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Lattice structures Part 1: mean fluid forces on single and multiple plane frames

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THE PREPARATION OF THIS DATA ITEM

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(Continued on inside back cover)

LATTICE STRUCTURES. Part 1: mean fluid forces on single and multiple plane frames

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LATTICE STRUCTURES Part 1: mean fluid forces on single and multiple plane frames

1. NOTATION

		SI Unit
A_e	total area enclosed by frame, including chord members, see Sketch 1.1	m^2
A_g	exposed area of gusset plate, see Sketch 1.1	m^2
A_s	shadow area of frame projected onto a plane parallel to that through the chord members, see Sketch 1.1 (note that A_s is independent of the inclination of the flow to the frame)	m^2
a	dimension of flat-faced member in 0x direction, see Sketch 1.2	m
B	overall width of frame, including chord members	m
b	width of flat-faced member, see Sketch 1.2	m
C_A and C_C or C_L	across-flow force coefficients, components normal to the flow direction, (across-flow force)/($\frac{1}{2}\rho V^2 A_s$), see Section 1.1	
C_D	drag coefficient, component along flow direction, (drag force)/($\frac{1}{2}\rho V^2 A_s$), see Section 1.1	
C_X	normal force coefficient, component along 0x direction, (X-force)/($\frac{1}{2}\rho V^2 A_s$), see Section 1.1	
C'_X	uncorrected value of C_X	
C_Y	across-frame tangential force coefficient, component along 0y direction, (Y-force)/($\frac{1}{2}\rho V^2 A_s$), see Section 1.1	
C_Z	along-frame tangential force coefficient, component along 0z direction, (Z-force)/($\frac{1}{2}\rho V^2 A_s$), see Section 1.1	
D	diameter of circular-section member	m
f_D, f_ϕ	correction factors for effects of D_b/D_c and frame solidity ratio	
f_{sj}	correction factor for effect of shielding on j th frame in an array	
f_α, f_β	correction factors for effects of incidence and yaw	
I_u	intensity of u -component of turbulence σ_u/V , see Section 2.5 and Table 8.3	
L	length of frame along 0z direction	m

For footnotes see end of Notation Section.

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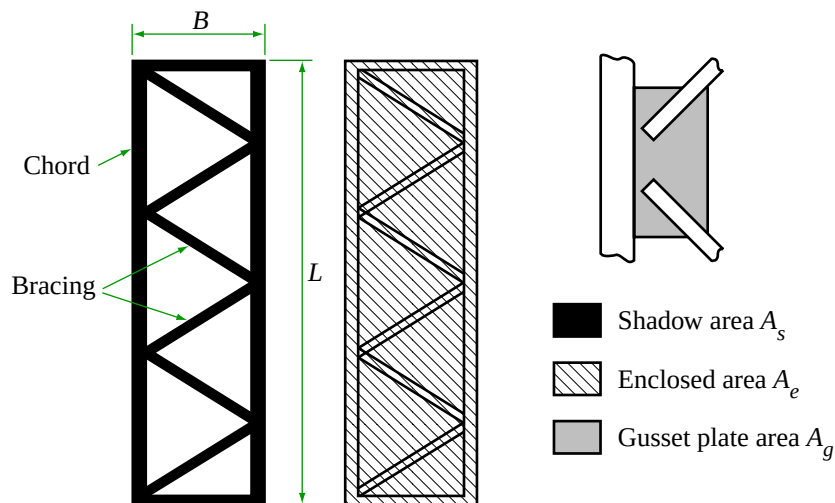
r_{L_u}	lateral integral length scale of u -component of turbulence, see Section 2.5 and Table 8.3	m
M	moment	N m
N	total number of frames in array	
Re_c	Reynolds number based on chord member diameter or along-flow dimension, VD_c/ν or Va_c/ν	
Re_{ec}	effective Reynolds number, $\lambda_R \lambda_T Re_c$	
s	spacing between multiple lattice frames, along $0x$ direction, see Sketch 1.3	m
V	time-averaged flow velocity, see Section 2.5	m/s
$0u, 0v, 0w$	flow axes, set of right-handed cartesian axes fixed with reference to mean flow direction, see Section 1.1	
$0x, 0y, 0z$	body axes, set of right-handed cartesian coordinate axes fixed with reference to frame, see Section 1.1	
z_{cpi}	moment arm from bay centre* to point about which moment is required	m
α	incidence angle [†] , angle between the $0xz$ plane and a plane containing the $0z$ axis and the flow velocity vector, see Sketch 1.4	degree
$\bar{\alpha}$	exponent for power law approximation to wind-speed profile, $(V/V_L) = (z/z_L)^{\bar{\alpha}}$	
β	yaw angle [†] , between the $0xy$ plane and a plane containing the $0y$ axis and the flow velocity vector, see Sketch 1.4	degree
ε	effective roughness height of member surface, see Section 2.5 and Table 8.2	m
$\lambda_R, \lambda_T, \lambda_{Tcrit}$	factors accounting for effects of member surface roughness and flow turbulence, see Section 3.2 and Figure 3a	
ν	kinematic viscosity of fluid	m ² /s
ρ	density of fluid	kg/m ³
ϕ	solidity ratio of frame or bay of frame, A_s/A_e	
Suffixes		
b	denotes value for bracing member	
c	denotes value for chord member	
g	denotes value for gusset plate	

