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

Introduction

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

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

The preservation and protection of old buildings require necessary information about their main structure durability to ensure safe operational use by inhabitants or other people. A proper assessment of the mechanical properties of old concrete using laboratory tests strongly impacts the level of precision in an expert opinion or economical design. The investigation of old concrete structures has been considered not only by engineers but also by scientists. Qazweeni and Daoud 1991 examined the physical, mechanical and chemical 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 dimeter 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 dimeter 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 m^3 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/cm^2) to 19.62

133 MPa (200 kg/cm^2). 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/cm^2,

137 determined for cylindrical samples) and was 137.34 MPa (1400 kg/cm^2) 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 m^3 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 $105 \pm 5°C$ 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 (PKN 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/m^3 for type A samples and from

180   1788 to 2105 kg/m^3 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/m^3, normal concrete with dry

185   density from 2000 to 2600 kg/m^3 and heavy concrete with dry density over 2600 kg/m^3. Only

186   24% of specimens can be classified as normal concrete with dry density over 2000 kg/m^3

187   (see Fig. 2). The mean value for all samples of dry density is 1929.2 ± 23.9 kg/m^3. 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/m^3 (135 to 160 lb/ft^3).

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

$$wa(\rho) = 49.0945 - 0.0205 \cdot \rho, \tag{1}$$

191   where for dry density $\rho \in (1706 \div 2119$ $kg/m^3)$. 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 (SO_4^{2-}). 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 SO_3 (conversion of sulfate SO_4 to SO_3 may

228   be assumed as 0.833 x SO_4 = SO_3). 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 (SO_4^{2-}) 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:

$$f_c = \frac{F}{A_c},$$
(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 bisectional (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/m^3 to 2100

299   kg/m^3. 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/m^3.

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 $E_{0.0\text{-}0.4}$, 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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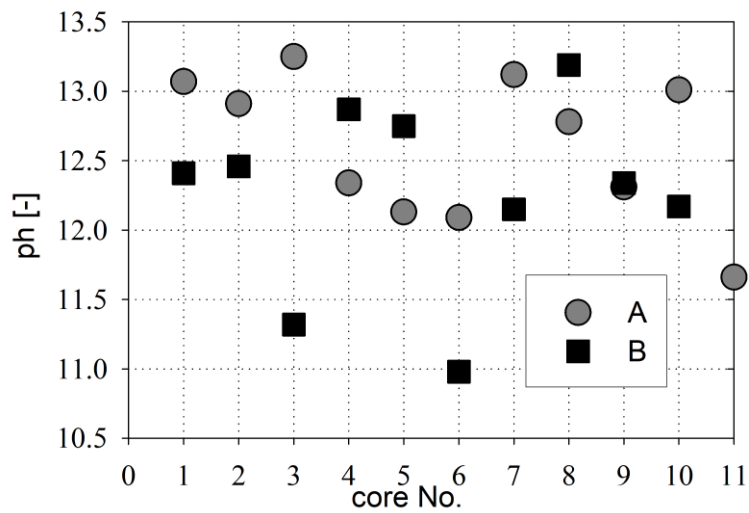
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295   **Figure Legends**

296

297   Figure 1. Core samples type A and B after cut geometry preparation
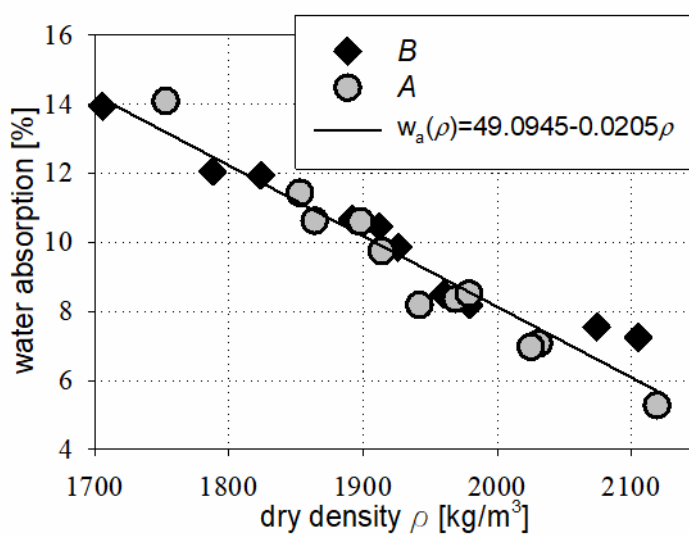
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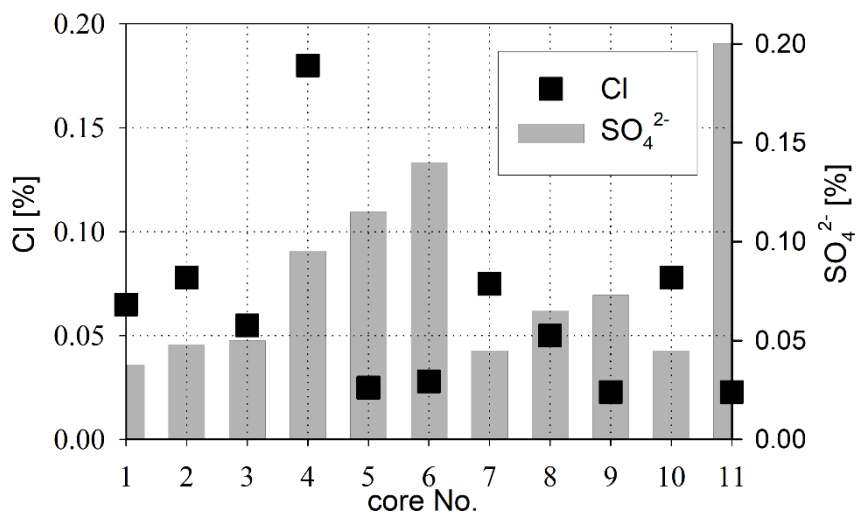299   Figure 2. Water absorption versus dray density
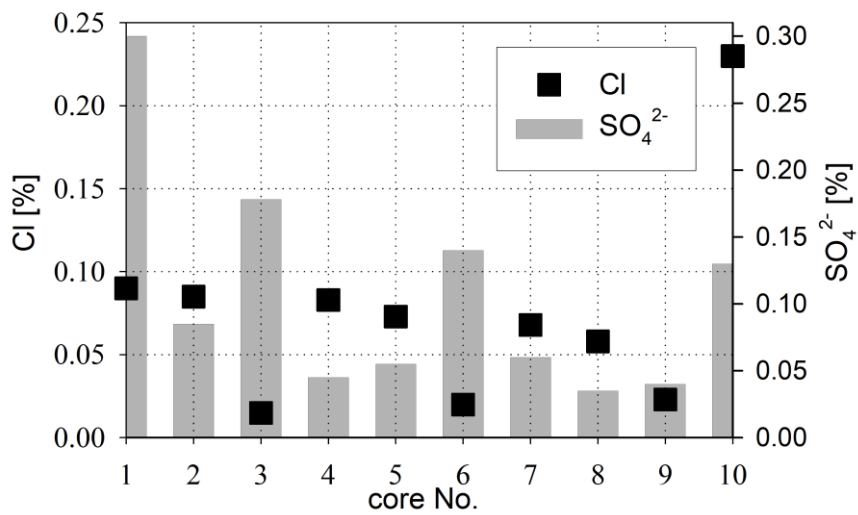
Figure 3. pH values of concrete specimens

