

1 **Chemical and mechanical properties of 70-year-old concrete**

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14 **Abstract:** The aim of this research is to determine the durability and strength of concrete
15 continuous footing based on the chosen mechanical, physical and chemical properties of the
16 concrete. The presented investigations are a part of opinions from experts on the bearing
17 capacity of concrete continuous footing and the possibilities of carrying additional loads and
18 extended working life. The cylindrical specimens were taken from continuous footing by a
19 concrete core bore hole diamond drill machine. The properties of old concrete are compared
20 with present and old standard requirements and guidelines. Large dispersions of the
21 cylindrical compressive strength (6.9 MPa to 29.3 MPa), density (1750 kg/m^3 to 2100 kg/m^3)
22 and water absorption (5% to 14%) were observed. A short literature survey concerning old
23 concrete properties is also given.

24 **Keywords:** Structural concrete; core-drilled samples, material characterization, mechanical
25 properties; chemical properties

26

27 **Introduction**

28 Concrete is one of the most popular materials used in civil engineering. In present
29 standards (see, e.g., CEN 2013), the intended working life of concrete in normal building
30 structures is assumed to be at least 50 years. Standards for concrete structure design indicate
31 the durability recommendations for concrete properties and other limiting values to resist
32 environmental influences. By providing improved compressive strength classes, water-
33 cement ratios, cement weights, and cover of rebars, to name a few, the designed working life
34 of reinforced or prestressed concrete structures may be raised to at least 100 years.

35 The design process of new reinforced or prestressed concrete structures is very well
36 specified by standards (see e.g., ACI 2014 or CEN 2004). In this domain, the designers have
37 considered the mechanical properties of concrete or reinforcement concrete for load capacity
38 requirements and intended working life. However, when designers must use opinions from
39 experts on old reinforced concrete structures, access to both structural design and structural
40 analysis is required. Additionally, the range of strength tests should be specified and
41 performed to determine the actual material properties of structural elements. When the
42 structural design (e.g., drawings) and structural analysis (e.g., static calculations) are
43 inaccessible, the opinions from experts are difficult to execute. To specify the durability and
44 bearing capacity of concrete construction, additional mechanical, chemical and physical tests
45 should be carried out.

46 The preservation and protection of old buildings require necessary information about
47 their main structure durability to ensure safe operational use by inhabitants or other people.
48 A proper assessment of the mechanical properties of old concrete using laboratory tests
49 strongly impacts the level of precision in an expert opinion or economical design. The
50 investigation of old concrete structures has been considered not only by engineers but also
51 by scientists. Qazweeni and Daoud 1991 examined the physical, mechanical and chemical
52 properties of concrete core specimens taken from a 20-year-old office building. The authors

53 concluded that the used concrete had low density, high absorption ratios and voids.
54 Furthermore, the observed failure of the concrete structure was caused by chloride and
55 carbonation attacks. Muntean et al. 2008 investigated the mechanical properties of old
56 concrete constructions that underwent the carbonation process. The main conclusion was that
57 the increased content of belite in the Portland cement had a positive influence on concrete
58 durability, particularly upon the rate of carbonation. Sena-Cruz et al. 2013 studied the
59 mechanical and chemical properties of structural materials of a reinforced concrete bridge
60 built in 1907. Laboratory tests showed a high porosity in the concrete (7-10%); nevertheless,
61 a concrete strength class greater than C30/37 and average modulus of elasticity
62 (approximately 30 GPa) were determined. Gibas et al. 2015 examined the compressive
63 strength of cored concrete specimens, chloride penetration and the rate of water absorption
64 of an unfinished concrete structure of a nuclear power plant, which was exposed for over 30
65 years to environmental conditions. The authors noted that the compressive strength was
66 above 60 MPa with low carbonation depth; however, the rate of water absorption and the
67 coefficient of chloride migration showed a large dispersion of concrete quality. Blanco et al.
68 2016 examined the chemical reactions leading to the degradation of a 95-year-old concrete
69 dam manufactured with sand-cement as a binder. The results revealed that the concrete in the
70 main dam body exhibited satisfactory mechanical properties with a pH of over 10 despite the
71 degradation of approximately 15 cm of the superficial dam layer. Dawczynski and Brol 2016
72 performed mechanical and chemical laboratory tests for 40-year-old reinforced concrete
73 precast bridge beams. Šimonová et al. 2017 performed three-point bending fracture tests on
74 structural concrete from a 1970s railway station and determined the modulus of elasticity,
75 fracture toughness, toughness and fracture energy. Pettigrew et al. 2016 performed laboratory
76 testing of nearly 50-year-old concrete bridge girders to specify the effective prestress,
77 flexural capacity, and deck punching shear strength.



