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Computer programs for response of structures to vortex shedding Structures of circular or polygonal cross section Part 1. Microsoft Excel module

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COMPUTER PROGRAMS FOR RESPONSE OF STRUCTURES TO VORTEX SHEDDING. STRUCTURES OF CIRCULAR

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COMPUTER PROGRAMS FOR RESPONSE OF STRUCTURES TO VORTEX SHEDDING. Structures of Circular or Polygonal Cross Section

Part 1. Microsoft Excel module

1. INTRODUCTION

ESDU 96030⁶ describes the nature of the lateral response to vortex shedding of structures of circular cross section. It then develops a method for calculation of this response together with the data required for its implementation. This method takes account also of the lateral response to buffeting by across-wind atmospheric turbulence components, using the methods of ESDU 89049⁵. Comparisons of predictions with both model and full-scale measurements and a discussion of methods of reducing the response to vortex shedding are also included in ESDU 96030.

The calculation method is complex and it can realistically be implemented only through a computer program. A program is currently available as a Microsoft Excel* spreadsheet Module.

This Item gives guidance on the use of the Excel Module. Section 2 considers installation and running[†] of the Module. Section 3 describes the input data required and Section 4 the output produced by the program. Section 5 describes a set of Worked Examples. Appendix A provides some guidance on values for input data.

The method can be applied for the following structure types and flow conditions:

- parallel-sided, tapered and stepped structures,
- circular or regular polygon cross section (8 or more sides),
- smooth or rough surfaces (for structures with ancillaries such as ladders attached, the method applies only if the ancillary is entirely within the main structure wake),
- cantilevered structures and structures between end fixings,
- vertical, horizontal or inclined structures,
- structures with or without strakes,
- uniform or shear flow,
- smooth or turbulent flow,
- normal or yawed flow (a yawed wind affects the response only if the structure is not vertical),
- natural wind (full scale),
- simulated wind (wind tunnel),
- internal flows in which the structure causes a blockage of less than 10%.

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† Some familiarity with the Microsoft Windows operating system and the Microsoft Excel spreadsheet program is assumed. For further guidance on these topics, consult the appropriate Manuals or Help Files.

Example applications include stacks (chimneys) and process plant towers, lighting standards and elements of lattice structures.

Several worked examples are described in Section 5 and some guidance on sources of input data is given in Appendix A.

2. THE EXCEL MODULE

The program is supplied as a Module for use with Microsoft Excel*.

The Module includes a Worksheet (Calc. Sht) for input of data and display of calculated results and a Visual Basic* program, run from this Worksheet, to execute the calculations.

2.1 Using the Excel Module

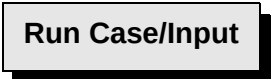
Entering the input data

The input data required by the program are entered on the Worksheet "Calc. Sht". The required input data required are described in Section 3 and some guidance on values is given in Appendix A.

As far as possible, where incorrect or incompatible data are entered, input warning messages are displayed to guide the user in making corrections.

Run Options

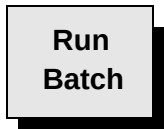
Once the appropriate data have been entered, two run options are available, accessed by buttons on the Worksheet "Calc. Sht"



Run Case/Input

Clicking this button runs the detailed-case response calculation for the value of $V_H/(n_j D_m)$ entered in Cell K 5. This generates (from the data input) a complete set of input data for the response calculation and outputs the *rms* and maximum deflections together with a comprehensive set of data for the intermediate parameters, as described in Table 4.1. These data may be useful in analysing particular runs.

If Cell K 5 is left blank, or a zero value entered, the required data for input to the batch calculation are calculated but the detailed calculation is not undertaken. (Version 4 or later prompts the user with a choice of running the batch calculation or closing the run.)



Run
Batch

Clicking this button runs the batch calculation for the values of $V_H/(n_j D_m)$ entered in Cells C 41 to C 70. The values may be entered in any order and will be sorted into ascending order by the program. Zero values (zero and blank values for Version 4 or later) are ignored. Graphs of mode shape and response deflection

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are generated automatically as the data are computed.

Case/Input must be run before Batch is run because it generates data required for the batch calculation. If changes to the input data are made, Case/Input must be re-run. However, the structural damping and strake location can be changed without re-running the Case/Input calculation.

The results from the program are written to the Worksheet "Calc. Sht".

Saving the Input and Results

- (1) The complete Workbook can be saved as an Excel Workbook file (with file extension .xls). Care should be taken to avoid overwriting the original supplied file. In this case the Workbook remains 'live' for future use. Further runs with changed input will overwrite the saved values. The Save Input/Output button on the Worksheet "Calc. Sht" provides a means of saving the results of any particular run in a form that will not be overwritten by subsequent use of the Workbook.

