Durability Requirements of Concrete in the Saudi Building Code: Comparison with the ACI 318 Code

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A **BUILDING CODE** comprises a set of legal, administrative and technical requirements that are concerned with buildings. It is based on scientific and engineering bases with the aim of ensuring **acceptable limits** of safety and public health, taking into consideration the properties of materials and local natural conditions, **the requirements of protection against fire and natural risks such as earthquake,** as well as the purpose of using the constructions.

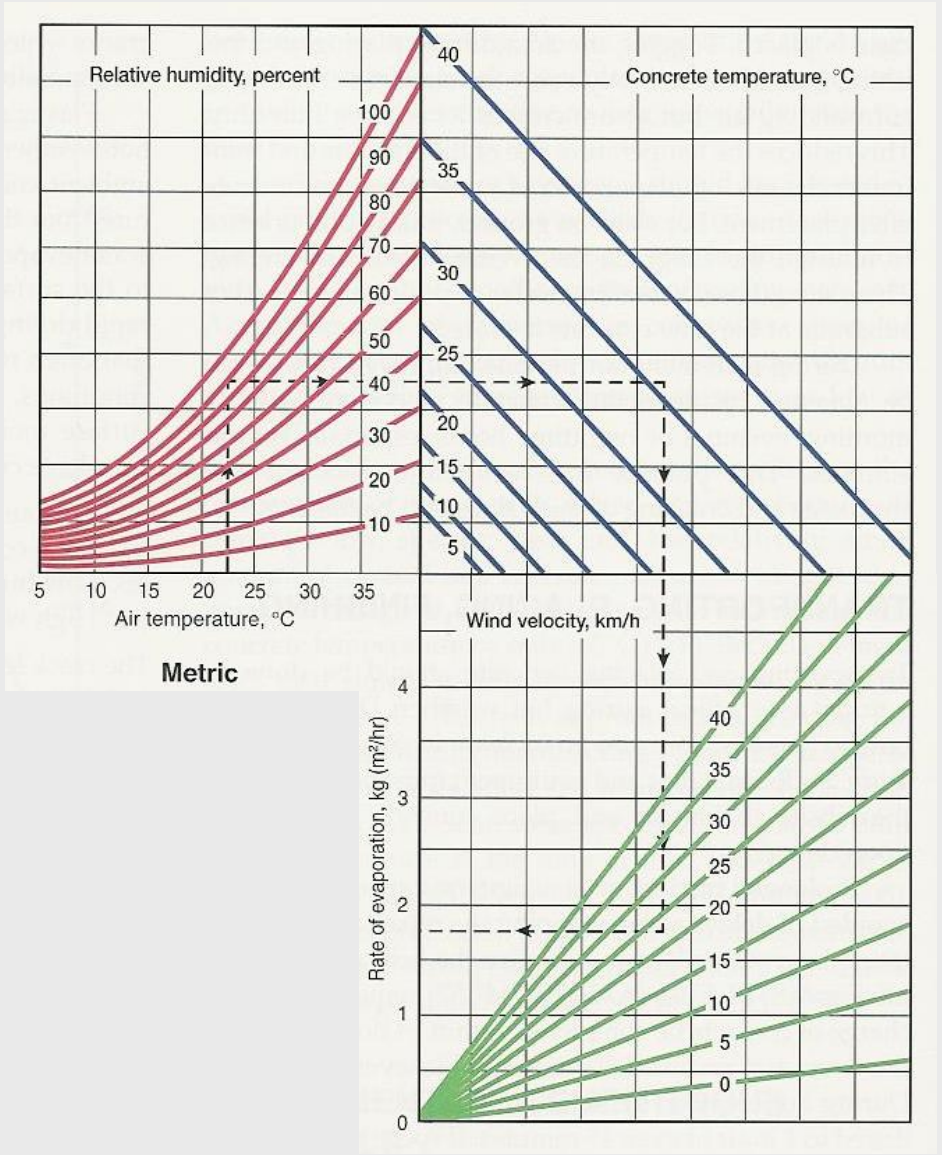
In the absence of local building codes, the construction industry in Saudi Arabia has been adopting standards and codes of practices from several other countries for the design and construction of the infrastructure.

