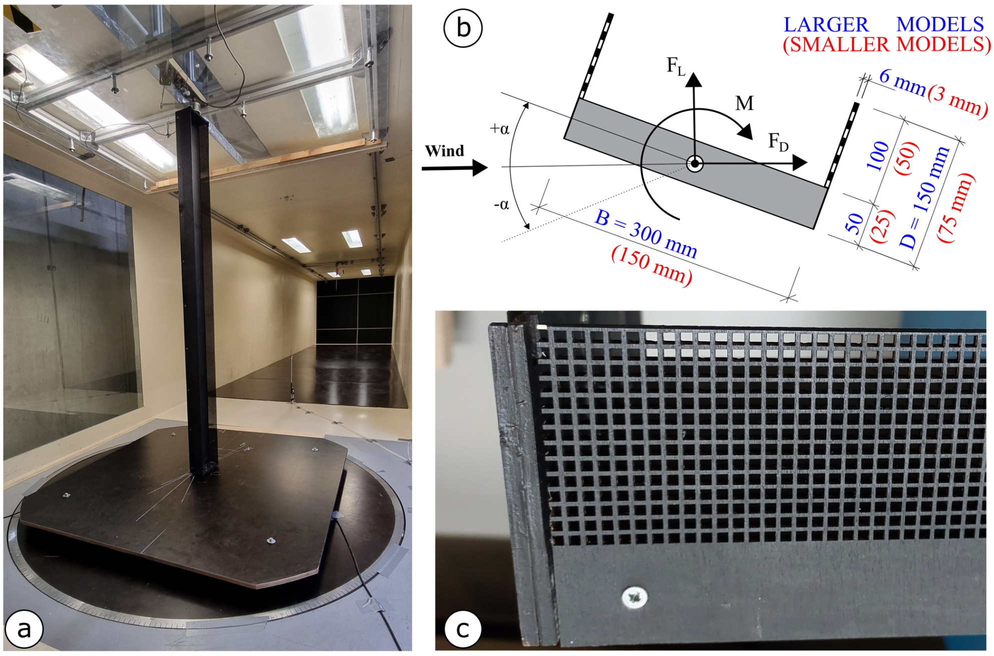

Fig. 1: (a) Photo of the smaller porous U-beam installed in the wind tunnel; (b) U-beam geometry; (c) Detail of the porous flange of the smaller model.

The porosity of the flanges was created using laser-cut square holes with side length 5 mm for large model and 2.5 mm for small model. The flange porosity created with this attitude is ca. 50 %. The laser-cut holes were manufactured in two versions of flanges, i. e. 6 mm thick plywood flange, here denoted as LUP2 and 3 mm thick plywood flange, here denoted as LUP3. The third version of the large model equipped with 3D-printed 6 mm thick flanges denoted as LUP1 was previously investigated by Hračov and Macháček (2022).

Each model was positioned vertically in the wind tunnel test section, which is 1.9 m wide and 1.8 m high. The models were attached at its top and bottom ends to the ATI Mini40 load cells to measure the aerodynamic forces exerted on the models at angle of attack $-14° < \alpha < +14°$. These load cells were attached to a synchronized rotation mechanism to allow a precise rotation of the model for desired angle of attack. Data from the load cells were recorded for time interval of 60 s at sampling frequency of 1000 Hz. The tests on the large model were conducted at wind speed 7 and 14 m/s, which correspond to Reynolds number $Re_1 = 7.2\times10^4$ and $Re_2 = 1.4\times10^5$, based on the along-wind dimension. The smaller model was tested only at wind speed of 14 m/s to achieve the same $Re=7.2\times10^4$ as for the large model. The wind tunnel flow was nominally smooth with low turbulence intensity up to 1%.