For footnotes see end of Notation Section.

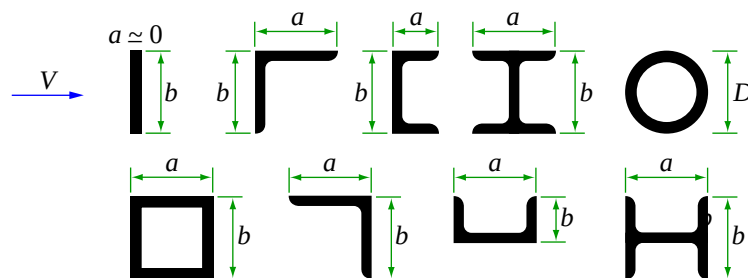
i	denotes value for i th bay* of frame
j	denotes value for j th frame in an array or its spacing from frame upstream
k	denotes value for a frame upstream of j th frame
X, Y, Z	denote values appropriate to X -, Y -, or Z -force components
α, β	denote values appropriate to incidence angle α or yaw angle β
0	denotes value for $\alpha = 0^\circ$ and $\beta = 0^\circ$ (note that other numerical suffixes denote either the incidence or yaw angle at which the force coefficient is valid or the position of a frame in an array, according to the context).

* A single bay is the minimum length of frame on which forces should be estimated (see Section 2.5.1).

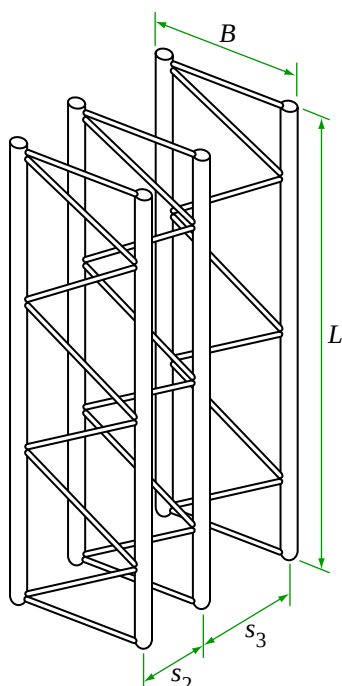
† Note that A_s is independent of the inclination of the flow to the frame.



