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Longitudinal turbulence intensities over terrain with roughness changes

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THE PREPARATION OF THIS DATA ITEM

The work on this particular Data Item was monitored and guided by the Wind Engineering Committee. This Committee first met in 1979 and now has the following membership:

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LONGITUDINAL TURBULENCE INTENSITIES OVER TERRAIN WITH ROUGHNESS CHANGES

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LONGITUDINAL TURBULENCE INTENSITIES OVER TERRAIN WITH ROUGHNESS CHANGES

1. NOTATION AND UNITS

		Units	
		SI	*British*
d	height above ground of effective zero-plane to account for general height (and density) of ground obstacles in built-up or wooded areas (see Table 3.1)	m	ft
g	peak factor		
$I_{u,zx}$	longitudinal turbulence intensity at height z above site and distance x downwind of change in terrain roughness, assuming site terrain is flat; $\sigma_{u,zx}/V_{zx}$		
K	wind speed profile factor at site; V_{zx}/V_{10_r} or $\hat{V}_{zx}/V_{10_r}$		
K_L	factor accounting for topographic effect on wind speed; $V_{z,hill}/V_z$		
V_{zx}	hourly-mean wind speed; wind speed averaged over 1 hour at height z above site and distance x downwind of change in terrain roughness, assuming site terrain is flat	m/s	mile/h
$\hat{V}_{zx}$	expected (or mean) maximum gust speed averaged over τ seconds, occurring in period of 1 hour, at height z above site and distance x downwind of change in terrain roughness, assuming site terrain is flat	m/s	mile/h
V_{10_r}	reference wind speed; hourly-mean value at $z = 10$ m over flat open country terrain $(z_0 \approx 0.03 \text{ m})$ extending uniformly upwind for at least 50 km (≈ 30 miles)	m/s	mile/h
x, x_1, x_2	distance (fetch) over which uniform terrain roughness extends upwind of site and upwind of first and second upwind changes in terrain roughness	km	mile
z	height measured from effective zero-plane (height above ground $= z + d$)	m	ft
z_0	surface roughness parameter (see Table 3.1)	m	ft

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$\sigma_{u,zx}$	standard deviation of along-wind fluctuating component of wind speed	m/s	ft/s

Subscripts

1, 2	relate respectively to conditions upwind of first and second step changes in terrain roughness upwind from site

2. SCOPE AND BASIS OF THE DATA

2.1 Scope

Values of turbulence intensity may be required for the calculation of response to turbulence or to account for its influence on mean loading. This Item provides convenient "look-up" tables of longitudinal turbulence intensities, I_u, for various combinations of terrain roughness at the site and upwind.

The Item is intended to complement ESDU 84011[5], which provides tables of wind speed factors, and the cases of single roughness changes covered by ESDU 84011 are also covered by the present Item. The present Item also includes Tables for a few commonly occurring cases of two upwind roughness changes. For cases not covered by the Tables, use of the computer program ESDUpac A9232[7] is recommended. This program incorporates more definitive methods for the effects of upwind changes in terrain on turbulence properties than the more simplified procedures described in this Item.

The data in the Tables (Sections 6 and 7) apply for nominally flat terrain (ground slope less than 0.05). Where a site is located on a hill, escarpment or cliff, the use of the program A9232[7] is recommended.

2.2 Basis of the Data

The data have been generated from the method given in ESDU 82026 and 83045 using some slight simplification introduced in ESDU 84011. For further background and details of the methods these sources[3, 4] should be consulted.