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

specimens

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

307　specimens
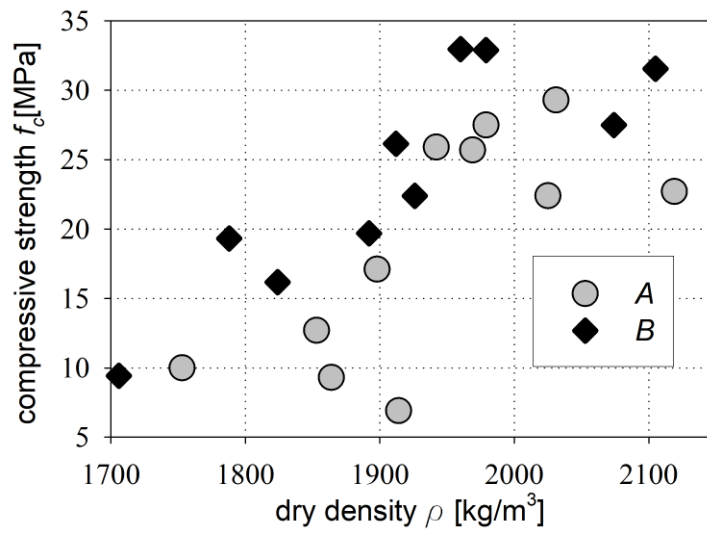

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309　Figure 6. Laboratory test stand

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311   Figure 7. Compressive strength versus dray density for core samples type A and B
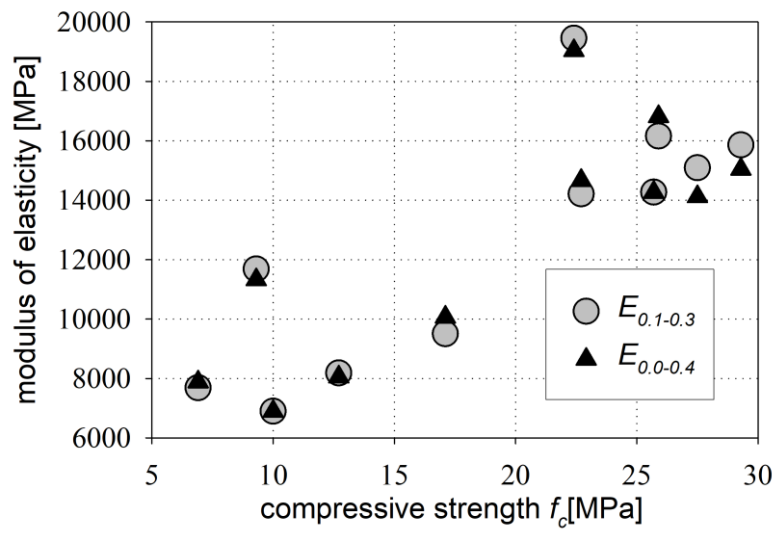
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314   Figure 8. Damaged concrete cores with visible coarse aggregate (stone)

315

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

317   cores type A

287 Table 1. Concrete strength [MPa] ([kg/cm^2]) depending on the amount of cement in 1 m^3 of finished concrete
288 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)	**19.62 (200)**

289

290

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	-	-

291

292 **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	-	-

293

294 **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	-	-

295