ENVIRONMENT DIFFERENCES IN GULF COUNTRIES-EFFECTS ON CONCRETE PRACTICE

by

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Abstract

The paper discusses several issues regarding the environmental and climatic aspects in the Gulf Region and the Arabian Peninsula. It shows that not all buildings on the Gulf must deteriorate or become unserviceable after short period of operation. There are numerous buildings that survived for 30 to 40 years and more without much maintenance or repairs. However, concrete is affected by the environment (climatic, topographical and geomorphologic conditions). Until recently, concrete was considered in the macro-environment, e.g. concrete in hot weather, cold weather or in salt contaminated atmospheres. The present approach is to study the effect of the meso- and even the micro-environment. Hence, the concrete and the structure as a whole should resist such micro-environment. From this perception, it is not possible to classify any region on the basis of one environment. The differences in temperature, humidity and large variations in geological formations and geomorphology in general can sometimes be felt within one city. Hence the differences between regions of the Arabian Peninsula are noticeably distinctive.

The author tries to lay the basic foundation about the different micro-environments; the degree of it's severity and perilous impact on the construction and durability of concrete construction in order to preserve existing buildings and have confidence in future structures. The paper is an attempt to shed some light on the practical options that engineers in this region could take to improve the quality and performance of concrete structures, thus, extending their life in the environment of the Gulf.

1. Introduction

International specifications and codes did not give adequate attention to the influence of the environment on concrete industry. What we have is only statements regarding negative results and precautions to be made while producing concrete in hot and cold climate. According to committee 305 of American Concrete Institute [1], the definition of hot climate is any mixture of high temperature of surrounding atmosphere, or the concrete mix, low humidity in the atmosphere, high wind speed conditions which increase the percentage of lost humidity in concrete (evaporation of water) as well as the hydration rate of cement causing harm to quality of fresh and hard concrete. The report of above mentioned committee did not take into consideration other environmental conditions such as topography and geomorphology, which may have a negative influence that could be as important as the influence of hot and cold climate, and the negative effects on concrete will increase by time. In addition to this, the word "hot climate" is vague and inaccurate, because it varies from one city to another according to its influence and temperature . The technical committee (TC-94) Concrete in Hot Climates of (Rilem International) took a different approach and specified divisions[2] and differences among : hot climate, dry or humid-moderate, arid, desert coast-inland ..etc. It is necessary to base the design of concrete structures on the evaluation of effects of hot climate and the environmental conditions that surround the structure directly, rather than making designs based on hot climate, and general environmental conditions of a vast area. We should design concrete with regard to : weather, topography, geography.. etc.., for the immediately surrounding conditions. The up-to-date approach is to differentiate between three levels of exposure. These are: macro- , meso- and micro- levels. The first represents the conditions prevailing in a region as a whole. The second may simulate those around the building or the structure, whereas the third represents the conditions immediately next to a concrete member or part thereof.

2. Environment Differences in Gulf Countries

2.1 General

Environment for the purpose of this paper means all outer conditions that surround concrete structures directly including weather conditions, topography, earth crust, geomorphology, ..etc., which affect raw materials, production, fabrication and reactions of concrete. In several researches, which are of interest to our region, reference is made to Gulf environment, mentioning one country or another, but with no accurate description. In one instance it means the environment of cities on Gulf coast; in others, the environment of all Arabian Gulf Countries including the whole of the Arabian peninsula. For instance the problem of corrosion of steel and deterioration of concrete is a major one in Arabian Gulf coast cities. Due to the number of active researchers in those cities especially in King Fahd University in Dhahran together with some foreign companies and Bahrain Engineers Society, the environment of this area and results of these researches became applicable on all Arabian Gulf including the vast area of Saudi Arabia. It is quite clear to the specialist that the climate and environment of Saudi Arabia and other Arabian Gulf countries differ from one region to another, and we cannot evaluate climate in such vast area. There is also a lot of differences between the environment in Kuwait and that of Oman although they both are immediately on the Gulf. The same can be said on generalizing the results. The differences in temperature, humidity, wind, rain, geology of soil and raw materials could be detected very easily in one country so how can we ignore the differences between east and west - north and south - and mid of Arabian Peninsula ?. Figs. (1-8) show clear variations of the environmental parameters such as maximum and minimum temperature, humidity and wind speed for some interior and coastal cities; the information are extracted from Refs. [3,4]. In addition there are topographic differences among beach, coastal areas, and interior - geological composition in hot dry and hot humid. One may classify the climate into distinct regions : beach (5m to 500m), the coastal region next to beach (5M to few Kms.) and greater differences between coastal and interior areas. An example of identifying differences can be indicated by salt deposits on concrete whose concentration depends more or less on how far we are from the beach, see Fig. 9. The negative effects of salt on structures may disappear few kilometers away.

