BUILDING CODE FOR REINFORCED CONCRETE COOLING TOWERS

By

F. SEBŐK

Department of Reinforced Concrete Structures, Technical University, Budapest

(Received: August 21st, 1980)

There are several ways to describe the role of building codes in civil engineering practice.

According to the first approach, the itemized rules define a system of requirements matching the spirit, engineering knowledge and possibilities of that age, and can be considered as a kind of building law. Its enforcement means for the society to safeguard its demand deemed to be essential; at the same time it exonerates the builder if its specifications have been respected.

In a less rigorous concept the building codes are manuals aiding professional skill. It is a world-wide phenomenon that both theoretical and laboratory research and site experience only slowly get to the user. The practicing engineer is prevented by overburdening, language difficulties, or sometimes, by the lack of fundamental knowledge, from utilizing in his daily work the newest, reliable information. Thus, the purpose of building codes may be described as to act as an encyclopedy of basic engineering knowledge.

These ideas became actual by the recent introduction of large r.c. cooling tower shells into the Hungarian building practice, motivating compilation of the relating major rules.

Issuing these specifications essentially relies on three sources. The most important support was obtained from reviewing some hundreds of papers in periodicals, research reports, doctor's theses and symposium lectures. Outstanding research programs have been carried out by Professors *W. Zerna, W. Krätzig* and their co-workers at the *Technical University in Hannover* and later, at the *Ruhr University in Bochum*. In other cases, dubious statements by whatsoever renowned famous authors published in acknowledged publications had to be accepted with reservation. There was an astonishing number of publications merely recapitulating earlier research results.

These considerations directed our attention to technical recommendations and standards of other countries directly or indirectly referring to cooling towers, presuming that their specifications rely on theoretically elaborated and practically proven data.

By the time, the most detailed regulations are found in the British Standards. Parts 3 and 4 of Code of Practice No. 4485 issued in 1977 and in 1975, resp., concern functional, thermal and structural design of cooling towers. Part 4 often refers to Part 2 of Chapter V of the basic standard CP 3 on the determination of wind loads. Interestingly, these specifications are rather explanatory than compulsory, in contrast with those in other countries.

Also Soviet standards SNIP II—6—74 are up-to-date national standards issued in 1974, specifying overall dispositions for determining wind loads, although without special concern of cooling towers.

Appendix 4 of load standard DIN 1055, still in virtue in the Federal Republic of Germany, has been issued in 1938, completed in the meantime by some dispositions by the federal state of Bavaria in 1969. Considering the revision of the standard now going on, improvements based on wind tunnel tests are admitted, provided they are granted by the local building authorities. Special expertizes have to be acquired for structures where behaviour is significantly affected by wind loads such as for arched surfaces or if air currents may cause dynamic overloads. Accordingly, the DIN specifications do not hold at all for cooling towers. This lack of regulation induced the *Union of Industrial Energetics (VIK)* to issue technical directives in 1970, practically enforced by building authorities.

A similar trend prevails in the USA where *ACI Working Committee 334* under the guidance of *D. P. Billington* and *P. L. Gould* has developed recommendations for reinforced concrete cooling towers. Its text with comments has been published in ACI Journal, January 1977, with several references on load standard ANSI A. 58.1 "Building Code Requirements for Minimum Design Loads in Buildings and Other Structures", issued in 1972.

National directives may be considered as comprised in *CEB (Comité Européen du Béton)* directives — in fact, rather general by character — published in November 1976 as Report 116-D. Valuable advices are found in *Proceedings of the IASS Symposium* held in *Brussels*, 1977, too.

Introduction of any of these in Hungary is, however, made difficult by the basic principles, different from those in other countries, as for instance our concept on safety, material quality testing, the established methods of design and construction. Thus, to pick out any item and fit it into the Hungarian standard system must be conditioned by the simultaneous consideration of every factor.

However, the listed building codes are lacking dispositions on several important problems, that impelled us to undertake independent researches in several scopes. Some of the results are first published in this booklet. For instance, valuable, from some aspects pioneering work was done by investigating wind effect on tall constructions and the stability of shell structures, guided by *Mr. Tamás Kármán* and *Dr. Endre Dulácska*.

