

Water cooling towers —

Part 4: Code of practice for structural design and construction

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Foreword

This Part of BS 4485, which has been prepared by Subcommittee B/525/15, Cooling towers, is concerned with the structural design and construction of natural draught and mechanical draught cooling towers. It is a revision of BS 4485-4:1975, which is now withdrawn.

As a code of practice, this British Standard takes the form of guidance and recommendations. It should not be quoted as if it were a specification and particular care should be taken to ensure that claims of compliance are not misleading.

This Part of BS 4485 contains three sections: a general section relating to all towers and two separate sections covering hyperboloidal shell natural draught towers and mechanical draught towers.

The method of design of concrete shells of natural draught towers has been the subject of extensive changes. This edition differs from the previous 1975 edition as follows.

- a) Wind loadings are based on hourly mean winds, as derived in BS 6399-2.
- b) An amplification factor to the wind loading is introduced to take account of the fluctuations in incident wind on the tower, and the effect on resulting stresses of tower resonant response in the incident wind. The factor is derived by an empirical equation, related to design wind speed and the natural frequency of the tower. It is derived from wind tunnel test results.
- c) Serviceability limit states are defined more fully and include an additional equation for buckling of the shell, and limitations to which uplift of foundations may be permitted under factored wind loading.
- d) Design is related to BS 8110, including the shell support system.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations. In particular, attention is drawn to the Reservoirs Act 1975 [1] and the need to ascertain at the time of the design of the cooling tower systems whether or not the cold water basin, especially if connected to other towers, comes within its scope.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 28, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

Section 1. General

1.1 Scope

This Part of BS 4485 gives recommendations for the structural design and construction of water cooling towers of the following types:

- a) type 1. Natural draught or assisted draught towers, in which the total air flow is wholly or partly induced by a reinforced concrete shell of hyperboloidal form;
- b) type 2. Mechanical draught towers, in which the total air flow is induced wholly by mechanical means within an enclosed structure.

It applies only to those cooling towers constructed or erected on site and excludes factory assembled towers. In addition, matters relating to construction and workmanship in concrete and other materials are dealt with only in so far as they are specific to cooling tower construction. Other items of construction are referred to in appropriate specifications.

This code of practice covers the design of towers up to 170 m in height. However certain restrictions apply to formulae used for towers greater than 120 m in height.

NOTE For cooling towers of type 1, shells similar in shape to the true hyperboloidal form may be considered. Where these other shapes are adopted then certain sections of this standard may not be strictly applicable.

1.2 References

1.2.1 Normative references

This Part of BS 4485 incorporates, by dated or undated reference, provisions from other publications. These normative references are made at the appropriate places in the text and the cited publications are listed on pages 27 and 28. For dated references, only the edition cited applies: any subsequent amendments to, or revisions of the cited publication apply to this Part of BS 4485 only when incorporated in the reference by amendment or revision. For undated references, the latest edition of the cited publication applies, together with any amendments.

1.2.2 Informative references

This Part of BS 4485 refers to other publications that provide information or guidance. Editions of these publications current at the time of issue of this standard are listed on page 28, but reference should be made to the latest editions.

1.3 Definitions

For the purposes of this British Standard the definitions in BS 6100-4 apply together with the following.

1.3.1

air flow

total quantity of air including associated water vapour flowing through the tower

1.3.2

arris knot

knot which emerges on an arris (see Figure 5)

1.3.3

basin kerb

top level of the retaining wall of the cold water basin

NOTE 1 Usually the datum point from which tower elevation points are measured.

NOTE 2 Basin kerb is also known as pond sill.

1.3.4

cell height

distance from the basin kerb to the top of the fan deck, but not including the fan stack

1.3.5

cell length

dimension parallel to the inlet louvred face

1.3.6

cell width

dimension at right angles to the cell length

1.3.7

circulating water flow

quantity of hot water which flows into the tower

1.3.8

coarse screen

grill located at the outlet of the cold water basin which retains large debris and prevents it from entering mechanical plant or pipework

1.3.9

cold water basin

device that underlies the tower to receive cooled water from the packing

NOTE Cold water basin is also known as basin or pond.

1.3.10

column anchor

device that attaches the tower structure to the foundation; it does not include the foundation bolt

1.3.11

distribution basin

elevated basin which distributes hot water over the tower packing

**1.3.12
distribution header**

pipe or flume which delivers water from the inlet connection to lateral headers, troughs, flumes or distribution basins

**1.3.13
distribution system**

those parts of a tower, beginning with the inlet connection, which distribute the hot circulating water throughout the tower to the point where it contacts the air

**1.3.14
drift eliminator**

system of baffles within the tower which reduces the quantity of entrained droplets of water in the outlet air

**1.3.15
face knot**

knot on a face, other than a splay or arris knot (see Figure 6)

**1.3.16
film packing**

arrangement of surfaces over which the water flows in a continuous film throughout the depth of the packing

**1.3.17
louvres**

- 1) Members installed in the wall of a type 2 tower or at the entry to a cross flow packing, which direct air flow into the tower and reduce blow-out of water from the tower.
- 2) Individual units forming the baffles of a drift eliminator.

**1.3.18
nominal tower dimensions**

dimensions used to indicate the effective size of cells or cooling tower. In the horizontal plane these are the approximate width and length of packed areas, and in the vertical plane the height above the basin kerb level

**1.3.19
packing**

material placed within the tower to increase heat and mass transfer between the circulating water and the air flowing through the tower

NOTE Packing is also known as pack or filling.

**1.3.20
packing support structure**

structure of beams and columns, generally in timber or concrete, which support the packing, distribution pipework or flumes and drift eliminator

**1.3.21
ringbeam**

thickened, lowermost part of the shell immediately surmounting the shell support columns, spanning the column heads

NOTE Ringbeam is also known as lintel.

**1.3.22
shell**

part of a type 1 tower which induces air flow

**1.3.23
shell support column**

inclined column or wall which spans the air intake opening and transmits the dead load of the shell, and any forces induced in it, to the foundation

NOTE Shell support column is also known as leg.

**1.3.24
shell support node**

junction between a pair of shell support columns and the ring beam

**1.3.25
splash bar**

a small section lath, generally of rectangular or triangular cross section, located in a splash packing to initiate the formation of droplets

**1.3.26
splash packing**

arrangement of horizontal laths or splash bars which promotes droplet formation in water falling through the packing

**1.3.27
splay knot**

knot cut more or less parallel to its long axis so that the exposed section is elongated

NOTE On triangular laths the length of the knot will frequently extend across the width of the face.

**1.3.28
spray nozzle**

device which dispenses cooling water from the distribution pipework so that it is uniformly distributed over the packing

**1.3.29
spray nozzle adaptor**

device incorporated in the distribution pipework which easily or securely fixes the spray nozzle in position

**1.3.30
sump**

lowered portion of the cold water basin floor for draining

NOTE Sump is also known as basin sump or pond sump.

1.3.31**water loading**

circulating water flow expressed in quantity per unit plan area of the packing

1.4 Symbols

For the purposes of this Part of BS 4485 the following symbols apply.

A_{φ}	area of reinforcement	T_t	turbulence adjustment factor
C_D	dynamic correction factor	$V_{g,z}$	design gust speed at height z
C_G	grouping correction factor	$V_{m,z}$	design mean wind speed at height z
$C_{P,\theta}$	pressure coefficient at angle θ from incident wind direction	V_s	site wind speed
E	static modulus of elasticity	V_z	wind speed at height z
f_y	steel characteristic strength	W_k	characteristic hourly mean wind load
G_k	characteristic dead load	z	height above ground
H	height of tower	Z_T	height of throat above underside of ring beam
h	shell thickness	θ	angular position measured from the incident wind direction
K	empirical factor (described in Annex E)	$\varphi I, \varphi G, \varphi F$	amplification factors for stress resultants
k	dynamic wind pressure constant	σ_{θ}	circumferential compressive membrane stress
N_{φ}	meridional stress resultant	σ_{φ}	meridional compressive membrane stress
$N_{\varphi,g}$	gust stress resultant at design gust speed	$\sigma_{\theta,cr}$	circumferential critical buckling stress
$N_{\varphi,m}$	mean stress resultant at hourly mean wind speed	$\sigma_{\varphi,cr}$	meridional critical buckling stress
$N_{\varphi,r}$	stress resultant from resonance of the shell due to wind turbulence	γ_B	factor of safety against buckling
$N_{\varphi,\theta}$	absolute value of shear stress resultant	ν	Poisson's ratio
n	lowest natural frequency of tower		
q_{cr}	critical dynamic wind pressure		
q_g	dynamic gust wind pressure at throat		
$q_{g,z}$	dynamic wind pressure at design gust speed		
$q_{m,z}$	dynamic wind pressure at design mean wind speed		
q_z	dynamic wind pressure at height z		
R_B	radius at underside of ring beam		
R_T	throat radius		
S_c	fetch factor		
S_d	direction factor		
$S_{g,z}$	gust wind speed factor		
S_h	topographic increment		
$S_{m,z}$	hourly mean wind speed factor		
S_t	turbulence factor		
T_c	fetch adjustment factor		

1.5 Materials and workmanship**1.5.1 Concrete****1.5.1.1 General**

The concrete should be a designed mix conforming to BS 8110-1, subject to the recommendations in 1.5.1.2 to 1.5.1.5.

1.5.1.2 Cement

Cement should conform to BS 12 or BS 4027.

1.5.1.3 Pulverized fuel ash (PFA)

Pulverized fuel ash should conform to BS 3892-1 and should be used in accordance with 3.3.5, 6.1.2 and 6.2.4 of BS 8110-1:1985.

1.5.1.4 Aggregates

Fine and coarse aggregates from natural sources, which conform to BS 882, should be used.

Particular attention should be given to the selection of dense aggregates of low drying shrinkage, in order to reduce adverse effects on strength, density, shrinkage, moisture movement, frost resistance or durability of the concrete.

In cooling tower shells the maximum size of aggregates should not exceed $C-5$ mm where C is the nominal specified cover to the reinforcement.

1.5.1.5 Admixtures

If admixtures are used they should conform to BS 5075. Appropriate production control measures should be applied to their use.

1.5.2 Reinforcement

Reinforcement to concrete should conform to clause 7 of BS 8110-1:1985.

1.5.3 Prestressing tendons

Prestressing tendons should conform to clause 8 of BS 8110-1:1985.

1.5.4 Precast concrete

1.5.4.1 Materials

The materials used in the manufacture of precast concrete components should conform to 1.5.1, 1.5.2 and 1.5.3.

1.5.4.2 Workmanship

1.5.4.2.1 Precast components which form part of the packing support structure should be manufactured within the dimensional tolerances specified in 6.11 of BS 8110-1:1985 except that the variations given in Table 1 should apply.

Table 1 — Dimensional deviations of precast components

Length of component m	Straightness of bow (deviation from intended line) mm
< 6	6
6 to 12	9
Add for each subsequent 6 m	3

1.5.4.2.2 Except as stated in 1.5.4.2.3 to 1.5.4.2.5, the nominal cover to precast components, other than in the shell, should be in accordance with 3.3 of BS 8110-1:1985, where the exposure condition in service, as described in Table 3.2 of BS 8110-1:1985, should be regarded as severe.

