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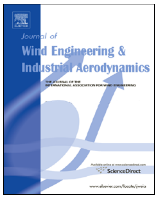

Wind forces on single and shielded angle members in lattice structures ☆

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ABSTRACT

In this paper, the aerodynamic loads on simplified lattice structures are evaluated taking into account the force on each individual member rather than the conventional methods accounting for the overall truss through solidity ratio and global shielding coefficients. Wind tunnel tests were conducted on single angle members to determine the aerodynamic force coefficients corrected for a blockage effect. Aerodynamic force coefficients were also determined for angle members in the wake of an upstream one to assess the shielding effects. The results show that blockage plays a critical role in the determination of aerodynamic force on angle members with wind tunnel measurements. The experimental results also show three phases for the effect of shielding. The proposed approach based on the contributions of each member of lattice structures allows for the determination of the side force in addition to the drag force. The wind force on typical trusses calculated by this method is compared to the results of methods proposed in different codes.

1. Introduction

Most antenna and transmission line towers are made of steel angle lattice structures designed to withstand wind loads either alone or in combination with ice. The wind loads can be evaluated by two methods: (i) a global approach in which the forces are evaluated directly on the whole truss or part of truss; (ii) a local approach where the wind forces are evaluated on each member separately.

The first method is adopted by most codes since the early 1980s (ASCE, 2010; IEC, 2003; CENELEC, 2001; CSA, 2004; EN1991, 2005). It is based on the solidity ratio of the lattice structure, χ, the ratio of projected to total area, a measure of the obstruction, and flow momentum loss caused by the lattice. Correction factors may be included in the method to account for the angle of attack of the wind and the aspect ratio of the truss. For example, EN1991 (2005) provides different charts for various lattice tower geometries and wind directions. Most codes consider that the resultant force is acting in the direction of the wind, so there is generally no method for the calculation of the orthogonal side force. Being developed for lattice structures and based and verified on a number of tests (Bayar (1986); E.R.A. (1934); Flachsbart and Winter (1955); Georgiou and Vickery (1979); Lindley and Willis (1974); Whitbread (1979)), this method is very effective for typical regular lattice in cross-flow. Out of this specific configuration, this method is difficult to apply in practice, as in the case of transmission line structures with irregular or complex geometry and varied angle of attack. As well, this method provides the same force for two trusses with the same χ, regardless of the solidity and separation of the downstream face. However, NBCC (2005) includes a modification factor of the wind force found with the solidity ratio method that depends on the spacing of the truss to take into account the shielding effect of the upstream lattice on the downstream one and the diffusion in its wake. NBCC (2005) proposes a variation of this method for wind that is not acting normal to a tower face. The force is calculated for each element and corrected to take into account the shielding effect. However, in NBCC (2005), this correction is a function of the overall solidity ratio. A fully local approach in which forces on each member is calculated directly for any type of truss configuration and wind direction would be a much needed extension of this method in the cases where the global approach is difficult to use in practice. Using a local approach, the wind force on a member outside of any wake can be evaluated directly with the force coefficient of the section alone. A stationary member with a bluff cross-section sheds vortices immersed in a wake whose mean velocity profile shows a deficit that progressively reduces with distance downstream. The wind mean forces on a member positioned in the wake of a stationary member need then to be calculated using a velocity value that differs from that of the unperturbed wind or force coefficients that take into account this shielding effect. At this time, there is no local method available to designers to determine the wind force on trusses made of angle members. This paper is a first step to provide such a local approach.

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Members of a spatial truss can be either in the undisturbed flow or in the wake of another or several other members. No experimental data exists at the authors' knowledge on the wake effect on angle members. For the angle member in the undisturbed wind flow, a few comparative values of the aerodynamic force coefficients are available (ASCE, 2010; NBCC, 2005; Sachs, 1978; Scanlan, 1997; Slater, 1969; Wardlaw, 1967). It is worth noting that ASCE (2010); NBCC (2005); Scanlan (1997) are directly or indirectly referring to Sachs (1978), which refers to SIA (1956), which means that there are only three sets of data (SIA, 1956; Slater, 1969; Wardlaw, 1967) with important variations among each other. For example, at an angle of attack of 0° (see Fig. 1), the values of the drag coefficient based on the leg area are: (NBCC, 2005) – 2.55, (Slater, 1969) model B – 3.29 and (Wardlaw, 1967) – 2.02. This lack of consistency in the drag coefficient of an angle member may be due to testing arrangement and underlines the need for additional experimental data for angle sections accounting for the effects of the wind tunnel's blockage, the *Reynolds* number, the turbulence intensity, the edge's shape, the thickness ratio, and the shielding from another member, since most of these variables are not treated in the literature.

This paper deals with a wind tunnel investigation of the wind force coefficients of an equal leg angle member in smooth and turbulent flows as well as in the wake of an identical one. The results are compared with available data and the local approach proposed is applied to the case of simplified lattice structures made of angle sections.