The about one and a half year of editing the building code comprised several committee meetings of staff and non-staff experts. In the meantime, working drafts underwent essential changes, taking comments from experienced institutions and enterprises into consideration. We are greatly indebted to the *Department for Technical Development* at the *Ministry of Building and Urban Development*, the *Building Research Institute*, the *Enterprise of Surveying and Soil Testing*, the *Industrial and Agricultural Building Design Office*, as well as to the *Departments* of *Fluid Mechanics* and of *Geotechnique* at the *Technical University*, *Budapest* for their valuable advices. So we are to Messrs *József Thoma*, *Gusztáv Söpkéz* and *László Mérei*, engineers at the *Design Office for Civil Engineering*.

The developed building code may be considered as representing the actual engineering niveau, excluding definite answers in several, important problems. For instance, the impact of aerodynamic effect on groups of towers, decisive for siting, cannot be considered as solved. Lack of the exact knowledge of the phenomenon forced us to formulate safe — although presumably rather uneconomical — specifications. Interaction between foundation and wall structure is difficult to evaluate even by computer techniques. Formulation of rules for the effect of inevitable constructional errors would exceed our possibilities, although — according to references — failure of thin shells by stability loss may often be attributed to deviations from the design geometry.

Accordingly, this compilation cannot be considered as final, even, as stressed under Chapter 1: "...deviations from its contents are conceded, and should be specially pondered in each case, in view of peculiar features, recent, reliable theoretical and practical results, provided they do not offend specifications of any other standard in virtue." Nevertheless, issuing this *Tentative Building Code* developed by the *Department of Reinforced Concrete Structures*, *Technical University*, *Budapest*, and the *Research Group of Engineering Mechanics* gratifies us to have made a contribution to the development of Hungarian building science.

BUILDING CODE

for designing the structure and construction technology of large reinforced concrete cooling towers

1. Introduction

Engineering problems of large reinforced concrete cooling towers are not concerned with by any Hungarian standard in virtue.

This building code — developed for the preparations of the Bicske power station — relies on related standards, special literature, research results and construction experience, provides recommendations for investors, designers and builders. Deviations from its contents are conceded, and should be specially pondered in each case, in view of peculiar features, recent, reliable theoretical and practical results, provided they do not offend specifications of any other standard in virtue.

The design has to cope with circumstances arising from the unusual tower height as, for instance, the possibility of inspection and maintenance, lightning protection, etc. The possibilities of other uses beyond direct, operational function (e.g. accommodation of instruments, geodetic marks) have to be examined, too.

2. Validity

Cooling towers in the sense of this Building Code are circular symmetric constructions for natural or mechanical draught cooling of industrial water. Ratio of total height to base circle diameter is 1.0 to 1.5, ratio of least to greatest diameter is 0.5 to 1.0. Large size is understood as a height of 75 to 150 m.

3. Siting

Towers have to be separated from each other and from natural or artificial ground objects of similar height, affecting the air flow, by at least $0.5D$ where D is diameter of the largest circle of cooling towers in the array. This minimum spacing may be reduced on the basis of reliable tests or data.

4. Principal structural members and their design

4.1 General

Principal structural elements of cooling towers are: the shell, the supporting columns and the foundation.

4.2 The shell

The shell is expected to produce air flow for cooling by creating pressure difference. Its shape has to be selected from air flow, structural and constructional aspects. The usual shape is cylindrical or a double-curvature surface of revolution, generally with a hyperbolic directrix. Its design has to strive to exclude no-strain deformation. To this purpose, reinforcing rings have to be developed, at least at the top and bottom edges of the shell, possibly by gradually varying the wall thickness.

4.3 Supporting columns

Supporting columns are usually V- or X-shaped. Much care has to be spent on the connection between bottom edge ring and supports, especially in case of prestressing or prefabrication. Shape and cross section of supporting columns have to be selected to provide minimum air resistance.

4.4 Foundation

Foundations usually consist of foundation rings, exceptionally of separate foundation bodies usually complemented by piling.

