
Specification for
**Water cooling
towers**

Part 4. Structural design
of cooling towers

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- | | |
|---|---|
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- | | |
|---|--|
| Concrete Society | Institution of Chemical Engineers |
| Cooling Water Association | Institution of Structural Engineers |
| Federation of Civil Engineering Contractors | United Kingdom Atomic Energy Authority |
| HEVAC Association | |



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Specification for Water cooling towers

Part 4. Structural design of cooling towers

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Foreword

This British Standard, prepared under the authority of the Mechanical Engineering Industry Standards Committee and at the request of the water-cooling industry, forms Part 4 of the British Standard series on water cooling towers and provides requirements for the structural design and construction of natural draught and mechanical draught cooling towers.

In this edition the basis of design for cooling towers constructed of reinforced concrete is generally that recommended in CP 114, 'Structural use of reinforced concrete in buildings' and for precast concrete CP 116, 'Structural use of precast concrete', both of which will ultimately be replaced by CP 110, 'The structural use of concrete': Part 1. 'Design, materials and workmanship'.

It should be recognized however that due to the difference in the basic design concept between CP 110 : Part 1 and existing Codes of Practice no attempt should be made to use CP 110 : Part 1 for sections other than those specified herein.

The appendices provide recommendations for the testing of reinforced concrete and prestressed concrete culverts designed to CP 2007, 'Design and construction of reinforced and prestressed concrete structure for the storage of water and other aqueous liquids' and the selection of stress grade timber for triangular section laths for cooling tower packing. In addition, guidance is given with respect to design calculation relating to vibration characteristics of cooling tower shells (see also 5.7) and a further appendix provides a brief summary of linear thin shell theory appropriate to the types of shells of revolution used as cooling towers.

Recommendations on the design of hyperbolic shells for earthquake loadings, are not included but work is proceeding and these will be given in a later edition.

Other Parts in this British Standard series are:

- Part 1. Glossary of terms
- Part 2. Methods of test and acceptance testing
- Part 3. Thermal and functional design of cooling towers*

* In course of preparation.

British Standard Specification for

Water cooling towers

Part 4. Structural design of cooling towers

1. Scope

This British Standard specifies requirements for the structural design and construction of water cooling towers of the following types:

- (1) natural draught hyperbolic concrete shell structure;
- (2) mechanical draught. (Concrete and timber structure.)

It applies only to those types of cooling towers constructed on site and excludes factory assembled cooling towers.

NOTE. The titles of the British Standards referred to in this standard are listed on the inside back cover.

2. Definitions

For the purposes of this British Standard the definitions given in Part 1 apply. For convenience, those relating to the terms used in this Part are repeated below:

- (1) *Air flow*. Total quantity of air including associated water vapour flowing through the tower.
- (2) *Basin kerb*. Top level of the retaining wall of the cold water basin; usually the datum point from which tower elevation points are measured.

NOTE. The term 'pond cill' is also applied to this definition, but is listed as a non-preferred term in Part 1.

- (3) *Cell height*. The distance from basin kerb to top of fan deck but not including fan stack.
- (4) *Cell length*. The dimension parallel to the inlet louvred face.
- (5) *Cell width*. The dimension at right angles to the cell length.
- (6) *Circulating water flow*. The quantity of hot water flowing into the tower.
- (7) *Cold water basin*. A device underlying the tower to receive the cold water from the tower, and direct its flow to the suction line or sump.

NOTE. The terms 'basin' and 'pond' are also applied to this definition, but are listed as non-preferred terms in Part 1.

- (8) *Column anchor*. A device for attaching the tower structure to the foundation: it does not include the foundation bolt.
- (9) *Distribution basin*. An elevated basin used to distribute hot water over the tower packing.
- (10) *Distribution header*. Pipe or flume delivering water from inlet connection to lateral headers, troughs, flumes or distribution basins.
- (11) *Distribution system*. Those parts of a tower beginning with the inlet connection which distribute the hot circulating water within the tower to the point where it contacts the air.
- (12) *Drift eliminator*. A system of baffles located in the tower designed to reduce the quantity of entrained droplets of water in the outlet air.
- (13) *Film packing*. An arrangement of surfaces over which the water flows in a continuous film throughout the depth of the packing.
- (14) *Louvres*. Members installed in a tower wall, to provide openings through which air enters the tower; usually installed at an angle to the direction of air flow to the tower.
- (15) *Nominal tower dimensions*. Dimensions used to indicate the effective size of cells, or cooling tower. In the horizontal plane, they refer to the approximate width and length of packed areas, and in the vertical plane to the height above basin kerb level.

