ESDU 93013

Issued December 1993
Re-issued March 2012

'Lift-curve slope' for structural response calculations

ESDU Copyright material. For current status contact ESDU.

Documents
Document Sharing Hub

Full document details: ESDU 93013-R1 2012

ESDU DATA ITEMS

Data Items provide validated information in engineering design and analysis for use by, or under the supervision of, professionally qualified engineers. The data are founded on an evaluation of all the relevant information, both published and unpublished, and are invariably supported by original work of ESDU staff engineers or consultants. The whole process is subject to independent review for which crucial support is provided by industrial companies, government research laboratories, universities and others from around the world through the participation of some of their leading experts on ESDU Technical Committees. This process ensures that the results of much valuable work (theoretical, experimental and operational), which may not be widely available or in a readily usable form, can be communicated concisely and accurately to the engineering community.

We are constantly striving to develop new work and review data already issued. Any comments arising out of your use of our data, or any suggestions for new topics or information that might lead to improvements, will help us to provide a better service.

THE PREPARATION OF THIS DATA ITEM

The work on this particular Data Item was monitored and guided by the Wind Engineering Panel. This Panel, which took over the work on wind engineering previously monitored by the Fluid Mechanics Steering Group, first met in 1979 and now has the following membership:

Chairman

Mr T.V. Lawson	—	Bristol University

Members

Mr A. Allsop	—	Ove Arup and Partners
Mr C.W. Brown	—	Independent
Prof. J.E. Cermak*	—	Colorado State University, USA
Dr N.J. Cook	—	Building Research Establishment
Prof. A.G. Davenport*	—	University of Western Ontario, Canada
Dr D.M. Deaves	—	Atkins Research and Development
Dr R.G.J. Flay*	—	University of Auckland, New Zealand
Dr A.R. Flint	—	Flint and Neill
Mr R.I. Harris	—	Cranfield Institute of Technology
Dr J.D. Holmes*	—	CSIRO, Australia
Dr R.P. Hoxey	—	Silsoe Research Institute
Prof. K.C. Mehta*	—	Texas Tech. Univ., USA
Mr R.H. Melling	—	Independent
Dr A.G. Robins	—	University of Surrey
Mr R.E. Whitbread	—	BMT Fluid Mechanics Ltd
Mr G. Wiskin	—	British Broadcasting Corporation.

* Corresponding Member

The technical work involved in the assessment of the available information and the construction and subsequent development of the Data Item was undertaken by

Mr K. Farnham	—	Engineer.

The person with overall responsibility for the work in this subject area is Mr N. Thompson, Head of the Wind Engineering Group.

ESDU Copyright material. For current status contact ESDU.

Documents
Document Sharing Hub

'LIFT-CURVE SLOPE' FOR STRUCTURAL RESPONSE CALCULATIONS

CONTENTS

		Page
1.	NOTATION AND UNITS	1
2.	BACKGROUND	3
2.1	Axis Systems	3
3.	BUILDING SHAPES OF RECTANGULAR SECTION	3
3.1	Tabulated Values of $dC_{FX}/d\phi$ and $dC_{FY}/d\phi$ for Building Shapes	4
4.	BRIDGE SECTIONS: $dC_L/d\phi$	6
4.1	Box-Girder Bridges	6
4.2	Cable-stayed Bridges	9
4.3	Suspension Bridges	10
4.4	Miscellaneous Bridges	11
5.	STRUCTURAL MEMBERS: $dC_{FP}/d\phi$ AND $DC_{FQ}/d\phi$	12
5.1	Equal-Leg Angle Section	12
5.2	Unequal-Leg Angle Section	12
5.3	Channel Section	13
5.4	I- or H-Section, a/b = ½	13
5.5	I- or H-Section, a/b = 1	14
5.6	T-Section	14
5.7	T-Shaped Compound Angle	15
5.8	X-Shaped Compound Angle	15
5.9	Pair of Channel Sections	16
6.	STRUCTURES OF CIRCULAR SECTION	16
7.	LATTICE TOWERS	16
8.	REFERENCES AND DERIVATION	17
8.1	References	17
8.2	Derivation	17
APPENDIX A	RATE OF CHANGE OF FORCE COEFFICIENTS WITH INCIDENCE FOR RECTANGULAR PRISMS	19
A1.	Mean Forces	19
A1.1	Rate of Change of Force Coefficients with Incidence	19
A1.2	Tables for	19

ESDU Copyright material. For current status contact ESDU.