Therefore, the Gulf climate and environment cannot simply be considered as one. It is more appropriate to define the Gulf environment as a series of meso- environments which represent topographical and geomorphologic conditions in each region. In order to account for environmental differences and the availability of suitable raw materials, contamination of soil and atmosphere with salts, and other elements harmful to the concrete; it is required to divide the Gulf states into several subdivisions. Draft [2] which the author participated in preparing with other researchers has taken some of these aspects into consideration within the work of Technical Committee TC-94-CHC "Concrete in Hot Climates". The objective of the author as a member of TC-94 was to include more details regarding the Gulf region in a comprehensive document suitable for all the hot climates. However, the committee decided instead to publish two papers in the "Materials and Structures" Journal which will give general guidelines for Macro-as well as micro-environments in hot climates. However, in order to develop and complete the required guidelines, specifications ...etc., a large and coordinated effort of engineers, contractors and others who work in the concrete industry in this part of the world is needed.

Moreover, it should be recognized that parts of one structure are exposed differently to aggressive environments. Fig. 10a illustrates a column in a causeway with five distinct exposure zones[5] , whereas Fig. 10b depicts a building column with four zones [6]. Although in one structural element (for each example) each of these zones has a particular micro- level of exposure

2.2 Properties of Aggregates in (Central-Eastern-Western) Regions of Saudi Arabia

In a detailed research about the properties of the aggregate in these regions [7,8] the author showed that there are major differences in the properties of the aggregate among these regions. These properties were compared with those required by given specifications. Given herewith is a summary of important results of this research including geomorphologic variations.

2.2.1 Geological Formations

Aggregates in the western region and the west of the central region (on the Red-sea) consist of crystalline rocks of pre-Cambrian age such as basalt and granite. Aggregates in the middle and eastern part of central region consist of crystalline rocks together with sedimentary layers increasing towards the Gulf. These sedimentary layers are mostly limestone. As for eastern region, aggregate consists of sedimentary layers mostly limestone but of younger geological age than the central region. Figs. 11,12&13 show aggregate samples from the three regions.

2.2.2 Density and Absorption

Rocks of western region are of higher density and less in water absorption when compared with eastern region soils. Limestone of central region is in-between. In some areas in central and eastern region water absorption exceeds the allowable percentage which is 3% according to the General Building Specifications of Saudi Public Works.

2.2.3 Very Fine Materials (Dust) Content & Gradation

In the western and central region valleys, the amount of dust is similar. As for the crushed aggregate, there is a clear difference, the reason is due to the crushing that seems to produce less dust in the western region than in the central region because of better rock materials less prone to pulverization. Regarding the eastern region, more dust originates during the crushing process. For this reason, natural sand is used instead of crushed materials in concrete. Also we found that the percentage of fine sand is exceeding the allowable levels in some places in the three regions. As for gradation, it is easy to have continuous and best gradation in the western and central regions. Good gradation is difficult to achieve in eastern region, because natural sand is very fine, limited in grading, and missing a lot of sizes.

Figs. 14&15 show the aggregates of these regions compared to acceptable levels of two standards.

2.2.4 Soundness

The soundness of coarse aggregates is less compatible with specifications in the eastern region than the western or central regions. The soundness of the fine aggregate (of crushers) is less satisfactory than the soundness of the coarse aggregates, because it contains weathered particles. In the eastern region, the soundness of the fine aggregates is better than that of the coarse aggregates. This is due to the fact that they are petrographically different; that is the soundness of the natural sands is better than the porous limestone dolomites.

2.2.5 Chlorides and Sulfates

Chloride and sulfate (SO_3) contents in the coarse aggregates increase from the west to the east. This tendency is more clear in sulfates than in chlorides. In addition to this, there are more salts in the fine aggregates than that found in the coarse aggregates, which is expected due to the higher dust content where salts tend to accumulate increasingly. Chlorides and Sulfates contents of the aggregates in the Western Region, are within the allowable percentages, but limits are exceeded, in some cases, in the central region. In the eastern region they exceed the limits in more cases. Section 3.5 deals with this issue in actual structures.

