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The Effect of High Temperatures on Concrete Structures in Kuwait

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ABSTRACT
This paper focuses on the effects of high temperatures on concrete structures in Kuwait as a country to support civil engineering research and growth. Concrete is the main civil engineering construction materials in the Arabian Gulf including Kuwait. In the past four decades almost all buildings in Kuwait had a concrete skeleton containing in-fill brick walls. High level of humidity limits the use of steel bars due to corrosion and rusting. High temperatures in Kuwait affect greatly the strength of concrete on the compression. The severity of Kuwait weather continues to pose various impacts on concrete structures and thus leading to local problems that demand analysis and solutions.

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I. INTRODUCTION

Kuwait is a small country in the Middle East bordering the Persian Gulf between Iraq and Saudi Arabia. At its most distant point, it is about 200km north to south located at the far northwestern corner of the Persian Gulf 17,820km^2 in size and 170km east to west largely consisting of desert. The country has an arid climate with huge temperatures difference between winter and summer. During summer, Kuwait records an average high daily temperatures ranging from 42 ^{0}C to 48 ^{0}C and a 54 ^{0}C as the highest recorded temperatures at Mitribah, making it the Asian highest temperatures ever and third highest in the world. The Kuwait's summer season is long with humid late summer followed by a colder winter weather with temperatures as low as 6 ^{0}C at night and 7-25 ^{0}C during the day (World Meteorological Organization, 2019). The ripple effect in temperature changes between the summer and winter is expansion and contraction of concrete materials leading to a significance negative impact on structures in Kuwait. When free to deformity, concrete materials will expand or contract because of such temperatures fluctuations.

The Kuwait combined effect of high temperatures and the salty environment makes the effect of the surrounding on the concrete structures more robust than that of any other part of the world. The fluctuating high temperatures and humidity at the coast and relative humidity and same high temperatures inland are the causes of extreme and harsh conditions harmful to concrete materials in Kuwait. This paper focuses on the effects of high temperatures on concrete structures in Kuwait as a country to support civil engineering research and growth.

The Problem of Excessive Heat gain in summer on Structures

Hot weather has the potential effects on fresh and newly formed concrete, the extreme concrete temperatures leads to increased water demand resulting to rise in the water cementitious ratio therefore lowering the strength and durability of the concrete. More so, increased temperatures in the Kuwait summer accelerates the rate of slump loss and can cause loss of entrained air. Concrete sets faster at higher temperatures thus demanding a faster rate of finishing operations, high temperature concrete curing in the early stages will lose strength by a months' time.

Plastic Shrinkage Cracking

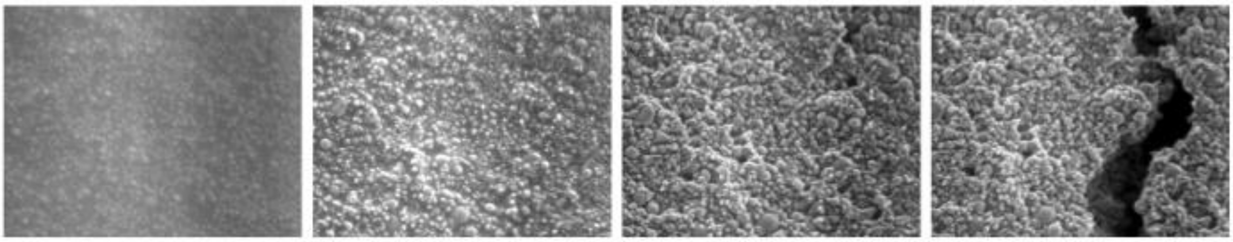


Figure 1: The impact of prolonged temperatures on concrete

Hot weather conditions in Kuwait accompanied by high wind velocity and low relative humidity causes high rate of concrete evaporation thus inducing plastic shrinkage cracking as well as wipe away the surface water of hydration. If the rate of evaporation exceeds 1.0kg/m^2/h then plastic shrinkage is reached. A plastic crack develops on fresh concrete within 1 to 8 hours on placing the concrete, rapid drops in the temperature of the concrete like slabs or walls are exposed to hot days with subsequent cool nights are the causes of thermal cracking in Kuwait's most structures.