Foundation structure has to minimize uneven subsidence. Support subsidences affecting a major sector (one-third, one-half) of the foundation are especially adverse, by entraining no-strain deformations affecting the entire shell structure and impairing its stability. The effect of no-strain deformations may be much reduced by applying a bracing ring on the upper edge of the shell.

5. Materials and material characteristics

5.1 Steel

The reinforcing steel should comply with the specifications of Hungarian standard MSz 15022/1.

5.2 Concrete

5.2.1 General requirements

The shell concrete should be at least grade B 280; in the case of slip-form building system, its one-day strength has to correspond to grade 28 N/mm^2.

Information is found in Appendix 1. Design characteristics of concrete are specified in MSz 15022/1—2.

5.2.2 *Cement*

Portland cement at least grade C 350 has to be applied. Properties of concretes made with sulfate resisting cement — advisable in aggressive environment — have to be checked in laboratory tests.

In the slip-form building system, the shell concrete has to be made with one and the same cement type throughout.

5.2.3 *Admixtures*

Admixtures applied to facilitate placing, to control setting and hardening times or to obturate pores should be supplied with certificate of suitability and of quality by the manufacturer or importer.

Properties of concretes made with an admixture have to be tested in laboratory in each case.

5.3 *Preliminary laboratory tests*

Preliminary laboratory tests have to supply reliable data for design and construction on:

- early half-, one- and two-day concrete strength and deformation characteristics;
- concrete hardening process;
- watertightness;
- every effect of the applied admixtures.

Dispositions needed to offset likely concrete impacts during construction (e.g. segregation during transport, thermal phenomena, excessive evaporation due to wind, shuttering movement) have to be foreseen.

At last, material modifications due to soft water corrosion and other anticipated aggressive effects have to be examined.

6. Loads and loading displacements

6.1 *Permanent loads*

Dead load is the permanent load of cooling towers.

Dead load is to be computed by multiplying the volume of the structure according to its design dimensions by density, given in standard MSz 510—76.

6.2 *Permanent accidental loads*

6.2.1 *Mechanical equipment*

Basic value of permanent accidental loads comprises nominal weights of formwork, hoisting equipment and other construction machines during erection.

In the final state of the cooling tower, nominal weights of installed equipment, as well as of other installations connected have to be accounted for.

6.2.2 *Thermal load*

The value of uniform warming up has to be reckoned with according to technology conditions.

In winter, a temperature difference of 10 °C across the wall is assumed to arise, that is, the outer surface is cooled so much below the inner one.

The possibility of uneven volume change due to moisture content variation across the shell thickness may be reckoned with as an additional ±5 °C (fictive) temperature difference.

In the summer season, sunshine and warming up of the air do not cause a permanent thermal load.

6.3 *Short-time, accidental loads*

6.3.1 *Snow and ice loads*

Under ordinary circumstances, snow and ice loads need not be reckoned with.

6.3.2 *Wind loads*

6.3.2.1 Determination of wind loads

The wind load value acting normally to the surface is given by

$$w = (c_{ex} - c_{in}) \cdot w_t$$

where w_t is the dynamic pressure at the given height, and c is the pressure coefficient depending on the position of the tested point around the circle.

6.3.2.2 Basic and extreme values of dynamic pressure

Basic and extreme values of dynamic pressure acting at height h of the construction have to be computed according to the basic code. The formula indicated there as to be valid up to 100 m may be applied up to 150 m. Analysis of the whole surface of the cooling tower simultaneously permits the use of the reducing factor 0.9.

6.3.2.3 Local modifications of dynamic pressure

The dynamic pressure value determined according to the previous clause may be modified upon engineering considerations by ±10%, depending on the ground roughness and building size.

6.3.2.4 External pressure coefficient of wind load in case of a solitary construction

External pressure coefficient of wind load c_{ex} may be assumed — in lack of exacter aerodynamic analyses — according to the following two tables — as a function of surface ribs

$$\beta = \frac{k}{s}$$

where k is the rib height and s is rib spacing at one-third height of the shell. Rib height should be at least 30 mm and rib width $2k$ to $5k$. φ is the central angle measured from the incident wind direction. For $\beta < 0.006$, standard values for smooth cylindrical constructions have to be applied.

