Latest developments in the standardization of concrete

Christoph Müller, VDZ
Chairman CEN/TC 104

JRC Side-event to the Standardization Summit - Construction Standards
3 June Riga
<table>
<thead>
<tr>
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<th>Concepts for durable concrete structures</th>
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<td>Conclusions</td>
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</table>
AGENDA

1. Concepts for durable concrete structures
2. Concrete Pavements – an overview
3. Conclusions
Relationships between EN 206 and standards for design and execution

EN 206
Concrete - Specification, performance, production and conformity

EN 1990 (Eurocode)
Basis of structural design

EN 1992 (Eurocode 2)
Design of concrete structures

EN 13670 Execution

EN 13369 Precast concrete

National building legislation and National building regulation (in the place of use)
Relationships between EN 206 and standards for constituents and test standards

EN 206
Concrete - Specification, performance, production and conformity

EN 197
Cement

EN 1008
Mixing water

EN 12620
Aggregates for concrete

EN 450
Fly ash for concrete

EN 13263
Silica fume for concrete

EN 15167
Ground granulated blast furnace slag for concrete

EN 13055
Lightweight aggregates

EN 934-1 and-2
Admixtures for concrete

EN 14889
Fibres for concrete

EN 12878
Pigments

EN 12350
Testing fresh concrete

EN 12390
Testing hardened concrete

EN 13791
Assessment of concrete strength in structures

EN 12504
Testing concrete in structures
7. Sustainable use of natural resources

The construction works must be designed, built and demolished in such a way that the use of natural resources is sustainable and in particular ensure the following:

- re-use or recyclability of the construction works, their materials and parts after demolition;
- **durability** of the construction works;
- use of environmentally compatible raw and secondary materials in the construction works.
Elements to ensure Concrete durability

Detection and specification of the exposure conditions

Concrete cover

Composition / performance of the concrete

Execution requirements: Curing etc.
Exposure conditions in Europe

Source: wikipedia
### European concrete standard EN 206: Requirements related to Durability (exposure classes)

<table>
<thead>
<tr>
<th>Exposure-class</th>
<th>European name</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>X0</td>
<td>Zero Risk</td>
<td>No risk of attack</td>
</tr>
<tr>
<td>XC</td>
<td>Carbonation</td>
<td>Carbonation</td>
</tr>
<tr>
<td>XD</td>
<td>De-icing salt</td>
<td>Chloride without sea water</td>
</tr>
<tr>
<td>XS</td>
<td>Sea</td>
<td>Sea water</td>
</tr>
<tr>
<td>XF</td>
<td>Frost</td>
<td>Frost and deicing salts</td>
</tr>
<tr>
<td>XA</td>
<td>Chemical Attack</td>
<td>Chemical attack</td>
</tr>
</tbody>
</table>
**Recommended limiting values for composition of concrete**

### Exposure classes

<table>
<thead>
<tr>
<th>Carbonation-induced corrosion</th>
<th>Chloride-induced corrosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>XC1</td>
<td>XS1 XD1</td>
</tr>
<tr>
<td>XC2</td>
<td>XS2 XD2</td>
</tr>
<tr>
<td>XC3</td>
<td>XS3 XD3</td>
</tr>
</tbody>
</table>

#### Maximum w/c
- XC1: 0.65
- XC2: 0.60
- XC3: 0.55
- XC4: 0.50
- XS1: 0.50
- XS2: 0.45
- XS3: 0.45

#### Minimum strength class
- C20/25
- C25/30
- C30/37
- C30/37
- C30/37
- C35/45
- C35/45

#### Minimum cement content kg/m³
- 260
- 280
- 280
- 300
- 300
- 320
- 340

#### Minimum air content %
- -
# Recommended limiting values for composition of concrete

<table>
<thead>
<tr>
<th>Exposure classes</th>
<th>Freeze/thaw attack with or without de-icing agents</th>
<th>Aggressive chemical environments</th>
</tr>
</thead>
<tbody>
<tr>
<td>XF1, XF2, XF3, XF4, XA1, XA2, XA3</td>
<td>Minimum strength class</td>
<td>National Application Rules</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Maximum w/c</th>
<th>0.55</th>
<th>0.55</th>
<th>0.50</th>
<th>0.45</th>
<th>0.55</th>
<th>0.50</th>
<th>0.45</th>
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</thead>
<tbody>
<tr>
<td>Minimum cement content kg/m³</td>
<td>300</td>
<td>300</td>
<td>320</td>
<td>340</td>
<td>300</td>
<td>320</td>
<td>360</td>
</tr>
<tr>
<td>Minimum air content %</td>
<td>-</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
## Comparison of cement application in Europe: Example “Concrete for exterior building elements (XF1)”