NOTE. The datum point for the height of all cooling towers is from basin kerb level.

- (16) *Packing*. Material placed within the tower to increase heat and mass transfer between the circulating water and the air flowing through the tower.

NOTE. The term 'filling' is also applied to this definition, but is listed as a non-preferred term in Part 1. The term 'pack' is defined as the whole of the packing.

- (17) *Shell*. That part of a natural draught tower which induces air flow.

(18) *Splash packing*. An arrangement of horizontal laths or splash bars which promotes droplet formation in water falling through the packing.

(19) *Sump*. A lowered portion of the cold water basin floor for draining down purposes.

NOTE. The terms 'basin sump' and 'pond sump' are also applied to this definition, but are listed as non-preferred terms in Part 1.

(20) *Water loading*. Circulating water flow expressed in quantity per unit of packed plan area of the tower.

3. Loadings (hyperbolic cooling towers)

3.1 Primary loadings

3.1.1 Wind

3.1.1.1 Windspeed prediction. The design windspeed, V_s , applicable to the design of cooling towers shall be determined from CP 3 : Chapter V : Part 2.

This design windspeed, V_s , should be based on the best available information for the immediate area, including the influence of local topographical features and should normally have a return period of 50 years. This design windspeed, V_s , shall, thereafter, be assumed to apply over the full height of the tower.

In accordance with 5.5.2 of CP 3 : Chapter V : Part 2, hyperbolic cooling towers shall be regarded as Class C structures and the appropriate S_2 factor from Table 3 of that Code of Practice shall be applied.

3.1.1.2 Air density and temperature. In determining the dynamic wind pressure, q , developed by the design windspeed, the influence of the elevated temperature of the air inside the tower during operation and its high moisture content shall not be taken into account. The following relationship shall be assumed:

$$q = k V_s^2$$

where $k = 0.613$

q is expressed in N/m² and

V_s is expressed in m/s.

3.1.1.3 Pressure distribution. The effects of wind loading on cooling tower shells are not fully understood and are not accurately determinate. It has been assumed hitherto, for design purposes, that the wind can be regarded as acting as a series of normal static pressure forces, the values of which vary with height and with angular position around the shell. With the horizontal distribution given in 3.1.1.4 a constant wind-speed with height shall be adopted for the design of towers based on the static concept. Recent observation and aerodynamic research has demonstrated, however, that this 'static' concept becomes less acceptable as tower arrays become more complicated and as tower sizes increase.

The specification clauses below are based on the earlier 'static' loading concept and it is believed that the adoption of these empirical rules will provide shells of adequate strength. Several hundred hyperbolic, or near hyperbolic shells, up to 115 m high, have been designed or checked against similar rules based on this assumption. Cumulative experience in the UK alone amounts to many thousands of years of tower exposure to wind and has been very largely satisfactory.

It is, therefore, recommended, as an interim measure, that tower shells of not more than 120 m height and not more than 100 m diameter, built either singly or in groups spaced in accordance with the recommendations of 5.1.3 shall be assumed to be loaded by the wind as specified in 3.1.1.4 and 3.1.1.5.

It is recommended that tower shells of greater height, or shells built at closer groupings, shall be subjected to aero-elastic model testing in a wind tunnel offering appropriate aerodynamic similitude. Such models shall include all adjacent local topographical features, buildings and other structures which are likely to significantly influence the loading pattern experienced by the tower in question.

3.1.1.4 Steady pressure distribution. It is recommended that the distribution of wind pressure loading on the outside of the shell be assumed symmetrically disposed with respect to the incident wind direction.

The distribution of pressure coefficients for the wind pressure on the outside of the shell should preferably be derived from wind tunnel testing of a model of the proposed tower shell shape. As this is not normally practicable, use may be made of the following distribution*. Of those measured, this distribution has been found to give rise to the most adverse uplift stress resultants in a shell of 115 m height and 90 m, 55.5 m and 50 m base, top and throat diameters respectively. Its direct use for towers of similar geometrical proportions is recommended, but an additional factor of not less than 10% should be added for towers of significantly different geometry.

* Determined during wind tunnel investigations at the Central Electricity Research Laboratories and the National Physical Laboratory.

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The pressure coefficient distribution to be used to determine the wind loading shall be of the form indicated in the diagram given in Fig. 1. This distribution shall be used at all heights of the tower, and includes an allowance for internal suction.