6.3.2.5 External pressure coefficients of wind load for tower groups

The wind load value increased by the interference of buildings standing in groups is advisably determined in a test simulating local conditions. Else, the following practical rules may be recommended:

Interference of the buildings has to be reckoned with if their axes are spaced at less than $2.5D$, where D is the diameter of the basic circle, or for a rectangular structure, the length of the diagonal.

Mathematical relationships

Ribbing	I	II	III
0.006 — 0.010	$1 - 2.3\left(\sin\frac{90}{73}\varphi\right)^{2,166}$	$-1.3 + 0.8\left\{\sin\frac{90}{24}(\varphi - 73)\right\}^{2,395}$	-0.5
0.010 — 0.016	$1 - 2.2\left(\sin\frac{90}{72}\varphi\right)^{2,205}$	$-1.2 + 0.7\left\{\sin\frac{90}{23}(\varphi - 72)\right\}^{2,395}$	-0.5
0.016 — 0.025	$1 - 2.1\left(\sin\frac{90}{71}\varphi\right)^{2,239}$	$-1.1 + 0.6\left\{\sin\frac{90}{22}(\varphi - 71)\right\}^{2,395}$	-0.5
0.025 — 0.100	$1 - 2.0\left(\sin\frac{90}{70}\varphi\right)^{2,267}$	$-1.0 + 0.5\left\{\sin\frac{90}{21}(\varphi - 70)\right\}^{2,395}$	-0.5

Ranges of validity

Ribbing	I	II	III
$0.006 \leq \beta < 0.010$	$0 \leq \varphi < 73°$	$73° \leq \varphi < 96°$	$96° \leq \varphi < 180°$
$0.010 \leq \beta < 0.016$	$0 \leq \varphi < 72°$	$72° \leq \varphi < 94°$	$94° \leq \varphi < 180°$
$0.016 \leq \beta < 0.025$	$0 \leq \varphi < 71°$	$71° \leq \varphi < 92°$	$92° \leq \varphi < 180°$
$0.025 \leq \beta < 0.100$	$0 \leq \varphi < 70°$	$70° \leq \varphi < 90°$	$90° \leq \varphi < 180°$

Columns I, II and III refer to segments of the circle area where the formulae hold

In the negative suction part of the diagram of the external pressure coefficient, the effect of interference may be reckoned with by an increasing factor of 1.0 to 1.25, referring to spacings $2.5D$ and $0.75D$, respectively. Between these limits, quadratic interpolation has to be applied.

6.3.2.6 Internal pressure coefficient

Internal pressure coefficient c_{in} for cooling towers may be taken as 0.5.

6.3.2.7 Wind load acting on the upper edge ring

Twice the wind load determined according to the precedings has to be applied for the interacting strip of about 2 m.

6.3.3 Thermal loads

6.3.3.1 Operating conditions

For natural draught-operation cooling towers, very strong colds may be assumed to cause — in addition to those under *6.2.2* — further temperature difference between the inner and outer wall surface, of 10 °C extreme value.

For wet-operation cooling towers, the wall likely to be soaked, this temperature difference should be taken greater by ±5 °C.

6.3.3.2 Standstill condition

In summer standstill and during construction, sunshine and warming up of outer air may be assumed to cause an extreme temperature difference of 20 °C across the shell wall, that is, the outer surface is warmer than the inner one.

This value refers to dry-operation cooling towers; wet operation combined with a volume change due to moisture may be reckoned with as a fictive temperature difference by further ±10 °C.

An admissible approximation is to consider the outer warming to affect the entire structure in circular symmetry.

6.4 Extraordinary loads

In modelling the structure, the possibility that at the riskiest section two neighbouring columns get uncoupled and do not bear any forces has to be reckoned with.

Seismic effect on the building has to be considered as an extraordinary load, where the propagation velocity of the seismic wave has to be taken into account.

6.5 Secondary effects

In conformity with the specifications of the standard, the effect of ground subsidence due to design loads and creep have not to be accounted for as accidental loads but by adequate modelling the structure or the structural material.

6.6 Comments

The above enumeration involves only the usual, major loads and effects on cooling towers. Their range may be completed after due estimation of local circumstances.