The codes adopted depended on the country of origin of the contractor/consultant. Hence, the constructed facilities exhibited signs of failure much ahead of their designed services life.

There are many causes of these failures!!!

To use **Hot Weather Chart**:

1: Enter with air temperature, move up to relative humidity.
2: Move right to concrete temperature.
3: Move down to wind velocity.
4: Move left, read approximate rate of evaporation.



Chloride and Sulfate Content in Atmospheric Air of the Arabian Gulf Coast and Pacific Coast

	Dhahran	Long Beach	Morehead City
Cl^- $\mu g/m^3$ of air	63.7	0.13 **(490)***	0.13 **(490)***
SO_4^{--} $\mu g/m^3$ of air	33.8	0.32 **(106)***	0.54 **(61)***

*Indicates the ratio of concentration with respect to Dhahran.

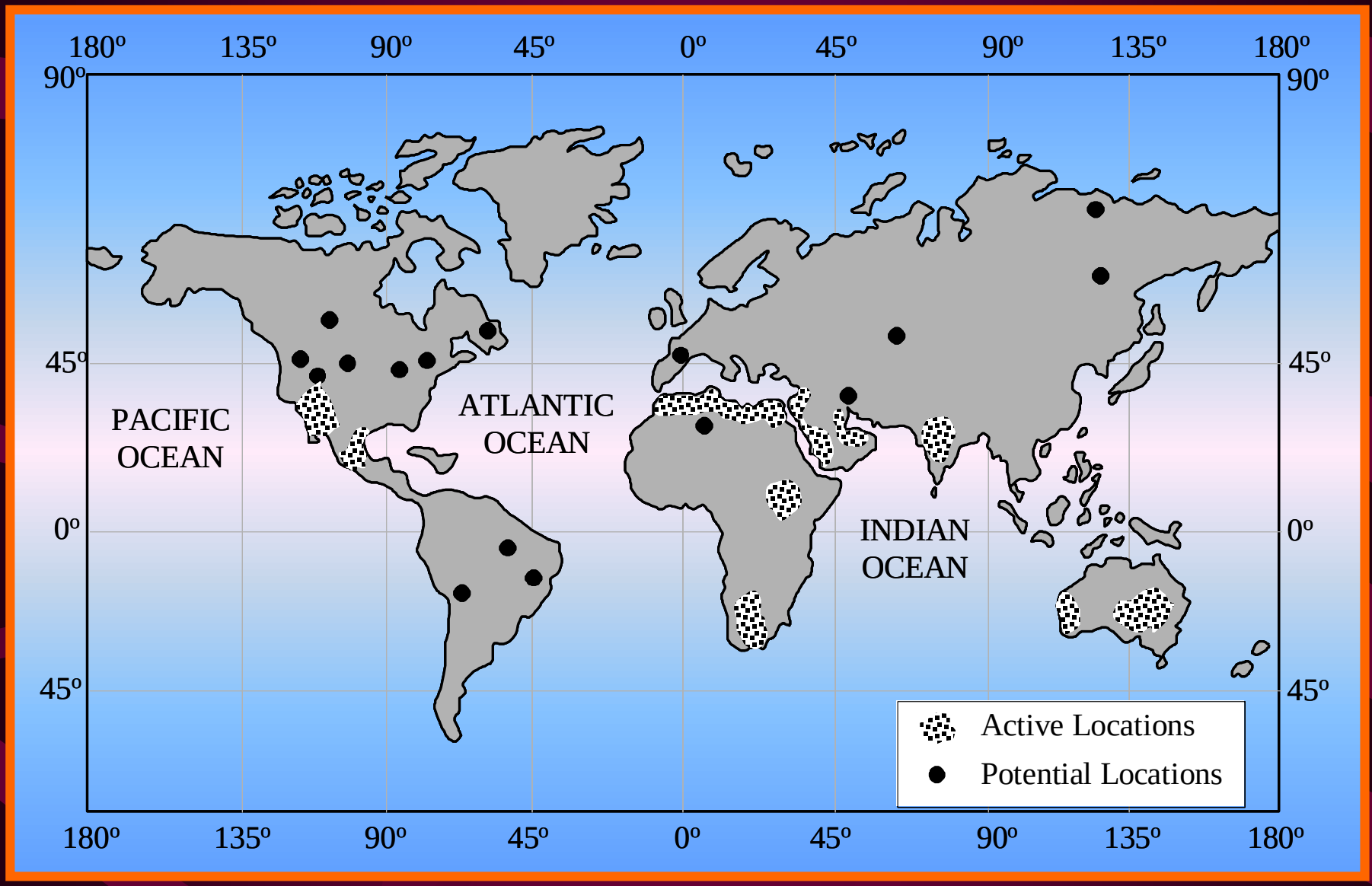
Major Ions in Sea Waters in the World

Major Ions	Concentration (mg/l)								
	Black Sea	Marmara Sea	Mediterranean Sea	North Sea	Atlantic Ocean	Baltic Sea	Arabian Gulf	BRE** Exposure	Red Sea
Sodium	4,900	8,100	12,400	12,200	11,100	2,190	20,700	9,740	11,350
Magnesium	640	1,035	1,500	1,110	1,210	260	2,300	1,200	1,867
Chloride	9,500	14,390	21,270	16,550	20,000	3,960	36,900	18,200	22,660
Sulfate	1,362	2,034	2,596	2,220	2,180	580	5,120	2,600	3,050
TDS	17,085	26,409	38,795	33,060	35,370	7,110	66,650	32,540	40,960
TDS Ratio*	3.90	2.52	1.72	2.02	1.88	9.37	1.00	2.05	1.63

**Building Research Establishment, England

*Concentration of total dissolved solids compared to the Arabian Gulf sea water

Distribution of Sabkha Soils in the Arabian Peninsula