1.5.4.2.3 When precast components are used in the shell, nominal cover to all reinforcement should be not less than 30 mm.

1.5.4.2.4 If the components of the packing support structure are situated in the airflow and it is necessary to minimize obstruction to the airflow, the nominal cover may be less than the value given in 1.5.4.2.2, but not less than 25 mm. The tolerance on this reduced cover should be ${}^+3_0$ mm.

1.5.4.2.5 If the airflow or circulating water contains an aggressive constituent(s), especially if industrial waste products are discharged, the cover in 1.5.4.2.2 and 1.5.4.2.3 should be increased by an amount appropriate for the anticipated operating conditions; it should be not less than that specified for the service conditions described as very severe, as given in Table 3.2 of BS 8110-1:1985. This also applies to any treatment which might be applied to the circulating water flow as a means of controlling algal growth, scaling and the like.

1.5.4.3 Erection

1.5.4.3.1 Lifting hooks and eyes for the lifting and erection of precast components should be removable.

1.5.4.3.2 Cast-in fittings should be in accordance with 1.5.11, except when fabricated from low carbon steel they should be protected in accordance with 1.5.12.

1.5.4.3.3 If jointing of precast components results in bolt heads being recessed in pockets then such pockets or other similar cavities should be filled with bitumen after erection.

1.5.4.3.4 Mating surfaces of precast components, crossed by a fixing bolt, should be treated with a coat of polymer modified hydraulic cement mortar, epoxy mortar, bitumen or similar material to protect the bolt from ingress of water.

1.5.5 Reinforced concrete

1.5.5.1 The materials used in the manufacture of reinforced concrete should conform to 1.5.1 and 1.5.2.

1.5.5.2 Reinforced concrete should conform to BS 8110 and/or BS 8007 as appropriate, except for the recommendations given in 1.5.5.3 to 1.5.5.8.

1.5.5.3 Concrete in the shell should have a characteristic strength sufficient to withstand the temporary loadings that will be imposed upon it but not less than 40 N/mm² at 28 days.

1.5.5.4 The supervision, setting out, checking and shuttering system should achieve a high degree of dimensional accuracy in accordance with 1.5.5.5 to 1.5.5.8.

1.5.5.5 The thickness of the finished concrete in the shell should not vary from the design thickness by more than ± 6 mm.

1.5.5.6 The interior surface of the shell should not vary from its stipulated position by more than ± 40 mm. In addition, the measured offset from any 3 m chord should not differ from the theoretical offset by more than ± 10 mm.

1.5.5.7 In the line of the shell in the vertical plane, the shell should not change direction, other than to form the curve of the tower, by more than 10 mm in any 1 m of slant height.

1.5.5.8 The shell should be surveyed at the appropriate level after the completion of each lift. Readings should be taken in at least one position on each primary formwork unit.

1.5.6 Prestressed concrete

1.5.6.1 Materials

The materials used in the manufacture of prestressed concrete should conform to **1.5.1**, **1.5.2** and **1.5.3**.

1.5.6.2 Workmanship

Prestressed concrete should conform to BS 8110. Where members are precast the recommendations of **1.5.4.2** should apply.

1.5.7 Timber

1.5.7.1 Structural softwoods should be in accordance with BS 4978:1988 and should normally be limited to the species stated in Table 9 of BS 5589:1989. Due care should be taken to select softwoods which are amenable to preservatives.

1.5.7.2 Hardwoods should be in accordance with BS 5756:1980.

1.5.7.3 Timber splash bars, which form the packing, will normally be of Redwood (*Pinus silvestris*). If other timbers, such as Douglar fir (*Pseudotsuga menziesii*) are offered, then the performance of such timber, when cut to the required cross-section and treated in accordance with **1.5.8**, should be comparable to or superior to that of Redwood. In all cases, timber used for splash bars should meet the visual stress grading recommendations of Annex A.

1.5.7.4 Other timber members, with a minimum dimension of less than 75 mm, such as eliminator louvres, air sealing barrier walls, doors and door frames, trap door walkways and handrails, should conform to the recommendations of **1.5.7.3**.

NOTE The recommendations for timber laths given in Annex A do not apply to the members covered by this sub-clause.

1.5.7.5 For the design of structure members (excluding damboards, see **1.8.2**) the stress and load values of suitable timbers, taking into account wet exposure conditions, should be in accordance with BS 5268-2.

NOTE Temperatures of up to 60 °C in cooling towers are not considered to affect timber strengths significantly. For applications above this temperature, specialist advice should be sought on permissible timber strength properties for design.

1.5.7.6 All softwoods should be treated against wood-destroying organisms in accordance with **1.5.8**.

1.5.8 Timber preservation

1.5.8.1 Softwoods should be treated against wood destroying organisms using suitable preservatives and methods of treatment in accordance with BS 5589 (with particular reference to Sections 4 and 5).

1.5.8.2 Preservative treatment should be checked in accordance with clause **9** of BS 5589:1989.

1.5.9 Asbestos-cement materials

Alternative fibres to asbestos are recommended for items used in cooling towers.

NOTE Attention is drawn to the regulations that are in force governing the cutting and installation of asbestos based materials, and the guidance notes issued by the Health and Safety Executive, particularly if any replacement or repair is necessary [2].

Asbestos-cement sheets and boards used in cooling towers should be in accordance with BS 690 except as follows.

If non-standard board is used, owing to size or fittings requirements, the sheets should be marked as being outside the range of BS 690.

Packings are normally specially manufactured and, whilst they should be generally in accordance with BS 690, the type of fibre and sheet dimensions may be varied.

1.5.10 Plastics

NOTE Guidance on the properties and use of plastics in cooling towers is given in Annex B.

1.5.10.1 Glass reinforced plastics fabrications, for use in cooling tower applications, should be to marine grade specification using “E” glass fibre reinforcement as chopped strand mat, rovings or fabric (BS 3496, BS 3691 and BS 3749). A gel coat finish should be applied to the inside face of any moulding to ensure that the glass fibres are protected by a resin coat without pinholes or holidays.

1.5.10.2 Mouldings should be free from voids or areas of poor wetting-out of glass fibre reinforcement.

NOTE Such defects can lead to “osmosis” generally manifested by the appearance of bubbles on the surface in contact with the water.

1.5.10.3 External cladding in extruded plastics should be treated against UV degradation. To avoid undue risk of biological slime or algae forming on the inside faces of cladding, the cladding materials should be relatively opaque.

1.5.10.4 Reference should be made to plastics manufacturers’ recommendations for temperature and chemical resistance values on all plastics materials.

1.5.11 Metalwork

1.5.11.1 The choice of materials used for sundry metalwork fittings should take account of the damp, warm atmosphere within the tower and the corrosive effect of chemicals in the water. If the materials used are not resistant to such conditions a suitable protective coating should be applied in accordance with **1.5.12**.

1.5.11.2 Cast iron for large fittings should be in accordance with BS 1452.

1.5.11.3 Malleable cast iron for small fittings should be in accordance with BS 6681.

1.5.11.4 Stainless steel should be in accordance with BS 1501, BS EN 10028-1 and BS EN 10029.

1.5.11.5 One of the following aluminium alloys: 1200 (SIC), 3103 (N S3), 5154 A (N S5) and 6082 (HS 30) should be used, conforming to BS 1470. Sheets used for fabrication should be not less than 1.6 mm thick.

If the water has a pH less than 6 or greater than 8.5 protection should be provided by anodizing or other processes.

Design stresses should be in accordance with BS 8118.

Aluminium is anodic to other materials and when joined to such materials electrolytic action can occur. Measures should be taken to prevent direct contact between aluminium and other metals.

1.5.11.6 Other metals and alloys should be used in accordance with British Standards.

1.5.11.7 Different metals/alloys should not be placed in contact with each other if there is a possibility of electrolytic action between them causing corrosion.

NOTE Attention is drawn to the possibility of stress corrosion occurring in stainless steel particularly where halides may be present.

1.5.12 Protective coatings and paint

1.5.12.1 In general materials that require no protective coating should be chosen so that maximum service life without repair or replacement is possible.

1.5.12.2 As a minimum protection, coatings should be applied as given in Table 2.

1.5.12.3 Bolts should have a coating of bitumen applied after assembly to protect areas of the threads where the original coating may have been damaged.

1.5.12.4 Epoxy resin paint, chloroprene rubber or other suitable painting systems may be used to give a protection not less than those given in Table 2. Material should be applied in accordance with BS 5493.

1.5.13 Adhesives

Where adhesives are used in cooling towers, the manufacturers should be fully informed of the working conditions and their advice should be carefully followed in respect of the conditions and method of application.

1.5.14 Pipework

1.5.14.1 Asbestos-cement pipework should be manufactured and installed in accordance with BS 3656. If operating and/or surge pressures in the distribution system are in excess of those which can be tolerated by pipework to this standard, then pipework should be in accordance with BS EN 512.

1.5.14.2 Thermoplastic pipework should be manufactured in accordance with BS 5556 and installed in accordance with the manufacturer's recommendations.

1.5.14.3 Glass fibre reinforced plastics (GRP) pipework should be designed, manufactured and tested in accordance with BS 5480.

1.5.14.4 Precast concrete pipes should be manufactured and tested in accordance with BS 5911-110.

1.5.14.5 Precast concrete pipes of glass composite construction should conform to BS 5911-101 and those reinforced by chopped, zinc coated, steel fibres should be installed and tested in accordance with the manufacturer's instructions.

NOTE DD 76-2 may be referred to also.

1.6 Packing support structures

1.6.1 General

Packing support structures should be designed and constructed to facilitate examination and maintenance.

1.6.2 Design

1.6.2.1 Structural considerations

1.6.2.1.1 Loadings

The following loadings should be considered:

- a) self weight;
- b) supported packing load, including water and accumulations of scale, silt, etc.;
- c) wind;
- d) ice (weight and the effect of wind on the ice sheet);
- e) maintenance loads with a minimum vertical load of 1.5 kN at any position.

NOTE In many cases it will be found that the most severe loading condition occurs during transport or erection.

Table 2 — Coatings of metal components

Type of metal	Coating	British Standard	Grade
Steel	Electroplated zinc ^a	BS 1706	Zn3
	Electroplated cadmium ^a	BS 1706	Cd3
	Hot dip galvanized	BS 729	NA
	Sherardized	BS 4921	Class 2
	Electroplated nickel	BS 1224	Medium application grade
	Electroplated nickel and chromium	BS 1224	Service condition no. 2
Copper or brass	Electroplated nickel	BS 1224	Medium application grade
	Electroplated nickel and chromium	BS 1224	Service condition no. 2
Aluminium	Anodized	BS 1615	AA10
Aluminium alloy	Electroplated nickel	BS 1224	Medium application grade
	Electroplated nickel and chromium	BS 1224	Service condition no. 2
Screw threads	Any of the above coatings covered by BS 3382	BS 3382	NA

NOTE 1 Where tolerances are important it is recommended that the manufacturer should also specify a maximum coating thickness (which should be not less than twice the minimum thickness).

