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Concrete Durability in the Arabian Gulf Region

Durabilité du béton dans la région du Golfe Arabique

Betondauerhaftigkeit im Gebiet des Arabischen Golfes

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SUMMARY

Deterioration of reinforced concrete structures in the Arabian Gulf region is an urgent problem that structural engineers must confront. Although durability of concrete is now recognised to be as important as its strength, structural engineers need to be more aware and better equipped for the challenge. There is a gap in design that must be overcome by developing national codes that reflect local conditions. The cooperation between materials specialists and structural engineers is essential to achieve this important goal. The paper highlights important elements in the process of "design and construct for durability."

RÉSUMÉ

La détérioration des structures en béton armé dans la région du Golfe Arabique est un problème urgent posé aux ingénieurs civils. La durabilité du béton est un élément aussi important que sa résistance, et les ingénieurs doivent en être conscients, et être équipés en conséquence. Des normes nationales doivent être établies, prenant en compte les conditions locales. La coopération entre les spécialistes en matériaux et les ingénieurs civils est essentielle. L'article met en relief les éléments essentiels dans le processus du projet et construction en vue d'une d'une bonne durabilité.

ZUSAMMENFASSUNG

Der Verfall von Stahlbetonbauten in den Ländern am Arabischen Golf ist ein akutes Problem für Bauingenieure. Obwohl die Dauerhaftigkeit des Betons heute weltweit für ebenso wichtig wie dessen Festigkeit gehalten wird, müssen die konstruktiven Ingenieure die Herausforderung bewusster und besser gerüstet annehmen. Die Entwicklung von nationalen Bauvorschriften gemäss den lokalen Bedingungen sollte die Lücken im Entwurf schliessen. Dieses wichtige Ziel ist nur durch Zusammenarbeit von Werkstoff- und Bauingenieuren zu erreichen. Dieser Beitrag beleuchtet wesentliche Punkte für ein dauerhaftes Entwerfen und Ausführen.

1 . INTRODUCTION

The durability aspects in reinforced concrete have gained a lot of significance lately.Worldwide attention has been reflected in recent issues of codes of practice [1-5] . One of the areas of the world that is in dire need of such attention is the Middle East and particularly the Gulf area. Saudi Arabia is one of the Gulf states; however it is a vast country that includes within its borders a wide variety of environments [6]. The country needs more than just adopting a foreign code of practice to be followed by engineers.The average structural engineer who is practicing in this area of the world , in the authors opinion , is neither aware of nor convinced with the problem . Those who are aware are not equipped with the knowledge necessary to enable them to design for durability . Table 1 shows values of salts and compressive strength of cores extracted from an office building in a coastal city on the Red Sea . The values prove without doubt that the designer and construction engineer had no idea about durability aspects. The building showed extensive corrosion and concrete deterioration only three years after it was handed over to the owner in 1991 . Design for durability is an attainable objective [7,8] ; it can become more and more possible through concerted efforts between materials scientists and structural engineers .

2. DURABILITY

2.1 Introduction to Durability :

ACI-201[9] defines the durability of hydraulic Portland cement concrete as its ability to resist weathering action , chemical attack , abrasion or any other process of deterioration ; i.e. durable concrete will retain its original form , quality and serviceability when exposed to its environment. Therefore concrete deterioration is not one phenomenon ; it is caused by many mechanisms. P.K Mehta [10] classifies the mechanisms into two major categories .

(a) Physical :

i) - Surface wear : abrasion , erosion and cavitation .
ii) - Cracking due to volume changes , structural loading and exposure to temperature extremes .

(b) Chemical :

i) -Soft water attack on calcium hydroxide .
ii) - Exchange reactions between aggressive fluids and components of hardened concrete paste .
iii)- Reactions involving formation of expansive products such as steel corrosion which is the most prominent cause in Saudi Arabia for concrete deterioration especially in coastal areas , and sulphates attack of concrete which also forms a considerable ratio of concrete problems in this country .