World Map Showing Active and Potential Sabkha Locations

Chemical Analysis of Sabkha Brine and Seawater

Ions (g/l)	Al-Jubail Sabkha Brine	KFUPM Beach Seawater
Na^{+}	78.8	20.7
Mg^{++}	10.32	2.30
K^{+}	3.06	0.73
Ca^{++}	1.45	0.76
Sr^{++}	0.029	0.013
Cl^{-}	157.2	36.9
Br^{-}	0.49	0.121
$(SO_4)^{--}$	5.45	5.12
$(HCO_3)^{-}$	0.087	0.128
pH	6.9	8.3
Conductivity*	208,000	46,200

*Microsiemens **Not reported

These failures forced the authorities to develop a **“national”** building code suitable for the local environmental conditions.

A Saudi Building Code National Committee (**SBCNC**) was formed by the Royal Decree No. 7/B/3230 dated June 12th, 2000 so as to prepare SBC, which when approved, **shall be binding for all public and private sectors.**

The **SBCNC** reviewed a number of the regional and international references and codes in addition to studying the standards, building systems and plans of the governmental departments and authorities including the **International Code Council (ICC)** issued in USA, the **European Code** and **Arab Codes.**

The National Committee was divided into **several sub-committees** to address the areas related to construction, such as concrete, steel, loads, inspection, soil, etc. Each sub-committee was charged with the preparation of the relevant parts in (SBC).

Concrete Sub-Committee: SBC 304

ACI 318, being the most widely used standard for concrete structures, was selected to be part of the SBC. The concrete sub-committee was charged to make the suitable modifications to suit to the environmental conditions of Saudi Arabia.