NOTE 2 Attention is drawn to the clauses concerning hydrogen embrittlement in the relevant standards. The plater should be informed of the specification of the steel to be plated.

NOTE 3 The cleaning and preparation of parts before coating should be carried out to the highest standard (see BS 773:1995).

^a Denotes preferred finishes. Zinc coatings are more suitable for general use including use in industrial atmospheres, and cadmium is more suitable for use in marine environments.

1.6.2.1.2 Stability

The structure itself and any other structure that could limit gross distortion should be designed to resist collapse under a horizontal acceleration of 0.02g. Special care should be taken to ensure that the structure is adequately braced in all directions at all stages of construction.

1.6.2.2 Timber members

The design of timber members should be in accordance with BS 5268-2.

1.6.2.3 Concrete members

The design of concrete members should conform to BS 8110 except for the recommendations in 1.5.4.2. Due attention should be given to the overall movements of the structure under the effects of temperature, shrinkage, creep and imposed loading; particularly if restraint is present.

1.6.3 Construction

1.6.3.1 Timber

1.6.3.1.1 All timber members should be factory cut, drilled, treated with preservative and delivered to site ready for erection.

1.6.3.1.2 Preservation of the timber members should be carried out in accordance with 1.5.8 after jointing, cutting and drilling. No timber should be ripped along the grain after treatment. Any timber cross-cut or drilled after treatment should have the cut surfaces protected by a liberal brush application of a suitable cut-end preservative.

1.6.3.1.3 The work should be carefully supervised to ensure the inclusion of all connectors and shear plates, especially those which are not visible in the completed structure.

1.6.3.2 Concrete

1.6.3.2.1 The reduced cover permitted in 1.5.4.2 for precast concrete members should not be used for cast in-situ concrete.

1.6.3.2.2 Joints may be bolted, dowelled, or cast in-situ. Bolts or dowels used for permanent connections should be of a material highly resistant to corrosion or fully protected by embedment or coating.

1.6.3.2.3 Erection tolerances should conform to BS 5606.

1.7 Packings, water distribution systems, eliminators and cladding

1.7.1 General

Packings should be designed and constructed to facilitate examination, maintenance, removal and dismantling.

1.7.2 Packings

1.7.2.1 *Timber packing*

1.7.2.1.1 Timber packing should comprise timber splash bars of rectangular or triangular or trapezoidal cross-sections, suitably supported by a timber or reinforced concrete structure. It should be firmly attached to the support structure in order to prevent displacement or damage by wind induced vibrations.

1.7.2.1.2 Timber should conform to **1.5.7**.

1.7.2.1.3 Splash bars should be treated with copper/chromium/arsenic (CCA) preservative in accordance with **1.5.8**.

1.7.2.1.4 Splash bars should be designed to withstand the stresses resulting from self weight and water loading.

1.7.2.1.5 Additional loading may result from ice formation in the absence of a de-icing system. If such a system is fitted, the effects of a malfunction of the system and the effects of cold water being distributed over the packing in inclement weather should be considered.

1.7.2.1.6 Finger jointing should be permitted in splash bars if the layout requires excessive lengths to be installed.

1.7.2.1.7 Finger jointing should conform to BS EN 385.

1.7.2.2 *Asbestos-cement packing*

1.7.2.2.1 Asbestos-cement packing should comprise corrugated or flat asbestos-cement sheeting installed on edge and suitably supported.

1.7.2.2.2 Asbestos-cement sheets for packing should conform to BS 690 except for the following:

- a) partial replacement of the asbestos fibre by an alternative fibre is permissible;
- b) thickness may be less than that specified in BS 690;
- c) variation in nominal moulded widths, giving a non-standard width of sheet, is permitted.

Non-standard sheets should be clearly marked to this effect.

Since corrugated asbestos-cement sheeting used in packing will in most cases have a profile identical to sheets used for roofing or cladding, their use for these other purposes should be strictly avoided.

1.7.2.2.3 Sheeting spacing should be maintained by the use of prefabricated spacers with tie rods if necessary.

1.7.2.2.4 Suitable bearing spacers should be provided between each sheet at the points of support to avoid local damage to the sheets.

1.7.2.2.5 Distribution pipework or other concentrated loadings on the upper surface of the sheeting, should be adequately spread to avoid local damage to the sheets.

1.7.2.3 *Plastics packing*

1.7.2.3.1 Plastics packing comprises either:

- a) splash packing consisting of laths or grids of cross splash bars, and installed in layers; or
- b) film packing, fabricated in modules generally of a proprietary design and installed one above the other to the requisite depth.

1.7.2.3.2 Plastics materials should conform to **1.5.10**.

1.7.2.3.3 The module type of construction used for the film packing, capable of withstanding the stresses resulting from self weight and water loading, should also take into account excess loads resulting from deposits on the packing which may result in high local crushing stress at points of support.

1.7.2.3.4 If a plastics splash packing is installed, the effects of ice build-up, described in **1.7.2.1.5**, should be taken into account.

1.7.3 Water distribution pipework

1.7.3 Pipework should be in accordance with **1.5.14**.

1.7.3.2 Pipework should have a wall thickness that allows the fixing of spray nozzles or adaptors.

1.7.3.3 Pipework and its supporting system should be able to accommodate all thermal stresses and movements due to changes in water and ambient temperatures.

1.7.3.4 Pipework should be fitted with sluicing valves so that pipes may be regularly flushed to remove debris, silt, etc. Such sluicing valves should be fitted regardless of whether the nozzles spray upwards or downwards.

1.7.3.5 The pipework should be capable of resisting surge pressures appropriate to the system and of at least twice the working pressure.

1.7.3.6 Joints in pipework should be formed using methods and components appropriate for the type of pipework adopted and should be capable of resisting the same loadings as the parent pipe.

1.7.3.7 Adhesives used in joint formation should be in accordance with **1.5.13**.

1.7.4 Drift eliminators

NOTE The form and function of drift eliminators is described in 8.2 of BS 4485-3:1987.

1.7.4.1 Asbestos-cement eliminators should be formed from asbestos-cement sheeting conforming to BS 690.

1.7.4.2 Proprietary eliminators should be fabricated from a thermoplastic material of a type described in Annex B.

1.7.4.3 Unless the eliminator is pre-formed in panels or modules of adequate dead weight, individual louvres should be secured by wedging in or nailing to the support member.

1.7.5 Cladding

1.7.5.1 Fixings and seals should be used to prevent leakage between joints or fixings.

1.7.5.2 Fixings should withstand the designed wind induced positive and negative pressures and any vibrations within the tower.

1.7.5.3 Surface treatment of the sheets should be considered depending on the nature of the water in the tower, it should be carried out in accordance with manufacturer's instructions.

1.8 Cooling tower fittings

1.8.1 General

Cooling tower fittings should be designed to withstand the often corrosive service conditions within the cooling tower and should conform to appropriate British Standards. Fittings specific to cooling towers should be in accordance with 1.8.2 to 1.8.6.

1.8.2 Damboards

Damboards may be used to isolate the cold water basin of larger towers. They should be designed to fit into guides set into the flow channel to provide a seal for water pressure from either side.

Boards should seal to the guides, and joints between boards should be rebated or tongued and grooved to minimize leakage. Butyl or similar rubber seals may be used.

Storage conditions should ensure minimal warping, and timber boards should be stored under water.

Timber boards should be designed in accordance with BS 5268-2, treated in accordance with 1.5.8 and shod with cast iron or other suitable material to prevent damage during lifting.

1.8.3 Coarse screens

Coarse screens should be designed to resist water pressures occurring with at least 25 % of the screen-free area blocked. Provision should be made for their removal for cleaning.

1.8.4 Aircraft warning lights

It is essential that the Civil Aviation Authority is consulted for specific guidance/advice on the need for and extent of aircraft warning lights.

Depending on the distance of the tower from the airfield, warning lights may need to be installed, in accordance with planning regulations, on towers above 92 m in height. Towers above 153 m in height should be lit.

Lamps should be fitted not closer than 6 m to the top. The lamps and associated cables should be suitably protected.

Lamps should be visible from every angle in azimuth 16 miles from the tower. The actual position and numbers of lamps or clusters should depend on the spread and intensity of the light, the estimated life of the lamp and the level of expected maintenance.

If steeplejack sockets are provided for access they should be in accordance with BS 3572.

1.8.5 Lightning protection

Lightning protection, if used, should be in accordance with BS 6651.

External protective systems are not normally required for concrete cooling tower shells. Sufficient protection is afforded by the existing reinforcement provided that good contact is maintained between bars through fixing with tying wire as follows:

- a) between lapped vertical bars;
- b) between vertical and horizontal bars;
- c) between the reinforcement in the shell and the supporting ringbeam and column bars.

An earth check should be carried out to see if additional lightning protection is required.

1.8.6 Barriers, ladders and walkways

Where there is vehicular access to a barrier it should conform to the relevant requirements of BS 6180.

Ladders should be in accordance with type A of BS 4211.

Metal walkways should be in accordance with BS 5395-3.

Wooden walkways should be in accordance with 1.5.7, 1.5.8, 1.6.1 and 1.6.2.1.

1.9 Water retaining structures

1.9.1 General

The distribution system, the cold water basin and sump or suction line should be designed, constructed and tested generally in accordance with BS 8007.

NOTE This clause applies to such structures made from reinforced or prestressed concrete.

1.9.2 Loads

1.9.2.1 *Internal water load*

The normal load should be taken as that corresponding to water at the normal operating level and pressure.

The maximum water load in closed sections of the distribution system should be accounted for. It will arise as a result of possible pressure surges from normal pump operation and possible blockages in the system as well as the pressures anticipated in the normal operation of the tower. Abnormal pressures may be alleviated by the incorporation of open topped stand pipe(s) or an open surge chamber of sufficient size to accommodate the maximum possible flow; the maximum pressure in such a system should be at least equivalent to a head of water 0.5 m above the top of the stand pipe(s) or surge chamber.

The maximum load in open flumes should be taken as equivalent to the pressure of water at the top of wall level and, in the cold water basin, equivalent to the pressure of water at basin kerb level.

1.9.2.2 *External water load*

The cold water basin may be below ground level. In this case the ground water may be at a higher level than the basin slab. In this event, the effect of external water pressure on the basin walls and bottom slab should be taken into account.

1.9.2.3 *Other loads*

If the water retaining structures support other sections of the tower the loads applied should be taken into account.

Loads arising from temporary construction conditions, construction plant and temperature gradients should also be considered.

1.9.3 Design

If the maximum water load is not more than 10 % greater than the normal load, the structures should be designed for the normal load.

If the maximum water load is more than 10 % greater than the normal load, the structures should be designed for 90 % of the maximum load.

Internal and external water pressures should be considered as acting in isolation.

If the pressures from external water cannot be practicably resisted, pressure relief "blow out" panels may be incorporated in the basin. They should be of such design, size and spacing that they will prevent damage to the structure from unbalanced external water pressure.