For calculation purposes this curve may be defined by the following even cosine Fourier expression.

$$a_0 + a_1 \cos \theta + a_2 \cos 2\theta + a_3 \cos 3\theta + a_4 \cos 4\theta + a_5 \cos 5\theta + a_6 \cos 6\theta + a_7 \cos 7\theta$$

where $a_0 = -0.000\ 71$ $a_4 = +0.107\ 56$

$a_1 = +0.246\ 11$ $a_5 = -0.095\ 79$

$a_2 = +0.622\ 96$ $a_6 = -0.011\ 42$

$a_3 = +0.488\ 33$ $a_7 = +0.045\ 51$

θ = angular position measured from the incident wind direction in degrees.

3.1.1.5 Pressure fluctuations. The 'steady' pressure coefficient distribution given in 3.1.1.4 has been determined under laboratory conditions and no full scale verification is yet available. It is clear, however, that further allowances should be made in assessing the wind loading for:

(1) load intensification due to natural turbulence in the incident wind, resulting from the bluff obstruction and wake;

(2) load intensification due to turbulence induced in the incident wind by adjacent cooling towers or other structures of significant dimension.

Wherever possible aero-dynamic advice should be sought on the appropriate magnitudes of (1) and (2) for the particular proposal.

In the recent past, load intensification factors varying from 1.0 to 1.10 for condition (1) and 1.0 to 1.30 for condition (2) have been adopted, yielding a maximum intensification factor of 1.10×1.30 to the combined effects.

3.1.1.6 Dead load. In assessing the self weight of the structure the (specific) weight of the concrete shell shall be taken as 22.5 kN/m^3 .

3.2 Superimposed loadings

3.2.1 Permanent fixings to shells. It is desirable to minimize the loadings brought upon the shell by permanent fixings.

When attachments are made, their effect upon the structure should be thoroughly investigated.

3.2.2 Ice loadings

3.2.2.1 Superstructure. The design and operation of the tower should be such as to minimize the formation of ice on the diagonal columns, the base of the shell and the internal packing.

If under extreme weather conditions ice may form, due allowance should be made in the structural design to withstand the additional loading.

3.2.2.2 Cold water basin and distribution system. When the cooling tower is not operating during freezing conditions, ice can form on the basin surface.

As these conditions are rare in the United Kingdom, it will normally be more economical to avoid the resulting loading by suitable preventative measures.

To prevent damage to the water distribution system, due to freezing, the system should be designed to be self draining.

3.2.2.3 Freezing of permeable concrete. Freezing within saturated permeable concrete can cause major deterioration of the structure, particularly the supporting columns and care should be taken to avoid such damage.

3.3 Constructional loadings. When the method of construction is determined, the engineer responsible for the structural design shall check the design for temporary loadings that occur during construction.

Factors causing temporary loadings may include the following:

- (1) barrowing of concrete
- (2) scaffolding and form work
- (3) correcting shutter alignment
- (4) hoist fixings
- (5) storage of materials on scaffold
- (6) temporary access
- (7) tower crane fixings
- (8) work temporarily omitted for access purposes