The longitudinal turbulence intensity is defined as the ratio of the standard deviation of the along-wind fluctuating components of wind speed to mean hourly wind speed at the same height and for the same conditions, *i.e.*

$$I_{u,zx} = \sigma_{u,zx}/V_{zx}\,. \tag{2.1}$$

The gust speed, $\hat{V}_{zx}$, can be related to the hourly-mean wind speed and the turbulence intensity by

$$\hat{V}_{zx} = (1 + gI_{u,zx})V_{zx}\,. \tag{2.2}$$

ESDU 84011 relates the gust speed, $\hat{V}_{zx}$ and the hourly-mean wind speed, V_{zx} to a reference wind speed by

$$V_{zx} = KV_{10_r} \quad \text{and} \quad \hat{V}_{zx} = KV_{10_r}\,, \tag{2.3}$$

where a value of K appropriate to the required gust averaging time (3600 seconds for the hourly-mean wind speed) is used. The peak factor, g, is a function of both the averaging time and the height above ground, but use of an averaging time of 1 second allows a single value of g to be used with sufficient

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accuracy to obtain turbulence intensities. Equation (2.2) can then be re-arranged to give

$$I_{u,zx} = \left(\frac{K_{1sec}}{K_{3600}} - 1\right) \Big/ 3.40 . \tag{2.4}$$

Values of $I_{u,zx}$ derived from Equation (2.4) with the values of K given by ESDU 84011 are tabulated in Sections 6 and 7.

The turbulence intensity will depend, to a small extent, on the magnitude of the reference wind speed (or, more precisely, on the gradient wind speed at the edge of the atmospheric boundary layer). The values derived for this Item are compatible with the wind speed data in ESDU 84011 and can be applied for V_{10_r} greater than 10 m/s with little error.

The data from this Item have been compared with data from the original Harris-Deaves method (References 1 and 2) which can be applied for a single change of roughness. Differences up to 0.005 in I_u were found but generally the agreement was much closer.

The foregoing derivation of turbulence intensities applies for sites on flat terrain. For sites near the crest of hills, ridges, cliffs or escarpments, the wind speed is increased from that over corresponding flat terrain. However, it is justifiable to assume that the rapid distortion of the wind flow over such topography $(\phi \geq 0.05)$ changes only the mean wind speed, V_{zx}, leaving the fluctuating component of wind speed, σ_u, largely unaffected.

The hourly-mean wind speed may then be related to the corresponding hourly-mean wind speed over flat terrain by

$$(V_{zx})_{hill} = V_{zx} K_L . \tag{2.5}$$

Hence from Equation (2.1), assuming σ_u is unaffected,

$$(I_u)_{hill} = I_u / K_L . \tag{2.6}$$

Values of the speed-up factor, K_L, can be obtained using ESDU 91043[6], or more conveniently, the program A9232[7].

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3. EFFECTS OF TERRAIN ROUGHNESS

In all cases estimates of the surface roughness parameter, z_0, have to be made at the site and upwind of the site in the required direction or directions from which it is assumed the wind or the wind originates. Table 3.1 provides typical values based on terrain description. In most cases there will be several changes of terrain upwind of the site being considered but many cases can be approximated by one or two significant changes between terrains in the general categories of Table 3.1. The furthest upwind terrain considered should extend uniformly for at least 50 km (30 mile) to provide an initial equilibrium condition. Small patches of non-uniform terrain (*e.g.* woods or villages in otherwise open country) can be ignored provided that the upwind and downwind terrains are the same and the fetch downwind to the next significant change is at least equal to the extent of the patch[3].

The height, z, at which turbulence intensity is obtained from the Tables is measured from the zero-plane displacement height, d, above the ground, so that height above ground is given by $(z+d)$. Approximate values of d are given in Table 3.1 based on the assumption that the zero-plane is about one or two metres below the general height of the surrounding buildings or trees. For more detailed information see ESDU 82026[3].

TABLE 3.1 Typical Values of Terrain Parameters z_0 and d

Terrain Description	z_0 (m)	d (m)
City centres Forests	0.7	15 to 25
Small towns Suburbs of large towns and cities Wooded country (many trees)	0.3	5 to 10
Outskirts of small towns Villages Countryside with many hedges, some trees and some buildings	0.1	0 to 2
Open level country with few trees and hedges and isolated buildings; typical farmland	0.03	0
Fairly level grass plains with isolated trees Very rough sea in extreme storms (once-in-50-yr extreme)	0.01	0
Flat areas with short grass and no obstructions Runway area of airports Rough sea in annual extreme storms	0.003	0
Snow covered farmland Flat desert or arid areas Inland lakes in extreme storms	0.001	0

Values of the turbulence intensity giving the variation with height over flat terrain are provided in the Tables in Sections 6 and 7. Each Table applies for a particular site roughness with specified changes upwind. Index Tables on pages 6 and 15 guide the user to the appropriate Tables for no change or one change in roughness and for two changes in roughness, respectively. For sites on hills, escarpments or cliffs the topographic factor should be applied as in Section 2.2.