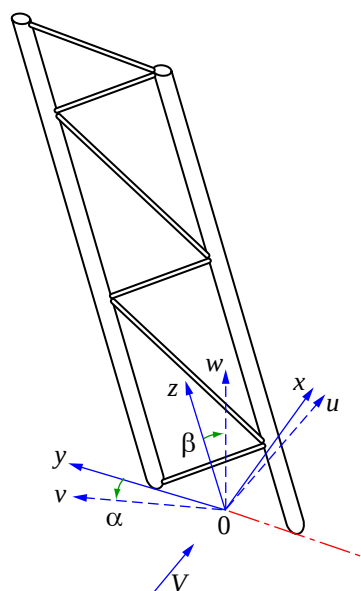
Sketch 1.1 Reference areas



Sketch 1.2 Examples of member shapes



Sketch 1.3 Multiple frame geometry



Sketch 1.4 Axis systems

1.1 Axis Systems and Force Coefficients

Two systems of axes are widely used in fluid loading studies: (i) a flow-axis system $0u, 0v, 0w$, fixed in relation to the mean flow and with $0u$ aligned along the mean flow direction and (ii) a body-axis system $0x, 0y, 0z$, fixed in relation to the structure and with $0x$ commonly aligned normal to a principal face of the structure. Whilst the flow-axis system is almost invariably used to describe flow properties, either system may be used to describe the flow-induced forces.

In this Item a body-axis system is used with the $0x$ axis normal to a plane containing the frame chord or leg members as shown in Sketch 1.4. The force coefficient components are then the normal force coefficient C_X and the across-frame and along-frame tangential force coefficients C_Y and C_Z respectively. The force coefficient components in a flow-axis system are the drag coefficient C_D along the flow direction, $0u$, and across-flow force coefficients C_C (or C_L) and C_A along the $0v$ and $0w$ directions. The force coefficients in the two systems can be related by:

$$\left. \begin{aligned} C_D &= C_X \cos \alpha \cos \beta + C_Y \sin \alpha - C_Z \cos \alpha \sin \beta, \\ C_C &= -C_X \sin \alpha \cos \beta + C_Y \cos \alpha + C_Z \sin \alpha \sin \beta \\ \text{and} \quad C_A &= C_X \sin \beta + C_Z \cos \beta \end{aligned} \right\} \quad (1.1)$$

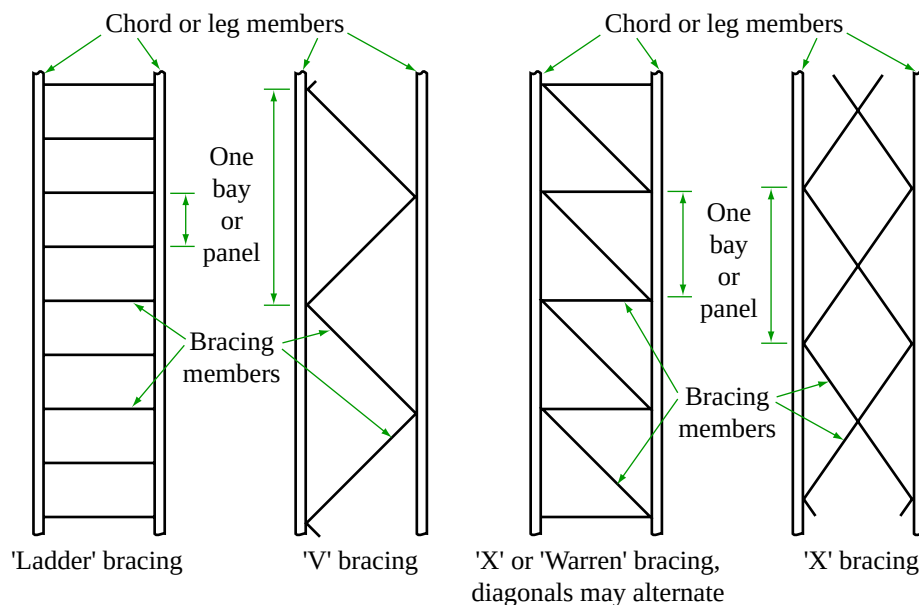
where the incidence and yaw angles, α and β , are defined in the Notation and shown in Sketch 1.4.