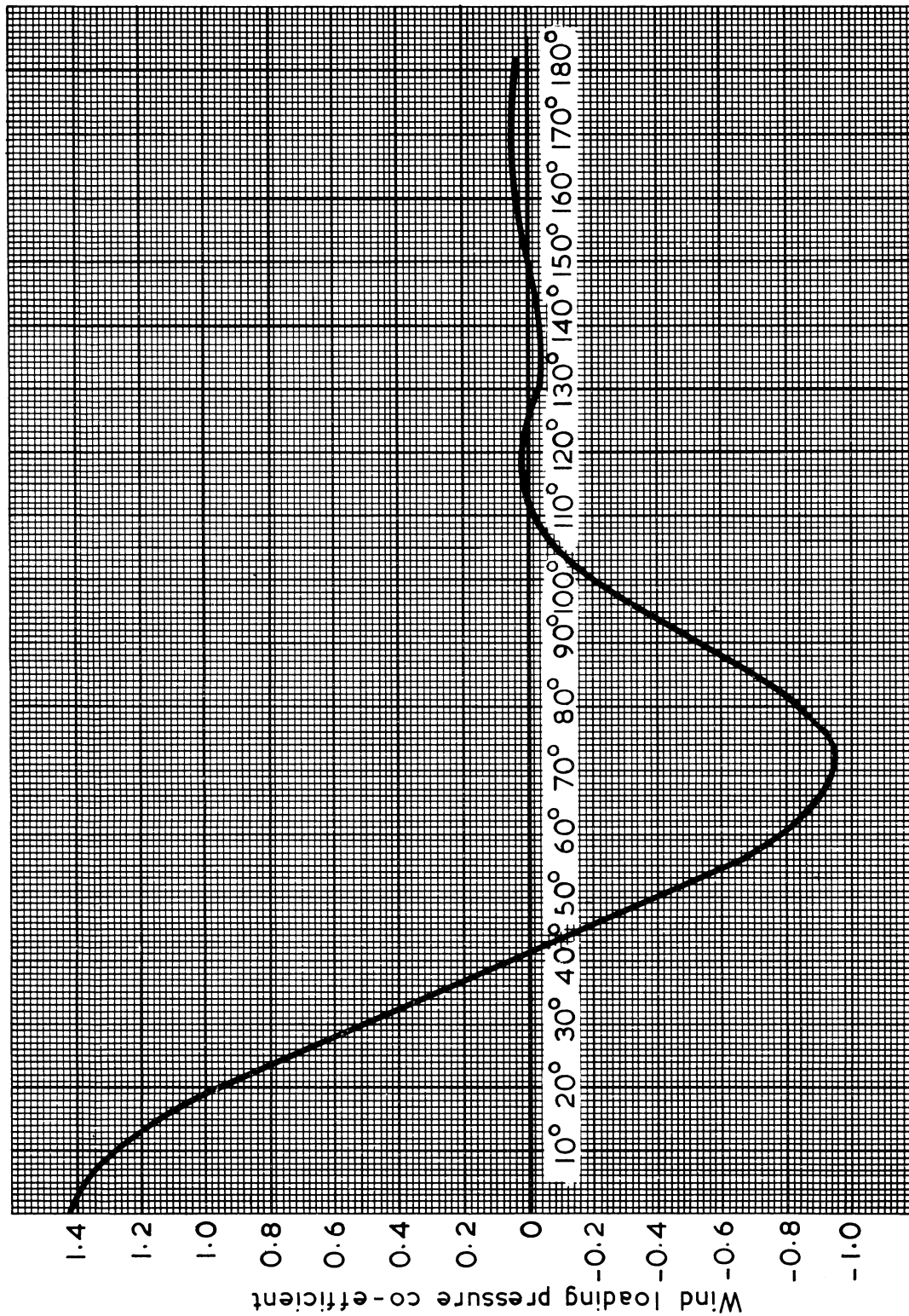


Fig.1. Pressure coefficient distribution for determination of wind loading

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4. Loadings (mechanical draught cooling towers)

4.1 Primary loadings

4.1.1 Wind loadings

4.1.1.1 Wind speed prediction. The design wind speed applicable to the design of mechanical draught cooling towers shall be determined from CP 3 : Chapter V : Part 2. This design windspeed, V_s , should be based on the best available information for the immediate area, including the influence of local topographical features and should normally have a return period of 50 years. This design windspeed, V_s , shall, thereafter, be assumed to apply over the full height of the tower above ground level.

In assessing the overall stability of the installation, due regard shall be given to the condition of wind loading with the tower out of commission and dry. Permissible stresses under wind loading conditions may be increased in accordance with Table 12 of CP 112.

4.1.1.2 Force coefficients. Mechanical draught cooling towers shall be designed for the structure as a whole using the force coefficients in Table 10, CP 3 : Chapter V : Part 2. Where appropriate, individual members shall be designed to withstand forces corresponding with the pressure and suction coefficients in Table 7, CP 3 : Chapter V : Part 2.

In the design of cooling tower structures force coefficients based on Table 1 shall be used to evaluate the fan casing wind loading.

Table 1. Force coefficients (fan casing wind loading)

	height/diameter ratio of tower			
	$\frac{1}{2}$	1	2	> 2
Fan casings without vertical ribbing	0.45	0.45	0.5	0.5
Fan casings with vertical ribbing up to 2% of diameter	0.7	0.7	0.8	0.8
Fan casing with vertical ribbing 8% of diameter	0.8	0.8	0.9	1.0

4.1.2 Dead loads. Dead loads shall include the actual weights of all structure, water loading, packings, fixings and permanent construction, together with all permanently installed plant and equipment required for the functional operation of the cooling tower. In assessing the self-weight of the structure, the (specific) weight of concrete shall be taken as 22.5 kN/m³; saturated timber in the internal portions of the tower taken as 10.2 kN/m³ and external (non-saturated) timbers e.g. fan casings, cladding and roof decking, shall be taken as 8.3 kN/m³.

4.1.3 Vibrational loading

4.1.3.1 Re-inforced concrete mechanical draught cooling towers, particularly with high fan stacks, should be designed with adequate re-inforcement to resist the effects of mechanically induced vibration in the structure, particularly having regard to the moving masses involved which may in the larger installations be substantially in excess of 1000 kg.