78 Scientific and technical papers about old concrete structures concern not only buildings
79 but also bridges, dams and tunnels. The range of mechanical and chemical tests applied in
80 the presented investigations are generally determined by the type of analyzed concrete
81 structure and its complicated character. A full-scale investigation of old concrete construction
82 elements is hardly ever performed (e.g., for a decommissioned bridge, see Pettigrew et al.
83 2016). Usually, concrete samples are taken from old construction for experimental testing.
84 Nevertheless, it can be seen that the subject of old concrete structures is taken into
85 consideration in many engineering and scientific investigations where different
86 methodologies and laboratory tests are performed to specify their properties. The authors are
87 aware of the fact that a review of scientific and engineering research applications of old
88 concrete is limited and pay attention to the chosen studies only.

89 A lack of universal tools for describing old concrete behavior implies new investigations
90 and laboratory tests. The aim of this research is to determine the durability and strength of
91 concrete continuous footing based on the chosen mechanical, physical and chemical
92 properties of concrete. Continuous footing is a 70-year-old structural element. The
93 investigation was a part of an opinion from an expert on the bearing capacity of concrete
94 continuous footing and the possibilities of carrying additional loads and having an extended
95 working life.

96

97 **Materials and Design**

98 The proposed research addresses experiments performed to determine the selected
99 mechanical, physical and chemical properties of 70-year-old concrete core samples. The
100 cylindrical specimens were taken from the continuous footing of an office building by a
101 concrete core bore hole diamond drill machine (see Fig. 1) from locations with similar
102 geometrical and boundary conditions. The thickness of the continuous footing was

103 approximately 70 cm, and the top surface was at an elevation of +13.2 masl (meters above
104 sea level). The altitude under the surrounding ground level was (+14.0 to 14.15 masl). The
105 office building was built in the early 1950s in Gdansk, Poland. The structural analysis was
106 carried out by Prof. W. Bogucki in March 1948.

107 It should be noted that collection of the core samples for uniaxial tensile tests was
108 difficult. Many cylindrical samples with lengths equal to twice the diameter were damaged
109 during the diamond drilling process. The core samples with visible defects after core drilling
110 were excluded from laboratory tests. In the investigated concrete, continuous footing coarse
111 aggregates with very coarse gravel, cobbles or layers of low strength concrete were
112 observed. Requirements from the ASTM C31 standard (ASTM 2018) state that the cylinder
113 length shall be twice the diameter and diameter shall be at least 3 times the nominal
114 maximum size of the coarse aggregate for old concrete structure. This requirement is often
115 impossible to fulfil for old concrete structures.

116 In the present investigation, two types of cylindrical samples were prepared from the
117 exploratory bore holes:

- 118 ● eleven samples of type A with diameter D equal to approximately 140 mm and length L
119 equal to approximately 280 mm (length to core diameter ratio $L/D=2$) and
- 120 ● ten samples of type B with diameter D equal to approximately 140 mm and length L
121 equal to approximately 140 mm (length to core diameter ratio $L/D=1$).

122 The dimensions of the concrete cores were taken according to standard EN 12504-1 (CEN
123 2009), where the preferred length/diameter ratios are 2.0 if the strength results are to be
124 compared to the cylindrical strength and 1.0 if the strength results are to be compared to the
125 cube strength of $15 \times 15 \times 15$ cm concrete specimens. At the time when the structural analysis
126 of the building was performed, use of the Polish standard PN-B-195 (



127 PKN 1945) was mandatory for the design of reinforced concrete structures. The designers
128 and contractors of concrete works had to follow the guidelines to obtain particular strength
129 characteristics for the concrete. Table 1 presents concrete strength depending on the amount
130 of cement in 1 m³ of finished concrete and on the degree of liquidity and the ratio of sand-to-
131 gravel or crushed stone according to guidelines given in standard PN-B-195 (

132 PKN 1945). The concrete strength was specified from 0 (zero) MPa (0 kg/cm²) to 19.62
133 MPa (200 kg/cm²). A zero concrete strength was defined to emphasize that the amount of
134 water should be limited in mix design. The present standards or guidelines define
135 requirements for the water-to-cement ratio without mentioning zero-strength concrete.