2. PURPOSE, SCOPE AND USE OF THIS DATA ITEM

2.1 Purpose and Scope

This Data Item provides data for estimating the mean fluid forces and moments on single and multiple plane lattice frames of generally conventional geometry, such as those shown in Sketch 2.1. It is the first of two Data Items that will supersede and extend the information on lattice structures in ESDU 75011*. The second Item will cover spatial lattice frames such as towers.

The present Data Item has application in the design of single-frame latticed support structures for cable and pipe runs, sign gantries and latticed members within more complex structures, and of multiple frame structures occurring in both unclad building frames and roof structures and in falsework.



Sketch 2.1 Typical lattice frame arrangements

The scope of the data presented is indicated in Table 2.1. Worked examples are provided in Section 6 and Calculation Sheets in Tables 8.4 to 8.8.

Two basic methods have been proposed for determination of force coefficients on lattice frames. The “bulk method” uses correlations of data derived for assembled frames or bays of frames. The “summation method” sums the forces on the individual members, assuming they are in two-dimensional flow, and adds a correction, in the form of a “joint force”, to allow for interference effects at the joints and departures from two-dimensionality. The data currently available for the bulk method allow reasonable generalisation to a wide range of frame geometries but the very few data available on “joint forces” (Derivations 12 and 20) do not allow this to be done for the summation method. Therefore, although both methods were presented in ESDU 75011, the bulk method is now to be preferred and this alone is presented in the present Data Item.

* A third Data Item covering “structural sections” such as angle and I-section beams will be issued to supersede the remainder of ESDU 75011.

The current British Draft Code of Practice for Lattice Tower Loading⁴ includes data from which wind-induced loads on single lattice frames may be estimated. The Codes of Practice of other countries may also include similar data for lattice frames, usually in those Codes concerned with general wind loading. By comparison with the British Draft Code this Data Item provides a means of allowing for the important effects of turbulence and surface roughness on frames with circular-section members and covers effects of inclined flow which are not included in the Draft Code. This Data Item also presents more comprehensive information on shielding effects for multiple frames.

TABLE 2.1 Scope of the Data Item

	<i>Member shape</i>		
	<i>Flat-faced</i>	<i>Circular</i>	<i>Other*, mixed</i>
Effect of shear flow	2.4.3		
Force coefficient, normal flow	3.1	3.2	3.3, 3.4
Effects of solidity ratio and solidity distribution	3.1	3.2	—
Effects of finite length	3.5, 4.1	3.5	3.5
Effects of taper of frame or members	3.5		
Gusset plates	3.6		
Effects of distributed ancillaries: ladders, cables, wire meshes, etc.	3.7.1		
Effects of concentrated ancillaries: sign boards, aerials, etc.	3.7.2		
Inclined flow, incidence effects	4.1.1	4.2.1	—
Inclined flow, yaw effects	4.1.2	4.2.2	—
Shielding effects, flow nominally normal to frames	5.1		
Shielding effects, flow inclined to frames	5.2		
Simple bridges, arrays of frames with light intermediate bracing	5.3		
Towers, crane jibs etc.	See ESDU 81028		
Worked examples	6.1	6.2	—
Calculation sheets	Tables 8.4, Table 8.8	Tables 8.5, 8.6, 8.7 and 8.8	Tables 8.6, 8.7 and 8.8

* ESDU 79026 and 80025 will also be required.

2.2 Limitations and Uncertainty

This Data Item may be used to estimate the mean loading induced by gas or liquid flows. For gas flows, the Mach number should be less than about 0.4. For liquid flows, the possibility of significant additional forces arising from free-surface effects or from cavitation should be investigated.

A particular application is to structures in the natural wind. The data may be used to derive the mean component of wind loading as part of a statistical approach to the total wind loading. For design purposes, it is necessary to consider also the fluctuating components. The calculation procedure of ESDU 76001³, using force coefficients from this Data Item, will provide values for the fluctuating components caused by turbulence buffeting. The data in this Data Item may also be used in a quasi-static, discrete gust loading approach to the total wind loading. Some of the implications in that approach which make it less reliable are discussed in ESDU 81017⁷.