3. Effects of Environment on Concrete Structures

3.1 General

In this paper an attempt is made to analyze the results of researches and information to explain effects of environment on concrete industry. Therefore, we should make different designs to each environment according to the results and depending on variation of weather, topography, geomorphology .. etc. This procedure will give positive effects; first, to increase life of structures, and secondly, to have economic structures according to environmental requirements. Since 1975 until now, lots of reports dealt with the corrosion problem in the Arabian Gulf [9-10]. It was found that bad materials and hard environmental conditions together with unskilled designs and executions caused most of the problems in existing structures. Other reports said that Gulf weather is the worst in the world in the concrete field, and it is next to impossible to see structures live their required life. Some researchers have more moderate opinion and suggest that problems are due to designs of concrete mixes and following modern technology, as well as the lack of quality control of concrete and execution. Upon studying such researches, one can find that there is a real problem in building deterioration, steel corrosion at early ages in the eastern coast of the Kingdom [9] and other cities on Arabian Gulf. We believe that there is an exaggeration of this problem, with or without intention, by some researchers of some companies who are trying to promote their products and services, yet we cannot deny this problem compared with other regions in the Arabian Peninsula such as western coast, but the problem must be put in the right prospective. Suppose the quality of designs and executions of concrete industry are almost the same, how can we explain that we have worst problems in eastern region. The problem is due to bad materials, much salt (in weather and soil) plus some environmental conditions which are harder in the eastern region than those of the western region. Ref. [11].

3.2 Historical Background

It is difficult to generalize the experiences in Gulf countries. However, the obvious similarities between Arabian Gulf countries provide a historical background which might be different in its scale, importance and priority from one country to another, but in general, indicate the problems of concrete in our Arabian Gulf. The historical background presented here reflects the author's own experience and readings [12-19]. The following subsections summarize the history of concrete in the Gulf.

3.2.1 Before the 1980's

Available local materials were used without understanding their limitations, problems and correct proportions. No tests were required to determine the suitability of materials used. Contractors , engineers , technicians and laborers were not adequately trained nor were they familiar with the area vis-a-vis materials as well as environmental and climatic conditions. In addition to these factors there was lack of construction standards and specifications , shortage in supervision and almost inexistence of maintenance.

When the construction boom started in the early seventies additional negative aspects appeared and more developments took place in various proportions. Designs were made in a hurry accompanied by hasty construction and unqualified supervision ; owners accepted low quality in return for fast profits. In the mid-to late-seventies inexperienced contractors joined the industry and minor development in the experience of construction staff started , together with the entry of foreign staff. Meanwhile partial knowledge started to accumulate regarding materials, specifications and solving problems. A variety of specifications, guidelines and technologies were utilized from numerous countries; Europe, USA and Asia. New problems appeared regarding the environment such as the rise of ground water table in many cities. The industry started at the end of the seventies to realize the consequences of using foreign specifications which do not address local problems such as hot weather , chloride and sulfate effects etc. A lot of ready mixed concrete was used without knowing its negative and positive effects. Maintenance started to be considered together with repair work of deficiencies.

3.2.2 After the 1980's until now

Results of research started to appear explaining causes of failures and deterioration of structures and those assisting in providing repair methods. A lot of attention was given to deterioration of concrete buildings caused by corrosion of reinforcement on the Gulf coast. Some specifications , booklets and general guidelines became available covering some environmental conditions but not all necessary aspects and not at the desired standards. Skills of workmanship improved especially in large projects. The industry expanded using ready-mixed concrete , with continuation of its negative and positive aspects (such as the common belief that it is always of good quality). Concrete deterioration cases increased and expansion of remedial repair with lack of preventive maintenance. Negative aspects of improper repair and maintenance started to appear.