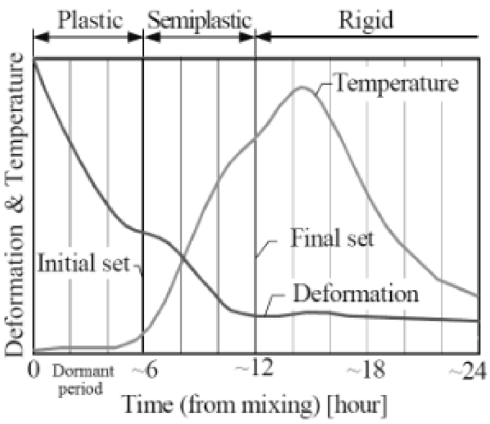


Figure 2 the three structural phases of concrete-autogenously shrinkage and hydration heat evolution.

A concrete heavier and coarser particle cures and settles better than finer ones thus exposing the grout on the concrete surface. This exposure to high temperatures and relative humidity increases loss of water from the concrete surface through evaporation thus causing volumetric strain.

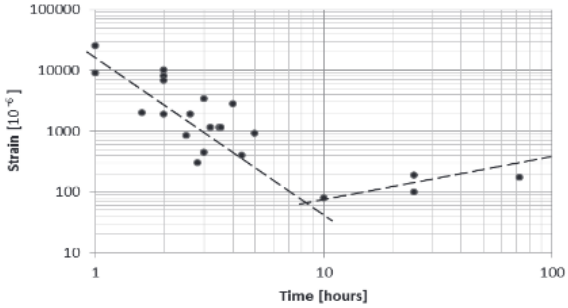


Figure 3 tensile strain capacity of fresh concrete, source: Boshoff & Combrinck (2013)

As this evaporation and strain happens, the concrete below which is not shrinking results in restraining the exposed layer from contracting therefore inducing tensile stresses at the bottom of the outer concrete leading to plastic shrinkage cracks while the outer part is still in plastic state without enough strength to withstand this stresses.

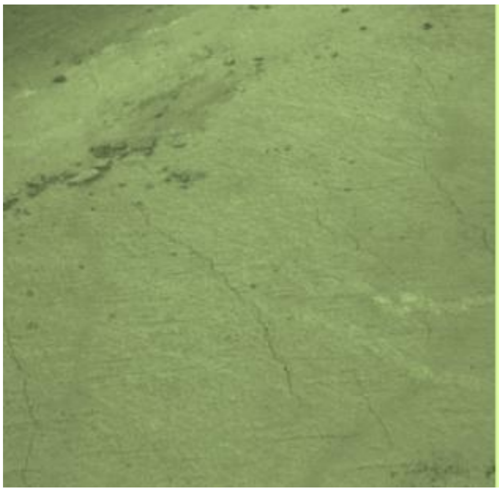


Figure 4: plastic shrinkage cracks due to evaporation

Evaporation

As evaporation has been the cause of plastic shrinkage cracking in fresh concrete, specific parameters in concrete technology must be put into considerations, when the water of evaporation rate is equal to or exceeds 1.0kg/m^2/h (AACI, 1999).

However, some experimental findings indicates that this value may be too high for some modern concrete compositions i.e. plastic shrinkage cracking may happen at evaporation rate of 0.2kg/m^2/h under hot weather conditions (Almusallan, et al.1999) reasons for evaporation includes:

- Heat water absorption into the water such as air temperatures, concrete temperature and solar radiation.
- Low relative humidity i.e. the ambient pressure is less than that in the water (Uno 199, Sayahi et al. 2014) which is further accelerated by wind.

The environmental factors that highly impacts the water evaporation rate are therefore air temperature, surface water temperature, wind and relative low humidity. According to Menzel (1954): $W = 0.44(e_0 - e_a)(0.253+0.096V)$

Where: W is weight (lb) of water evaporated per square foot of surface per hour (lb/ft^2/h), e_0 is the pressure of saturated vapor at the temperature of evaporating concrete surface (psi), e_a is the vapour pressure of the ambient air (psi) and V is the average horizontal wind speed at 20 inches (500mm) above the concrete surface (mph).