Specific limitations on the application of the data are included as comments in the text or on the Figures. Where possible an estimate of the uncertainty of the data is given on the Figures, based on the spread of experimental data. These uncertainties apply only to variation in the parameter directly being considered and the combined application of two or more corrections may increase the uncertainty. The ranges of experimental data on which the correlations are based are given in Table 8.1.

2.3 Use of the Data Item

- (i) Note the general scope and applicability of the Item, as set out in Sections 2.1 and 2.2, in relation to the problem under consideration.
- (ii) Select the appropriate Calculation Sheet or Sheets from Tables 8.4 to 8.8. The Calculation Sheets form a convenient, self-contained guide to the calculation procedure and reference the appropriate Figures for data. The Figures include estimates of uncertainty and important limitations are noted. For repeated calculations the data in this Item can be programmed. Two worked examples are given in Section 6 and advice on the input data required for the calculations is given in Section 2.5.
- (iii) To make best use of the Item, read also the appropriate background notes, selected by reference to Table 2.1. This is particularly important for cases where data are tentative or extrapolated or where frames of unconventional geometry are being considered. Reference to Table 8.1, giving ranges of parameters covered by experimental data may also assist in establishing applicability in such cases.

2.4 Summary of Calculation Procedure

2.4.1 Flow normal to the frame

For many practical situations the loading case of most interest will be that with flow normal to the frame. This gives the maximum resultant force and moment on a single frame. For this case, the Y- and Z-forces are approximately zero (but see Section 3.1) and the X-force on the *i*th bay or frame section is given by

$$X_i = \frac{1}{2} \rho V_i^2 A_{si} C_{X0i} \quad (2.1)$$

and the moment induced by this force is given by

$$M_{yi} = X_i z_{cpi}, \quad (2.2)$$

where z_{cpi} is the distance between the point about which the moment is required and the centre-of-pressure location for the bay, which is assumed to be at the mid-point of the bay.

2.4.2 Flow inclined to the frame

More generally the X -, Y - and Z -forces on the i th bay or frame section are given by

$$X_i = \frac{1}{2}\rho V_i^2 A_{si} C_{Xi}, \quad (2.3)$$

$$Y_i = \frac{1}{2}\rho V_i^2 A_{si} C_{Yi} \quad (2.4)$$

and
$$Z_i = \frac{1}{2}\rho V_i^2 A_{si} C_{Zi}. \quad (2.5)$$

The moments about the y - and x -axis directions are given by

$$M_{yi} = X_i z_{cpi} \quad (2.6)$$

and
$$M_{xi} = Y_i z_{cpi}, \quad (2.7)$$

where again z_{cpi} is the moment arm to the bay centre. The twisting moment, M_z , about the Oz axis is zero unless ancillaries are distributed asymmetrically.

2.4.3 Shear flow

The effect of a shear flow, that is a flow with a velocity varying along the frame, is allowed for in the calculation method by use of the mean velocity over each bay or section of the frame.

2.5 Input Data Required

2.5.1 Frame geometry

Unless the frame considered is completely uniform over its length and is immersed in a uniform flow it will be necessary to divide the frame into convenient sections and consider the loading on each separately. Suitable division points will usually be apparent on inspection. A single bay or panel (as shown in Sketch 2.1) is the minimum length that should be considered.

The required geometrical parameters for the frame (or for each bay of the frame) are set out in Table 2.2.