3.3 Investigations of Distressed Buildings

In this section a summary is presented of the current situation, as reported in the literature, in order to evaluate the size of the problem, its causes and remedies :

- Investigating 62 buildings on the Gulf coastal region showed deterioration mainly due to steel corrosion [20]. This proves that the cause was poor quality concrete with neither adequate quality control nor construction supervision.
- In another research investigating 42 concrete structures[21], it was found that inadequate concrete cover was one of the main reasons causing the deterioration of these buildings. Ref.[22] proves this by examining more than 100 specimens taken from different old buildings in the coastal Gulf area. They found that deterioration decreases or even disappears with increased cover. Secondly, the chloride limit in concrete and its constituents considerably exceeded the allowable values in the specifications[23].
- The shortcomings in design, construction, bad materials and exposure to the environment played a great role in the extent of damage to the concrete[24-29].
- Some researchers categorized the Gulf environment as the worst and severest in the world[24] and that it is impossible for a concrete structure to survive its required life. Others[20,25] were less critical and referred the problem to bad mix design, not following modern technologies, lack of quality control, improper construction practices and untrained workmanship.
- In some researches results tend to be exaggerated. Fig. 16-A indicates a division of problems encountered in one research into six categories which may be confusing and do not give practical use; whereas one could put it in three categories as that given in Fig. 16-b. This clarifies the problem with fewer divisions and puts it in a more practical and realistic prospective.
- Most of the problems could have been avoided if preventive maintenance was applied. The problems could have been less severe had the buildings been originally designed properly and constructed according to proper standards that provide impermeable durable concrete.
- The author conducted research [30] to investigate the quality of ready mixed concrete in the three main regions of Saudi Arabia and found that most plants do not produce good quality concrete.
- In a study investigating 70 buildings in some districts in Makka [31], the damages found in these buildings were mostly cracks and deflections due to design and/or execution errors and

hot weather deformations and lack of supervision and quality control for hot weather concreting.

- In the literature review, which the author has conducted, no report was found indicating the ratio of damaged structures compared to undamaged buildings in a region, city or neighborhood. From experience the author found that there is a high percentage of good structures on the coastal areas of the Gulf, some of them have survived 30-40 years without problems, even with no or very little maintenance [13,32,33].
- Fig. 17 illustrates the above point, that good concrete can withstand a severe environment. The picture shown are for two sub-columns only a few meters apart. One is extremely deteriorated while the other is in excellent condition.
- The matter requires various studies to survey some cities representative of the different micro- environments. These studies should consider buildings and structures, both damaged and undamaged, i.e. compare damaged structures with undamaged ones over the entire area. This would give a clear and true picture of the size of the problem and its severity. It should indicate the true average age of structures in the Arabian Gulf.
- In studies to assess more than 400 buildings all over the Kingdom [33], it was found that the first cause of deterioration in concrete is bad execution especially in early age of concrete. The cause that came in second place is related to soil, underground water, and leakage from septic tanks and underground pipes. The third place was taken by corrosion due to saline environment and hot weather. The research also indicated that corrosion of reinforcement is worst in eastern region, and on the coast of Arabian Gulf. It tapers down towards the interior of the peninsula.

3.4 Ready Mixed Concrete

In a detailed study on ready mixed concrete in the three regions in the Kingdom[34-36], it was found that the concrete quality is not as required, even those produced by big companies, only 12% of factories which were included on the study produce good concrete, 24% of factories produce concrete of acceptable level, and about 64% of them produced bad or very bad concrete. Fig. (18) shows that 60% of factories, included in the study, by taking samples of their concrete, produce concrete with no enough strength at a time or in different times throughout the years. The same figure shows that 50% of factories aggregates do not have the required properties specified in the general specifications of building construction issued by the Ministry of Public Works & Housing in Saudi Arabia [8] in one or more requirements. Meanwhile, 38% of factories use water which is not in accordance with specifications. There was no clear variations in concrete industry in the three regions, but the higher percentage of materials used (not in accordance with specifications : water aggregates) were in the eastern region.

3.5 Salts in Concrete

During the last 10 years (1985-1995) Central Laboratories for Material Testing of the Ministry of Public Works tested 851 concrete samples from structures all over the Kingdom. Tests showed that 289 samples contained chlorides exceeding allowable levels. Fig. 19 shows the distribution of samples in the Kingdom and it is clear that the highest percentage of samples which contain chlorides above the allowable in the eastern region 57%, Then the western region 19% and the central region 14%, lastly in the south 10%. Fig.20 depicts the distribution of samples containing sulfates exceeding the allowable levels; it shows again that the highest percentage is in the eastern region 56%, then northern 25%, central region 17% and the western region comes last at 2%. In Fig.21 we can observe how samples were affected by chlorides and sulfates in the eastern region especially near the coast. This effect is decreased towards the central and western regions. These results support the main subject of this paper, that is the environment surrounding structures is playing a major role in them, in concrete industry, maintenance and operation of buildings.