4.1.3.2 The tower structure and the beam support for the fan equipment shall be designed to reduce the blanking of the air flow into the fan and to make sure that the consequential aerodynamic buffeting is not significant under all normal operating conditions.

4.1.3.3 It is recommended therefore that supporting beams for the mechanical equipment be positioned off-centre, e.g. in the form of an 'H' construction, to ensure that the fan blades are not subjected to simultaneous buffeting along their entire length as would be the case for a fan blade passing a radial beam.

4.2 Superimposed loadings. The superimposed load on the roof of the cooling tower shall be in accordance with the recommendations of CP 3 : Chapter V : Part 1.

4.3 Constructional loadings. Factors causing temporary loadings may include the following:

- (1) transporting of concrete and other materials
- (2) scaffolding and formwork
- (3) hoist fixings

- (4) storage of materials on scaffold
- (5) work temporarily omitted for access purposes
- (6) wind loading on partially constructed frame structures
- (7) the movement of heavy components of mechanical equipment, gear boxes and motors, upon the roof of the cooling tower.

5. Design considerations (hyperbolic cooling towers)

5.1 Size, shape, siting and spacing. Those responsible for the structural and thermal design of a cooling tower installation should, when selecting the site and layout of the plant consider the following requirements.

5.1.1 Size. The base diameter, the air intake opening height, the associated tower height and the throat diameter are initially determined by thermal design considerations.

5.1.2 Shape

5.1.2.1 Shell geometry. Structural studies on the ellipsoidal, truncated cone, cylindrical and hyperboloid shell, show that the hyperboloid offers very substantial material economies compared with the other mentioned shapes. At the present time the hyperboloid is recommended for cooling tower shells.

As the range of possible hyperbolic shell shapes is infinite, it is recommended that designs be confined to the following major dimensions given in 5.1.2.2.

5.1.2.2 Height to diameter ratio. Towers having a H/D (total height/base diameter) ratio between 1.2 and 1.55 have been constructed with the H/D ratio decreasing with increasing height of tower. The level of the throat has varied between $0.15H$ and $0.25H$ measured from the top of the cooling tower (see Fig. 2). When it is intended to construct cooling towers of other proportions, these should be carefully studied before adoption.

5.1.3 Siting and spacing. It is recommended that cooling towers be spaced at a clear distance of not less than 0.5 times the base diameter of the largest tower in the array.

At this spacing, aerodynamic interference occurs and the design recommendations in this British Standard apply to groups of towers of this spacing.

5.2 Basis of design. The method of design shall accord with the general principles of structural mechanics and those relating to the design of reinforced concrete. The following stipulations are made:

- (1) In analysing the shell, a shell theory shall be used (see Appendix D).
- (2) It may be assumed that all tensile meridional stress-resultants are taken by reinforcement, except that allowance may be made for the deadweight of that part of the shell situated directly above the horizontal arc under consideration, bounded by the meridians at each end of the arc.
- (3) It shall be assumed that the concrete can resist diagonal tension within the limits of shear stress specified for concrete in 303 of CP 114.
- (4) It is recommended that shells of cooling towers be designed on an elastic basis using the following load factors:

Wind loading	1.4
Dead weight	1.0

The values of the stresses arising from these factored loadings should not exceed 87% of the specified characteristic strength of the reinforcement, as given in BS 4449 or BS 4461, or 45% of the specified 28-day cube strength of the concrete.

- (5) Attention is drawn to the possibility of shell vibrations, but at the present time insufficient information is available for recommendations to be made.

NOTE. Conversion of wind pressure to stress-resultants and moments in the shell. The design of cooling tower shells has developed over several decades, improvements both in the simulation of wind loadings and in the assumed structural form having been made. In recent years access to digital computers has allowed improvements in methods of analysis, and several proven programs for hyperbolic tower shells now exist.

'Membrane' analysis methods, which assume all moments in the shell to be negligible and which consider the effect of direct stress resultants and tangential shear stress resultants only, have been improved upon by 'bending' analyses. These methods avoid the 'membrane' assumption and automatically determine mutually compatible moments and stress resultants over the shell, thereby supplementing the information available from the 'membrane' solutions. Although the two approaches give similar values of the stress resultants for the previously considered range of wind loadings, and also demonstrate that the meridional stress resultants are not strongly influenced within the range of boundary conditions found in practice, the use of the more comprehensive form of analyses provides a sounder appreciation of the stress distribution and is therefore recommended.