TABLE 2.2 Frame Geometry

<i>Parameter</i>	<i>Comment</i>
Enclosed area, A_e Shadow area, A_s } see Sketch 1.1 Solidity ratio, A_s/A_e	Evaluated preferably from detailed dimensions or from scaled drawings but Appendix A1 gives equations which allow a straight-forward estimation of A_s to within about ± 10 per cent provided that the bracing connections are close to the bay limits. Values are required for each bay or frame section.
Chord member diameter, D_c Surface roughness parameter, ϵ/D_c Diameter ratio, D_b/D_c	For circular-section members only. An assessment of ϵ may be made from Table 8.2.
Shadow area of flat-faced members, $A_{s,flat}$ Shadow area of circular-section members, $A_{s,circ}$	For frames with a mixture of member types.
Shadow area of gusset plates, A_g , and ancillaries	Gusset plate area included in A_s for frames of flat-faced members, required separately for frames of circular-section members. See Section 3.7 for treatment of ancillaries.
Flow incidence angle, α Flow yaw angle, β	Angles α and β are zero for flow normal to the frame.
Frame spacing ratios [*] , s_j/B Frame spacing ratios [*] s_j/b_c or s_j/D_c	Ratios in terms of chord dimensions should be checked if $s_j/B < 0.75$. Note also whether bracing on successive frames is in-line or crossed.

* Note that s_j denotes spacing of the j th frame from the one upstream of it.

2.5.2 Flow properties

The required flow properties are set out in Table 2.3.

TABLE 2.3 Flow Properties

<i>Parameter</i>	<i>Comment</i>	
	<i>Uniform flow</i>	<i>Shear flow</i>
Velocity, V	Single value required for frame location.	Use mean value over each bay. Table 8.3 summarises velocity profile data for the natural wind, more detail is given in ESDU 82026.
Turbulence intensity, I_u Lateral scale of turbulence, rL_u	Required for frames of rounded-section members only. Table 8.3 summarises values for the natural wind and gives approximate values for some internal flow environments. ESDU 85020 and 86010 provide more detailed information for the wind*. Single value required for frame location.	
		Use value at centre of each bay.
Fluid density, ρ	Standard reference value for air = 1.23 kg/m^3 . Nominal value for fresh water $\approx 1000 \text{ kg/m}^3$ and for sea water $\approx 1025 \text{ kg/m}^3$. Note, however, that these values vary appreciably with temperature, and with pressure for air and salinity for sea water, even over the typical ranges experienced under natural conditions.	
Fluid kinematic viscosity, ν	Standard reference value for air = $1.45 \times 10^{-5} \text{ m}^2/\text{s}$. Nominal value for fresh water $\approx 1 \times 10^{-6} \text{ m}^2/\text{s}$ and for sea water $\approx 1.08 \times 10^{-6} \text{ m}^2/\text{s}$. Note that, as for density, appreciable variations from these values do occur.	

* Note that in ESDU 86010 the lateral integral length scales are denoted by ^yL_u and ^zL_u where in that case y and z are wind-axis directions rather than body-axis directions as used in this Data Item. The most appropriate scale for the present purpose is that nearest to an across-frame direction.

2.5.3 Force coefficients

The force coefficients are presented in terms of basic coefficients to which correction factors are applied to allow for secondary effects. Section 3 discusses force coefficients and corrections for flow normal to a single frame. Section 4 considers corrections required to allow for the effects of flow inclination and Section 5 covers the case of two or more parallel frames.

3. SINGLE LATTICE FRAMES NORMAL TO THE FLOW

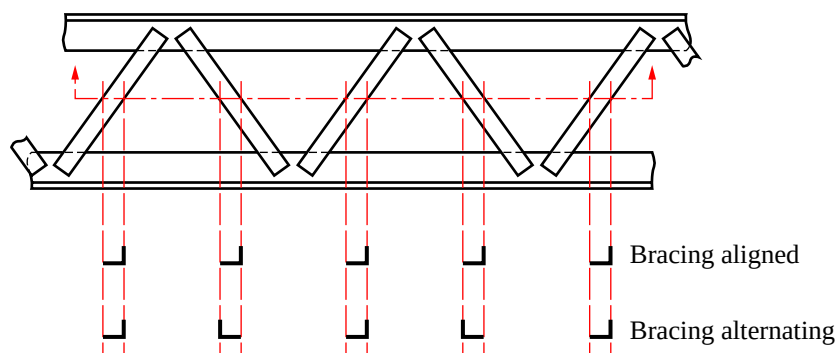
For the case of flow normal to the frame, the drag coefficient, C_{D0} , is equal to the normal force coefficient, C_{X0} . The along-frame and across-frame force coefficients C_{Z0} and C_{Y0} are zero except in the case of certain asymmetries in bracing members as discussed in Section 3.1.