Accordingly, several changes were made to ACI 318. However, the **major revisions** were made to the durability requirements and hot weather requirements (**Chapter 4 and Section 5.13, respectively**). These changes were based on the **local experience and research data developed over last 30 years.**

Modifications to ACI 318 in SBC

Due to the space limitations, the changes made in the chapters related to **DURABILITY (Chapter 4) and HOT WEATHER (Section 5.13)** are only addressed in this presentation.

Modifications to Chapter 3 (MATERIALS)

The changes made to Chapter 3 of ACI 318 for adoption in SBC are detailed below.

Code/ Comm	Statement in ACI	Statement in SBC
R3.2.1 a	----	**The C_3A content of cement intended for corrosion resistance should not be less than 8 percent.**

Code 3.4.1	Water used in mixing concrete shall be clean and free from injurious amounts of oils, acids, alkalis, ….	Water used in **mixing or curing** concrete shall be clean and free from injurious amounts of oils, acids, alkalis, salts,

Modifications to Chapter 4

(DURABILITY REQUIREMENTS)

In view of the severity of the geomorphic and climatic exposure conditions in the Arabian Peninsula, many changes were made to this chapter. These are detailed as fallows:

Comm.	Maximum water-cementitious materials ratios of 0.40 to 0.50 that may be required for concretes exposed to sulfate-bearing soils or groundwaters, or for preventing corrosion of reinforcement will typically be equivalent to requiring an f_c' of about 35 to 28 MPa, respectively.	Concrete exposed to sulfate-bearing soils or groundwater, seawater, or for preventing corrosion of reinforcing steel or salt weathering should be designed for maximum water-cementitious materials ratio, **minimum cementitious materials content** and appropriate type of cement. Maximum water-cementitious materials ratios of 0.40 to 0.50 that may be required for concretes exposed to sulfate-bearing soils or groundwaters, or for preventing corrosion of reinforcement will typically be equivalent to requiring an f_c' of about 35 to 28 MPa, respectively.

R4.1.1	For concrete exposed to **deicing chemicals** the quantity of fly ash, other pozzolans, silica fume, slag, or blended cements used in the concrete is subject to the percentage limits in 4.2.3. ….	**Deleted** (The same in Code 4.1.1)

	4.2–Freezing and thawing exposures	4.2–Freezing and thawing exposures
Code 4.2.1	Normalweight and lightweight concrete exposed to freezing and thawing or deicing chemicals shall be air-entrained with air content indicated in Table 4.2.1 …..	**Not applicable in the Kingdom**. In the Commentary, it is mentioned: Freeze-thaw conditions are rarely observed in the climatic conditions of the Kingdom.

4.3 – Sulfate Exposures

Code 4.3.1	Same except	Concrete to be exposed to sulfate-bearing groundwater or soils shall conform to the requirements of Table 4.3.1 or shall be concrete prepared with a cement that provides sulfate resistance and that has a maximum water-cementitious materials ratio, **minimum cementitious materials content** and minimum compressive strength from Table 4.3.1.

REQUIREMENTS FOR CONCRETE EXPOSED TO SULFATE-BEARING SOILS OR WATER (Table 4.3.1 in ACI 318).

Sulfate exposure	Water soluble sulfate (SO_4) in soil, percent by weight	Sulfate (SO_4) in water, ppm	Cement type	Maximum water-cementitious materials ratio, by weight, normal weight aggregate concrete	Minimum f_c', normal- weight and lightweight aggregate concrete, MPa
Negligible	$0.00 \le SO_4 < 0.10$	$0 \le SO_4 < 150$	-	-	-
Moderate[+]	$0.1 \le SO_4 < 0.20$	$150 \le SO_4 < 1500$	II, IP(MS), P(MS), I(PM)(MS), I(SM)(MS)	0.50	28
Severe	$0.20 \le SO_4 \le 2.00$	$1500 \le SO_4 \le 10{,}000$	V	0.45	30
Very severe	$SO_4 > 2.00$	$SO_4 > 10{,}000$	V plus pozzolan[++]	0.45	30

* When both Table 4.3.1 and Table 4.2.2 are considered, the lowest applicable maximum w/cm and highest applicable minimum f_c' shall be used.