(2)

Save Input/Output

Clicking this button enables the input and output data to be saved to a separate Worksheet. The graphs can be saved at the same time by first holding down the SHIFT key and clicking the mouse on each graph in turn to select it and then clicking the Save Input/Output button. The program prompts for the name of the Worksheet on which the data are to be saved. In Version 3 or later, if a sheet of the specified name does not exist in the current Workbook, a new Worksheet is created. In earlier versions, a sheet of the specified name must already exist in the current Workbook or no save is made. The copy saved is unaffected by subsequent changes to "Calc. Sht". Further input/output and graphs can be saved to the same Worksheet using the same procedure and will be appended to the previously-saved data and will not overwrite it.

Printing from the Excel Module

The Worksheet "Calc. Sht", or any other Worksheet created to save data, can be printed in part or as a whole. To print part of a sheet, select the area to be printed by dragging the cursor across the selection, choose File/Print... and within the print menu, choose Selection before printing.

The File/Page Setup... menu can be used to choose specific printing requirements. It is usually more convenient to print in landscape page format and a size reduction to approximately 55% will allow avoidance of inconvenient page breaks. On the Sheet sub-menu tick Row and Column Headings if the row numbers and column letters are to be printed and leave Black and White unticked if the cell shadings are required. On the Header/Footer sub-menu, custom headings and page numbers can be added to the printed page.

3. INPUT TO THE PROGRAM

Tables 3.1 and 3.2 describe the input data required by the program. Some guidance on obtaining data is given in Appendix A. Each entry is identified by its Excel row and column reference on the Worksheet named "Calc. Sht". On the displayed Calc. Sht, cells into which entries must be made appear in green or have green column headings, cells for which alternative or optional entries are allowed appear in grey or have grey column headings. Values in cells with blue column heading are always calculated by the program.

Dimensional values must be entered in SI units.

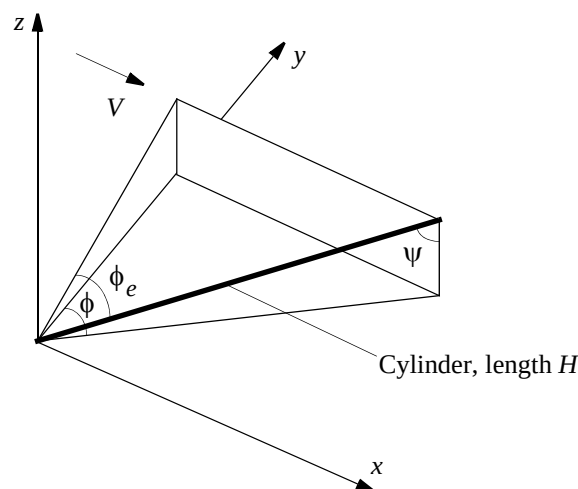
When the Worksheet "Calc. Sht" is scrolled vertically, the column headings remain in view at the top of the screen. Similarly, when scrolling from left to right, the columns up to r/H remain in position at the left of the screen.

The program requires input data to define the local diameter, mode shape, mass distribution, wind speed and turbulence at selected points, r/H , along the structure. A set of default values of r/H is provided. These values can be altered but it is recommended that all of the default values for $r/H > 0.9$ are used. Intermediate values of r/H can be added up to a total of 32. If extra values are added, the number of calculation nodes (Cell B 5) must be altered to the appropriate number. Extra values can be added in any order at the bottom of the list and will be sorted into descending order (together with any associated input data) by the program,

If a step change occurs in a particular property, this can be covered by entering the same value of r/H in successive rows with, for a step change in diameter, for example, the two diameter values representing the step entered in the appropriate column in the order following the direction of decreasing r/H .

In cases where a property changes rapidly over a short length of structure (other than at a step change), sufficient values of r/H should be used to keep changes between successive values small (ideally $< 10\%$) especially over the top few diameters of a cantilever structure.

Where a complete structure consists of two significantly different components, such as a mast on top of a large tower, the possibility of the smaller component responding to vortex shedding independently of the larger should be considered.