3. Blockage corrections in wind tunnel

The bluff-body correction method developed by Maskell (Maskell, 1965) and implemented in ESDU 80024 (ESDU, 1998) calculates the blockage correction as follows

$$\frac{C_{Ff}}{C_F} = \frac{1}{1 + \varepsilon C_D\, S/A}$$

where C_{Ff} is the corrected force (drag C_D or lift C_L) coefficient, C_F is uncorrected force coefficient, C_D is uncorrected drag coefficient, S is frontal blockage area of the body and A is the cross section area of the wind tunnel. The S/A ratio is therefore the wind tunnel blockage ratio. The blockage correction parameter ε (0.83) is given for rectangular prisms with cross-dimensional dimensions B and D by the formula

$$\varepsilon = 1.11 - 0.14B/D \;\; for \;\; 0.75 < B/D < 3$$

The use of bluff-body correction method is recommended when the Reynolds number is lower than 10^6 and the uncorrected drag coefficient C_d is higher than 0.8.

The calculation of the frontal blockage area S was based on three approaches. In first variant, the entire U-beam maximum size area projected into a plane perpendicular to the main flow direction was calculated.

In second variant, the area of the holes was subtracted from the area calculated in the first variant. In third variant, only the windward projected area of the U-beam was calculated, i. e. the side of the U-beam and its railing with the area of the holes subtracted. The calculated blockage ratios for the porous large U-beam *S/A* as a function of the angle of attack α are presented in Figure 2. It is obvious, that all the *S/A* values are bigger than the 5% threshold, where the corrections become necessary.

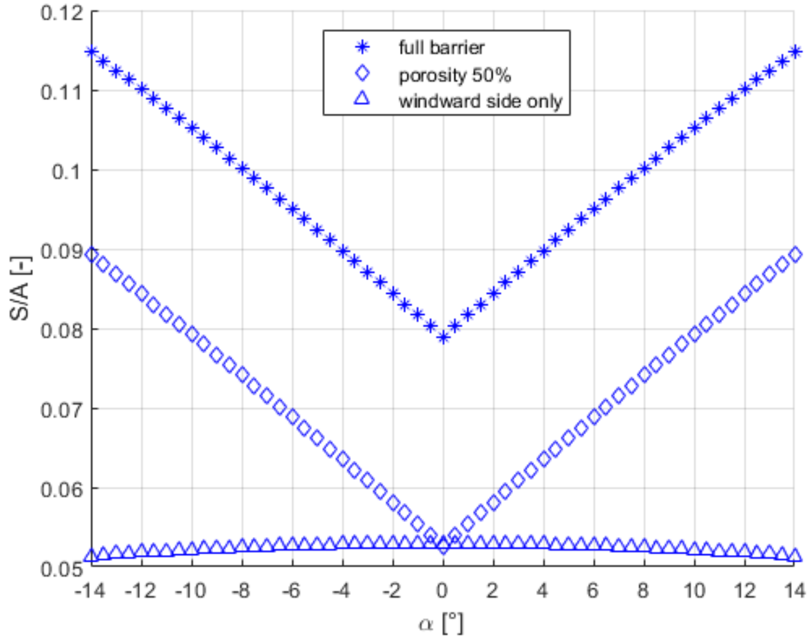

Fig. 2 Blockage ratios S/A for the large porous U-profile (LUP)

The uncorrected and corrected C_d values of the SUP and LUP2 variants are presented in Figure 3, where solid lines denote original data, dash-dotted lines denote corrected values without subtraction of the holes (full flanges) and dashed lines denote corrected values for 50% porous flanges. The dots represent corrections for SUP and LUP2 calculated on the base of including only the projected windward area into the blockage ratio S/A with the area of the holes subtracted.