136 In the structural analysis, the permitted strength for concrete was 19.62 MPa (200 kg/cm²,
137 determined for cylindrical samples) and was 137.34 MPa (1400 kg/cm²) for steel. The
138 structural designer in 1948 adopted the highest strength for the concrete defined by standard
139 PN-B-195 (

140 PKN 1945), as shown in Table 1. The mix design of the old concrete requires 400 [kg]
141 Portland cement in 1 m³ of concrete mix and contents of approximately 600 [kg] sand and
142 approximately 1200 [kg] gravel with rammed consistency. The production technology was
143 probably based on portable concrete mixers with handmade proportions of concrete
144 components. The rammed consistency can refer to present specification as a consistency with
145 a lower slump in a slump test (see, e.g., ASTM 2015).

146 In accordance with the present European EN 206 standard (CEN 2013), the
147 environmental conditions XC2 (wet, rarely dry) for reinforced concrete continuous footing
148 completely abandoned taking soil into account. For this exposure class, a minimum designed
149 concrete C25/30 (with 25 MPa of characteristic cylindrical compressive strength and 30 MPa
150 of characteristic compressive cube strength at 28 days) should be assumed for the present
151 European structural design of continuous footing.



152 **Laboratory tests**

153 *Tests of water absorption*

154 The water absorption tests were carried out following Annex G - EN 13369 (CEN
155 2001b). To measure the water uptake capacity of concrete samples, the specimens were
156 soaked in drinking water to a constant mass and then oven dried in a ventilated drying oven
157 at $105 \pm 5^\circ\text{C}$ to a constant mass. A water absorption test for concrete can estimate the
158 permeability and porosity (pore structure) of concrete samples (see, e.g., Kelham 1988).
159 However, mercury intrusion porosimetry (MIP) may also be used to investigate the pore
160 structure of cement-based materials (see, e.g., Ma 2014). It is known that the concrete pore
161 structure is an important factor that influences concrete durability and resistance against
162 carbonation and chloride migration (see, e.g., De Schutter and Audenaert 2004).
163 Additionally, the ASTM C1585 standard (ASTM 2013) emphasizes that the water absorption
164 depends on concrete mixture proportions, presence of chemical admixtures and
165 supplementary cementitious materials, composition and physical characteristics of the
166 cementitious component and of the aggregates, entrained air content, and type and duration
167 of curing.

168 The water absorption results versus dry density are presented in Fig. 2. The absorption
169 values range from 5.28% to 14.09% for type A samples and from 7.24% to 13.94% for type
170 B samples. The mean value of water absorption is $9.58\% \pm 0.51\%$. The result of the mean
171 value is presented as a sum of mean values and standard error of the mean of the specified
172 range. All water absorption results indicate poor concrete quality according to the
173 International Federation for Structural Concrete (FIB) report (CEB-FIP 1989). The FIB
174 report (CEB-FIP 1989) categorized concrete quality as poor when water absorption values
175 are greater than 5%, average quality for 3 to 5% and good quality for 0 to 3% water
176 absorption. On the other hand, according to the PN-88/B-06250 standard (PN 1988), the

177 water absorption of concrete should not be greater than 5% in the case of concrete exposed
178 to atmospheric conditions.

179 The dry density values ranged from 1753 to 2119 kg/m³ for type A samples and from
180 1788 to 2105 kg/m³ for type B samples. The obtained values of water absorption are directly
181 connected with the specified values of dry density. While the dry density values are
182 increasing, the water absorption values are strongly decreasing. According to the EN 206
183 (CEN 2013) standard, the concrete can be categorized into three main density grades:
184 lightweight concrete with dry density from 800 to 2000 kg/m³, normal concrete with dry
185 density from 2000 to 2600 kg/m³ and heavy concrete with dry density over 2600 kg/m³. Only
186 24% of specimens can be classified as normal concrete with dry density over 2000 kg/m³
187 (see Fig. 2). The mean value for all samples of dry density is 1929.2 ± 23.9 kg/m³. On the
188 other hand, the ACI 318-14 standard (ACI 2014) indicates normal weight concrete with a
189 density between 2160 and 2560 kg/m³ (135 to 160 lb/ft³).

190 The water absorption $w_a(\rho)$ can be described as a function of dry density ρ :

$$wa(\rho) = 49.0945 - 0.0205 \cdot \rho, \quad (1)$$

191 where for dry density $\rho \in (1706 \div 2119 \text{ kg/m}^3)$. Good compatibility occurs between the test
192 results and the assumed straight-line approximation function (see Fig. 2). The computed
193 determination coefficients fulfill the condition $R^2=0.94$. It can be concluded that for the
194 investigated specimens of 70-year-old concrete, the increase of water absorption is connected
195 with a linear decrease of dry density values specified by Eq. (1).