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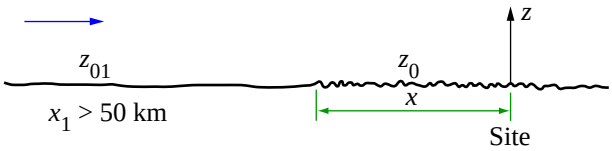
For cases not covered by the Tables and for more than two changes, the computer program A9232[7] should be used. The effects of topography (on mean wind speed) are included in the program.

4. EXAMPLE

It is required to estimate the turbulence intensities at 15 m and 30 m above the ground at a flat site located in a small town near the coast when the wind is blowing off the sea. The corresponding reference hourly-mean design wind speed (50-year return period) for this case is assessed to be 22 m/s (corresponding to $z_{0_r} = 0.03$ and $z_r = 10$ m). The site location is illustrated in Sketch 4.1.



Sketch 4.1

From Table 3.1, for such a high wind speed, the sea roughness will be such that $z_{01} \approx 0.01$ m. For a small town, $z_0 \approx 0.3$ m and typically $d = 7$ m.

From the Index table in Section 6 the appropriate Table is Table 6.9 from which, interpolating for $x = 0.5$ km, the appropriate turbulence intensities are $I_u = 0.22$ at $z = 8.0$ m $(z + d = 15$ m) and $I_u = 0.21$ at $z = 23$ m $(z + d = 30$ m).

5. REFERENCES

1. DEAVES, D.M. — Computations of wind flow over changes in surface roughness. J. Wind. Engng. Indust. Aerodyn., Vol. 7, pp. 65-94, 1981.
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3. ESDU — Strong winds in the atmospheric boundary layer. Part 1: mean-hourly wind speeds. ESDU 82026, London,1982.
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7. ESDU — Computer program for wind speeds and turbulence properties: flat or hilly sites in terrain with roughness changes. ESDU 92032 and ESDUpac A9232, London, 1992.

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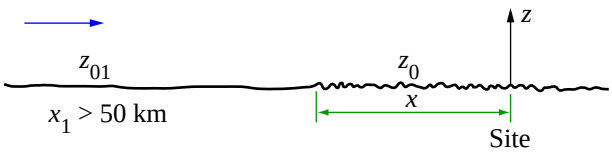
6. TURBULENCE INTENSITIES FOR NO CHANGE OR ONE CHANGE IN ROUGHNESS

Roughness Changes

Providing there are no significant roughness changes within about 50 km upwind of the site, the turbulence intensity can be taken as the equilibrium value (given by the column headed $x \geq 600$ km) in any Table listed in the Index Table below appropriate to the given site roughness, z_0. For example, for z_0 = 0.003 m, Table 6.27 or Table 6.28 could be used.

Single Change in Terrain Roughness



The required values of turbulence intensity may be obtained from the Tables appropriate to z_0 and z_{01} which may be located through the Index Table below. Values of I_u at intermediate values of x can be obtained by linear interpolation with respect to log x.

Index to Tables for One Roughness Change

Upwind z_{01} (m)	*Site* z_0 (m)						
	0.7	0.3	0.1	0.03	0.01	0.003	0.001
0.7		6.6	6.12	6.18			
0.3	*	*	6.13	6.19	6.24	6.27	
0.1	6.1	6.7	*	6.20	6.25		6.29
0.03	6.2	6.8	6.14	*	6.26	6.28	6.30
0.01	6.3	6.9	6.15	6.21	*		
0.003	6.4	6.10	6.16	6.22		*	*
0.001	6.5	6.11	6.17	6.23			

* For the cases marked with an asterisk there are no roughness changes.

Two Changes in Terrain Roughness

See Section 7.

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