4. Recommendations

The problem, its magnitude and causes were critically investigated in the previous sections. Now some suggestions and recommendations are introduced on how to treat the existing situation and to take a look at the needed future work to avoid past mistakes. This section has been subdivided to deal mainly with existing and new structures with future views. More details about these aspects are given in Ref. [37,38].

4.1 Existing Structures

These cannot be left without any treatment, especially those on the coast. They require at least routine checks, regular maintenance and, if necessary repair. It is emphasized that a great deal can be achieved through proper maintenance and effective repair (with due consideration to micro-environment) which improves the performance of structures and extends their life. Excellent experiences were developed in this area which can be adopted in saving existing structures [13,39,40]. This requires consideration of the following :

- Government Buildings should be investigated by a qualified organization that would perform routine inspections and supervise preventive maintenance or repair, if needed, every three to five years [41,42].
- Similarly, private buildings should be inspected by municipalities or qualified consulting offices. It should be done at reasonable periods according to the severity of climate and environment [42].
- Awareness about the substantial return from funds spent on proper preventive maintenance and repair should be directed to owners of buildings and those in charge of financial appropriations in the construction sector. This should be conducted through media campaigns and all other means.

Design, supervision and construction of repairs should be carried out and approved by qualified and experienced agencies and contractors (Give the bread to a good baker).

Fig. 22 depicts a proposed cycle for the above mentioned principles in a self explanatory graph

4.2 New Structures

In the following , recommendations were divided into two categories for two types of structures ; namely, for ordinary and important structures as such:

4.2.1 Ordinary Structures

Ordinary structures mean those buildings constructed by citizens as private homes or residential and commercial buildings of limited number of floors and small budget. It is difficult to demand high technology, expensive specifications, and stringent requirements because this renders them expensive and unprofitable. Meanwhile, these projects are usually executed by contractors, technicians and laborers who know little about modern technology which requires special skills. Therefore, positive aspects desired from such a requirement will be lost, and some negative aspects may even appear. For example when using new types of cement which contain slag, fly ash or silica fume without proper mixing, pouring, vibration and curing, these cements become ineffective or even of less value than ordinary Portland Cement. Similar problems could occur by using coated steel bars.

Therefore, the design for concrete elements in such structures should follow at least ACI-305 [1] recommendations and severe micro- environment requirements to ensure impermeability and provide sufficient concrete cover to protect steel which are important factors in the durability of concrete. This is sufficient until the development and approval of an alternative document more appropriate for the Gulf environment, such as the one proposed by the author [34]. Municipalities (if they have the manpower) or qualified consulting offices should act as neutral qualified bodies to ensure the design, approve it, inspect the supervision for the construction and supervise concrete quality in the plant and proper execution at the site.

4.2.2 Large (important) Structures

Those are projects of prestigious value and higher cost which their owners should spend an additional percentage of their value during the design and construction stages to reflect the potential reduced cost for maintenance, repairs and to improve the performance of the structure. It is recommended that the planning, design and construction, occupancy stages.. etc. should follow the approach (How to design and construct in hot weather) demonstrated in [2] and outlined in this paper. In addition, a clear and comprehensive Quality Assurance and Quality Control system should cover the entire life cycle of the structure in accordance with the systems given in [36,43,44]. Accordingly, useful usage of modern methods, high technology and new materials in such projects is profitable and should be evaluated and considered (such as proper protection by reinforced plastic layer, additional permanent forms, materials or facades, coated bars, cathodic protection ... etc.).

Fig. 23 gives a flow diagram of the building development process in general.

4.3 Efforts Coordination

There is insufficient information or database regarding the history of concrete practices, its background and the present and future situation in Arabian Gulf countries. One of the main objectives of this paper is to initiate the establishment of such a database to provide information to researchers solving local problems , to help development and to avoid negative aspects.

Native and foreign engineers and others concerned with concrete in Gulf countries should assume their role to serve the building sector and, in particular, the concrete industry, which is the cornerstone for construction in the Gulf. Part of this can be achieved by attending and taking an active role in the technical committees which prepare reports about hot weather, such as ACI Committee 305 or RILEM Technical Committee TC-94, where Europeans who have no substantial hot weather in their countries prepare reports and specifications for Gulf countries, whereas natives participation in such activities is still very limited.