The values of C_{X0} for solidity ratios, $\phi (= A_s/A_e)$ of 0 and 1 can be derived for some cases and have been used to extrapolate data from smaller ranges of ϕ . The limiting solidity case of $\phi = 0$ can be considered as a frame comprising two chord members only, an infinite distance apart and with no bracing. For this case $C_{X0} = C_{Dc}$. At the opposite extreme, $\phi = 1$, two limits are plausible. Firstly when the frame consists of two chord members touching and secondly when the chord members are separated but the bracing fills the area between them. These two rather different configurations do, in practice, give similar limiting values of C_{X0} (References 1, 2 and 28).

3.1 Frames of Flat-faced Members

The normal force coefficient, C_{X0} , is given directly by Figure 1 as a function of frame solidity ratio, ϕ , for typical lattice frames constructed from flat-faced members such as flat strips, angle sections, channel sections and box sections*. For such nominally sharp-edged members the force coefficients are essentially independent of Reynolds number for Re_c greater than about 10^3 . Over most of the range of solidity ratio, C_{X0} is not strongly dependent on the actual member shape but as $\phi \rightarrow 0$ where $C_{X0} = C_{Dc}$, allowance must be made for the variation of C_{Dc} with member shape. Several cases are shown on Figure 1. The data show no significant variation with the pattern of bracing for a range of typical ladder, V, X and N arrangements, but force coefficients for constructions such as grids of crossed strips do differ significantly†. Figure 1 therefore gives also a curve for “grids and meshes” (taken from Reference 1 and based on data for grids, perforated plates and wire meshes) that should be used for grid-like constructions having a near-uniform solidity distribution over the face of the frame.

For frames with angle-section bracing members, small across-frame forces may be generated when the bracing member flange alignments alternate and small along-frame forces when all bracing members are the same way round (Sketch 3.1).



Sketch 3.1

* Typically with $a_c/b_c < 0.3$ or approximately square. In particular the data may not apply for sections with $a_c/b_c \approx 0.67$ which give very high drag coefficients for isolated members.

† The discrepancy is probably associated with differences in flow pattern. For typical lattice frames, the pattern is one of flow around the individual members; for grids and perforated plates it tends to be flow around the plate outline with a small flow through the holes into the wake.

Figure 1 is based on wind-tunnel data for nominally smooth, uniform flow. The few data available (Derivation 14 for single frames, Reference 6 for lattice towers) suggest that turbulence intensities up to 10 per cent increase the force coefficients by a small amount which is, however, within the scatter of data for smooth flow.

3.2 Frames of Circular-section Members

The normal force coefficient is given by

$$C_{X0} = C'_{X0} f_{\phi} f_D \quad (3.1)$$

where C'_{X0} is given by Figure 2a, f_{ϕ} by Figure 2b and f_D by Figure 2c.

For frames of circular-section members and (rounded-section members in general), the force coefficient is a function of Reynolds number and surface roughness. It has been found, however, that the relatively few data available can be tentatively correlated with the effective Reynolds number for the chord cylinder, $Re_{ec} = \lambda_R \lambda_T Re_c$, as shown in Figure 2a. The parameters λ_R and λ_T allow for the effects of surface roughness of the members and turbulence properties of the flow and allow a rational extrapolation of the wind-tunnel data, on which Figure 2a is based, to more turbulent flows such as the natural wind. Values of λ_R and λ_T , evaluated for the chord cylinder, can be obtained from Figures 3a to 3b and Re_{ec} then estimated using the calculation procedure on Calculation Sheet 2.

Over the solidity range $0.15 \leq \phi \leq 0.45$, C_{X0} shows no systematic variation with ϕ within the overall uncertainty of the data. However, a tentative correction factor f_{ϕ} , shown in Figure 2b, has been derived using the limiting cases of $\phi = 0$ and $\phi = 1$. As with frames of flat-faced members, the data for frames of circular section members show no significant variation with the pattern of bracing for typical V, X and N arrangements. However, for the case of near-uniform solidity distribution represented by wire-mesh-like constructions, force coefficients are higher and of similar order to those for flat-strip grids¹ as shown by the curve for “grids and meshes” on Figure 1.