2.2 Awareness of The Problem :

There are many engineers who are under two major misconceptions ; first : strong concrete is durable , and second : using sulphate resisting cement is a guarantee against deterioration .The first concept may have some truth whereas the second is opposite in some cases such as when concrete is exposed to chlorides it makes the rate of deterioration faster . Misconceptions like this linger on while accumulation of scientific rational data continues to develop . The literature is presently full of papers ,essays , research and some books on the subject of durability . There is no doubt that materials specialists have done great efforts in this field but there is still a lot more to be done . However , there is an unintentional gap that separates them from structural engineers . In a recent conference in France on durability [11] that the author attended , he was one of five structural design engineers among close to three hundred materials specialists. This gap is perhaps even wider in the Middle East and the Gulf . The knowledge acquired by materials specialists over the past two decades are not anywhere near fully utilized by structural engineers. The average design engineer needs three important things ; first : to be convinced of the necessity of taking measures to promote durability of concrete , second : to be educated of what should be done,thirdly : he should be supported by local codes that guide him in design . The third objective must be the ultimate goal for all those who are working in the field of design and construction of concrete .

The implementation of durability measures in construction must rise to the level of correct design to achieve the desired effect .The site engineer must have the same awareness for he is the one who will make things work , together with the construction workers .All the above facts are axioms that are perhaps known in many parts of the world ; the lack of awareness in this area together with extremely aggressive environment have created problems such as those shown in Fig.1.

2.3 Durability - Responsibility of the Structural Engineer :

In the process of designing a building the structural engineer develops a very close cooperation with the geotechnical engineer . In durability related design a close relationship must develop between the structural engineer and the materials scientist . In Saudi Arabia and many parts of the world this relation is still in its infancy . Owners (clients) look at the structural engineer as the professional who is responsible about the structure's integrity , strength , serviceability and durability because he is the one that coordinates all design efforts . The structural engineer from his point of view must be able to provide his client with a design that he can claim to possess the above mentioned qualities .Therefore, it must be clear to the structural engineer in this area of the world that durability is ultimately his responsibility ; after the project leaves his desk nobody will think of durability unless he specifies the measures to be carried out . If not equipped to design for durability he must seek support from materials scientists . This is required intensively until codes are more clear , elaborate and specific about requirements for durability . This is also essential until local materials and local experiences are well established in the behavior related to durability .

3. DESIGN FOR DURABILITY

This section includes the steps that structural engineers should follow to have a rational strategy in designing for durability . For space constraints , it will be limited to the design for protection against the corrosion of reinforcing bars , since it is the most common form of building deterioration related to durability in Saudi Arabia and is number one cause in the Eastern Region[6]. However, the same logic may be applied for the other forms of deterioration.

3.1 Predesign Information

i) - Identify the environment , the possible cause of deterioration and the mechanisms involved , e.g. the distance from the sea water .. etc .

ii) - Recognize construction technology available in the region and affordable by the owner; a form of quality control and assurance must be applied .

iii)- Establish desired service life of the structure and level of maintenance affordable .

iv)- Evaluate the economics of the durability measures .

v) - Secure the help of materials scientist for consultations during design and construction .

vi)- Discuss durability measures with contractors who have good reputation in the field because the cooperation of the contractor is very important in the implementation phase.

3.2 Environment and Deterioration Mechanisms :

Characterizing the environment has recently been accepted as two-fold : macro-environment which deals with the whole region or area where the structure is built and micro-environment where the aggressivity of the environment around every single member or part of member in the structure is determined . Fig (2) depicts two examples: the first is a pier of a causeway where five micro-environments can be identified ; these are underwater , tidal , splash water , spray water and atmosphere . The second example of Fig (2) is a building column in which four zones of micro-environments are identified . This architectural form is not the best as far as durability is concerned ; it is much better in coastal environments to have columns indoors . Recognizing the possible mechanisms of deterioration and transportation in each member of the structure is extremely important . Steel corrosion mechanisms according to P.Schiessl [12] could be one of the following :

i) - Carbonation which causes reduction in the concrete cover alkalinty (e.g. industrial environment).

ii) - Chloride ions acting as a catalyst in the electro-chemical reaction that forms iron-oxides or rust (e.g coastal environment) .

iii)- Ingress of oxygen and/or humidity to the steel through cracking or porous concrete .