<table>
<thead>
<tr>
<th>State</th>
<th>max. w/c</th>
<th>min. c</th>
<th>CEM I</th>
<th>CEM II</th>
<th>CEM III</th>
<th>CEM IV</th>
<th>CEM V</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>kg/m³</td>
<td></td>
<td>S</td>
<td>L/LL</td>
<td>M</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A</td>
<td>B</td>
<td>A</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td>Austria</td>
<td>0.55</td>
<td>300</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>(x)</td>
</tr>
<tr>
<td>Belgium</td>
<td>0.55</td>
<td>300</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>(x)</td>
<td>x</td>
</tr>
<tr>
<td>Denmark</td>
<td>0.55</td>
<td>150</td>
<td>(x)</td>
<td></td>
<td>(x)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Finland</td>
<td>0.60</td>
<td>270</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>France</td>
<td>0.60</td>
<td>280</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>(x)</td>
<td>(x)</td>
</tr>
<tr>
<td>Germany</td>
<td>0.60</td>
<td>280</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>(x)</td>
<td>(x)</td>
</tr>
<tr>
<td>Ireland</td>
<td>0.60</td>
<td>300</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
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</tr>
<tr>
<td>Italy</td>
<td>0.50</td>
<td>320</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
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</tr>
<tr>
<td>Norway</td>
<td>0.60</td>
<td>250</td>
<td>x</td>
<td>x</td>
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</tr>
<tr>
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<td>x</td>
<td>(x)</td>
<td>(x)</td>
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- **X**: use allowed
- **(x)**: with limitations
- **●**: use not allowed

* An (x) indicates that there are qualifications, e.g. types of main constituents.
Comparison of cement application in Europe:
Example “Concrete for exterior building elements (XF1)”

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<th>CEM V</th>
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<td></td>
<td>kg/m&lt;sup&gt;3&lt;/sup&gt;</td>
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<td>S</td>
<td>L/LL</td>
<td>M</td>
<td></td>
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* an (x) indicates that there are qualifications, e.g. types of main constituents.

Do all these concretes have the same performance?
Carbonation in the laboratory

Storage: 1 day in the mould
6 days under water,
> 7 d 20 °C / 65 % r. H.

Range of performance in the laboratory

CEM I bis CEM III/B

\[ c = 260 \text{ kg/m}^3 \]
\[ w/z = 0.65 \]
Well-tried and proven in practice

- locally available materials
- ambient conditions
- local design/building tradition
Future of EN 206

Approach: Durability/Resistance classes of concrete?

today:

Exposure classes normative ("standardised ambient conditions") and national requirements for concrete

new:

Definition of (lab)performance of concrete regarding durability (resistance classes) and national regulation for application of concrete according to the respective ambient conditions (on the basis of SLD?)
Proposal of resistance classes carbonation (Basis: 7d under water and 50a in 20 °C /65 r. H.)

Relative frequency

Carbonation depth $x_c$ [mm]

10% probability

$X_{c,90} = 90\%$ quantile

Corresponding carbonation rate $k$ [mm/a$^{0.5}$]

RC20

RC30

RC40

RC50

RC60

TU Munich, Gehlen, Greve-Dierfeld (presentation Brussels 22.10.2014)
Connection between resistance class and concrete cover