$E = (T_c^{2.5} - r.T_a^{2.5})(1+0.4V)*10^{-6}$

$$E = 5([T_c + 18]^{2.5} - r\ .\ [T_a + 18]^{2.5})(V + 4) \times 10^{-6}$$

where
E = water evaporation rate, (kg/m^2/h)
T_c = concrete (water surface) temperature, (°C)
T_a = air temperature, (°C)
r = relative humidity, (%)
V = wind velocity, (km/h).

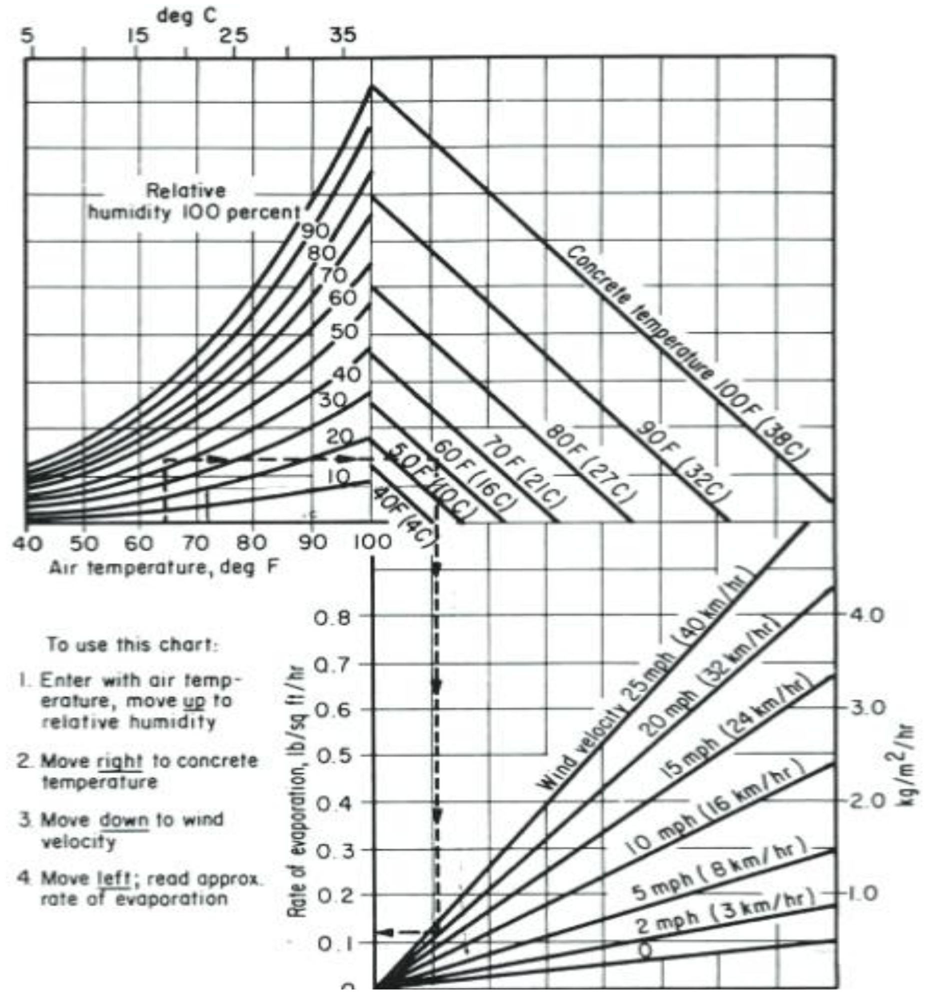


Figure 5 ACI Nomograph showing the estimation for surface water evaporation rate of concrete i.e. ACI hot weather concreting evaporation Nomograph, source: from ACI (1999).

Table 1 evaporation rate comparison an hour after placing on conventional concrete in varying environmental conditions, using the two formulas above