Construction and other joints should have waterstops and sealers in accordance with BS 8007.

Connections to pipes should incorporate puddle flanges or other similar sealing devices.

1.9.4 Testing

The structures should be tested for watertightness in accordance with section 9 of BS 8007:1987.

1.10 Foundations and bases

1.10.1 Foundations

The foundations should be designed in accordance with BS 8004.

Differential settlements within the foundations that support cooling tower shells (type 1 towers) should be minimized. If differential settlement is anticipated, its magnitude and location should be evaluated for allowance in the design.

Attention should be paid to the potential differential movements between the shell support, pond and packing support foundations owing to their different intensities of loading and/or different foundation types (e.g. piled and contact).

In derivation of foundation design parameters the potentially saturated ground conditions around and under cooling towers should be taken into account.

1.10.2 Bases

The reinforced concrete bases should be designed in accordance with BS 8110 to transmit to the foundations all the forces in the shell support structure, plus any loadings arising from the cold water basin.

The possible effect of loading resulting from temporary works or maintenance should also be considered.

Section 2. Hyperboloidal cooling towers (type 1 towers)

2.1 Basis of design

NOTE The basis of design applies to shells of hyperboloidal and offset hyperboloidal form.

2.1.1 The design of the reinforced concrete shell and its supports should be in accordance with BS 8110 except where amended by specific recommendations of this standard.

2.1.2 In the design of the shell structure a shell theory based on bending analysis should be used.

2.1.3 Aero-elastic model testing in an atmospheric boundary layer wind tunnel should be undertaken to determine the stresses in the shell if the tower being designed is greater than 120 m in total height and one or more of the following conditions apply:

- the tower forms part of a tower group (i.e. of two or more towers);
- the tower is close to large buildings;
- the tower is liable to be affected by topographical features;
- the tower has unusual proportions or any novel structural design features.

Such testing should be used to confirm the applicability of the design methods given in this standard. Appropriate methods of testing are considered in Annex C.

2.2 Loading

2.2.1 Dead loads

Dead loads should be calculated from the actual weights of the materials used.

2.2.2 Wind loads

2.2.2.1 General

The derivation of wind loads in BS 6399-2 applies except for.

- the derivation of design gust speed, $V_{g,z}$ (see 2.2.2.3);
- the effects of nearby structures on the mean and fluctuating pressures on the tower shell (see 2.2.2.6).

Two design wind speeds are used to derive the wind loads on the tower: the design mean wind speed, $V_{m,z}$, which is the hourly mean wind speed (in m/s), and the design gust speed, $V_{g,z}$, which is not a profile of the physical wind speeds of a predetermined duration but is specified to produce appropriate design stresses on the windward meridian of an isolated cooling tower. Both design wind speeds relate to wind speeds which vary with height z (in m) above ground level; the probability of exceeding their predetermined values is 0.02 in any one year.

Wind speeds should be derived in accordance with BS 6399-2 and 2.2.2.2 and 2.2.2.3. A value of 1.00 for S_d should normally be used.

The value of S_h used should not be less than 0. Upwind of the topographic crest the average S_h should not be greater than 0.12 over the height of the tower at its centre-line. Downwind of the topographic crest the average S_h should not be greater than 0.12 over the height of the tower on the windward meridian. Otherwise specialist advice should be sought.

2.2.2.2 Design mean wind speed

The design mean wind speed is given by

$$V_{m,z} = V_s S_{m,z}$$

where

$$S_{m,z} = S_c (1 + S_h) \text{ for country terrain; and}$$

$$S_{m,z} = S_c T_c (1 + S_h) \text{ for town terrain.}$$

S_c , T_c and S_h are as given in BS 6399-2 and vary with effective height (H_e).

2.2.2.3 Design gust speed

The design gust speed is given by

$$V_{g,z} = V_s S_{g,z}$$

where

$$S_{g,z} = S_c \left\{ 1 + 3.5 S_{t,H} \left(\frac{z}{H} \right)^{1/2} + S_h \right\} \text{ for country terrain;}$$

$$S_{g,z} = S_c T_c \left\{ 1 + 3.5 S_{t,H} T_{t,H} \left(\frac{z}{H} \right)^{1/2} + S_h \right\} \text{ for town terrain;}$$

S_c , T_c , S_h are as given in BS 6399 and vary with effective height (H_e);

$S_{t,H}$ and $T_{t,H}$ are constants equal to the value of S_t and T_t evaluated at the height of the tower, H , above ground level.

2.2.2.4 Dynamic wind pressure

The following relationship should be assumed for the dynamic wind pressure q (in N/m²) at height z metres.

$$q_z = k V_z^2$$

where

$$k = 0.613$$

V_z is the relevant wind speed $V_{m,z}$ or $V_{g,z}$ (in m/s) as defined in 2.2.2.2 and 2.2.2.3.

2.2.2.5 Pressure distribution

The pressure coefficient distribution used to determine the wind loading on shells should be of the form given in Figure 1.

This distribution includes an allowance for internal suction and should be used over the complete tower height with the dynamic wind pressure, q_z .

For calculation purposes this curve may be defined by the following expression:

$$C_{p,\theta} = \sum_{n=0}^{n=7} a_n \cos n\theta$$

where

$$\begin{aligned} a_0 &= -0.00071 & a_4 &= 0.10756 \\ a_1 &= 0.24611 & a_5 &= -0.09579 \\ a_2 &= 0.62296 & a_6 &= -0.01142 \\ a_3 &= 0.48833 & a_7 &= 0.04551 \end{aligned}$$

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

NOTE For further information on the derivation of this distribution refer to Annex D.

2.2.2.6 Adjacent structures

The effect of nearby structures on the mean and fluctuating pressures over the shell surface can be severe (particularly for adjacent towers of similar size). It is not possible to specify design pressure distributions to allow for these effects so correction factors are given in 2.3.5.3 for meridional stress resultants calculated in an isolated cooling tower shell.

2.2.3 Imposed loads

Loading of the shell by permanent fixings should be minimized. The local effects of attachments on the structure should be investigated.

2.2.4 Foundation settlement loads

If the design of the foundation is such that differential settlements will occur within the shell support structure, these should be taken into account in the design of the tower shell and should be treated as an additional loading case.

2.2.5 Constructional loads

Loads arising during construction should be taken into consideration in the design.

NOTE Constructional loads may include the following:

- a) transportation of concrete;
- b) scaffolding and formwork;
- c) correcting shutter alignment;
- d) hoist fixings;
- e) storage of materials on scaffold;
- f) temporary access;
- g) tower crane fixings.

2.2.6 Thermal loads

Thermal loads on towers caused by solar and operational variations do not significantly affect the ultimate limit state unless there are rapid changes of section in the shell or the supports are very stiff in the direction normal to the shell. Normal serviceability requirements are met by the minimum reinforcement provided in the shell (see 2.3.5.5.1).

2.3 Design considerations

2.3.1 Ultimate limit state design

Partial safety factors should be applied to the loads specified in 2.2 as follows:

- a) for design of the tower shell:
 - load combination i) $1.0G_k + 1.5\varphi_G W_k$
 - Load combination ii) $1.4G_k + 1.5\varphi_G W_k$
- b) for design of the shell support structure:
 - load combination iii) $1.0G_k + 1.5\varphi_F W_k$
 - load combination iv) $1.4G_k + 1.5\varphi_F W_k$

where

- G_k is the characteristic dead load;
- W_k is the hourly mean wind load;
- φ_G and φ_F are amplification factors defined in 2.3.5.2.

NOTE The partial factor of 1.5 applied to wind load has been increased from the 1.4 value used in BS 8110 in view of the sensitivity of the structure to wind loading.

Partial safety factors in accordance with 2.4.2 of BS 8110-1:1985 should be applied to the characteristic strength of the materials.

2.3.2 Buckling design

2.3.2.1 General

Buckling design should be undertaken in accordance with BS 8110 for the tower under characteristic loads, as appropriate.

2.3.2.2 Local buckling of the shell

The factor of safety against buckling should be checked by the following procedure under the loading combination of $(1.0G_k + 1.0\varphi_I W_k)$, where φ_I is an amplification factor defined in 2.3.5.2.

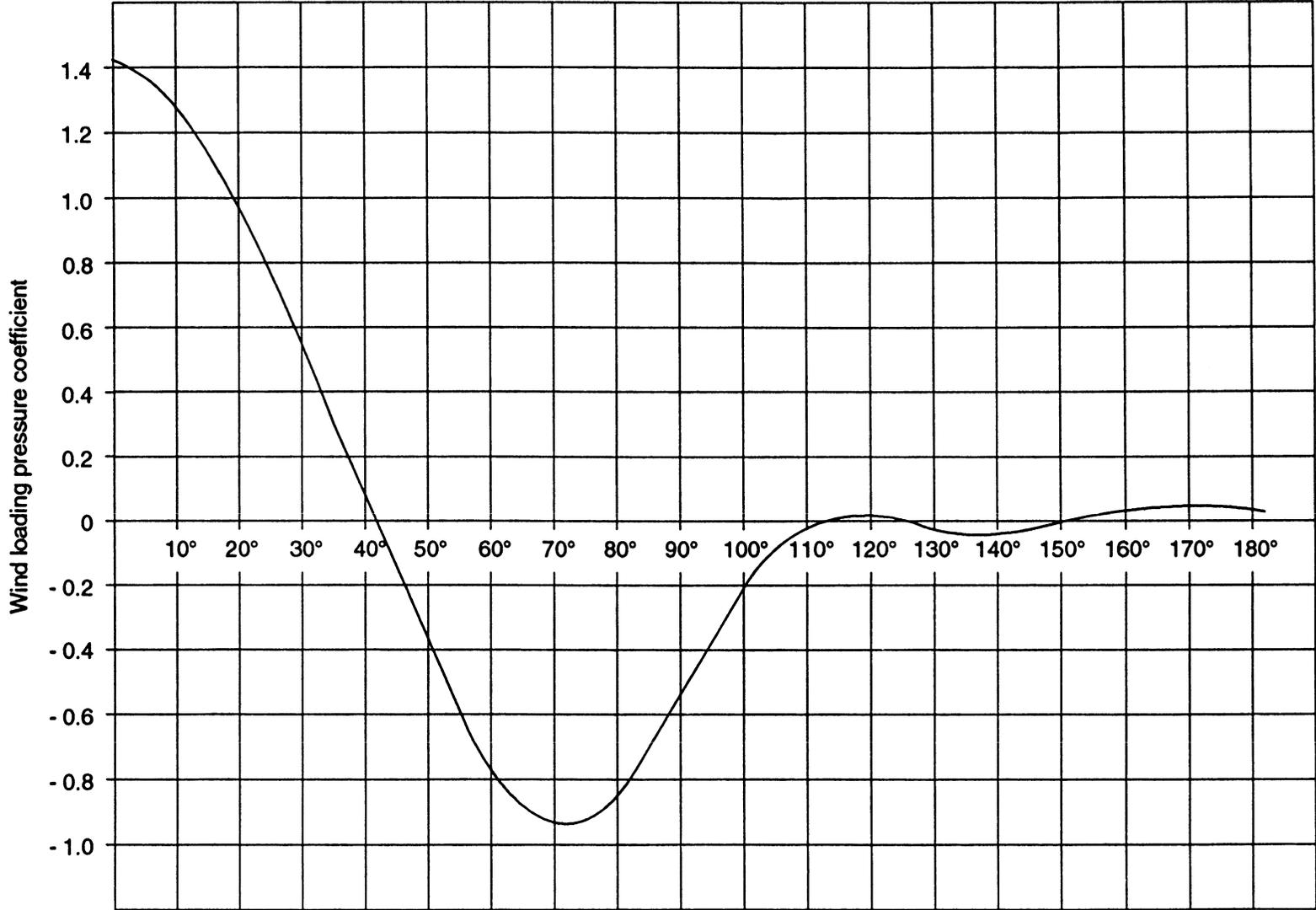


Figure 1 — Pressure coefficient distribution for determination of wind loading

The critical stresses are given by:

$$\sigma_{\theta,cr} = \frac{0.985E}{(1-\nu^2)^{\frac{3}{4}}} \left(\frac{h}{R_T}\right)^{\frac{4}{3}} \lambda_{\theta} \times 10^9$$

$$\sigma_{\varphi,cr} = \frac{0.612E}{(1-\nu^2)^{\frac{3}{4}}} \left(\frac{h}{R_T}\right)^{\frac{4}{3}} \lambda_{\varphi} \times 10^9$$

where

- $\sigma_{\theta,cr}$ is the circumferential critical stress (in N/m²);
- $\sigma_{\varphi,cr}$ is the meridional critical stress (in N/m²);
- E is the short-term static modulus of elasticity as defined in 7.2 of BS 8110-2:1985 (in kN/mm²);
- ν is Poisson's ratio;
- h is the shell thickness (in m);
- R_T is the throat radius (in m).

λ_{θ} , λ_{φ} are determined by interpolation from Table 3, where R_B is the radius at the underside of the ring beam (m) and Z_T is the height of the throat above the underside of the ring beam (m).

The factor of safety against buckling γ_B is found by solving:

$$0.8\gamma_B \left(\frac{\sigma_{\theta}}{\sigma_{\theta,cr}} + \frac{\sigma_{\varphi}}{\sigma_{\varphi,cr}} \right) + 0.2\gamma_B^2 \left\{ \left(\frac{\sigma_{\theta}}{\sigma_{\theta,cr}} \right)^2 + \left(\frac{\sigma_{\varphi}}{\sigma_{\varphi,cr}} \right)^2 \right\} = 1$$

where

- σ_{θ} and σ_{φ} are the coincident circumferential and meridional compressive membrane stresses.

If either stress is tensile its value should be set to zero.

The value of γ_B should be not less than 5 at any point in the shell.

NOTE The derivation of the formulae in this clause is given in [3].

2.3.2.3 Snap-through buckling of the shell

The calculation of the factor of safety against a snap-through buckling of the tower shell uses:

$$q_{cr} = 0.052E \left(\frac{h}{R_T}\right)^{\frac{7}{3}} \times 10^9$$

where

- q_{cr} is the critical dynamic wind pressure (in N/m²);
- E is the short-term static modulus of elasticity of concrete as defined in 7.2 of BS 8110-2:1985 (in kN/mm²);
- h is the minimum shell thickness (in m);
- R_T is throat radius (in m).

The factor of safety against buckling, γ_B , is given by:

$$\gamma_B = \frac{q_{cr}}{q_g}$$

where q_g is the dynamic wind pressure of the design gust speed of the wind $V_{g,z}$ at the throat height of the tower (derived from 2.2.2.3 and 2.2.2.4).

The value of γ_B should not be less than 5.

2.3.3 Foundation lift-off

Foundation lift-off is defined as the condition when the uplift (tensile) forces on any discrete element of the shell support structure, derived by linear elastic analysis of the tower structure, equals or exceeds the dead weight of the support structure, and its base, plus the permissible capacity of any anchorage system provided, e.g. ground anchors, rock anchors, tensile piles.

The tower design should be checked against lift-off using the following criteria:

- a) under the loading $1.0G_k + 1.0\varphi_F W_K$, no lift-off should occur;
- b) under the loading $1.0G_k + 1.5\varphi_F W_K$, the arc over which lift-off occurs, if any, should not exceed 30° of the circumference of the tower.

NOTE If lift-off occurs as in condition b), linear elastic analysis of the tower no longer applies. Limited non-linear study of a typical tower indicates that certain resultant stresses, in particular maximum meridional tension, may be increased by about 25 % to 30 % under a lift-off extending over 36° of the tower.

A linear eigenvalue buckling analysis was carried out in the same study and showed that the buckling load factor of 8 for the fixed base case (lift-off over 36°) reduced to 4.2 when uplift occurred. From the non-linear analysis it was found that uplift extended physically over 90° of arc centred on the windward meridian.

2.3.4 Cracking

Cracking of the concrete shell is controlled in normal circumstances by the provision of reinforcement in accordance with this Part of BS 4485. If particular limits to cracking are to be applied to the shell, and for other members generally, cracking should be checked in accordance with the recommendations of BS 8110 (see 2.2.3.4 in BS 8010-1:1985, and 3.2.4 and 3.8 in BS 8010-2:1985). The calculated maximum crack width should not exceed 0.3 mm, but where cooling water carries constituents aggressive to reinforced concrete, calculated crack widths should be limited to 0.1 mm or 0.2 mm depending upon the severity of likely corrosion. The calculation of crack width should be made in accordance with 3.8 of BS 8110-2:1985.

Table 3 — Determination of λ_θ and λ_φ

R_T/R_B	λ_θ			λ_φ		
	$R_T/Z_T = 0.250$	$R_T/Z_T = 0.333$	$R_T/Z_T = 0.416$	$R_T/Z_T = 0.250$	$R_T/Z_T = 0.333$	$R_T/Z_T = 0.416$
0.571	0.105	0.162	0.222	1.28	1.20	1.13
0.600	0.102	0.157	0.216	1.33	1.25	1.17
0.628	0.098	0.150	0.210	1.37	1.30	1.23
0.667	0.092	0.138	0.198	1.45	1.37	1.31
0.715	0.081	0.124	0.185	1.56	1.49	1.43
0.800	0.063	0.096	0.162	1.74	1.73	1.68
0.833	0.056	0.085	0.151	1.85	1.85	1.82

2.3.5 Shell design

2.3.5.1 General

2.3.5.1.1 Upper edge of tower

The uppermost edge of the tower shell should be designed as a smooth transition from the thickness of the main body of the shell to the chosen thickness of the upper edge (typically $2.5 \times$ shell thickness). The effect of cornices or access walkways, if required, should be included in the analysis.

2.3.5.1.2 Boundary conditions at lower edge of shell

The analysis of the shell should take account of the column, base and foundation stiffnesses. A separate analysis of the lower portion of the shell as a ring beam should be carried out unless the column supports are included in the analysis as discrete elements.

2.3.5.2 Amplification factors for wind loading

The amplification factors for stress resultants, φ_I , φ_G and φ_F should be evaluated using the meridional stress resultant on the windward meridian of the tower shell.

The following notation is used for meridional stress resultants:

- $N_{\varphi,m}$ is the mean stress resultant caused by the design hourly mean wind speed, $V_{m,z}$;
- $N_{\varphi,g}$ is the gust stress resultant caused by the design gust speed, $V_{g,z}$;
- $N_{\varphi,r}$ is the stress resultant caused by resonance of the shell due to wind turbulence.

The stress resultants are evaluated as follows:

Determine $N_{\varphi,m}$ from an analysis of the shell using a dynamic mean wind pressure

$$q_{m,z} = k(V_{m,z})^2 \text{ from 2.2.2.2, 2.2.2.4 and 2.2.2.5.}$$

Determine $N_{\varphi,g}$ from an analysis of the shell using a dynamic gust wind pressure

$$q_{g,z} = k(V_{g,z})^2 \text{ from 2.2.2.3, 2.2.2.4 and 2.2.2.5.}$$

Estimate the resonant stress resultant in the tower from:

$$N_{\varphi,r} = BK \frac{V^4}{n^2} (\text{N/m})$$

where

$$V = V_s;$$

$B = 1\ 800$ for the bottom third of the shell, $1\ 200$ for the middle third of the shell and 900 for the top third of the shell;

n is the lowest natural frequency of the tower (in Hz);

K is the empirical factor (see Annex E).

NOTE The calculation of the lowest natural frequency (n) is an important factor in deriving $N_{\varphi,r}$ and should be determined by a finite element analysis (see Annex F) or a method of equivalent accuracy.

Using the necessary correction factors for the effects of adjacent structures, i.e. C_G and C_D evaluated in accordance with 2.3.5.3, the amplification factors are defined as:

$$\text{i) } \varphi_I = 1 + \frac{\sqrt{(N_{\varphi,g} - N_{\varphi,m})^2 + (N_{\varphi,r})^2}}{N_{\varphi,m}}$$

which is evaluated at a height above the base of the shell equal to the distance between adjacent shell support nodes (a constant).

$$\text{ii) } \varphi_G = 1 + \frac{\sqrt{(C_G \cdot N_{\varphi,g} - N_{\varphi,m})^2 + (C_D \cdot N_{\varphi,r})^2}}{N_{\varphi,m}}$$

as evaluated at the shell section height in question (a variable).

$$\text{iii) } \varphi_F = \varphi_G$$

which is evaluated at a height above the base of the shell equal to the distance between adjacent shell support nodes (a constant).

2.3.5.3 Correction factors

Nearby structures (particularly adjacent towers) can considerably increase the meridional stress resultants. C_G and C_D correct the stresses derived for an isolated tower (see Table 4).

Table 4 — Correction factors for stresses due to adjacent structures

Correction factors	Grouping class	Top third of shell	Middle third of shell	Bottom third of shell
C_G	1	1.0	1.0	1.0
C_D		1.0	1.0	1.0
C_G	2	1.10	1.15	1.15
C_D		1.25	1.25	1.25
C_G	3	1.33	1.20	1.25
C_D		1.75	1.75	1.75
C_G	4	1.5	1.25	1.33
C_D		2.0	2.0	2.0

NOTE Grouping classes are as follows:

Class 1. Isolated; adjacent structures are not closer than 10 times their maximum dimension.

Class 2. Single tower, adjacent buildings, typical of electric power plant, are within 0.5 times the tower base diameter.

Class 3. Two towers spaced centre to centre at 1.5 times tower base diameter; adjacent buildings, typical of electric power plant, are within 0.5 times the tower base diameter.

Class 4. Three (or more) towers spaced centre to centre at 1.5 times tower base diameter; adjacent buildings, typical of electric power plant, are within 0.5 times tower base diameter.

Obviously not all possibilities of tower group spacing and layout can be covered. Interpolation between the identified groupings should not be attempted. Published results of wind tunnel investigations are sparse; [8], [9] and [10].