196 *Chemical properties*

197 The chemical laboratory testing program consists mainly of three sets of tests:
198 measurement of the pH value, determination of water-soluble chloride salts (Cl⁻) and sulfate
199 ions (SO₄²⁻). The samples of concrete for chemical analysis were taken from the bottom part

200 of core samples (bottom part of continuous footing) after a cut-off of approximately 4-5 cm
201 cylindrical samples from the exploratory bore holes. Their general concentration, including
202 the pH of the test samples (series A and B), was tested after dissolving a given amount of the
203 mass of the crushed concrete in distilled water. After filtration through membrane filters
204 (MCE type) with a pore size of 45 μm , the obtained filtrates were tested according to the
205 standards. The pH was measured according to ISO 10523 (ISO 2008). The extract with
206 chloride ions was analyzed in accordance with the Volhard method described in EN 1744-
207 1+A1 (CEN 2009), while the extract with water-soluble sulfate ions was analyzed according
208 to EN 1744-1+A1 (CEN 2009).

209 The pH value is one of the most useful factors for specifying the ability of concrete to
210 protect steel rebar. The pH values range from 11.0 to 13.3, while the mean value is equal to
211 12.4 ± 0.1 (see Fig. 3 and Table 2). It can be seen that only three measurements (14%) are
212 below the value of 12. The mean pH value is approximately similar to freshly made concrete,
213 which may vary in the range of 12.5-13.5 (see, e.g., Duffó et al. 2009). As carbonation
214 proceeds, the pH value of the concrete pore solution decreases. When the pH value decreases
215 below 9.5, corrosion of the reinforcing steel rebars may be observed.

216 The alkaline reaction of concrete protects the reinforcing steel against corrosion.
217 Acidifying substances in the environment that cause the neutralization of concrete include
218 chloride and soluble sulfate. The water-soluble chloride salts and sulfate ions in Tables 3 and
219 4 are specified as a percentage of cement weight. The chloride content of a concrete expressed
220 as the percentage of chloride ions by mass of cement shall not exceed the 0.2% limit for
221 concrete containing steel reinforcement according to standard EN 206 (CEN 2013).
222 Following the ACI 318 standard (ACI 1989) for reinforced concrete that will be exposed to
223 chlorides or will be damp in service, the limits are 0.15% and 0.30%, respectively. On the
224 other hand, an excessive amount of sulfate, derived from aggregates or other constituents in
225 concrete, can cause disruption due to expansion (see, e.g., Concrete Society 2014). The



226 standard BS 8110-1 1985 edition (BSI 1985) had a limit of 4% by mass of cement based on
227 the total acid soluble sulfate method expressed as SO₃ (conversion of sulfate SO₄ to SO₃ may
228 be assumed as 0.833 x SO₄ = SO₃). This restriction was abandoned in the standard BS 8110-
229 1 1997 edition (BSI 1997).

230 The water-soluble chloride salt values range from 0.015% to 0.23%, and the mean value
231 is 0.067% ± 0.011% (see Fig. 4 and 5). One of the concrete specimens was identified with a
232 value over the 0.2% limit of cement weight specified by standard EN 206 (CEN 2013). When
233 the chloride content in concrete is close to the 0.2-0.3% of cement weight, it can be concluded
234 that the concrete is being exposed to chloride attack.

235 The sulfate ion (SO₄²⁻) values range from 0.035% to 0.30%, and the mean value is equal
236 to 0.094% ± 0.015% (see Fig. 4 and 5). The low concentration of sulfates ions in concrete
237 samples indicates that the low contamination is due to external sources (e.g., groundwater).
238 When high values of water-soluble chloride salts and sulfate ions are observed in concrete
239 located in the ground environment, examining the soil properties should be taken into
240 consideration.

241 *Mechanical tests*

242 The uniaxial experimental tests used the Advantest 9 C300KN mechanical testing
243 apparatus, as shown in Fig. 6. The experiments were performed to failure of the concrete
244 cylinder specimens and used a constant rate of loading with the range of 0.6 MPa/s according
245 to EN 12390-3 (CEN 2001a). The compressive strength was calculated using the following
246 equation:

$$f_c = \frac{F}{A_c}, \quad (2)$$

247 where f_c is the compressive strength, F is the maximum load at failure, and A_c is the cross-
248 sectional area of the specimen.



