formulated in PN-EN 12620+A1:2010. In Annex F it is stated that the aggregates can be considered resistant to freeze-thaw attack when the water absorption of the aggregates determined in accordance with PN-EN 1097-6:2013 is not greater than 1%. However, many satisfactory aggregates have higher absorption values. In such cases, resistance to freezing of aggregates shall be declared in accordance with the relevant category based on either a freeze-thaw value determined in accordance with PN-EN 1367-1:2007 or a magnesium sulfate value determined in accordance with PN-EN 1367-2:2010. The magnesium sulfate test is considered most appropriate for situations where the aggregates may be exposed to seawater or de-icing salts. Following an informative Annex F, freeze-thaw severity related to climate and end use are specified in categories which can be used to set the required level of categories freeze-thaw resistance or magnesium sulfate soundness (Table 1).

ments of code A aggregated described in NF P 18-545:2004 [11] – it means that $WA_{24} \leq 2,5\%$ measured according to PN-EN 1097-6:2013. In qualification stage of aggregate freeze-thaw susceptibility can be measured according to PN-EN 1367-1:2007 (F) or PN-EN 1367-2:2010 (MS) or PN-EN 1097-2:2010 (LA), or PN-EN 1097-6:2013 (WA_{24}). In suitability test and conformity control these tests are not required.

The use of fly ash, either as an addition or as a constituent of the cement, is acceptable on condition that the loss on ignition of the fly ash respects Category A of PN-EN 450-1:2012 (loss of ignition, L ≤ 5% measured according to PN-EN 196-2:2013). In RCC-CW qualification stage for nominal concrete mix it is repeated after PN-EN 206:2014 that concrete subject to exposure classes XF2, XF3 or XF4 shall have a minimum air content of 4% measured according to PN-EN 12350-7:2011. In addition for concrete subject to exposure classes XF3 or XF4 and formulated with an air-entraining admixture, the qualification test shall include (for the one of the nominal concrete mix) a measurement of the spacing factor $\bar{L}$ according to PN-EN 480-11:2008 with the following criteria:

- $\bar{L} \leq 250$ μm for concrete subject to exposure class XF3;
- $\bar{L} \leq 200$ μm for concrete subject to exposure class XF4.

This requirement could be replaced by the performance tests based on French experience using freezing map and de-icing map of France (Figure 1). They present freezing zones divided onto:

- mild freezing conditions – less than 3 days with temperature < -5°C;
- moderate freezing conditions – other cases than mild or severe;
- severe freezing conditions – more than 10 days with temperature < -10°C;

and de-icing zones based on number of days with de-icing:

- not frequent: n < 10;
- frequent: 10 ≤ n < 30;
- very frequent: n ≥ 30.

In Poland, the appropriate map could be prepared by IMGW based on years of observations, eg. for the Suwałki station in the period 1971-2010 the average number of very cold days with T_{max} <-10°C was 5, but 7 times in a 40 year period, the number of very cold days was more than 10 and 13 times was >-5 (Figure 2). However, if we consider as the criterion days T_{min} <-10°C in Warsaw these days in winter average is 18 [7].

Following RCC-CW [17] for concrete in XF3 and XF4 in place of the measurement of the factor $\bar{L}$ or in case

Table 1. Categories for aggregate freeze-thaw resistance and the requirements for freeze-thaw severity category related to end use in continental climate according to PN-EN 12620+A1:2010

Tabela 1. Kategorie mrozoodporności kruszywa i wymagania dla poszczególnych kategorii nasilenia zamrażania-rozmrażania w zależności od końcowego zastosowania w klimacie kontynentalnym zgodnie z PN-EN 12620+A1:2010

PN-EN 1367-1:2007		PN-EN 1367-2:2010		PN-EN 12620+A1:2010	
Freeze-thaw	Category	Magnesium sulfate value	Category	Environmental conditions	Climate
% loss of mass	F	% loss of mass	MS	(XF acc. to PN-EN 206:2014)	Continental
≤ 1	F_1	≤ 18	MS_{18}	Frost free or dry situation	Not required
≤ 2	F_2	≤ 25	MS_{25}	Partial saturation, no salt (XF1)	F_2 or MS_{25}
≤ 4	F_3	≤ 35	MS_{35}	Saturated, no salt (XF3)	F_1 or MS_{18}
> 4	$F_{Declared}$	> 35	$MS_{Declared}$	Salt – seawater or road surfaces (XF2, XF4)	F_1 or MS_{18}
No requirement	F_{NR}	No requirement	MS_{NR}	Airfield surfacings (XF4)	F_1 or MS_{18}