2.3.5.4 Openings in shells

The edges of openings in shells should be formed at right angles to the middle surface of the shell.

The shell analysis should take account of openings with any dimension in excess of 2 m.

Openings with no dimension in excess of 2 m should have reinforcement provided in accordance with Figure 2.

If possible, right angled corners to openings should be avoided. However, if they are unavoidable, then trimmer reinforcement should be provided.

If possible, the clear distance between any two openings should be not less than the major dimension of either opening. However, if this is not possible, the two openings should be considered as a single opening equal in size to the two openings and the concrete between them.

2.3.5.5 Reinforcement

2.3.5.5.1 General

For shells with a thickness of 160 mm or greater, two layers of steel reinforcement should be used to form meshes adjacent to the internal and external faces.

Deformed steel with a characteristic yield stress of 460 MPa, in accordance with BS 8110, should have the minimum percentages of reinforcement given in Table 5 distributed equally between each layer.

Table 5 — Minimum reinforcement in shell

Section of tower	Minimum meridional reinforcement %	Minimum circumferential reinforcement %
Bottom two-thirds of shell	0.3	0.3
Top third of shell	0.3	0.4

2.3.5.5.2 Design procedure

In the meridional direction of tower shells the amount of reinforcing steel used is chiefly determined by the membrane forces present; the moments in this direction are relatively small. A conservative estimate of the area of reinforcement required A_φ (in mm^2/m) is:

$$A_\varphi = \frac{N_\varphi + |N_{\varphi,\theta}|}{(f_y/1.15)}$$

where

N_φ is the meridional stress resultant under load combination i) (see 2.3.1) (in N/m)

$N_{\varphi,\theta}$ is the absolute value of the shear stress resultant under load combination i) (see 2.3.1) (in N/m)

f_y is the steel characteristic strength (in N/mm^2).

In the circumferential direction the amount of reinforcing steel used should be determined using the membrane forces and bending moments, owing to the significance of bending moments in this direction. Circumferential reinforcement, in addition to the minimum percentages given in Table 5, should be provided to protect against stresses generated by differential foundation settlement.

References [5] to [7] give calculation methods for determining the amount of reinforcement needed in shells under such loadings.

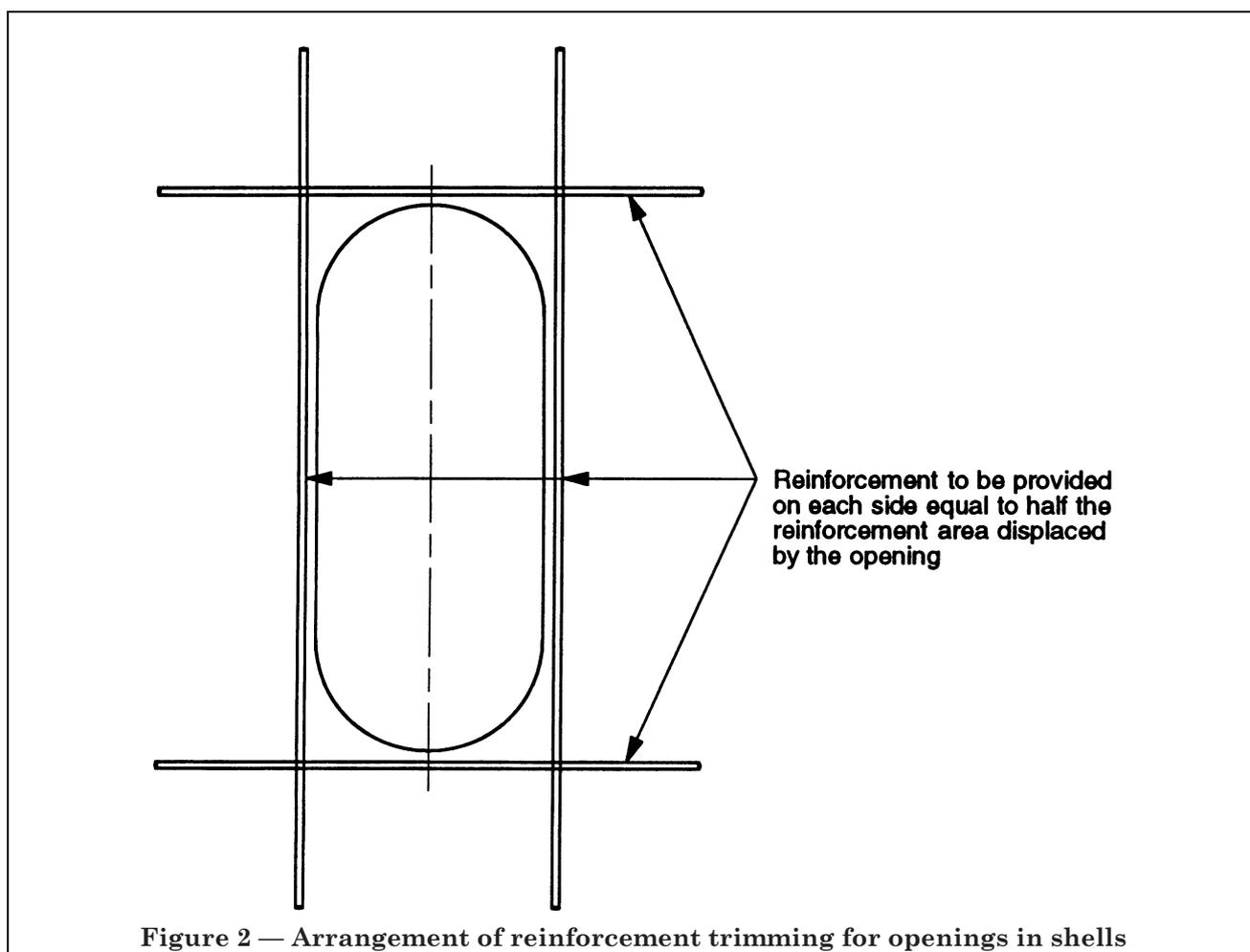
NOTE The amplification factor φ_G is based upon meridional stresses above the ring beam (see 2.3.5.2). Measurements of circumferential stresses show significantly higher amplification factors due to fluctuating stresses [4]. However, these stresses are not likely to require reinforcement greater than the minimum requirements, as given in Table 5, for towers less than 120 m in height.

The minimum percentages of circumferential reinforcement given in Table 5 are deemed to be adequate for towers satisfying all of the following criteria:

- height less than 120 m;
- ring beam diameter less than 100 m;
- height/ring beam diameter greater than 1.20 and less than 1.55;
- height of throat/height of tower greater than 0.75 and less than 0.85;
- clear distance between towers greater than 0.5 of pond diameter.

2.3.5.5.3 Detailing

The diameter of circumferential steel should be not less than 8 mm and the diameter of meridional reinforcement should be not less than 10 mm. Where two distinct layers of reinforcement are placed, the horizontal reinforcement shall be external to the meridional steel, (see Figure 3).



The spacings of bars should not exceed twice the shell thickness, or 250 mm vertical spacing between the circumferential reinforcement and 300 mm spacing between the meridional reinforcement, whichever is the less.

Splicing of the meridional reinforcement should be distributed around the shell circumference so that not more than one-third of the steel laps in any lift. If grouped splices are used the subtended arc should not exceed 3° .

The nominal cover should be not less than 30 mm.

The design should take into account that in the lower regions of the shell the inclination of the shell makes the placing of concrete more difficult so that cover may need to be increased (or the aggregate size reduced) to prevent bridging by the coarse aggregate between the shutters and the reinforcement.

2.3.6 Shell support structure design

The provisions of this Part of BS 4485 apply to shells in which the support structures generate restraints predominantly as a membrane continued in the tangential plane of the lower part of the shell.

Columns should be designed in accordance with 3.8 and 3.9 of BS 8110-1:1985.

Under ultimate limit state conditions a redistribution of up to 10 % of the design wind loading on any column may be made to adjacent similarly inclined columns.

Unless a more detailed analysis is made, the effective lengths of columns and walls should be determined utilizing Table 3.21 of BS 8110-1:1985 taking the end condition at the top as 1 tangentially and as 2 radially.

The end condition at the bottom should be chosen by consideration of the restraint provided by the foundation.

If columns are in tension it is sufficient to design for axial force only.

2.4 Construction

2.4.1 Basic construction plan

2.4.1.1 A basic construction plan should be prepared for the cooling tower shell and shell supports.

2.4.1.2 The plan should include the following elements, and any other information relevant to the construction of the shell and column:

- a) method statement for operation of climbing rigs, if used, hoisting equipment, etc.;
- b) criteria for removal of formwork and imposition of construction loads;
- c) method of transporting concrete to working levels;
- d) setting out method with details of any instrumentation to be used;
- e) type and make-up of formwork to be used on the tower shell;
- f) method of storing and curing concrete test cubes recommended in 2.4.3.2.

2.4.1.3 The plan should include key values, required by the method of working, for the following items:

- a) minimum concrete strength for the operation of climbing access rigs and/or hoisting equipment attached or supported by the partially completed structure;
- b) minimum concrete strength of previous lift for pouring of fresh concrete in successive lift.

2.4.2 Shell construction requirements

(see also 1.5.5)

2.4.2.1 The shell support columns should be cast in position or located in position if precast. They should be supported by temporary propping such that the deflection of the column heads, subjected to temporary works loadings, does not exceed 5 mm.

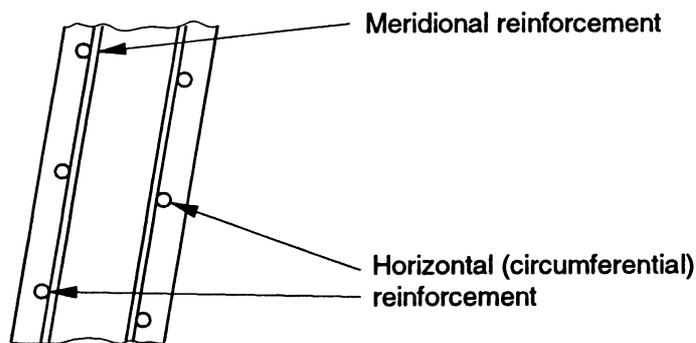


Figure 3 — Arrangement of reinforcement in the shell

2.4.2.2 No props should be removed until a complete lift of the ring beam, not less than 1 m deep, has been cast and has attained a compressive strength, as determined by match cured test cubes, of not less than 20 N/mm².

2.4.2.3 No climbing rigs, hoisting equipment, etc. should be attached to the shell within a 36° arc from a stop end until the first lift of the ring beam is completed.

2.4.3 Quality control of shell concrete

2.4.3.1 The striking of formwork should only be carried out when the concrete has reached an appropriate maturity level.

2.4.3.2 The operations of pouring fresh concrete and of moving climbing rigs and/or hoisting equipment should be governed by the results of match cured compressive test cubes.

NOTE A match cured test cube is defined as a cube that is manufactured, stored, cured and tested in such a way that it realistically reflects the behaviour of the parent concrete.

2.4.3.3 At least four test cubes should be made from samples taken at the point of discharge into the formwork at locations diametrically opposite to each other in any lift pour.