249 Uniaxial tensile test results of compressive strength versus dry density are presented in
250 Fig. 7. The compressive strength of cylinder specimens ranges from 6.9 MPa to 29.3 MPa
251 for type A samples and from 5.9 MPa to 37.3 MPa for type B samples. The mean values of
252 compressive strength are 19.05 ± 2.45 MPa for type A and 25.08 ± 3.29 MPa for type B
253 samples. Taking into account the mean values of compressive strength, it can be seen that the
254 concrete can be classified to compressive strength class C20/25 (cylinder/cube) according to
255 standard EN 206 (CEN 2013) and fulfils the minimum requirements for compressive strength
256 for structural concrete (min. $f_c = 17.24$ MPa (2500 psi)) indicated by standard ACI 318-14
257 (ACI 2014).

258 A wide scatter of compressive strengths due to variations in density properties can be
259 observed. For a dry density values over 1920 kg/m^3 , all values of compressive strength are
260 over 20 MPa. Additionally, the mean value of compressive strength for normal concrete type
261 (specimens with density above 2000 kg/m^3) is 27.96 ± 2.45 MPa.

262 Additionally, a wide scatter in compressive strength may depend on the types of
263 aggregate used to prepare the old concrete mix. Some concrete cores exhibited coarse
264 aggregates (large stones, see Fig. 8) with cavities and pores. It should be noted that the
265 measured compressive strength of a core will generally be lower than that of a corresponding
266 properly melded and cured standard cylinder tested at the same age.

267 *Modulus of elasticity*

268 The determination of the modulus of elasticity for diamond-drilled concrete cores of type
269 A (cylinders having the length to diameter ratio $L/D=2$) was specified according to guidelines
270 given by the ASTM C469M standard (ASTM 2014). The cylindrical specimens were stored
271 and tested at room temperature (approximately 20°C) in air-dry conditions. It should be noted
272 that only cores with a length-to-diameter ratio greater than 1.50 may be used in a
273 compressometer device for measuring the static modulus of elasticity. The modulus of

274 elasticity of the concrete corresponds to the average slope of the stress-strain responses
275 captured during cyclic loading. The modulus of elasticity $E_{0.0-0.4}$ in an applicable customary
276 working stress range from 0 to 40% of the ultimate concrete strength was specified.
277 Additionally, the modulus of elasticity $E_{0.1-0.3}$ ranging from 10% to 30% of ultimate concrete
278 strength was determined. The value of one-third of the ultimate strength is required in the
279 ISO 1920-10:2010 standard (ISO 2010). On the other hand, the EN 1992-1-1 (CEN 2004)
280 standard defines the modulus of elasticity as a secant value between 0% and 40% of the
281 ultimate strength for concrete with quartzite aggregates, and for limestone and sandstone
282 aggregates, the value should be reduced by 10% and 30%, respectively. The ASTM C469M
283 standard (ASTM 2014) also indicates a 40% ultimate load to calculate the modulus of
284 elasticity.

285 The modulus of elasticity ranges from 6890 MPa to 19030 MPa for $E_{0.0-0.4}$ and from 6890
286 MPa to 19450 MPa for $E_{0.1-0.3}$ (see Fig. 9). The differences between the $E_{0.0-0.4}$ and $E_{0.1-0.3}$
287 values are small (0-7%). The mean values of the modulus of elasticity are 12560 ± 1200 MPa
288 for $E_{0.0-0.4}$ and 12630 ± 1240 MPa for $E_{0.1-0.3}$. The obtained result can be bisectonal (see Fig.
289 9) as below and over 20 MPa of the compressive strength (it corresponds to a dry density
290 below and over 1920 kg/m^3 , respectively). When compressive strength values are increased,
291 the modulus of elasticity values substantially increase.

292 Discussion and Conclusions

293 The main objective of the present investigation was to assess the state of 70-year-old
294 concrete built in the continuous footing of an office building. On the basis of the selected
295 mechanical, physical and chemical properties, the following conclusions may be drawn:

- 296 • The water absorption of concrete specimens ranging from approximately 5% to 14%
297 indicates poor concrete quality.