Group	Condition	Case	Concrete temperature, C (F)	Air temperature, C (F)	Relative humidity, percent	Wind speed, kph (mph)	Evaporation Eq.(2.1)Menzel, kg/m^2/hr (lb/ft^2/hr)	Eq. (2.3) [Eq. (2.2)] Uno, kg/m^2/hr (lb/ft^2/hr)
1	Increase wind speed	1	21 (70)	21 (70)	70	0 (0)	0.07 (0.015)	0.06 (0.012)
		2				8 (5)	0.19 (0.038)	0.17 (0.036)
		3				16 (10)	0.30 (0.062)	0.28 (0.061)
		4				24 (15)	0.42 (0.085)	0.40 (0.086)
		5				32 (20)	0.54 (0.110)	0.51 (0.110)
		6				40 (25)	0.66 (0.135)	0.63 (0.135)
2	Decrease relative humidity	7	21 (70)	21 (70)	90	16 (10)	0.10 (0.020)	0.09 (0.20)
		8			70		0.30 (0.062)	0.28 (0.061)
		9			50		0.49 (0.100)	0.47 (0.102)
		10			30		0.66 (0.135)	0.66 (0.143)
		11			10		0.86 (0.175)	0.85 (0.184)
3	Increase concrete temperature and air temperature	12	10 (50)	10 (50)	70	16 (10)	0.13 (0.026)	0.12 (0.026)
		13	16 (60)	16 (60)			0.21 (0.043)	0.20 (0.041)
		14	21 (70)	21 (70)			0.30 (0.062)	0.28 (0.061)
		15	27 (80)	27 (80)			0.38 (0.077)	0.41 (0.085)
		16	32 (90)	32 (90)			0.54 (0.110)	0.53 (0.115)
		17	38 (100)	38 (100)			0.88 (0.180)	0.70 (0.150)
4	Decrease air temperature	18	21 (70)	27 (80)	70	16 (10)	0.00 (0.000)	0.00 (0.004)
		19		21 (70)			0.30 (0.062)	0.28 (0.061)
		20		10 (50)			0.60 (0.125)	0.66 (0.143)
		21		−1 (30)			0.81 (0.165)	0.87 (0.187)
5	Cold air high RH and wind	22	27 (80)	4 (40)	100	16 (10)	1.00 (0.205)	1.13 (0.235)
		23	21 (70)				0.63 (0.130)	0.72 (0.154)
		24	16 (60)				0.35 (0.075)	0.45 (0.088)
6	Cold air and variable wind	25	21 (70)	4 (40)	50	0 (0)	0.17 (0.035)	0.17 (0.035)
		26				16 (10)	0.79 (0.162)	0.84 (0.179)
		27				40 (25)	1.75 (0.357)	1.84 (0.395)
7	Average weather conditions	28	27 (80)	21 (70)	50	16 (10)	0.86 (0.175)	0.88 (0.183)
		29	21 (70)				0.49 (0.100)	0.47 (0.102)
		30	16 (60)				0.22 (0.045)	0.20 (0.036)
8	High concrete and air temperature + low RH	31	32 (90)	32 (90)	10	0	0.34 (0.070)	0.32 (0.069)
		32				16 (10)	1.64 (0.336)	1.60 (0.345)
		33				40 (25)	3.58 (0.740)	3.50 (0.760)