Three transport mechanisms are also recognised ; i.e diffusion , permeation and capillary action .

Identifing this information is necessary for the design to counteract the cause or provide needed protection .

3.3 Concrete Properties :

The following list includes the properties that provide high performance concrete that is capable of withstanding exposure to severe environments :

i) - Low permeability provided by low porosity structure of cement paste and sound aggregates .
ii) - Low heat of hydration that avoids the formation of microcracking during early ages of concrete.
iii) - Low water cementitious material ratio.
iv) - High early strength and continued development of strength .
v) - Shrinkage control at early ages until enough tensile strength is developed .
vi) - Low plastic shrinkage .
vii)- Provide factors that promote workability and control of slump loss .

3.4 Design and Construction Measures :

In order to achieve the above properties the structural engineer has, often, many options to choose from . However there are five items that he must provide ; these are :

i) - Use of correct amount and type of cementitious material and low water /cement ratio .
ii) - Provide enough concrete cover to prevent oxygen , water and other chemicals from reaching steel . He can follow as guideline international codes [1-5] until local codes are developed .
iii) - Ensure adequate compaction of concrete to provide dense concrete , adequate bond with reinforcement and eliminate entrapped air . Thus , promoting steel protection by concrete alkalinity .
iv) - Perform necessary curing .
v) - In cases of very severe exposure provide pore blocking inhibitors mixed in concrete or applied on the surface to minimize ingress of moisture and other chemicals through concrete.

3.5 Steel protection options :

Two of the methods of steel protection are epoxy or zinc coating . These methods are often reckoned as second lines of defense; their use must be weighed against maintenance cost if the first lines of defense fail ; namely , the impermeable , dense, alkaline concrete cover . In other instances zinc coating is essential in repair jobs where chlorides are involved .

3.6 Choices of Cementitious materials :

The use of slag (ASTM C989) or Fly-ash (ASTM C 618) may be considered in order to improve qualities of concrete . Silica fume can also be used with high range water reducers (Super plasticizers) . The local unavailability of these materials can affect the construction cost .They may be used only in parts of structure that are more prone to deterioration by corrosion such as the lower parts of exterior columns, concrete exposed to environment .. etc .

3.7 Economics :

The engineer must be aware of both macro-and micro - environments because durability measures are very expensive and should be applied only where needed . For example , in the building columns of Fig. (2.b), durability measures that are applied on different zones of the column are different ; underground part could be protected by coating , sulphur resistant cement and enhanced cover , whereas the lower part of the ground floor may have some pozzolan such as silica-fume as well as hydrophobic coating protection. Top floors do not need any particular protection . In Saudi Arabia , one of the areas that need special measures in most environments is the lower part of columns which are usually more exposed to weathering [13]. In this context it is worthy to mention that owners of new buildings must be educated not to go always for the " lowest bid " , they must know how to evaluate the bids with respect to durability, quality control , quality assurance and the anticipated maintenance cost required to extend the life of a deteriorated structure . A buyer of an existing structure must seek an evaluation of the structure vis-à-vis its expected life .

3.8 Quality Control - Construction :

Durability is the hostage of execution . Quality control and quality assurance are very important in achieving the properties of the structure planned by designer . Without proper construction methods durability will never be attained .The role of the construction supervisor engineer is very important .

4. CONCLUSIONS

The structural engineer is responsible to the client for the integrity , strength , serviceability and durability of the structure. In Saudi Arabia and other parts of the world durability has assumed importance in recent years due to many failures especially in the Arabian Gulf region . The structural engineer is urged by the author to assume the durability responsibility and invoke all available resources to design for assumed life of the structure . He should seek the cooperation of materials scientists as well as the contractor to provide the proper design and the correct implementation of durability measures in construction. Given in the paper are elements that engineers should be aware of to confort the problem of reinforced concrete deterioration .