2.4.3.4 These cubes should be taken at least once every two lifts or every 3 m of shell height, whichever is the lesser.

2.4.3.5 Two test cubes should be match cured for a period of time considered to be representative of the pouring cycle.

2.4.3.6 One of the match cured cubes should be crushed; if its compressive strength falls below the key value given in the basic construction plan for the operation of pouring fresh concrete, then after an appropriate period of time the second cube should be crushed. No further concrete should be poured until the concrete in the corresponding lift has achieved sufficient strength to withstand any loads which are to be imposed upon it.

2.4.3.7 The two remaining test cubes should be match cured for a period of time representative of the rig moving cycle and should then be tested.

2.4.3.8 If the compressive strength of either cube falls below the key value given in the basic construction plan for the operation of moving climbing rigs and/or hoisting equipment, no lifting operation should be carried out until the concrete in the lift which is required to withstand the loadings from rig and/or hoisting equipment has achieved sufficient strength to do so.

Section 3. Mechanical draught towers (type 2 towers)

3.1 Characteristic loads

3.1.1 Dead loads

Dead loads should be calculated from the actual weights of the materials used.

3.1.2 Imposed loads

The characteristic imposed loads should be calculated in accordance with BS 6399-1.

The effects of dynamic loading from machinery or fans on the structure should be considered. This should take account of the possibility of breakage of a fan blade.

3.1.3 Wind loads

The design wind speed applicable to the design of mechanical draught cooling towers should be determined from BS 6399-2.

In assessing the overall stability of the installation, the effect of wind loading on a dry and out of commission tower should be considered.

3.1.4 Temperature effects

Allowance should be made in the design both for overall thermal expansion of the structure and for temperature gradients across sections.

Temperature gradients should be derived from the maximum air or water temperature within the tower and the corresponding minimum ambient temperature.

3.2 Design considerations

3.2.1 Design standards

Sections of reinforced concrete structures which retain water should be designed in accordance with BS 8007. Other reinforced concrete should be designed in accordance with BS 8110.

Steel structures should be designed in accordance with BS 5950.

Timber structures should be designed in accordance with BS 5268-2.

3.2.2 Resonance

The natural frequencies of members supporting machinery or fans should be calculated under normal working conditions. No such calculated natural frequency should lie within $\pm 20\%$ of the frequency of any dynamic loading applied by the machinery or fan when operating at normal working speed.

NOTE To ensure compliance with this criterion it may be necessary to consider more than just the first mode of vibration of the fan support structure.

The supporting structure for the fan equipment should be in accordance with the fan manufacturer's requirements. However, it is recommended that the fan supporting structure should be arranged so that the fan blades are not subjected to simultaneous buffeting along their entire length, and that no supporting beam should be positioned directly along the radius of a fan blade.

The tower structure and the beam support for the fan equipment should be designed to minimize blockage of the air flow into the fan and to ensure that the consequential aerodynamic buffeting is not significant under any normal operating condition.

Annex A (normative) Recommendations for stress graded timber triangular section laths

A.1 General

All section laths should be manufactured from *Pinus sylvestris* or other approved timber species.

In no case should the finished sawn size be less than the design dimensions.

After conversion to size, the laths should be stress graded in accordance with the rules given below.

Each lath should be graded by assessing the characteristics covered by A.2 to A.7 inclusive.

A.2 Rate of growth

A.2.1 Measurement The rate of growth should be measured on one end of the lath and should be taken as the average number of growth rings per 25 mm intersected by the longest possible line normal to the growth rings and passing through the centre of the lath.

A.2.2 Grading limits

There should be not less than six growth rings per 25 mm.

A.3 Checks, shakes and splits

A lath should not contain checks, shakes and splits.

A.4 Wane

A lath should not have wane.

A.5 Pith

A lath should not contain pith in the tension zone.

A.6 Slope of grain

A.6.1 Measurement

The slope of grain should be measured over a distance sufficiently great to determine the general slope, disregarding local deviations caused by knots.

A.6.2 Grading limits

A lath should not have a slope of grain steeper than 1 in 6.

A.7 Knots

A.7.1 Size

The maximum permissible size of knots should be in accordance with Table A.1.

A.7.2 Measurement

A.7.2.1 Splay knots

A splay knot (see 1.3.27) should be measured on the face where the end grain of the knot can be seen. Its size should be taken as the width between the arris of the section and a line touching the knot parallel with the arris (see Figure A.1).

A.7.2.2 Arris knots

The size of an arris knot (see 1.3.2) should be measured on the face containing the larger portion of the knot and should be taken as the width between the arris and a line touching the knot parallel with the arris (see Figure A.2).

The size of an arris knot, which emerges at an arris other than that associated with the right angle of the section, should be measured in the face. It should be taken as the width between the arris and a line touching the knot parallel with the arris (see Figure A.2).

A.7.2.3 Face knots

The size of a face knot (see 1.3.15) should be measured between lines enclosing the knot and parallel with the arrises of the lath (see Figure A.3).

A.7.2.4 Multiple knots

If two or more knots are in line, i.e. partially or completely enclosed by the same parallel lines and separated lengthwise by less than 200 mm, the effective width of the knots should be the distance between two parallel lines which enclose the knots.

If two or more knots occur in the same cross-section, the sum of their maximum sizes, determined as in A.7.2.1 to A.7.2.3, should be taken as the effective width of the knots.

A.7.3 Grading limits

The maximum permissible size of solid live knots, according to span, for a 38 mm × 38 mm side dimensioned lath is given in Table A.1.

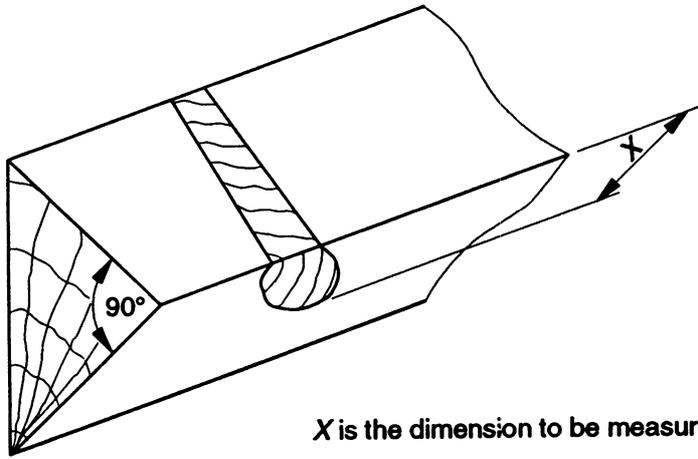
Table A.1 — Permissible knot size for a 38 mm × 38 mm lath

Span m	Knot size	
	In tension zone mm	Other zones mm
Less than 1.5	18 (13)	22 (16)
1.5 to 1.90	16 (11)	20 (14)
1.91 to 2.30	14 (10)	16 (11)
2.31 to 2.70	12 (8)	14 (10)

NOTE The knot sizes given in full apply to completely or partially intergrown knots. The knot sizes in parentheses apply to encased (dead) knots.

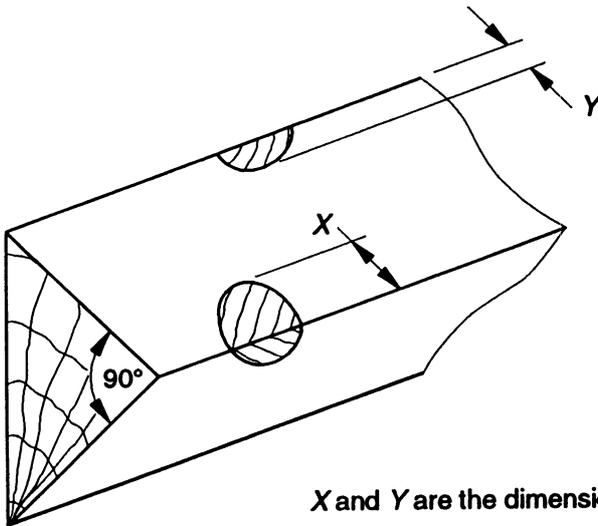
For triangular sections of a different dimension the recommendations for knot size should be varied pro rata to the side dimensions.

For laths installed on a single span, the maximum sizes of the knots may be increased outside the middle third of the span. These may increase proportionally towards the end of a lath to sizes 25 % larger than the values given in Table A.1.



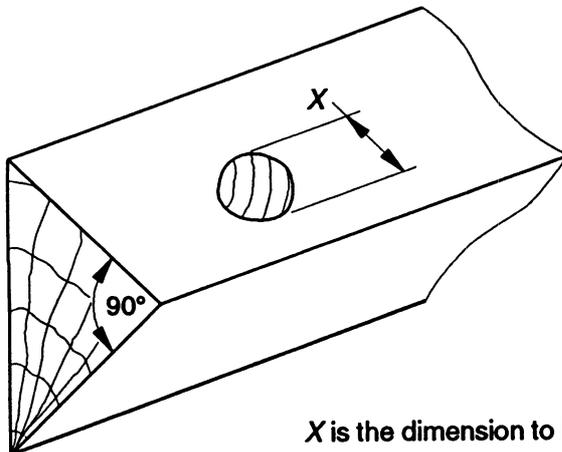
X is the dimension to be measured

Figure A.1 — Splay knot



X and Y are the dimensions to be measured

Figure A.2 — Arris knot



X is the dimension to be measured

Figure A.3 — Face knot

Annex B (normative)

Guidance on the use of plastics materials

B.1 Thermosetting materials

Thermosetting plastics used in cooling towers are generally of an epoxy or polyester type consisting of a resin and hardener. They usually take the form of glass fibre reinforced plastics components. Once set, the resin is not softened by heat. The material is used in package cooling tower casings, fan blades, cold water tanks and fitments, for example, brace straps and nozzles, etc.

Thermosetting plastics offer good stability, resistance to heat and UV degradation although certain colour finishes can be affected by exposure to strong sunlight.

Resins normally used in thermosetting plastics mouldings can present a fire hazard but additives can be used to minimize this potential problem.

B.2 Thermoplastic materials

Thermoplastic materials require a heat forming process to mould the component; if subjected to heat the material will soften. Thermoplastic materials in general use are high impact polystyrene (HIPS), polyvinylchloride (PVC), polypropylene, acrylonitrile-butadiene-styrene (ABS) and high density polyethylene (HDP).

All the above materials are flammable but PVC will only burn if subjected to a sustained external source of heat. Many plastics give off toxic fumes when burning. Additives can be incorporated into most plastics to reduce the risk of ignition.

Thermoplastic materials are used in the manufacture of components for cladding, packing plates or trays and nozzles, and also for pipe distribution systems. Thermoplastics are formed as injection or extrusion mouldings from a heated reservoir of plastics material. They may also be formed by a vacuum forming process in which an extruded or calendered flat sheet is heated to a controlled softening temperature. The sheet is then moulded over a former, generally by drawing a vacuum, thus using atmospheric pressure to press the softened plastics sheet over the mould shape.