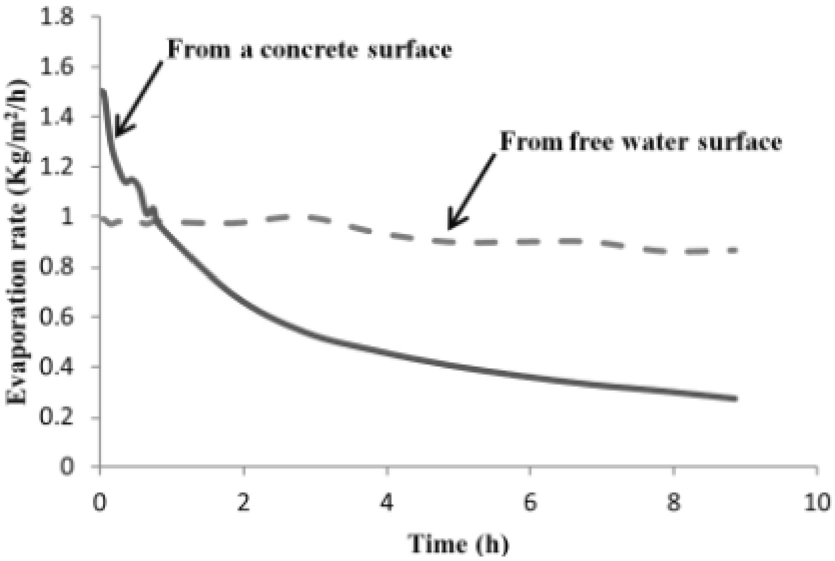


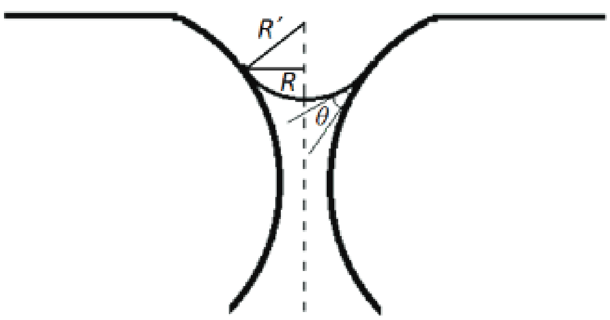
Figure 6: evaporation rate of free water and water accumulated on surface of conventional concrete

Capillary Pressure

Particle arrangement in the concrete paste is irregular depending on the region because of the air entry, meaning that different values for maximum capillary pressure for Kuwait are as follows:

$$P_c = -\frac{2\gamma_w}{R} \cdot \cos\theta = -\frac{2\gamma_w}{R'}$$

where
P_c = capillary pressure in the pore liquid (Pa)
R = radius of curvature of the meniscus in case of full wetting (θ = 0)
R' = radius of curvature of the meniscus for an arbitrary wetting angle (θ > 0)
γ_w = surface tension of the pore liquid (0.073 N/m for water)
θ = wetting angle, (deg.).



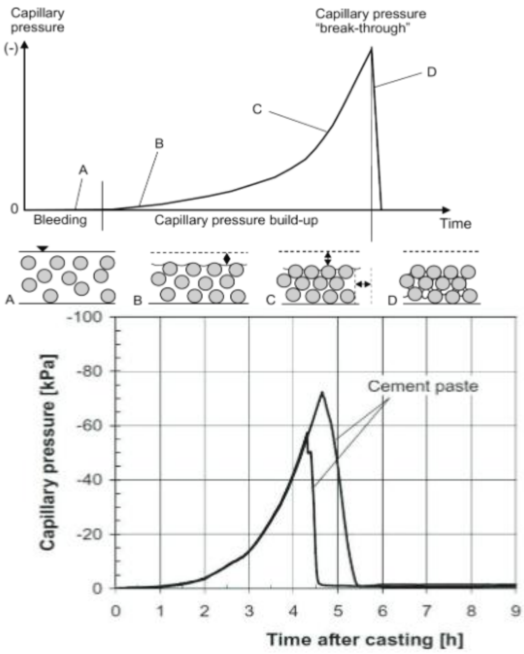


Figure 7 mechanism of capillary pressure build up, source: Slowik, et al. (2008)

The temperature changes between the summer and winter causes expansion and contraction of concrete materials leading to a significance negative impact on structures in Kuwait. When free to deformity, concrete materials bleeding after being placed will expand or contract because of such temperatures fluctuations. The aggregates and cement settles downwards due to gravity/sedimentation. If there is no obstruction in this process, the impact of plastic shrinkage makes the concrete breaks back at any restrained points hence forming cracks over it. These cracks have a tapered profile where it is broad at the surface extending downwards to the reinforcement or restraining element looking like the obstruction layout.