[+] seawater.

[++] Pozzolan that has been determined by test or service record to improve sulfate resistance when used in concrete containing Type V cement.

REQUIREMENTS FOR CONCRETE EXPOSED TO SULFATE-BEARING SOILS OR WATER (Table 4.3.1 in SBC 304).

Sulfate exposure	Water soluble sulfate (SO_4) in soil, percent by weight	Sulfate (SO_4) in water, ppm	Cement type	Maximum water-cementitious materials ratio, by weight,	Minimum Cementitious Materials content, kg/m^3	Minimum f_c' MPa
Negligible	$0.00 \le SO_4 \le 0.10$	$0 \le SO_4 \le 150$	-	-	-	-
Moderate$^+$	$0.1 \le SO_4 \le 0.20$	$150 \le SO_4 \le 500$	II	0.50	330	28
Severe	$0.20 \le SO_4 \le 2.00$	$1500 \le SO_4 \le 10,000$	V	0.45	350	30
Very severe$^+$	$SO_4 > 2.00$	$SO_4 > 10,000$	V plus pozzolan^{++}	0.45	350	30

* If sulfate ions are associated with magnesium ions, supplementary protection, such as application of a barrier coating, is required.

$^{++}$ Pozzolan that conforms to relevant ASTM standards or that is shown to improve the sulfate resistance by service records should only be used.

$^+$ Note: The moderate exposure does not include seawater.

R4.3.1; 1st paragraph	Same except	Concrete exposed to injurious concentrations of sulfates from soil or groundwater should be made with a sulfate-resisting cement. Table 4.3.1 lists the appropriate types of cement and the maximum water-cementitious materials ratios, **minimum cementitious materials contents** and minimum compressive strength for various exposure conditions. In selecting a cement for sulfate resistance, the principal consideration is its tricalcium aluminate (C_3A) content. For moderate exposures, Type II cement is limited to a maximum C_3A content of 8.0 percent under ASTM C 150. For severe exposures, Type V cement with a maximum C_3A content of 5 percent is specified. **Type V cement may be used when Type II cement is not available.**

4.4 - Corrosion Protection of Reinforcement

Code 4.4.2	Same except	If concrete with reinforcement will be exposed to chlorides from **(deicing chemicals, salt, salt water, brackish water) soil, groundwater**, seawater, or spray from these sources, **requirements of Table 4.4.2 (Table 4.2.2 in ACI 318)** for water-cementitious materials ratio, cementitious materials content, cement type and concrete strength, and the minimum cover over reinforcing steel requirements of 7.7 shall be satisfied. See 18.16 for unbonded tendons.

REQUIREMENTS FOR CONCRETE EXPOSED TO CHLORIDE-BEARING SOIL OR WATER (Table 4.4.2 in SBC 304).

Chloride exposure	Water soluble chloride (Cl) in soil, percent by weight	Water soluble chloride (Cl) in water, ppm	Cement type	Maximum water-cementitious materials ratio,	Minimum cementitious materials content, kg/m^3	Minimum f_c' MPa
Negligible	Up to 0.05	Up to 500	--	--	--	--
Moderate	0.05 to 0.1	500 to 2,000	--	0.50	330	28
Severe	0.1 to 0.5	2,000 to 10,000	I	0.45	350	30
Very severe	More than 0.5	More than 10,000	I$^+$ pozzolan$^+$	0.40	370	35

$^+$ Pozzolan that conforms to relevant standards shall only be used.

R4.4.2; 3rd para.	----	The requirements for **protection of concrete against carbonation** are not provided as it is expected that the use of quality concrete and adequate cover over reinforcing steel, as specified in the Code, will minimize this problem.

Code 4.4.3	----	For the **permanently submerged, tidal, splash and spray zones of marine structures,** the requirements for **very severe exposure** in Table 4.4.2 shall be satisfied.