It is believed that establishing an institute in the Gulf to serve this important function is long overdue; such identity is important to pioneer scientific research, specifications, guidelines and suitable methods to improve the quality of concrete, protect and maintain buildings in order to extend their life span in the hot and aggressive environment of the Gulf. It could be useful to establish a Gulf organization, subordinate to the council of Gulf Ministers for Housing and Public Works, with the responsibility of unifying the efforts of serving concrete industry by developing a database and information system for concrete practices in the Gulf, including a general survey covering the points mentioned in this paper. Gulf countries should coordinate efforts to actively participate in international organizations which are interested in concrete in hot weather and severe climates.

4.4 Future Views

1. Local building codes must take into consideration the severe Gulf environmental conditions.
2. Quality control and quality assurance systems for concrete in the plant and at the site must be prepared and approved by proper jurisdictions. An exemplary system is proposed by the author in Ref. [43].
3. Approving codes and assigning agencies for implementing the codes, quality control and quality assurance systems.
4. Not all engineers and technicians are qualified to deal with concrete work in plant and/or on the site, so necessary qualification and structured training programs should be detailed. The responsible bodies for this training and certification should be assigned.
5. Applied research should be directed to serve concrete industry through studying hot weather and aggressive environment effects on concrete, evaluating sources for appropriate raw materials, applying new technologies, developing maps for various micro environments in the Gulf.. etc.

6. It should be strongly emphasized that routine protective maintenance and proper repair should never be forgotten as it is the basic factor that saves concrete from deterioration in the Gulf region. Sufficient funds should be allocated for such purposes.
7. Manuals and specifications should be prepared for maintenance and repair methods. In both exposure to environment must be accounted for at the appropriate level; namely: macro-, meso- or micro- environment.

5. Conclusions

The paper explained that the overall concept of hot and cold environment (Macro-Environment) is not sufficient for the design of concrete structures. It is very important to include other detailed environmental considerations; i.e. the environmental factors surrounding the structure (meso- environment) and in close contact with its concrete members (micro-environment). Variations of the environment in the different regions of the Arabian Peninsula were discussed. These included weather conditions, topographic formations, material constituents of concrete and salt concentrations. It was obvious that the structures in the Eastern region were more affected by environment; more so than those in central and western regions. It was also apparent that buildings in the eastern region near the coast or in its vicinity were more affected than those away from the coast. The paper concludes that it is of utmost importance to consider environmental conditions in the specifications of design, construction, operation and maintenance of structures.

Therefore, it will be more rewarding economically to design, execute and maintain structures in light of the severity of environmental conditions to which it is exposed; thus we can improve concrete durability and extend the life of structures .

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Fig.1: Maximum Temperatures in some Inland Cities, K.S.A.

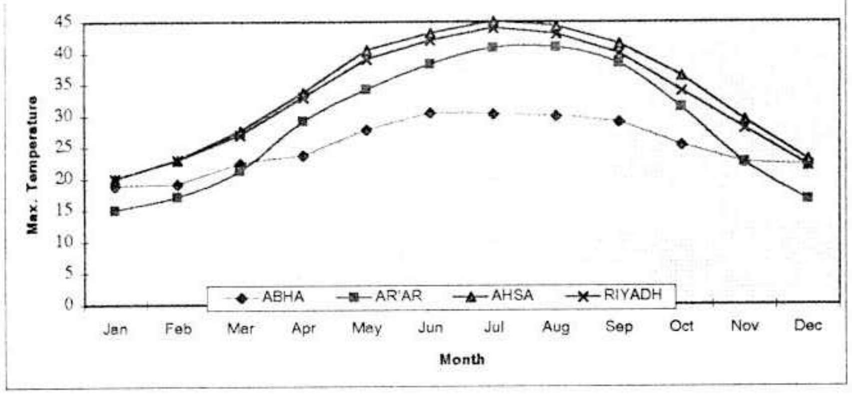


Fig. 3: Minimum Temperatures in Coastal Cities K.S.A.