In undermined areas, consequences of collapse of underground cavities or of soil subsidences, the effect of dynamic collision of vehicles to the supporting columns, and any effect likely to affect the strength of the cooling tower have to be examined.

7. Safety and destination factors

7.1 Safety factors

Safety factors have to be assumed in conformity with specifications of standard series MSz 15020. Safety factor for the thermal load has to be uniformly taken as 1,2.

7.2 Destination factors

Calculations for the final, operating state of cooling towers may involve a destination factor $\gamma = 1.0$; a higher factor in general is not justified by the importance of the construction, except for nuclear power stations.

Destination factor for short-time meteorological loads related to some temporary construction, standstill condition of the building may be reduced on probabilistic considerations.

7.3 Simultaneity factor

Simultaneity factor for combined loads has to be assumed in conformity with the quoted standard.

8. Determination of stresses

Analysis of shells may rely on the membrane theory; the effect of disturbances at the edges has, however, to be determined also by the bending theory.

Shell width interacting with the reinforcing ring is six times the wall design thickness.

The lower edge ring may be calculated for loads in its curved plane as a deep beam; its curvature may be omitted.

Displacements of supports covering short sectors of the foundation (e.g. failure of one or at most two neighbouring columns) affect stresses of the shell in fact only in the vicinity of the lower edge, so they can be considered as edge disturbances.

The analysis should handle subsoil, foundation, supports and shell as a structural unit since their interaction is significant.

A separate analysis of structural members is but an approximation, with consequences to be pondered.

Numerical methods (such as methods of finite differences or finite elements, analogy of bar systems etc.) are convenient, but correctness of computer outputs has to be ascertained with a maximum of care by the designer.

9. Stability analysis

9.1 General

Stability analysis of cooling towers has to reckon with the detrimental effects of concrete cracks, calculated and random eccentricities as well as of the inelastic properties of concrete. Buckling modes likely to affect the shell structure are:

— radial buckling (with a horizontal, circular wave);
— local buckling (with a combined wave surface over a small area);
— annular buckling (meridional wave);
— general buckling (combined wave surface throughout the shell).

In the general buckling analysis of hyperbolic shells the possibility of no-strain buckling should always be considered.

9.2 Initial, random eccentricity

In general buckling analysis, an initial random eccentricity

$$e_{0,\mathrm{ran}} = R/3000$$

while in local and annular buckling analysis

$$e_{0,\mathrm{ran}} = R/1000$$

may be assumed where R is the curvature radius of the horizontal section at mid-height of the shell structure. The calculated eccentricity $e_{0,\mathrm{calc}}$ has to be determined by the bending theory at the maximum buckling amplitude.

Stability analysis has to involve the more adverse of eccentricities from

$$e_0 = e_{0,\mathrm{ran}} + \frac{1}{2} e_{0,\mathrm{calc}}$$

$$e_0 = \frac{1}{2} e_{0,\mathrm{ran}} + e_{0,\mathrm{calc}}.$$

10. Dynamic analyses

10.1 Dynamic effect of wind load

In analysing cooling towers for the dynamic effect of wind load, critical natural frequencies have to be assumed.

The standard value specified for slender towers has to be accounted for as dynamic wind load.

10.2 Seismic effect

As an extraordinary load the seismic effect has to be reckoned with, if the structure is built in a site where an earthquake grade VI, VII, VIII or IX of the seismic intensity scale MSK 64 may occur. Mass forces have to be determined from the acceleration corresponding to the grade.

For shell-structure cooling towers, also the effect of vertical seismic accelerations has to be accounted for. The value of the vertical seismic effect is 25% of the horizontal one.

10.3 Natural frequency of the shell

The lowest natural frequency of shells is that for no-strain or similar deformations.

Determination of the natural frequency has to take into consideration that it is also subject to deformations of the supporting structure and of the soil, as well as to cracks in the r.c. structure.

11. Constructional rules

11.1 Minimum wall thickness

Wall thickness of the shell must not be less than 170 mm.

11.2 Minimum shell reinforcement

Cross-sectional area of reinforcement in either direction shall not be less than 0.2% of the cross-sectional area.