The thermoplastics mentioned above give good resistance to acid or alkali conditions but some can be attacked by solvents, fatty acids and petroleum products, if present in the circulating water.

Polypropylene, with its resistance to high temperature, is a suitable material for injection moulded nozzles and has been used for packing material. However, it is a relatively flexible material and requires good support due to its inherent flexibility in the thin sections used in packings. Polypropylene, as with polyethylene, cannot be joined by solvent-type glues; it requires hot air welding if it is to be joined to other materials.

B.3 Plastics packing

Packing materials, whether vacuum formed or injection moulded, can be supplied in new/virgin material or regrind material. Regrind material is recycled material compounded with a percentage of new material. It generally gives a dark grey or blackish colour owing to the mixing of various colours of recycled plastics. It is economically used for packing materials since the limitation on colour is of no importance in the interior of the cooling tower. In addition, the quality of the material can be controlled to provide adequate strength and heat resistance for average cooling duties. In high temperature applications, it may be necessary to use a new or virgin material which can be specially formulated to provide the required heat resistance provided that it is economically viable.

Plastics packings are lightweight but, particularly in the case of plate packings, the extended surface may allow biological slime to build up. Therefore, particular care should be taken with water treatment to prevent sliming or algae growth. If the circulating water contains particulate matter, many of the particles may be retained on the slime coated surfaces which could lead to a considerable overloading of the support structure.

Although plastics packing materials can be supplied to resist high inlet temperatures in normal use, a fan failure in a mechanical draught cooling tower, operating under a high temperature regime, could lead to a rapid temperature rise and possible pack failure. Therefore, suitable limit controls or bypass systems should be installed.

B.4 Effect of low temperatures

Plastics materials exposed to extremely low temperatures can become brittle and subject to damage by wind induced vibration. Care should be taken with fastening systems and installation of any plastics components under cold weather conditions.

Annex C (informative) Wind tunnel testing

Testing of model structures in wind tunnels with simulated atmospheric boundary layer (ABL) incident flow is now a well established technique. UK and overseas facilities which can undertake this type of work are listed in [11].

Because of Reynolds number effects, a suitable surface roughness has to be applied to the model shell to simulate the flow that will occur at full-scale with a Reynolds number of about 10^8 . This is well above that which can be achieved in tunnel test facilities. A series of studies of this problem has been conducted [12].

The fluctuating stresses in a model shell can be calculated from the measurement of pressures and corresponding correlations over the shell surface [8] and [13]. Even for isolated cooling towers this is a complex procedure requiring considerable data measurement and computing. When adjacent buildings of significant size (particularly other towers) are present, the work required by this approach in order to estimate the maximum stresses is prohibitive. Fortunately aero-elastic models can be utilized and stresses quickly and reliably derived from electric strain gauge measurements [14], [15] and [16].

Annex D (informative) Circumferential wind pressure distribution for hyperboloidal towers

The pressure distribution specified in 2.2.2.5 is based on wind tunnel tests made for the Ferrybridge Committee of Inquiry [17]. The pressure coefficient distributions at the highest and lowest positions are ignored, symmetrical pressure coefficient distributions are derived for each height by obtaining the averages of $C_p(h, \theta)$, and $C_p(h, 360^\circ - \theta)$. These symmetrical pressure coefficient distributions are then averaged and the internal suction coefficient subtracted to provide a wind loading pressure coefficient distribution for the shell. Fourier series coefficients giving a best fit to this modified distribution are estimated and give the form shown in Figure 1.

Annex E (normative) Estimation of resonant stresses

The estimation and treatment of wind loadings on structures which behave quasi-statically (where the natural frequency is so high that the dynamic response is insignificant) is well documented. For structures which may suffer a dynamic response, for example cooling towers, a different technique for analysing the wind forces is required.

A more precise description of variation of wind speed with time is required for dynamic analysis and it is convenient, for this purpose, to regard the wind function as the sum of a mean velocity and of a time varying or turbulent component with zero mean. This latter component will, in turn, induce quasi-static and resonant response dependent upon the dynamic properties of the structure in question. The worst wind situation occurs during the period of the highest mean wind speed, the magnitude of which may be predicted from either.

- meteorological records of highest mean wind speed recorded annually for the site in question;
- the basic wind speed, V_b , as defined in BS 6399.

In the light of current knowledge of the dynamic behaviour of large cooling towers, the resonant response to the time varying component of the wind in this worst period has been assessed from wind tunnel research on cooling tower groups. Empirical expressions are proposed for the calculation of dynamic loadings.

Wind tunnel testing of the effects of grouping on the stresses in cooling tower shells, carried out in the UK since 1969, has established that resonance effects, and the accompanying stresses, become relatively more important as tower heights increase. Large towers show greater resonance effects than smaller towers and it follows that in the design of even larger towers very large vibrations and stress levels are possible. Therefore, careful consideration should be given to resonance effects at the design stage.

The following expression is empirical and is based upon wind tunnel research on tower groups and single towers and generally verified by measurements on full scale towers [14].

The expression for the peak resonant meridional stress resultant (in N/m) at the bottom of the thin shell is

$$N_{\phi,r} = \frac{1800KV^4}{n^2}$$

where

- $N_{\phi,r}$ is the peak resonant meridional stress resultant;
- K is an empirical factor(see below);
- G is a grouping factor,
- n is the lowest natural frequency of the tower (in Hz); and
- $V = V_s$.

In applying the formula above, the value of G is incorporated in the factor C_D given in Table 4. The factor K incorporates air density, effects of turbulence intensities and wind shear in open country and structural effects including 1 % critical damping.

On the basis of wind tunnel tests to date, a value of K of 1/6 000 is applicable to counterflow towers. Where a higher air entry exists, for example to accommodate cross-flow packing, a value of K of 1/4 000 should be used.

The values suggested above are based on the results of wind tunnel tests on a limited range of towers. It is possible that different design practice, such as variable thickness shells with no distinct ring-beam or with very deep stiffening at the upper free edge, or other stiffening, or with very high inlets, might invalidate the empirical factors stated above.

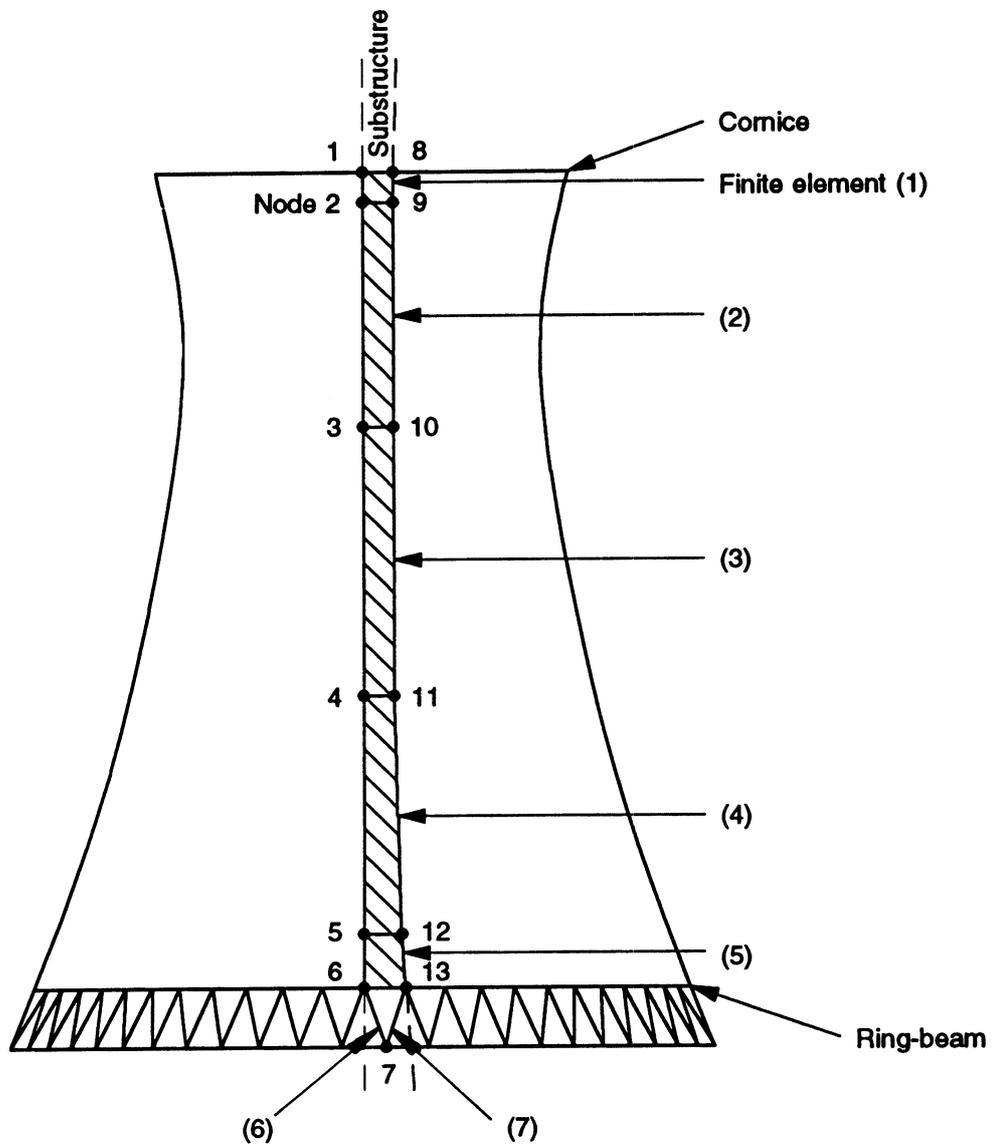
The tests are all conducted in a simulated atmospheric boundary layer flow appropriate to open level country (mean wind speed exponent with height of 1/7). Resonance in smoother or rougher terrain has been assumed to be the same since more turbulent flow is linked with lower mean speeds and vice-versa.

Annex F (informative)

Derivation of natural frequencies of hyperboloidal towers

For an accurate determination of the frequencies of free vibration of cooling towers, the flexibility of the shell supports and foundations should be included in the analysis. The (bottom) ring-beam and (top) cornice stiffening can also have a significant effect. The finite element method is a convenient tool when allowance must be made for such distinct structural features.

A cooling tower is a shell of revolution on discrete supports and is therefore a rotationally periodic structure, i.e. a circular entity formed by a number of identical substructures which are repeated to form the complete structure. In this case the behaviour of the complete tower can be modelled with a finite element mesh of a single substructure (Figure 1) by applying appropriate constraints between the left, and right-hand boundaries for particular circumferential wavelength [18]. Using this technique, considerable savings in computing storage requirements and CPU time are obtained. Nelson has reported comprehensively on research with this method using double curvature quadrilateral shell elements and the results are in good agreement with measurements on model and full-scale cooling towers [19]. Fricker used flat quadrilateral shell elements to investigate the collapse of the Fiddlers Ferry Cooling Tower, again making use of periodic substructures [20].



NOTE Angle subtended at axis of revolution by substructure is 360° divided by number of shell support modes.

Figure F.1 — Typical finite element representation of cooling tower with column supports

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