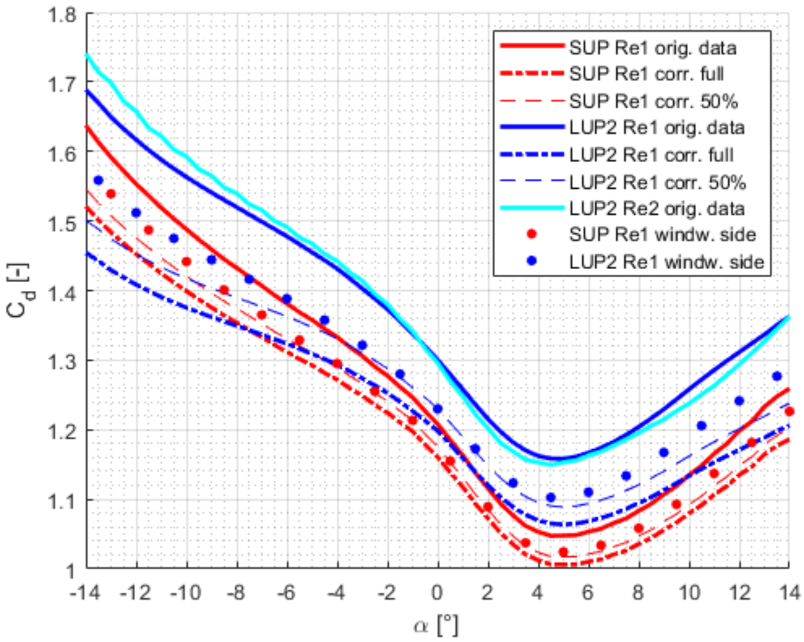

Fig. 3 Uncorrected and corrected values of the drag coefficient CD of the small porous U-beam (SUP) and 2nd version of the large porous U-beam (LUP2)

The uncorrected and corrected C_d values of the SUP and all three LUP versions (LUP1-3) are presented in Figure 4, with the same linestyle notation as in Figure 3. The values for SUP and LUP1-3 presented in Figure 4 correspond to the same Reynolds number $Re_1 = 7.2\times10^4$.

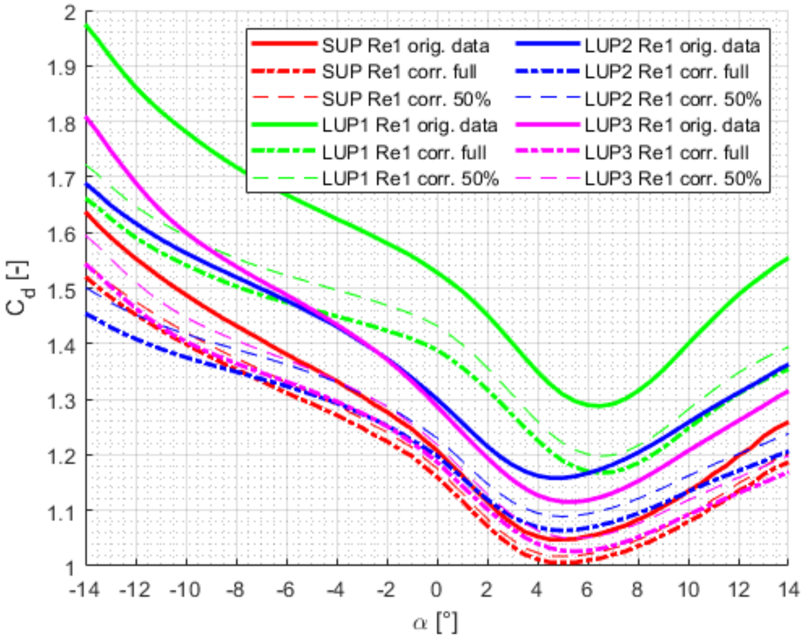

Fig. 4 Uncorrected and corrected values of the drag coefficient C_D of the small U-beam (SUP) and all versions of the large U-beam (LUP1-3)

4. Conclusions

The analysis of wind tunnel blockage corrections of the drag coefficient was performed for various blockage ratios with or without subtraction of the U-beam railing porosity. The Maskell correction method for bluff body flow suggested in ESDU 80024 was applied to correct the drag coefficients for small and large U-beams, both with porous or non-porous calculations of the U-beam flanges. There was a notable difference in resulting corrections with or without subtraction of the area of the holes. The usage of the method without the holes subtraction is recommended for the angle of attack from -7 to 6 degrees as the corrected values are closer to each other than the uncorrected values.

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