Design service life $t_{SL}$

- $c_{min} = 18$ mm is required for XC4
- $c_{min} = 27$ mm is required for XC4

$c_{min}$

RCX [mm]

semiprobabilistic calculation $RC_{30}$

$c_{min} = 18$ mm is required for XC4

semiprobabilistic calculation $RC_{50}$

$c_{min} = 27$ mm is required for XC4

$\beta_0 \approx 1,5$

curing 7 Tage ($k_c=1$)
Connection between resistance class and concrete cover

Design service life $t_{SL}$

- Semiprobabilistic calculation $RC_{30}$
  - $c_{min} = 18 \text{ mm}$ is required for XC4

- Semiprobabilistic calculation $RC_{50}$
  - $c_{min} = 27 \text{ mm}$ is required for XC4

$\beta_0 \approx 1.5$

Curing 7 Tage ($k_c=1$)

TU Munich, Gehlen, Greve-Dierfeld (presentation Brussels 22.10.2014)
Resistance classes vs. current practice in Germany

### Chart:

- **Title:** DIBt limit
- **Y-axis:** $V_{c,140d}$ in mm/$\sqrt{a}$
- **X-axis:** CEM I, CEM II/B-M, CEM III/A, CEM III/B
- **Legend:**
  - RC20
  - RC30
  - RC40
  - RC50
  - RC60
- **Legend Values:**
  - CEM I
  - CEM II/B-M
  - CEM III/A
  - CEM III/B
- **7d pre-storage**

### Table:

<table>
<thead>
<tr>
<th>c</th>
<th>w/c</th>
<th>g</th>
</tr>
</thead>
<tbody>
<tr>
<td>450 g/mixture</td>
<td>0.50</td>
<td>1350 g/mixture</td>
</tr>
</tbody>
</table>

Preliminary storage: 7d
Resistance classes in EN 206?

Chances

- A common European system for specifying the durability of concrete (at present durability requirements are determined by provisions valid in the place of use).

- Further harmonization of EN 206 would be possible

- A system that enables a significant increase in the use of new materials (e.g. low carbon cements, secondary and recycled materials) without compromising the durability of concrete.
Resistance classes in EN 206?

**Challenges**

- Differentiation of the evaluation background that was implemented in current practice in some countries → depending on the test methods

- Responsibility of the designer: „Pre-decision“ regarding choice of building material → Does the designer know, what materials are available in the concrete plant?

- In the event of a real „trade-off“ the quality assurance along the value-added chain would have to be put on a new basis
European test/research program

Tools and procedures to proportion concrete mixes in the most sustainable and economic manner without compromising durability or strength.
European test/research program

Tools and procedures to proportion concrete mixes in the most sustainable and economic manner without compromising durability or strength

Funding by the EU required!
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Activities in CEN/TC 227/WG 3: Materials for concrete roads including joint fillers and sealants

- New group TG 1 + 2:
- Status of the different standards: discussion on the need of changes
  - EN 13877-1 Concrete pavements - Part 1: Materials
  - EN 13877-2 Concrete pavements - Part 2: Functional requirements for concrete pavements
  - EN 13877-3 Concrete pavements - Part 3: Specifications for dowels to be used in concrete pavements
- 3 meetings (first meeting Stockholm, 2014-03-24)
- Example for aspects to be discussed: part 2: Freeze-thaw requirements have no relation to the test method
Scaling of concretes with artificial air-voids
slab test vs. CDF test

Slab test acceptance criterion

CDF-acceptance criterion
Damage due to Alkali-Silica-Reaction (ASR)

Pictures: Landesbetrieb Bau Sachsen-Anhalt
ASR performance test

- method for evaluation of damage potential of concrete compositions
- 60°C concrete test of the Research Institute of the Cement Industry (FIZ), Düsseldorf

<table>
<thead>
<tr>
<th>preliminary storage</th>
<th>alternating storage cycle 1 (14d)</th>
<th>cycle 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 d 20°C 100%</td>
<td>5 d 60°C oven</td>
<td></td>
</tr>
<tr>
<td>6 d 60°C 100%</td>
<td>2 d 20°C NaCl*</td>
<td></td>
</tr>
<tr>
<td>14 d 20°C 65%</td>
<td>6 d 60°C 100%</td>
<td></td>
</tr>
<tr>
<td>1 d 20°C 100%</td>
<td>1 d 20°C 100%</td>
<td></td>
</tr>
<tr>
<td>* e.g. 3% NaCl solution</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

age in days

0 28 35 42
Drill core halves of pavements in 60°C concrete test - 3% NaCl solution