Sketch 3.1 Effective wind yaw angle

This page Amendment D

TABLE 3.1

Cell Reference	Entry	Description
F 1	Site	Name identifying the site or the case being run.
B 2	H (metres)	Overall height or length of the structure (in metres).
B 3	z_{base} (metres)	Height of lowest point on structure above ground level (in metres).
B 4	$\varepsilon \times 10^3$	Surface roughness $\times 1000$ (in metres).
B 5	Number of nodes	Number of locations on structure at which local conditions are calculated in the response calculation.
B 6	Wind:- profile α	Wind-speed-profile exponent. This entry can be omitted if the actual wind speed profile is entered in the column V_z/V_H (Cells N 5-36). Turbulence intensity of u -component at top of structure. This entry can be omitted the actual turbulence intensity profile is entered in the column I_{uz} (Cells O 5-36); otherwise the program calculates a profile based on $\sigma_{uz} = \text{constant}$. Longitudinal turbulence length scale of u -component in x -direction (along- wind) at the highest point on the structure (in metres).
B 8	At top of structure:- I_{uH}	
B 9	L_{ux}	
B 11	Mode properties:- Shape profile index	Index N_1 in cantilever mode shape, $(r/H)^{N_1}$. From Version 4, 'pinned' or 'fixed' can be entered also, to select beam first mode shapes for those end conditions. This entry can be omitted if the actual mode shape is entered in the column μ_j (Cells H 5-36). Natural frequency of the structure (in Hz). Structural damping ratio of the structure (ratio of actual damping to critical damping).
B 12	Natural frequency, n_j (Hz)	
B 13	Damping ratio, ζ_s	
B 16	If polygonal section:- number of sides	Number of sides for a polygonal structure (8 or more). If omitted denotes a circular-sectioned structure. (Radius of rounding of edges of a polygonal structure)/(inscribed diameter). Omitted for a circular-sectioned structure.
B 17	edge radius: r/D	
B 20	Helical strake:- upper r/H	If no strake is fitted, set entries in Cells B 20 and B 21 both to 1.0. r/H at upper end of helical strake. r/H at lower end of helical strake.
B 21	lower r/H	
B 22	Structure type	Enter 1 for a cantilever structure, 2 for a beam type structure. Setting this entry to 2 will model also a case such as a tower with a large observation platform at the top around which the flow may be predominantly two-dimensional although the structure behaves as a cantilever.
B 24	Inclination Wind: ϕ (deg)	Wind yaw angle, between projection of structure onto a horizontal plane and a normal to the mean wind direction in that plane (in degrees). See Sketch 3.1. Inclination of the structure from vertical (in degrees). See Sketch 3.1.
B 25	Structure: ψ (deg)	

TABLE 3.1 (Continued)

C 5-36	Node number	Set by program.
D 5-36	r/H from base	Non-dimensional location along structure, $r/H = 1$ at top, a minimum value of $r/H = 0.001$ should be used. Because of large variations in the excitation force near the tip of a cantilever structure, values of r/H in the top region should be chosen to include, or approximate modes at 0, 0.25, 0.5, 1 and 2 diameter from the tip.
E 5-36	D_z	Local diameter* of structure, inscribed diameter for polygonal section (in metres).
F 5-36	D_{mz} (m)	Calculated by program. Integrated mean diameter between current location and $r/H = 1$ location.
G 5-36	r'/D_{mz} from top	Calculated by program. $(H - r)/D_z$.
H 5-36	μ_j (mode shape)	Mode shape values. If entry in Cell B 11 is omitted, a user-defined set of mode shape values at the specified r/H values should be entered here. These can be calculated using the standard Excel facilities by entering the appropriate mode shape expression in the cells.
I 5-36	m (kg/m)	Local mass/unit length* at the specified r/H values can be entered here or the mode-generalised mass can be entered in Cell J 5.
J 5	m_j	The mode-generalised mass can be entered here or local mass/unit length at the specified r/H values can be entered in Cells I 5-36, in which case the mode-generalised mass is calculated by the program.
J 8	m_e	Calculated by program. An equivalent uniformly-distributed mass that would give the same modal properties.
K 5	$V_H/n_j D_m$	Reduced velocity, based on wind speed at the highest point of the structure, V_H , and integrated overall mean diameter, D_m . A range of values can be entered additionally in Cells C 41-70 for a batch calculation. If this value is omitted, or zero entered, the Run Calc/Input calculation calculates the input required for the Run Batch calculation but does not calculate a response.
L 5-36	Ht abv gnd z (m)	Calculated by program. Height above ground.
M 5	V_H (m/s)	Calculated by program from entry in Cell K 5. Mean wind speed at the highest point on the structure.
N 5-36	V_z/V_H	Wind-speed profile. If entry in Cell B 6 is omitted, a user-defined set of ratios of (local mean wind speed at the specified r/H)/ V_H values should be entered here.
O 5-36	I_{uz}	Wind turbulence-intensity profile. If entry in Cell B 8 is omitted, a user-defined set of turbulence intensity values at the specified r/H values should be entered here.
Columns P 5-36 to AM 5-36 are calculated by the program.		
	Calculation of E_β	
AN 5	Case No.	Response case choice. If calculation of a specific loading response is required in addition to the deflection, a factor linking the two can be derived by using a response function or influence function (see table on spreadsheet or Table A1.4).

* Step changes can be accommodated by entering the same value of r/H in two successive rows with the corresponding diameter or mass values in the order following the direction of decreasing r/H . See Example 3 for illustration.

The following input is required for the batch calculation spread sheet.