Code 4.4.4	**----**	For **concrete structures near to or on the coast and exposed to airborne salt but not in direct contact with seawater,** the requirements for **severe exposure** in Table 4.4.2 shall be satisfied.

Code 4.4.5	**----**	For **superstructures in coastal areas and not directly exposed to airborne salt,** the requirements for **moderate exposure** in Table 4.4.2 shall be satisfied.

R4.4.5	----	In the coastal areas, such as in Jeddah, Yanbu, Dammam, Jizan, and others, **the substructures are exposed to chloride- and sulfate-bearing soil and/or groundwater.** In such situations, the requirements of 4.5 shall be considered.

4.5 - Sulfate plus Chloride Exposures

Code 4.5.1	-- --	If **concrete is exposed to both chlorides and sulfates,** the lowest applicable maximum water-cementitious materials ratio and highest minimum cementitious materials content of Tables 4.3.1 and 4.4.2 shall be selected. The corresponding highest f_c' shall be the governing value for quality control purposes. **The cement type shall be the one required by Table 4.4.2.**

R4.5.1	----	**Since reinforcement corrosion is the major form of concrete deterioration,** in a chloride-sulfate environment, as sulfate ions do not penetrate deeper into the concrete cover, it is suggested to use the cement type specified in Table 4.4.2, rather than that dictated by the severity of the exposure conditions.

4.6 - Sabkha Exposures

Code 4.6.1	-- --	**Concrete structures exposed to sabkha** shall meet the requirements for very severe exposure in Table 4.4.2, except that **the water-cementitious materials ratio shall not be more than 0.35.** In addition, **the exposed surfaces shall be protected by appropriate means, such as tanking or epoxy-based coating.**

4.7 - Salt Weathering

Code 4.7.1	----	**Concrete structures amenable to salt weathering** shall be protected by applying an appropriate barrier coating.

R4.7.1	----	Concrete exposed to splash in a marine environment and soil with shallow groundwater table or water from irrigation is susceptible to deterioration due to salt weathering in the hot and arid environment of the Kingdom. **In addition to utilizing quality concrete,** it may be necessary to provide additional protective measures, such as the application of an appropriate barrier coating

Cont'd: R4.7.1	----	In marine structures, the protection should be provided in the splash zone. **Tanking or application of a barrier coating in portions exposed to soil is necessary for the substructures.**

Modifications to Chapter 5

(CONCRETE QUALITY, MIXING, AND PLACING)*

The modifications made to Chapter 5 of ACI 318 for adoption in SBC are detailed below. **Due to the uniqueness of the climatic conditions of the Arabian Peninsula,** significant additions have been made to **Section 5.13 (Hot Weather Requirements)** and the **Section on Cold Weather Requirements has been deleted**.

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* **Many changes in the units have been made and not reported herewith.**

Code / Comm.	Statement in ACI	Statement in SBC
Code 5.1.1	Concrete shall satisfy the durability criteria of Chapter 4. For concrete designed and constructed in accordance with the code, **f_c' shall not be less than 17 MPa.**	Concrete shall satisfy the durability criteria of Chapter 4. For concrete designed and constructed in accordance with the code, **f_c' shall not be less than 20 MPa (cylinder standard)**

Code 5.1.2	Requirements for f_c' shall be based on tests of cylinders made and tested as prescribed in 5.6.3.	Requirements for f_c' shall be based on tests of **150 × 300 mm cylinders** made and tested as prescribed in 5.6.3.