Damage category III: substance loss (crumbling)
Damage category II: incipient and pronounced cracks
Damage category I: discolouration in the area of the transverse joints/joint intersections or shrinkage cracks

No damage

Average expansion of two drill core halves [mm/m]

Storage time [days]
Drill core halves of pavements in 60°C concrete test - 3% NaCl solution

- Damage category III: substance loss (crumbling)
- Damage category II: incipient and pronounced cracks
- Damage category I: discolouration in the area of the transverse joints/joint intersections or shrinkage cracks

Average expansion of two drill core halves [mm/m] vs. storage time [days]
ASR performance test

- Drilled core from the top layer (D > 8)
- BAB A5 Direction Karlsruhe, Km 631,0
- Year of construction 1988
- Year of sampling 2006
- Age on sampling: 18 years
- Condition of the pavement:
  - no damage
  - slight cracking
BAB A5 Direction Karlsruhe, Km 631,0 — 2006

Age: 18 years

Pictures: Siegfried Riffel, 2006
BAB A5 Direction Karlsruhe, Km 631,0

Age: 26 years

Picture: Siegfried Riffel, 2014
Airfields made of concrete

Test solution: 0.6 mol/l KF-HOT

Expansion in mm/m vs Age in days

- Suitable
- Not suitable
Concrete for traffic areas

- Roads
- Airport runways
- Rigid railway tracks for high-speed rail traffic
- Heavily loaded urban roads or industrial areas
Concrete for motorways
Concrete not only for motorways
Bus stop and complete bus lanes

Complete bus lanes with concrete pavement

Bus stop with concrete pavement

Concrete coloured with pigments
Normal traffic on asphalt pavement
Example: Road crossing
Concrete: Deformation stability at high temperatures

Road crossing in Vienna

Cars are stopping and accelerating
Problems may occur in asphalt layers
Instead of crossings: Roundabouts are often used. Concrete solutions build in Austria and Switzerland.

Roundabout in Switzerland: Paving of concrete with a slipform paver.
First roundabout in Germany (Bad Sobernheim, 2007)

- Situated in an industrial area: Many lorries
- Example of a successful application
- Presentation to authorities and construction firms
- New roundabouts in concrete are planned
- Advantages for communities
  - Less maintenance
  - Lower life-cycle costs
Example: Concrete for ring roads

Ring roads in Saxony (East Germany, Leipzig)
Concrete also for lower loads
Farm roads (2 lines are paved)

Environment-friendly
Sealing of ground is minimized
Water can drain between the lanes
Concrete roads in Latvia

- Roller Compacted Concrete (RCC) has been proven as a practical solution under Latvian climate conditions (roads, streets, parking lots and industrial areas; several RCC pilot road sections, first RCC road in Latvia designed for very heavy loads)

- Using the potentials of concrete pavements in road construction the infrastructure in Latvia could be strengthened
AGENDA

1. Concepts for durable concrete structures
2. Concrete Pavements – an overview
3. Conclusions
Resistance classes in EN 206?

- A common European system for specifying the durability of concrete (at present durability requirements are determined by provisions valid in the place of use)

- Further harmonization of EN 206 would be possible

- A system that enables a significant increase in the use of new materials (e.g. low carbon cements, secondary and recycled materials) without compromising the durability of concrete → Sustainability !!

- Several questions to be answered: European test/research program

- **Funding by the EU required!**
Concrete pavements in road construction

- Concrete is a sustainable solution
  - not only for motorways, but also for
  - heavily loaded traffic areas (bus lanes, roundabouts, road crossing etc.)

- Roller Compacted Concrete (RCC) has been proven as a practical solution in Latvia (several RCC pilot road sections)

- Using the potentials of concrete pavements in road construction the infrastructure in Latvia could be strengthened
Thank you for your kind attention!

Dr. Christoph Müller
VDZ gGmbH - www.vdz-online.de
christoph.mueller@vdz-online.de