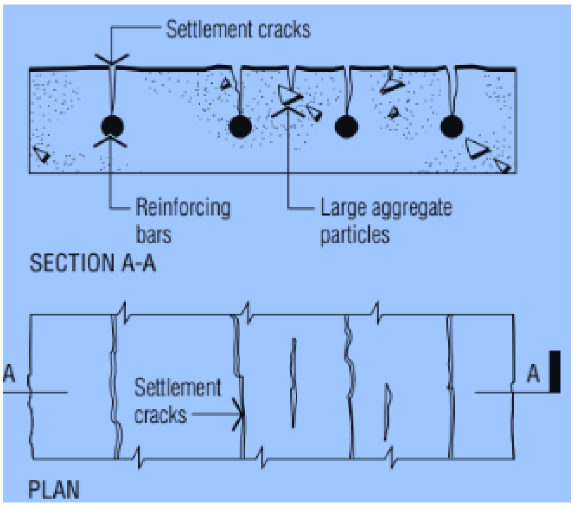


Figure 8 settlement cracking

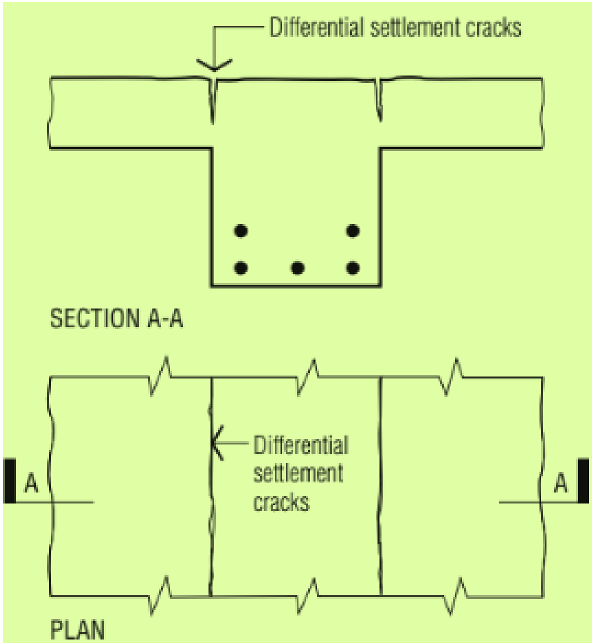


Figure 9: differential settlement cracking

The cracks further exposes the reinforcement thus posing great danger of corrosion of steel and poor durability problems in structures.

Early Age Thermal Cracks

In Kuwait, high surrounding temperatures and high concrete temperature are the main concreting problems. Hydration of cement is more rapid when the concrete temperature exceeds the normal. This effect is coupled with low relative humidity of the air as a norm of hot regions leading to more evaporation of mix water particularly at the surface of concrete that causes plastic shrinkage cracks. Thermal cracking on the other hand occurs in mass concrete structures as a result of restraint concrete contraction after a spike in heat of hydration of cement. If there is no shielding mechanism for fleshly placed mass of concrete from the air temperature, then the rapid evolution of cement heat of hydration causes a development of a temperature gradient within the concrete since the inner concrete is hot as the outer one losses heat to the surrounding. This induces the tensile stress on the surface concrete and compressive stresses on the inner concrete hence surface cracks. In the cooling phase, the surface concrete contracts thus sealing off any tensile cracks formed in the heating phase. Nevertheless, the outer concrete is restraining the interior concrete from further contraction. This induces more tensile stresses on the interior concrete. It is this tensile stress because of cooling restraint that leads to thermal cracking of mass concrete structures.

Building Deterioration in Kuwait and Dry Shrinkage Cracks

High temperatures, aggressive and harsh environment causes cracks that exposes the structures hence leading to premature deterioration of the concrete buildings and structures because of depassivation, sulphate attack or expansive cracking of the reinforcement in the concrete due to chloride concomitant ions and carbonation (Fookes, 1993). These cracks expose steel reinforcements hence causing corrosion by chloride attack or sulphate even to the hardened concrete (Rasheeduzzafar et al, 1994). The failure of pre-stressed concrete pavement in 700 of some airports in Kuwait is examples of harsh weather condition’s related concrete deterioration (Rasheeduzzafar et al, 1994). According to Rasheeduzzafar et al, (1994) study, the last two decades’ concrete building structure deterioration has increased in an alarming rate in Kuwait. This challenge is not only observed in small structures, but also in many crucial and prestigious structures have also deteriorated. The damaged structure in Figure 4 below was due to high concentration of chloride due to strong steel corrosion after exposure by cracks due to extreme weather conditions in Kuwait.