Documents
Document Sharing Hub

Full document details: ESDU 93013-R1 2012

'LIFT-CURVE SLOPE' FOR STRUCTURAL RESPONSE CALCULATIONS

1. NOTATION AND UNITS

		SI Unit
A	reference area; bL for buildings and angle sections, aL for bridge decks	m^2
a	depth of section shape in along-wind direction or deck width at zero incidence	m
b	width of section shape normal to wind direction at zero incidence	m
C_D	drag coefficient; value of C_F parallel to wind direction	–
C_F	force coefficient; $F/(½\rho V_H^2\ A)$	–
C_L	lift coefficient; value of C_F normal to wind direction	–
C_{FP}	value of C_F in $0P$ principal-axis direction	–
C_{FQ}	value of C_F in $0Q$ principal-axis direction	–
C_{FX}	value of C_F in $0X$ body-axis direction	–
C_{FY}	value of C_F in $0Y$ body-axis direction	–
C'_X	basic force coefficient in $0X$ direction for sharp-edged prism at zero incidence in low turbulence, uniform flow	–
C'_Y	basic force coefficient in $0Y$ direction for sharp-edged prism at 90° incidence in low turbulence, uniform flow	–
F	component of resultant mean force in plane of section in particular direction	N
H	height above ground of top of structure	m
H_B	barrier height	m
I_u	intensity of u-component of turbulence	–
I_w	intensity of w-component of turbulence	–
k_i, k_l	correction factors for effect of turbulence intensity and scale on C'_X	–
k_r	correction factor for effect of rounded edges on C'_X	–
k_s	correction factor for effect of non-uniform velocity profile on C'_X	–

Issued December 1993
Re-issued March 2012 – 20 pages

ESDU Copyright material. For current status contact ESDU.
Documents
Document Sharing Hub
Full document details: ESDU 93013-R1 2012

$k_{\phi x}$	correction factor for effect of incidence on C'_X	–
$k_{\phi y}$	correction factor for effect of incidence on C'_Y	–
L	length of structure; $L = H$ for buildings	m
P, Q, R	system of rectangular Cartesian co-ordinates defined along principal axes	–
r	edge radius of rectangular section	m
V	mean wind speed	m/s
X, Y, Z	system of rectangular Cartesian co-ordinates defined along body axes with $0X$ aligned to wind direction at zero incidence	–
z	height above ground	m
α	power law index giving variation of wind speed with height; $V_z/V_H = (z/H)^{\alpha}$	–
ρ	air density	kg/m^3
ϕ	flow incidence to reference axis	degree

Subscripts

H	denotes value at height H
z	denotes value at height z
ϕ	denotes value at incidence ϕ
0	denotes value for $\phi = 0°$
90°	denotes value for $\phi = 90°$

ESDU Copyright material. For current status contact ESDU.

Documents
Document Sharing Hub
Full document details: ESDU 93013-R1 2012

2. BACKGROUND

ESDU 84049[1*] and ESDU 91010[2] describe methods for calculating the response of structures to buffeting by across-wind turbulence components and to galloping, respectively. Both calculations require as an input the rate of change of an appropriate force coefficient with wind direction, $dC_F/d\phi$.

Although buffeting and galloping can be potential problems at any wind incidence, they most often require consideration for situations in which the wind direction is along one of the principal axes of the structure. For most regular cross-sectional shapes this wind direction will usually coincide with a body axis and often with a condition for which C_L is zero, commonly considered as the zero incidence condition. The more important response is usually that approximately normal to the mean wind direction and the relevant force coefficient is C_{FQ}.