2. Experimental program and facilities

2.1. Experimental program

The experimental program consisted of two parts, the first dealing with the force measurement on a single angle member under different flow conditions and the second, with the measurements of the shielding effect of an upstream angle member on its downstream companion. In the case of a single angle section, the independent similitude criteria are the Reynolds number, the level of turbulence, the blockage ratio, the angle of attack for the flow, the thickness ratio, and the edge's shape for the geometry of the angle sections. The dependant similitude criteria were the lift and drag coefficients. In the case of an angle section located in the wake of an upstream one, the additional independent similitude criteria were the ratio *s* of the longitudinal distance, *H*, and the leg width of the angle member, *b*.

2.2. Models

Seven equal legs angle sections were tested. Round end-plates (thickness: 6.4 mm, diameter: 177.8 mm) were mounted at the ends of each model. The models were installed horizontally at mid-height of the test section, normal to the flow. A gap of approximately 12.5 mm was left between the end plates and the tunnel walls. Table 1 summarizes the main dimensions of the angle members and the variables tested. The aspect ratio of the models was much larger than 10 for most of the tests in order to reduce the importance of the effects of the tunnel wall boundary layer: the values of the aspect ratio are 70.9, 35.5, 17.7, and 8.8 for the models with the leg dimension of 25.4, 51, 102, and 204 mm respectively. The momentum thickness of the boundary layer at the model location was calculated as 0.55% of the test section height using boundary layer theory and previous measurements made upstream of the model location.

In the case of angle sections, two shapes of edge are readily available: the round type for most steel angles and the sharp one for most aluminum angles. The first and last letters of the specimen names indicate respectively the material (A for aluminum and S for steel) and the edge's shape (S for sharp and R for round edges). The two middle numbers, such as 102 × 6, define the leg width, *b*, and its thickness, *t*. Two pairs of angle sections, S51 × 3R

Table 1
Specimens tested in the first part of the experimental program.

Specimen	Section	Material	Edge	*b* (mm)	*t* (mm)	*b*/*t*	Blockage ratio (%)
S25 × 3R	L25 × 3.2	**S**teel	**R**ound	25.4	3.175	8.0	1.40
S51 × 3R	L51 × 3.2	**S**teel	**R**ound	50.8	3.175	16.0	2.79
S102 × 6R	L102 × 6.4	**S**teel	**R**ound	101.6	6.35	16.0	5.58
S102 × 9R	L102 × 9.5	**S**teel	**R**ound	101.6	9.525	10.7	5.58
A51 × 3S	L51 × 3.2	**A**lu.	**S**harp	50.8	3.175	16.0	2.79
A102 × 6S	L102 × 6.4	**A**lu.	**S**harp	101.6	6.35	16.0	5.58
A203 × 13R	L203 × 13	**A**lu.	**R**ound	203.2	12.7	16.0	11.16

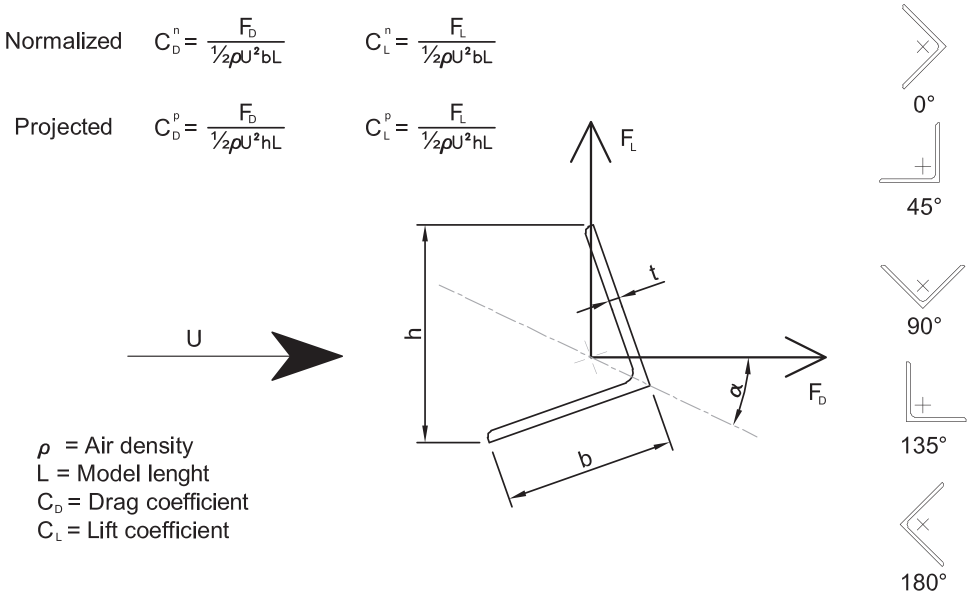

Fig. 1. Sign convention and definitions.