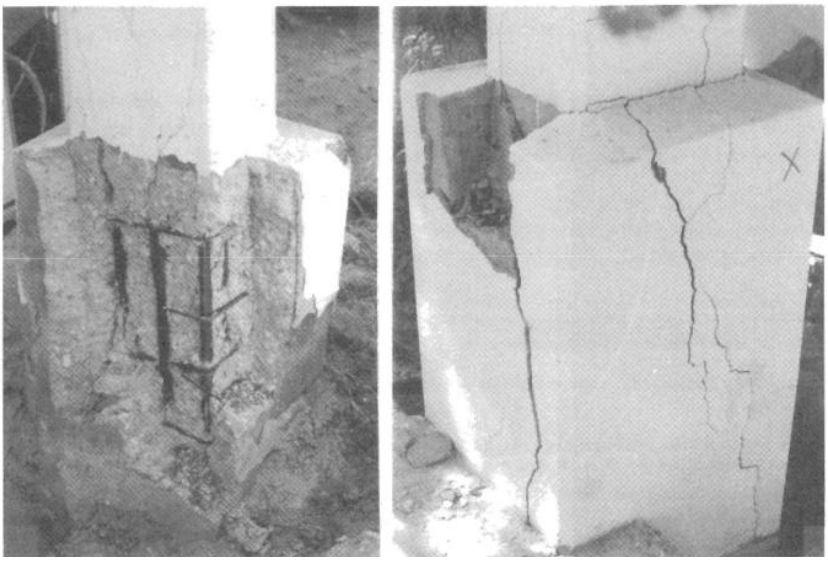


Figure 10: damaged concrete column showing large spalls and cracking

Concrete Protection

The remedies for improving concrete durability in the region with such hot weather condition are:

- The production of dense and impermeable concrete, using the apt design and construction practices and the adding supplementary cementing materials.
- The use of surface coatings or
- Using metallic or non-metallic coatings and chemical inhibitors. Blended cements produce durable concrete because of their techno-economic benefits.

II. CONCLUSION

Dry shrinkage cracks happen in hardened concrete, since not all the water in the concrete mix is used by cement hydration process. During concrete curing and hardening, the excess water is lost to the atmosphere hence concrete shrinkage. As the shrinkage happens, the elements within the concrete like reinforcement bars restrain the concrete from shrinking therefore causing a tensile stress and as a result are the dry shrinkage cracks.

This research sought to establish the effects of extreme temperatures on concrete structures in Kuwait. The research found and explained various effects most of them being broad classification of cracks in concrete and their impacts on structural integrity and durability. This research indicates that hot and extreme weather conditions are a major challenge to concrete structures in Kuwait.

REFERENCES

[1]. Al-Khaiat, H. (1995). Effect of Pollution from Kuwait Oil Wells Fires on Concrete Properties. KFAS 92-08-01
[2]. Aitcin, P. (1994) Durable concrete - current practice and future trends. AU, 144
[3]. Fookes, P., (1993). Concrete in the Middle East - past, present and future: a brief review. Concrete
[4]. Kayyali, O., Haque, M. (1988). Effect of carbonation on the chloride concentration in pore solution of mortars with and - without flyash. Cement and Concrete Research
[5]. Nasser, K., AI-Manaseer, A. (1987). Comparison of Nondestructive Testers of Hardened Concrete. ACI Mat. J. 84(5) 374.
[6]. Neville, A. 1981). Properties of Concrete. The English Language Book Society and Pitman, 3rd edition,
[7]. Rasheeduzzafar Dakhil, F. & Al-Ghatani, A. (1984). Deterioration of concrete structures in the environment of the Middle-East. AC1 Material Journal.
[8]. Tomsett, H. (1978). In Situ Strength Evaluation of Concrete ACI. Fall Meeting, Houston, Texas.
[9]. Neville, A. M. (2011). Properties of Concrete. Pearson Education Limited.
[10]. Arioz, O. (2007). Effects of elevated temperatures on properties of concrete. Fire Safety Journal.
[11]. Krishna S., Rao, M. (2005). The Effect of Elevated Temperature on Concrete Materials and Structures —A Literature Review. ASIAN JOURNAL OF CIVIL ENGINEERING (BUILDING AND HOUSING).
[12]. Askar H., Probert S., Batty W. (2001). Windows for building sin hot arid countries, Cranfield University, UK.
[13]. Knowles R. (2003). The solar envelope: it's meaning for energy and buildings, University of Park, US.
[14]. Lomas K. (2006). Architectural design for an advanced naturally ventilated building form, The Montfort University, UK.
[15]. Steemers K., Raydan D., Ratti C. (2003). Building form and environmental performance: archetypes, analysis and an arid climate, University of Cambridge, UK,

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