Minimum diameter of reinforcement for tensile and compressive load is 10 and 12 mm, resp.

11.3 Reinforcement spacing

The shell has to be reinforced by two layers, where meridional bars are inside and circular ones outside. Between the two layers a free distance of at least 70 mm should be kept.

At least four ties have to be applied each square meter.

Reinforcement spacing must not exceed 250 mm.

11.4 Reinforcing bar splices

At a working level, at most one fourth of meridional bars may be spliced. Splices have to be distributed uniformly along the whole circumference. At most three neighbouring bars may be spliced.

11.5 Design of openings

Corners of openings have to be reinforced by at least one and a half times the bar area cut by the hole. Near corners, diagonal bars have to be applied.

11.6 Concrete cover

Concrete cover in the shell and the supporting columns is at least 20 mm and more in moist and aggressive environment.

12. Design considerations for the construction

12.1 Material testing

Design concrete properties — such as early strength — have to be continuously checked according to MSz 4720—80 during construction.

12.2 Building accuracy and checking

12.2.1 Tolerances

Checkpoints adjusted to a horizontal circle of the cooling tower must not deviate from the design geometry by more than 50 mm. An effective deviation over 80 mm may be tolerated in 5% of the checkpoints but the error limit of 100 mm must not be exceeded anywhere.

Beside the local inaccuracies of the circle, the indicated limits comprise the off-centred displacements due to axis position that must not be more than half of the total value.

Readings of two neighbouring checkpoints must not differ by more than 30 mm.

Wall thickness must not differ from the design value by more than —5 or +15 mm.

In the case of non-compliance with the limits above, the designer shall calculate the effect of these deviations.

12.2.2 *Checking survey*

Construction accuracy has to be checked by frequent measurements. After a rise by not more than 5 m, position of points uniformly distributed around the shell circumference has to be determined. These points have to be assigned by steered units of the slip-form building system, else at 4 to 8 ° central angles apart. Measurements should suit ±10 mm accuracy determination of

- position of the axis,
- true mean radius,
- deviation of checkpoints from the mean radius.

Measurements and evaluation of results have to be carried out to deliver directly utilizable data within a few hours.

12.2.3 *Correction requirement*

The path of the shuttering has to be modified if any reading deviates from its design value by 20 mm, without regard of it being originated from construction inaccuracy or other effects (e.g. uneven subsidence).

Appendix I

Recommendations for concreting cooling towers made in slip-form using ready-mixed concrete

The concrete has to be made with a high early strength, finely ground high-alumina cement. Its residue on the sieve 0.09 (No. 4900) has to be less than 12 percent by mass, its Blaine specific surface has to be higher than 250 m^2/kg. These requirements are economically met by Portland cement C 350 (MSz 4702). With careful consideration the use of other qualities may be admissible, too.

Freshly mixed concrete, low in fines, is generally stiffer and also of higher early strength. Clay and silt contents are rather detrimental. Fineness modulus should be 6.0 to 7.2. Fines content below 1 mm must not be higher than 10 to 27 percent by mass. Maximum particle size $D_{\max}$ should be as large as possible complying with other prescriptions.

The 0.30 m thick bottom layer of aggregates stored on the ground must not be applied for high early strength concrete.

In designing the concrete composition, the cement dosage should range from 290 to 360 kg/m^3, depending on aggregate grading.

The concrete should be of plastic consistency. Taking the range between the lower and upper limit curve of aggregate class I, the optimum water/cement ratio ranges from 0.46 to 0.50.

A concrete of the described composition, taking also Chapter 5 of this Building Code into consideration, meets requirements for concretes B 280/200, placed in slip-form by the usual technology and cured under natural hardening conditions.

Appendix II

Approximate method of stability analysis

In lack of any exacter method, a simplified stability analysis of the ribless shell is allowed.

Let us determine the linear critical force n_K^{lin} of the homogeneous elastic shell according to the linear buckling theory, and the upper snap-through critical force $n_{K,0.5}^{up}$ of the elastic homogeneous shell with an initial eccentricity $e_0 = 0.5h_t$ by the non-linear buckling theory.