- 298 ● The dry density of concrete cores ranged from approximately 1750 kg/m³ to 2100
299 kg/m³. Most concrete specimens were classified as lightened concrete, while only
300 24% of specimens were normal concrete (according to the EN 206 (CEN 2013)) with
301 a dry density over 2000 kg/m³.
- 302 ● The pH values indicate that corrosion of the reinforcing steel rebars should not be
303 observed. Nevertheless, the steel rebar corrosion was detected by visual inspection in
304 two core samples in a place where a very low concrete cover was measured.
305 Generally, all reinforcements with proper concrete cover were in good condition
306 without any corrosion center. The specified values of water-soluble chloride salts and
307 sulfate ions showed that the investigated concrete was not exposed to chloride attack
308 with a low concentration of sulfates ions.
- 309 ● The cylindrical compressive strength (for type A specimens) ranged from 6.9 MPa to
310 29.3 MPa (with a mean value equal to 19.05 ± 2.45 MPa) and cube compressive
311 strength (for type B specimens) ranged from 5.9 MPa to 37.3 MPa (with a mean value
312 equal to 25.08 ± 3.29 MPa). The wide scatter of compressive strength with the
313 modulus of elasticity, ranging from 6890 MPa to 19030 MPa for $E_{0.0-0.4}$, indicated
314 poor concrete quality.
- 315 ● The 70-year-old concrete had a high scatter of chemical and mechanical properties.
316 The wide scatter in density, water absorption, compressive strength and modulus of
317 elasticity resulted in a very low quality control during construction. The poor quality
318 of old concrete can be explained by production technology, which was probably based
319 on portable concrete mixers with handmade proportions of concrete components.
320 Additionally, a lack of uniform compaction during the placement of mix concrete was
321 observed during core drilling. It may be pointed out that the 1st reinforced concrete
322 code (NACU 1910) indicates that *reinforced concrete may be used in accordance*
323 *with good engineering practice*, but sometimes, old structures are poor quality.

324 Concrete and reinforced concrete structures require proper operational use and
325 appropriate protection from environmental conditions. Several existing reinforced concrete
326 buildings, bridges and viaducts reached a critical state of degradation, and evaluation of their
327 durability and mechanical properties is indispensable. Construction and building inspection
328 should indicate a critical state of structure element degradation. Expert opinion of old
329 concrete construction should be accompanied by in situ inspection and testing of concrete
330 specimens taken directly from construction elements. A general evaluation of the mechanical
331 properties of old concrete is not inefficient. In several cases, it is necessary to incorporate
332 scientific and engineering communities to evaluate the performance of old structures. The
333 authors are hopeful that the described investigation sparks interest a wide group of engineers
334 and scientists to take into consideration the subject of old concrete structures.

335



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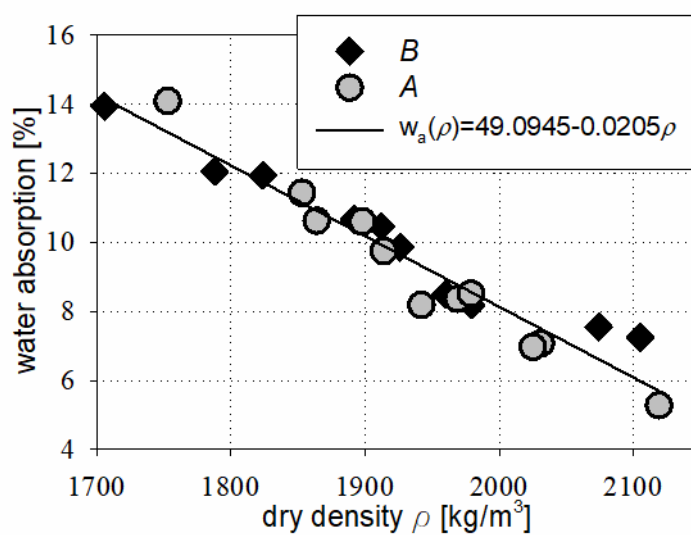
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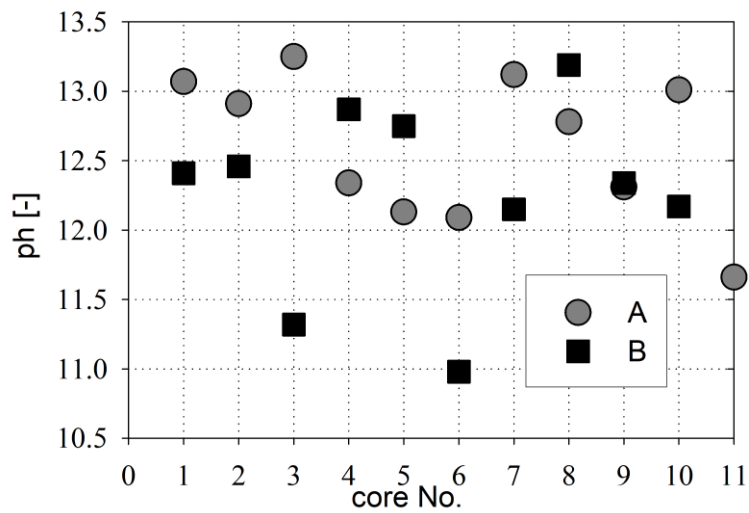
Figure 1. Core samples type A and B after cut geometry preparation