Requirements given in RCC-CW

In RCC-CW the basic requirements for concrete resulting from XF exposure classes that are expressed in limiting values for composition and properties of concrete are increased [16]. Additional requirements related to freeze-thaw attack are formulated both for aggregates as a component and concrete as a final product as well.

Aggregates for concrete subject to exposure classes XF3 and XF4 should not be liable to frost damage according to NF P 18-545 [11]. In addition, the water absorption of both fine and coarse aggregates shall comply with the require-

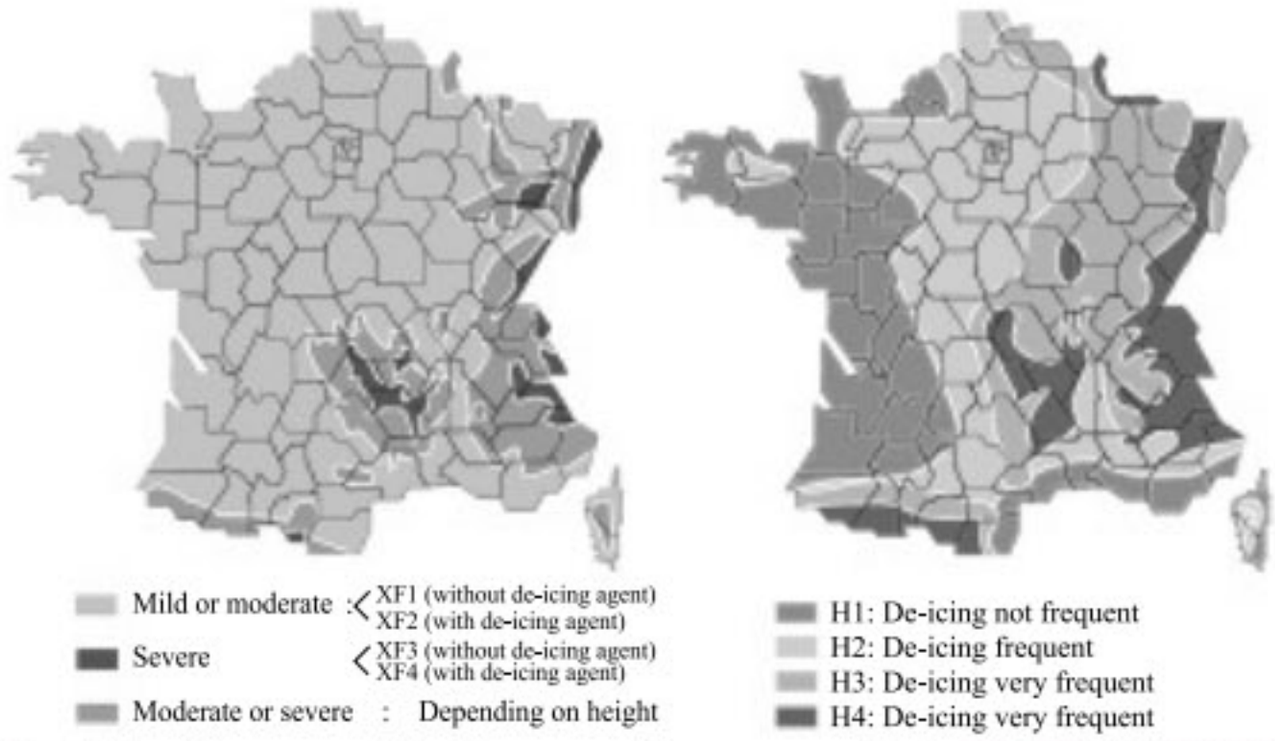

Fig. 1. Freezing map and de-icing map of France according to NF EN 206/CN [12]

Rys. 2. Mapa nasilenia zamrażania-rozmrażania oraz odladzania we Francji zgodnie z NF EN 206/CN [12]