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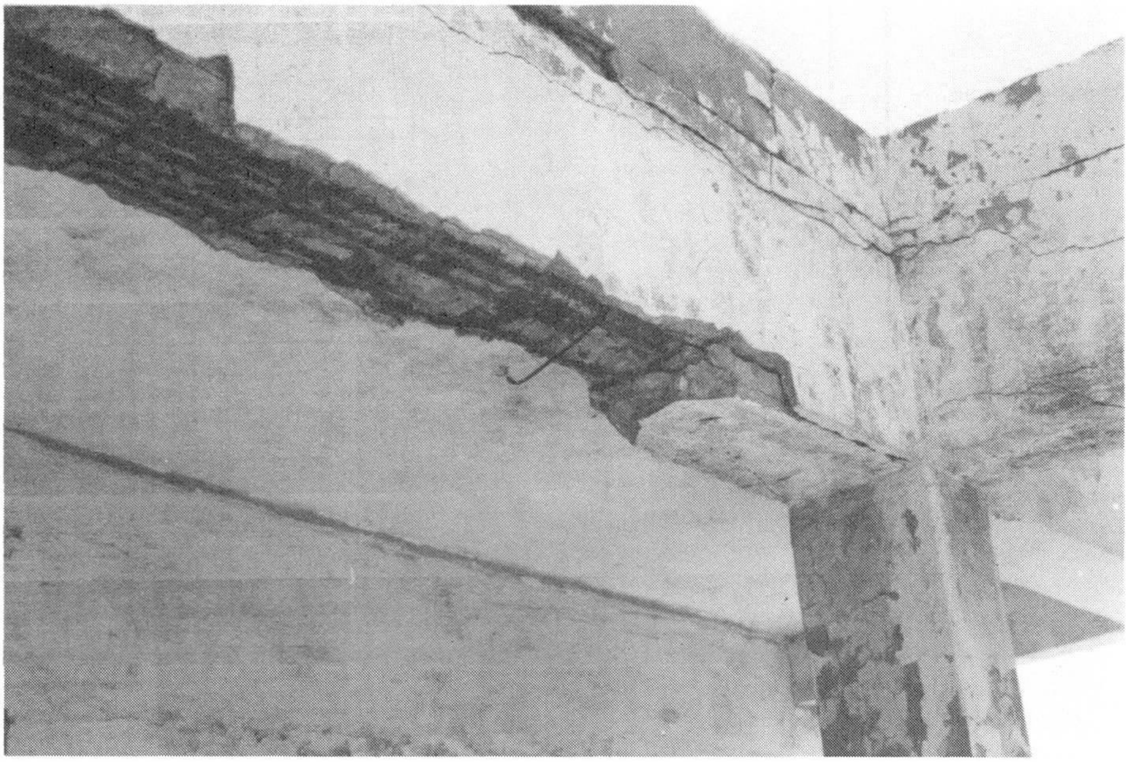