This Item provides information on the rate of change with incidence of force coefficients in the principal axis directions for a range of building shapes of rectangular cross-section, bridge deck sections and structural member sections. Cross references are also given for structures of circular section and lattice towers.

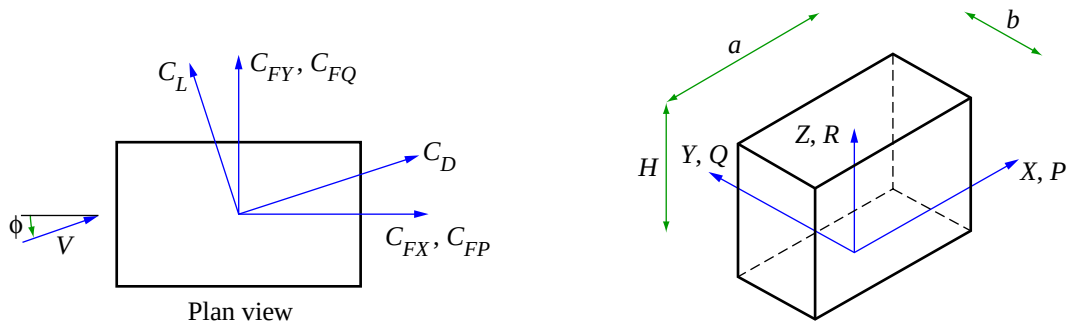
2.1 Axis Systems

The sign convention for this Item uses a right-handed coordinate system for the principal and body axes. The plan view in Sketch 3.1 shows a view along the negative 0*R* principal axis or negative 0*Z* body axis (here assumed coincident) of a building shape. For a bridge section it is assumed that the side force coefficient is C_L and for structural section shapes wind incidence and sign conventions are shown in Section 5. The side force coefficient C_{FY} or C_{FQ} is sometimes taken as positive in the opposite direction to that shown. Since the sign of $dC_F/d\phi$ is important, care should be taken to ensure that the data from this Item are compatible with the sign convention used in the calculation procedure adopted.

3. BUILDING SHAPES OF RECTANGULAR SECTION

It is assumed that the principal axes 0*P* and 0*Q* are aligned to the body axes 0*X* and 0*Y*.

ESDU 80003[11] gives the variation of mean force coefficient with wind incidence for various building shapes of rectangular cross section. The variation of force coefficient with incidence is dependent on the side length ratio (*a*/*b*), aspect ratio (*H*/*b*), turbulence properties of the incident wind, corner radius and wind shear. The derivation of values of $dC_{FX}/d\phi$ and $dC_{FY}/d\phi$ from these data is explained in Appendix A, but for convenience values for typical configurations are summarised in Tables 3.2 and 3.3 for $\phi = 0°$ and 90° and for values of I_{uH} = 0.05, 0.1 and 0.15.



Sketch 3.1 Rectangular prism dimensions and force directions

* The procedure in ESDU 89049 is available as a computer program in ESDUpac B9236.

ESDU Copyright material. For current status contact ESDU.
Documents
Document Sharing Hub
Full document details: ESDU 93013-R1 2012

3.1 Tabulated Values of $dC_{FX}/d\phi$ and $dC_{FY}/d\phi$ for Building Shapes

The values presented in Tables 3.2 and 3.3 are evaluated for full-scale body shapes for which the corner radius is small $(r/b \approx 0, k_r = 1)$ and for which the length scale of turbulence is large compared to the building width $(k_l \approx 1)$. In uniform flow $k_s = 1$, but in practice wind speeds in the atmospheric boundary layer vary with height and for these cases k_s is less than unity and can be approximated by

$$k_s = \frac{1}{2\bar{a} + 1}. \tag{3.1}$$

Typical values of $\bar{a}$ and k_s are given in Table 3.1.

TABLE 3.1 Typical values of $\bar{a}$

Terrain	$\bar{a}$	k_s
Open sea, desert	0.13	0.79
Open country	0.16	0.76
Suburbs	0.22	0.69
Town and city centres	0.3	0.63

ESDU Copyright material. For current status contact ESDU.