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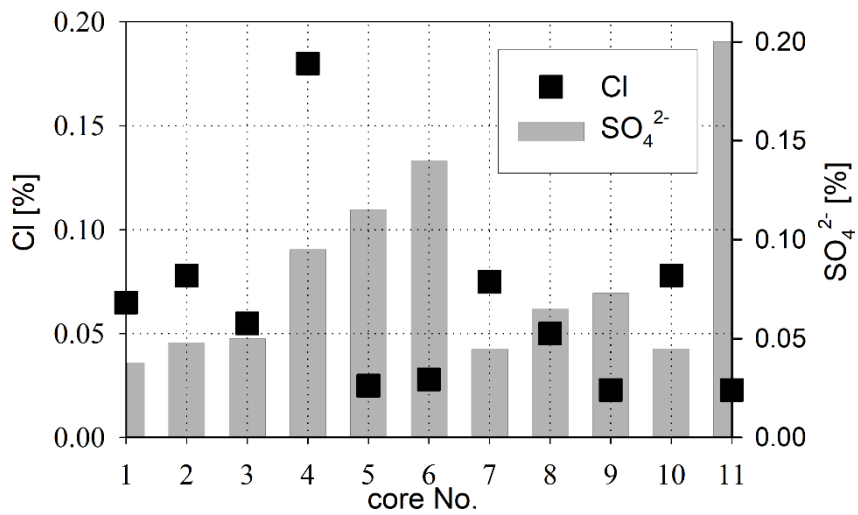
Figure 2. Water absorption versus dry density



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Figure 3. pH values of concrete specimens



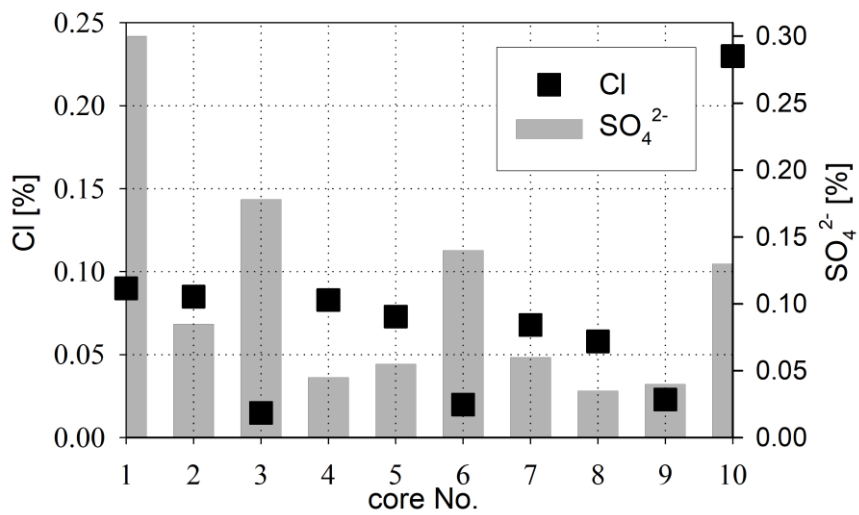
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Figure 4. Chloride and soluble sulphate content as a percent of cement weight for A type

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specimens



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Figure 5. Chloride and soluble sulphate content as a percent of cement weight for B type

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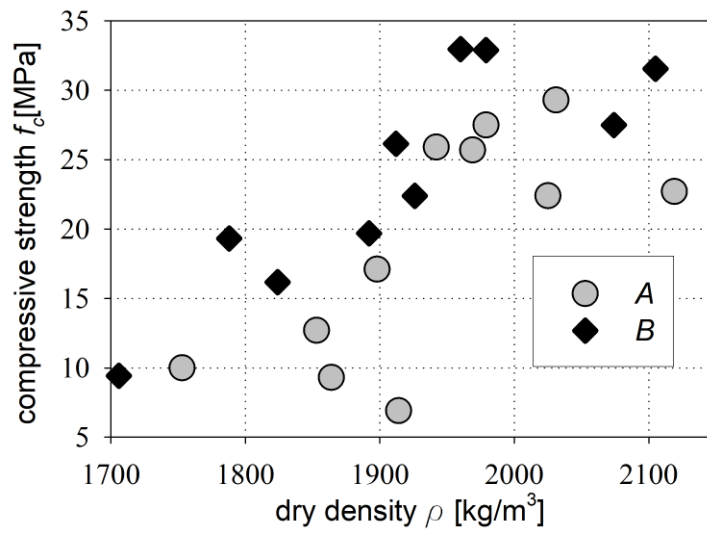
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Figure 6. Laboratory test stand