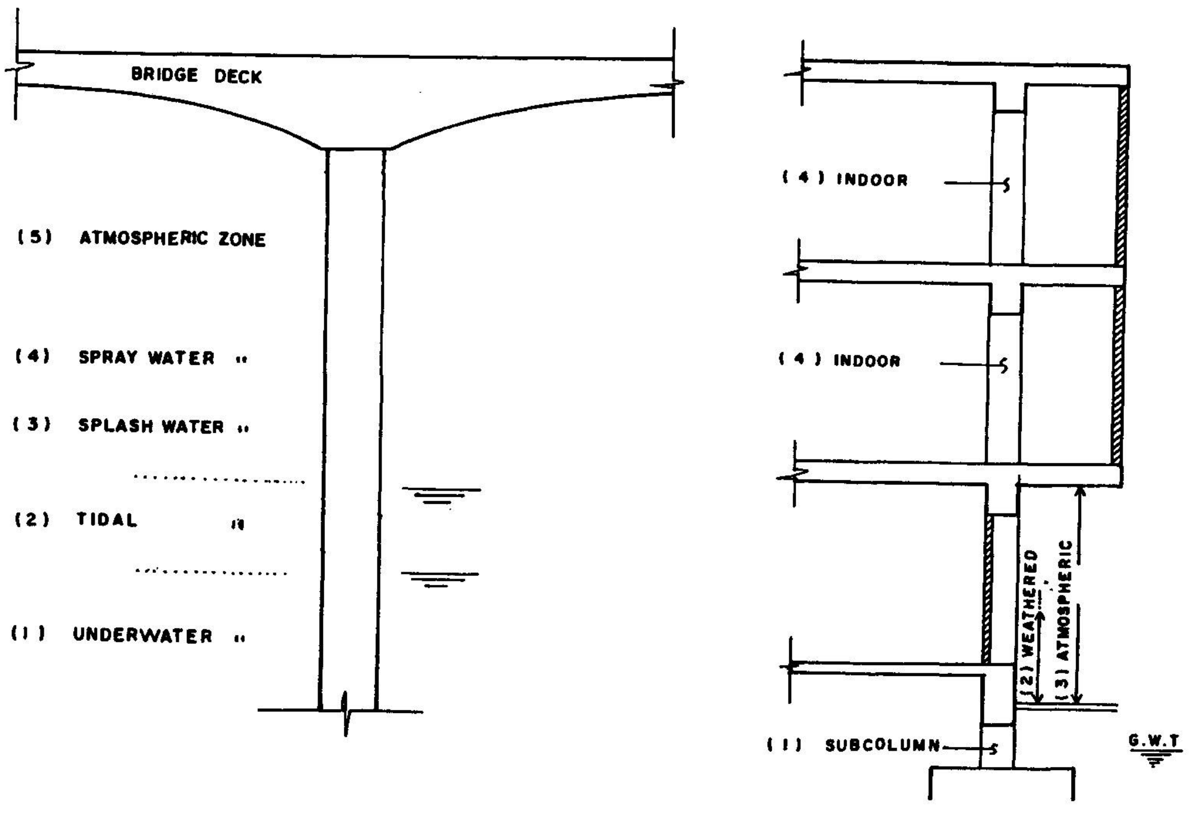
Fig. 1. DETERIORATED STRUCTURE IN A GULF CITY

TABLE 1 :- CHEMICAL AND CORE TEST RESULTS
OFFICE BUILDING - CITY OF WAJH - RED SEA COAST

LOCATION → / PROPS ↓	REQUIRED	GRD.FLR.COLS.	1st FLR. COLS.	2nd FLR.COLS.	FIRST FLOOR		SECOND FLOOR	
		C1 C4 C7 C2 C5 C8 C3 C6 C9	C11 C13 C10 C12 C14	C16 C18 C17 C19 C20	SLAB S1 TO S5	BMS B1 B2 B3	SLAB S6 TO S10	BMS B4 TO B6
CEMENT CONTENT KN/M3	3.5	3.53 2.90 2.44	X 1.85 2.32	– 1.99	2.78	3.46	2.47	2.68
CL/CEMENT %	≤ 0.4%	1.021 0.616 1.134	X 1.384 2.012	– 2.434	0.708	1.106	2.035	1.414
ALKALINITY pH	12 - 13	12.2 12.0 11.9	X 11.5 11.5	– 12.0	12.3	12.5	12.2	12.2
CORE TEST CUBE f'_c N/mm2 (MPa)	25 LOW	28.9 19.4 16.0 30.4 23.9 16.2 30.5 24.2 18.6	0.0* 11.3 X 19.8	0.0 9.5 0.0 19.3 0.0	14.9 30.7 27.9 34.7 28.6	12.9 16.2 27.5	16.7 30.3 22.0 31.3 25.4	8.1 11.3 28.1

X Sample was not extracted .
* Sample crumbled during extraction .

REMARKS :- 1st AND 2nd FLOOR COLUMNS. : WEAK CONCRETE .
– CHLORIDE / CEMENT RATIO GREATER THAN ALLOWABLE .
– CEMENT CONTENT VERY LOW FOR DURABILITY REQUIREMENTS .



(2.a) Pier of a Causeway **(2.b) A column in a building**

Fig.2 MICRO-ENVIRONMENT PRACTICAL EXAMPLES