R5.1.2	----	Cubic specimens (150 x 150 x 150 mm) in accordance with SASO 79 may be used in evaluating the compressive strength, using the following correction factor: $f_c' = k\,(f_{cubic})$ where k = 0.8

Code Comm.	**5.10 - Depositing**	**5.10 - Placing**
Code 5.10.4	Retempered concrete or concrete that has been remixed after initial set shall not be used unless approved by the engineer.	**Retempering** of concrete with water or concrete that has been remixed after initial set **shall not be allowed.**

Code	5.12 Cold weather requirements	5.12 Cold weather requirements*
Code	5.13 Hot weather requirements	5.13 Hot weather requirements

✶ Codes 5.12.1, 5.12.2 and 5.12.3 as well as R5.12 have been deleted from SBC 304 (Not applicable in the Kingdom)

R5.13	Recommendations for hot weather concreting are given in detail in “Hot Weather Concreting” reported by **AC1 Committee 305**[5.15] (Defines the hot weather factors that effect concrete properties and construction practices and recommends measures to eliminate or minimize the undesirable effects.)	Hot weather is any combination of high ambient temperature, high concrete temperature; low relative humidity; wind speed; and solar radiation that tends to impair the quality of fresh or hardened concrete.

Code 5.13.2	**----**	The **temperature of fresh concrete** shall be kept as low as practicable but **shall not exceed 35°C at the time of placing.**

R5.13.2	**----**	**Local experience** has shown that when reasonable precautions are employed by the batching plants, **concrete with a temperature of less than 35° C can be delivered to jobsite[5.16].**

Code 5.13.3	----	The use of chemical admixtures, such as **retarders and water reducers,** shall be considered to offset the negative effects of hot weather.

Code 5.13.4	----	Unless otherwise required, concrete shall be proportioned for **a slump of not less than 75 mm at the time of placing** to permit prompt placement and effective consolidation in the form. Concreting shall be done at the lowest ambient temperature, preferably early in the morning or late in the afternoon. Delivery of concrete to the job site shall be scheduled so that it will be placed promptly on arrival.

Cont'd: Code 5.13.4	----	The construction activity shall be carefully planned to **avoid cold joints.** If construction joints become necessary, they shall be made in accordance with Section 6.4 of this code.

Code 5.13.5	----	**Retempering of concrete** by the addition of water to compensate for loss of workability **shall not be allowed.**

Code 5.13.6	----	All necessary precautions shall be taken to **prevent plastic shrinkage cracking.** In particular, precautions should be taken during placing of concrete to avoid excessive evaporation of mix water.

Code 5.13.7	----	**Curing of concrete** shall commence as soon as the surfaces are finished and it shall continue **for at least the first seven days.** Moist curing for the entire curing period is preferred. However, **if moist curing cannot be continued beyond three days,** concrete should be protected from drying with curing paper, heat-reflecting plastic sheets, or membrane-forming curing compounds.

R5.13.7	----	Curing is more critical under hot weather conditions. **Early curing is essential when pozzolanic cement concrete is utilized.**

Code 5.13.8	----	Tests on fresh concrete and specimen preparation shall be strictly in accordance with the relevant ASTM standards by qualified technicians.
	----	**Air temperature, concrete temperature, and general weather conditions at the time of concrete placement shall be recorded.**

Cont'd: Code 5.13.8	----	Inspection of concrete shall be detailed and emphasized in the project specifications to ascertain that adequate precautions are taken to minimize the adverse effects of hot weather on concrete properties.

CONCLUDING REMARKS

SBC has been developed to cater to the Saudi geomorphic and climatic exposure conditions. After a thorough survey of all international codes of practices, the ACI 318 was selected for the Concrete Sub-committee.

CONCLUDING REMARKS (cont'd)

The Concrete Sub-Committee of SBCNC critically evaluated the requirements of ACI 318 along with the data developed in Saudi Arabia over the last 30 years of through research and field experience.

CONCLUDING REMARKS (cont'd)

Major modifications for the severe exposures, such as sabkha and those leading to severe salt weathering, have been incorporated in this chapter. The other major revision, was in the Section dealing with hot weather concreting.

CONCLUDING REMARKS (cont'd)

The authors, on behalf of SBCNC, would welcome comments or suggestions to further improve the SBC.

For more details about the Saudi Building Code, please look at:

http://www.sbc.gov.sa


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Thank You