Since the values of Re_{eb} and ε/D_b will differ from those for the chord members some influence of the relative sizes and proportions of chord and bracing members might be expected. For the data available, a trend only with D_b/D_c was discernable and a tentative factor f_D is shown in Figure 2c. This effect is probably associated with the chord member becoming less effective as an “end plate” on the bracing members as D_b/D_c increases.

The along-frame and across-frame forces are approximately zero unless large asymmetries occur in the bracing.

3.3 Frames of Non-circular Rounded-section Members

Frames with members of cross-sectional shapes such as rounded hexagonal, octagonal or near-axisymmetric elliptical sections are occasionally encountered but no data were found for frames of rounded-section members other than circular. In the absence of such data, it is suggested that the force coefficients are obtained by factoring the corresponding coefficients for frames of circular-section members by the ratio C_D (chord member shape)/ C_D (circular cylinder). The drag coefficient for the chord member shape can be obtained from ESDU 79026⁵ and for a circular cylinder from ESDU 80025²⁵.

3.4 Frames of Mixed Member Sections

Frames constructed from members of a mixture of cross-sectional shapes are sometimes encountered. In the absence of specific data it is suggested that the force coefficients are estimated by taking values for equivalent lattices constructed completely of each member type and weighting each value according to the shadow area contribution of that member shape. For a mixture of flat-faced and circular-section* members this leads to the following equation;

$$C_{X0}(\text{mixed lattice}) = C_{X0}(\text{flat-faced}) \frac{A_{s, \text{flat}}}{A_{s, \text{(total)}}} + C_{X0}(\text{circular}) \frac{A_{s, \text{circ}}}{A_{s, \text{(total)}}}. \quad (3.2)$$

If the shadow area of one member type is less than 10 per cent of the total any change in force coefficient indicated by Equation (3.2) will be much less than the uncertainty of the data and the force coefficients for the dominant member type can be used.

3.5 Effects of Finite Length and Taper

3.5.1 Finite length (finite aspect ratio)

The data presented in Sections 3.1 and 3.2 apply for two-dimensional flow conditions when the frame has no free ends and is, effectively, infinitely long. The few data available (for frames of flat-faced members with $0.2 \leq \phi < 0.8$ and aspect ratios in the range $1 < L/B < 10$) for frames with one or two free ends suggest that no reduction from the two-dimensional flow values should be allowed for finite-length frames. However, at the limits $\phi = 0$ and $\phi = 1$, as noted in the introduction to Section 3, the frame force coefficients are equal to those for equivalent solid structures which do vary with L/D_c or L/b_c as shown by References 1, 2 and 7. Between these limits and the range of ϕ for which data are available the effects of finite length cannot be assessed and it is suggested that it is assumed that there is no effect for all practical lattice frames normal to the flow†.

3.5.2 Taper

The effects of taper of the frame outline are unlikely to significantly alter the force coefficients in the present case except through the effect on shadow area, A_s , and solidity ratio, ϕ . No data were found on the effects of taper of individual frame members and it is suggested that they are assumed to appear only through A_s and ϕ .

3.6 Gusset Plates

Lattice frames are often fitted with gusset plates at the joints for strengthening purposes or for ease of construction. Because the flow patterns around flat-faced and circular-section members are different, the interference and additional forces introduced by the presence of gusset plates on lattice frames also differ according to the member shape.

For frames of flat-faced members the presence of the gusset plates can be allowed for by including their area in the shadow area of the frame and in the calculation of solidity ratio. For frames of circular-section members the additional force can be expressed in terms of an increment in force coefficient given approximately by

* A similar procedure is suggested where non-circular rounded-section members are included.

† But see Section 4.1.2 for frames in yawed flow.