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Figure 7. Compressive strength versus dry density for core samples type A and B



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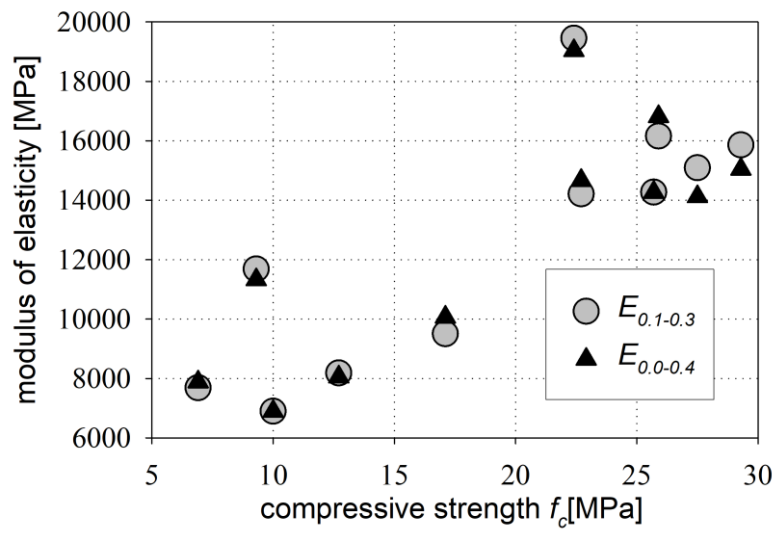


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Figure 8. Damaged concrete cores with visible coarse aggregate (stone)





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316 Figure 9. Modulus of elasticity versus compressive strength for diamond-drilled concrete

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cores type A

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Table 1. Concrete strength [MPa] ($[\text{kg}/\text{cm}^2]$) depending on the amount of cement in 1 m^3 of finished concrete on the degree of liquidity and the ratio of sand to gravel or crushed stone

The amount of cement [kg] in 1 m^3 of concrete mix	Volume ratios					
	sand to gravel 1:1 or sand to stone gravel 1:0.8			sand to gravel 1:2 or sand to stone gravel 1:1.6		
	liquid	plastic	rammed	liquid	plastic	rammed
200	0 (0)	2.94 (30)	5.89 (60)	3.92 (40)	8.83 (90)	11.77 (120)
300	4.90 (50)	8.83 (90)	11.77 (120)	9.81 (100)	13.73 (140)	15.69 (160)
400	9.81 (100)	13.73 (140)	15.69 (160)	13.73 (140)	17.66 (180)	<u>19.62 (200)</u>

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Table 2. pH values of concrete specimens (series A and B)

Samples	pH	Samples	pH
A1	13.1	B1	12.4
A2	12.9	B2	12.5
A3	13.3	B3	11.3
A4	12.3	B4	12.9
A5	12.1	B5	12.8
A6	12.1	B6	11.0
A7	13.1	B7	12.2
A8	12.8	B8	13.2
A9	12.3	B9	12.3
A10	13.0	B10	12.2
A11	11.7	-	-

Table 3. The content of chloride ions (Cl⁻) in concrete as a percent of cement weight

Samples	Cl [%]	Samples	Cl [%]
A1	0.065	B1	0.090
A2	0.078	B2	0.085
A3	0.055	B3	0.015
A4	0.180	B4	0.083
A5	0.025	B5	0.073
A6	0.028	B6	0.020
A7	0.075	B7	0.068
A8	0.050	B8	0.058
A9	0.023	B9	0.023
A10	0.078	B10	0.230
A11	0.023	-	-

Table 4. The content of sulphate ions (SO_4^{2-}) in concrete as a percent of cement weight

Samples	SO_4^{2-} [%]	Samples	SO_4^{2-} [%]
A1	0.038	B1	0.300
A2	0.048	B2	0.085
A3	0.050	B3	0.178
A4	0.095	B4	0.045
A5	0.115	B5	0.055
A6	0.140	B6	0.140
A7	0.045	B7	0.060
A8	0.065	B8	0.035
A9	0.073	B9	0.040
A10	0.045	B10	0.130
A11	0.200	-	-