Documents
Document Sharing Hub
Full document details: ESDU 93013-R1 2012

TABLE 3.2 Values of $\frac{1}{k_s}\frac{dC_{FX}}{d\phi}$ for building shapes*

H/b	a/b	$\phi = 0$			$\phi = 90°$		
		$I_{uH} = 5\%$	$I_{uH} = 10\%$	$I_{uH} = 15\%$	$I_{uH} = 5\%$	$I_{uH} = 10\%$	$I_{uH} = 15\%$
1	0.25	–0.08	–0.09	–0.09	–3.48	–4.17	–4.14
1	0.5	–0.08	–0.10	–0.09	–3.54	–4.36	–4.20
1	1	0.25	0.28	0.26	1.51	1.75	1.62
2	0.25	–0.07	–0.08	–0.08	–3.38	–3.85	–3.68
2	0.5	–0.08	–0.09	–0.08	–3.46	–4.00	–3.61
2	1	0.27	0.30	0.27	2.52	2.80	2.53
2	2	0.74	0.91	0.88	–0.18	–0.22	–0.22
4	0.25	–0.08	–0.08	–0.07	–3.60	–3.72	–3.30
4	0.5	–0.08	–0.08	–0.07	–3.62	–3.74	–3.22
4	1	0.17	0.18	0.16	1.81	1.87	1.66
4	2	0.76	0.87	0.79	1.53	1.76	1.59
4	4	0.72	0.86	0.85	1.45	1.73	1.72
8	0.25	–0.09	–0.08	–0.07	–3.92	–3.72	–3.28
8	0.5	–0.09	–0.09	–0.08	–4.27	–4.04	–3.56
8	1	0.20	0.19	0.16	2.05	1.94	1.71
8	2	0.81	0.84	0.72	1.64	1.70	1.46
8	4	0.72	0.82	0.79	1.46	1.66	1.59

TABLE 3.3 Values of $\frac{1}{k_s}\frac{dC_{FY}}{d\phi}$ for building shapes*

H/b	a/b	$\phi = 0$			$\phi = 90°$		
		$I_{uH} = 5\%$	$I_{uH} = 10\%$	$I_{uH} = 15\%$	$I_{uH} = 5\%$	$I_{uH} = 10\%$	$I_{uH} = 15\%$
1	0.25	–1.45	–1.73	–1.72	–0.72	–0.86	–0.85
1	0.5	0.18	0.22	0.22	–0.74	–0.91	–0.88
1	1	–1.51	–1.75	–1.62	–0.25	–0.28	–0.26
2	0.25	–1.46	–1.66	–1.59	–0.72	–0.82	–0.79
2	0.5	–1.53	–1.76	–1.59	–0.76	–0.87	–0.79
2	1	–2.52	–2.80	–2.53	–0.27	–0.30	–0.27
2	2	3.54	4.36	4.20	0.08	0.10	0.09
4	0.25	–1.49	–1.54	–1.37	–0.74	–0.76	–0.68
4	0.5	–1.64	–1.70	–1.46	–0.81	–0.84	–0.72
4	1	–1.81	–1.87	–1.66	–0.17	–0.18	–0.16
4	2	3.46	4.00	3.61	0.08	0.09	0.08
4	4	3.48	4.17	4.14	0.08	0.09	0.09
8	0.25	–1.47	–1.39	–1.23	–0.73	–0.69	–0.61
8	0.5	–1.81	–1.72	–1.51	–0.90	–0.85	–0.75
8	1	–2.05	–1.94	–1.71	–0.20	–0.19	–0.16
8	2	3.62	3.74	3.22	0.08	0.08	0.07
8	4	3.38	3.85	3.68	0.07	0.08	0.08

* Note that values in the Table must be multiplied by the factor k_S (Table 3.1) to obtain values of $dC_F/d\phi$.

ESDU Copyright material. For current status contact ESDU.

Documents
Document Sharing Hub

Full document details: ESDU 93013-R1 2012