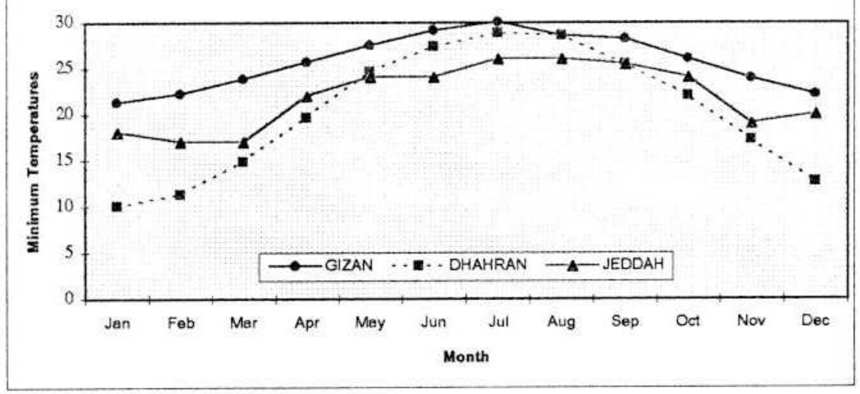


Fig.2: Difference between Max. and Min.. Temperatures in Coastal Cities, K.S.A.

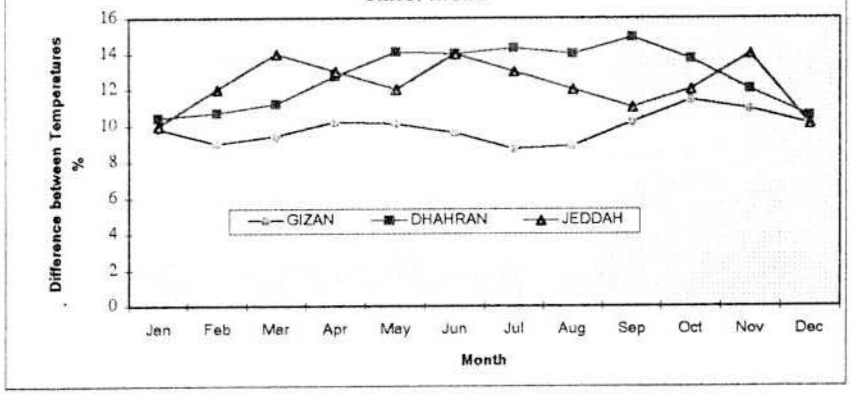


Fig. 4: Mean Temperatures in some Cooastal Cities in Gulf Cuntries

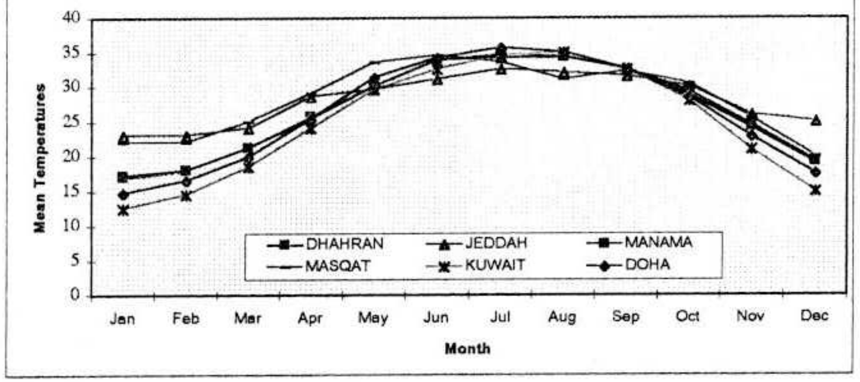


Fig. 5: Change of Mean wind Velocity in Coastal Cities, K.S.A.

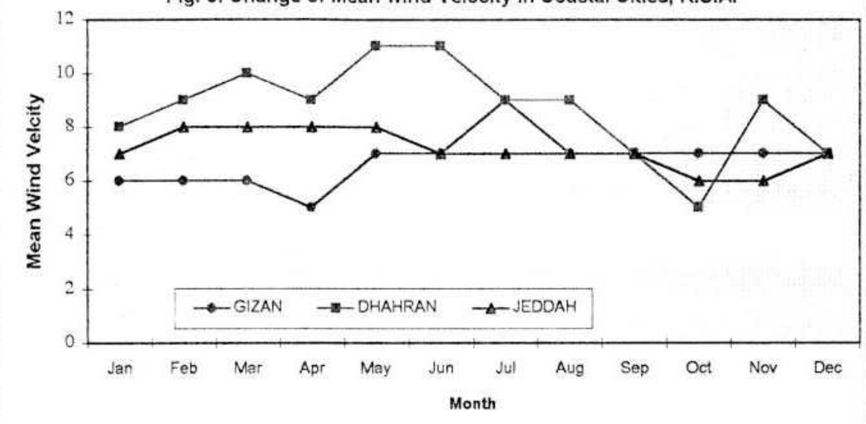


Fig. 7: Mean Relatiive Humidity in some inland Cities, K.S.A.