Quotient of $n_{K,0.5}^{up}$ by n_K^{lin} is $\varrho_{0.5}$:

$$\varrho_{0.5} = \frac{n_{K,0.5}^{up}}{n_K^{\mathrm{lin}}}\,.$$

Upper critical force of the elastic homogeneous shell is obtained as:

$$n_K^{up} = \varrho \cdot n_K^{\mathrm{lin}}$$

where the approximation

$$\varrho = \frac{1}{1 + 2\left(\frac{1}{\varrho_{0.5}} - 1\right)\frac{e_0}{h_t}}$$

is allowed.

Here h_t is the shell design thickness.

The effect of cracking in reducing the critical load may be reckoned with by using the multiplying factor:

$$\beta_r = \left(1 - \frac{2e_0}{h_t}\right)^3 \left[1 + 2\left(\frac{1}{\varrho_{0.5}} - 1\right)\frac{e_0}{h_t}\right](1 - \psi) + \psi$$

β_r values vs. $e_0/h_t, \psi$ and $\varrho_{0.5}$ have been tabulated below.

ψ values *vs.* one-way reinforcement percentage μ:

$n\mu$ %	0	0.1	0.2	0.3	0.4
ψ	0	0.32	0.51	0.68	0.83

where

$$n = E_a/E_b\,.$$

Factor β_r

$\varrho_{t,s}$	ψ \ e_0/h_t	0	0.1	0.2	0.3	0.4	0.5
1.0	1	1	1	1	1	1	1
	0.8	1	0.90	0.84	0.81	0.80	0.8
	0.6	1	0.80	0.69	0.63	0.60	0.6
	0.4	1	0.71	0.53	0.44	0.40	0.4
	0.2	1	0.61	0.37	0.25	0.21	0.2
	0	1	0.51	0.22	0.06	0.01	0
0.75	1	1	1	1	1	1	1
	0.8	1	0.91	0.85	0.82	0.80	0.8
	0.6	1	0.82	0.70	0.63	0.60	0.6
	0.4	1	0.73	0.55	0.45	0.41	0.4
	0.2	1	0.64	0.40	0.26	0.40	0.2
	0	1	0.55	0.24	0.08	0.01	0
0.5	1	1	1	1	1	1	1
	0.8	1	0.92	0.86	0.82	0.80	0.8
	0.6	1	0.85	0.72	0.64	0.61	0.6
	0.4	1	0.77	0.58	0.46	0.41	0.4
	0.2	1	0.69	0.44	0.28	0.21	0.2
	0	1	0.61	0.30	0.10	0.01	0
0.25	1	1	1	1	1	1	1
	0.8	1	0.96	0.90	0.84	0.81	0.8
	0.6	1	0.93	0.79	0.67	0.61	0.6
	0.4	1	0.89	0.69	0.51	0.42	0.4
	0.2	1	0.86	0.58	0.34	0.22	0.2
	0	1	0.82	0.48	0.18	0.03	0

The effect of plastic behaviour to reduce the critical load may be reckoned with by using coefficient

$$\xi = \frac{1}{1 + \left\{\frac{\varrho\beta}{1.2} \cdot \frac{n_K^{\text{lin}}}{n_{H0}}\left[1 + \frac{10}{3}\left(\frac{e_0}{h_t}\right)\right]\right\}^2}$$

where

$$n_{H0} = F_b \cdot \sigma_{bH} + F_a \cdot \sigma_{aH},$$

ultimate compressive load of shell surface of unit width before buckling. Its determination has to consider the extreme values of structural thickness.

Accordingly, extreme value of the critical force inducing buckling of the shell is obtained from

$$N_{K,H} = \frac{\xi \cdot \beta_r \cdot \varrho \cdot n_K^{\text{lin}}}{K}$$

to be compared with critical compressive force N_M. Coefficient K results from:

$$K = 1.25 + \frac{5}{3}(1 - \varrho_{0.5}) \,.$$

Summary

Introduction of large cooling towers in this country demands the official regulation of structural design and construction technology. Principles of relevant technical directives and the final text of the Building Code as a result of discussions have been presented here.

Dr. Ferenc SEBŐK, H-1521 Budapest