Table 3. Requirements for freeze-thaw resistance in accordance with OST D-05.03.04 Concrete pavements [13]

Tabela 3. Wymagania dla mrozoodporności betonu zgodnie z OST D-05.03.04 Nawierzchnia z betonu cementowego [13]

Exposure Class	Factor $\bar{L}$ PN-EN 480-11:2008	Category PN-EN 13877-2:2013	PKN-CEN/TS 12390-9:2007 Mass lost after		m_{56}/m_{28}
			28 cycles (m_{28})	56 cycles (m_{56})	
		FT0	–	–	–
XF3	≤ 0,250 mm	FT1	m_{28} average ≤ 1,0 kg/m², while no single result > 1,5 kg/m²	–	–
XF4	≤ 0,200 mm	FT2	m_{28} average ≤ 0,5 kg/m²	m_{56} average ≤ 1,0 kg/m², while no single result > 1,5 kg/m²	≤ 2

ce presented in LST 1974:2012 [8]. It is limited to 5% and defined as:

$$\Delta f_c = (f_{c28} - f_c^{Ncycle})/f_{c28}$$

where

f_c^{Ncycle} – compressive strength after N cycles of freezing-thawing (for XF4 it is recommended Ncycle = 300);

f_{c28} – 28 days compressive strength.

In BS 8500-1:2006 [1] there is Table A.8 that gives concrete properties and limiting values to resistthe XF exposure classes. These recommended concrete qualities are suitable for an intended working life of both „at least 50 years" and „at least 100 years". There are other limits minimum cement content for lower and higher strength concrete in specific exposure classes and they depends on aggregate size. Requirement for minimum air content is also applicable to lower strength concrete is specific exposure classes (Table 4).

Similar concept is in German DIN 1045-2:2008 [3] but due to more severe climate the requirements are more restricted as the limit value of air content depending on the aggregate size is: up to 8 mm ≥ 5,5%; up to 16 mm ≥ 4,5%; up to 32 mm ≥ 4,0%; up to 64 mm ≥ 3,5%. Probably in the nearest future the same idea will be implemented in new version of PN-B-06265:2004.

Summary

NPP construction in Poland has to be based on standards or some technical guidelines. The only guide that covers almost all aspects of construction phases is RCC-CW published by AFCEN. The problem is that it is based on French experience and European Norms (EN) but also partially on French National Standards, that are not always compatible polish conditions. Resistance to freeze-thaw cycles is, next to ASR [5], one of the example where there is a need for to adapt these requirements.

Table 4. Limiting values for composition and properties of concrete to resist freezing and thawing according to BS 8500-1:2006 [1]

Tabela 4. Wartości graniczne dla składu i właściwości betonu z uwagi na mrozoodporność zgodnie z BS 8500-1:2006 [1]

Exposure class	Min. strength class	Max w/c ratio	Min. air content and min. cement or combination content (kg/m³) for max. aggregate size			
			32/40 mm	20 mm	14 mm	10 mm
XF1	C20/25	0,60	3,0 260	3,5 280	4,5 300	5,5 320
	C28/35	0,60	– 260	– 280	– 300	– 320
XF2	C25/30	0,60	3,0 260	3,5 280	4,5 300	5,5 320
	C32/40	0,55	– 280	– 300	– 320	– 340
XF3	C25/30	0,60	3,0 260	3,5 280	4,5 300	5,5 320
	C40/50	0,45	– 320	– 340	– 360	– 360
XF4	C28/35	0,55	3,0 280	3,5 300	4,5 320	5,5 340
	C40/50	0,45	– 320	– 340	– 360	– 360

Reference

[1] BS 8500-1:2006 Concrete – Complementary British Standard to BS EN 206-1 – Part 1: Method of specifying and guidance for the specifier.

[2] CEN/TR 15177 Testing the freeze-thaw resistance of concrete – Internal structural damage.

[3] DIN 1045-2:2008 Concrete, reinforced and prestressed concrete structures – Part 2: Concrete – Specification, properties, production and conformity – Application rules for DIN EN 206-1 (in German).

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[6] Jóźwiak-Niedźwiedzka D. 2008. „Metody badania mrozoodporności betonu" w *Trwałość betonu: metody badań właściwości determinujących trwałość materiału w różnych warunkach eksploatacji*, Sawicka V. (Ed.) p: 161 ÷ 181. Opole. Wydawnictwo Instytut Śląski.

[7] Kossowska-Cezak U. 2014. „Zmiany wieloletnie liczby termicznych dni charakterystycznych w Warszawie (1951–2010)". *Prace Geograficzne* 136: 9 ÷ 30. Kraków. Instytut Geografii i Gospodarki Przestrzennej UJ. DOI: 10.4467/20833113PG.14.001.1639.

[8] LST 1974:2012 Rules for the Application of LST EN 206-1 and Additional National Requirements (in Lithuanian).

[9] NF P 18-424:2008 Bétons – Essai de gel sur béton durci – Gel dans l'eau – Dégel dans l'eau (in French).

[10] NF P 18-425:2008 Bétons – Essai de gel sur béton durci – Gel dans l'air – Dégel dans l'eau (in French).

[11] NF P 18-545:2011 Granulats – Éléments de définition, conformité et codification (in French).

[12] NF EN 206/CN:2014 Béton – Spécification, performance, production et conformité – Complément national à la norme NF EN 206 (in French).

[13] OST D-05.03.04. 2011. Concrete pavements (in Polish). GDKiA.

[14] OST M-13.01.00. 2011. Structural concrete in bridge construction, GDKiA (in Polish).

[15] PKN-CEN/TS 12390-9: 2007 Testing hardened concrete – Part 9: Freeze-thaw resistance – Scaling.

[16] Piotrowski Tomasz. 2016. „Wymagania RCC-CW dotyczące betonu przy budowie elektrowni jądrowych PWR w świetle PN-EN 206:2014". *Materiały Budowlane* 529 (9): 89 ÷ 91; DOI: 10.15199/33.2016.09.35.

[17] RCC-CW. 2015. Rules for Design and Construction of PWR nuclear civil works. AFCEN.

[18] SS 13 72 44:1995 Concrete testing; Hardened concrete; Scaling at freezing (in Swedish).

[19] XP P 18-420:2012 Béton – Essai d'écaillage des surfaces de béton durci exposées au gel en présence d'une solution saline (in French).

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