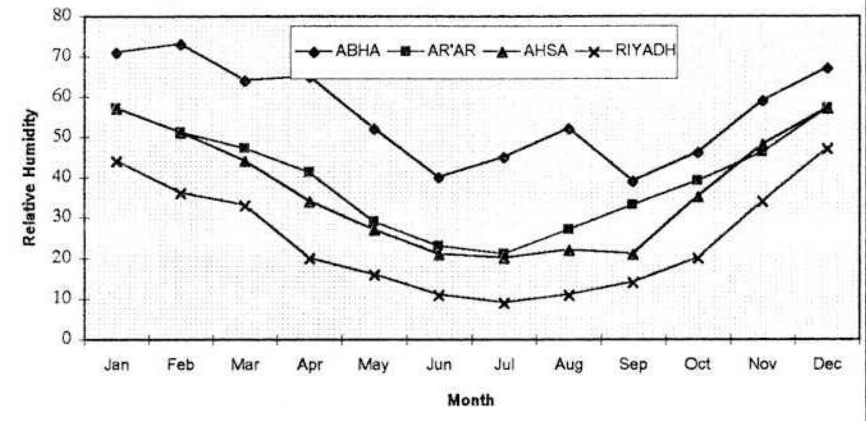


Fig. 6: Change if Mean wind velocity in some Cities of Gulf Countries

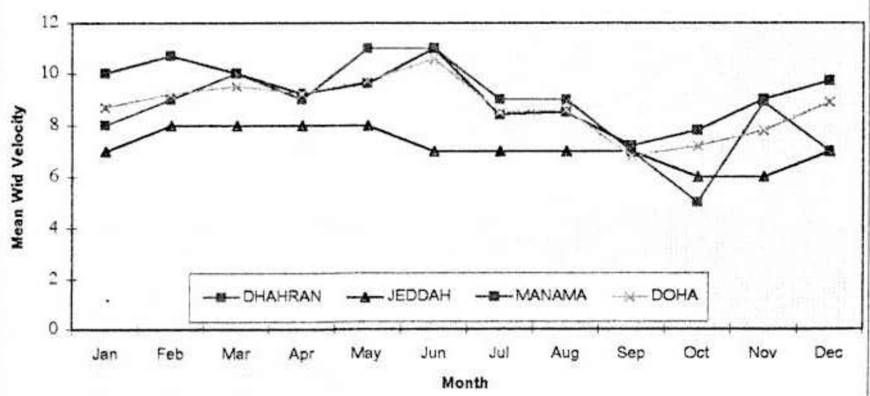
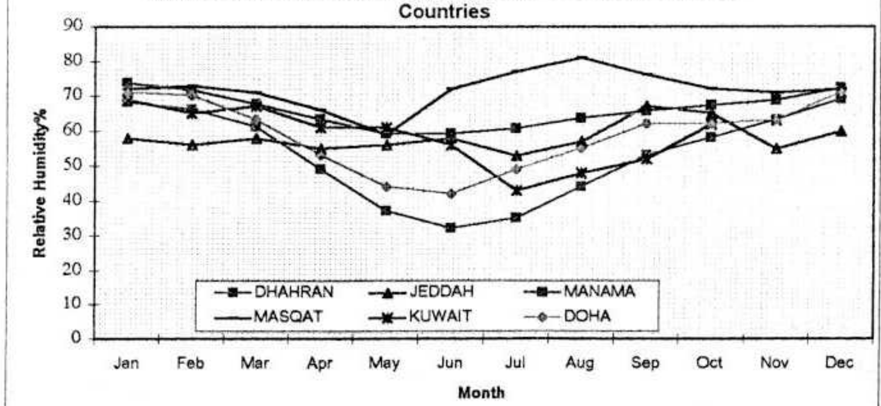


Fig.8: Relative Humidity Changes in some Coastal Cities in Gulf Countries



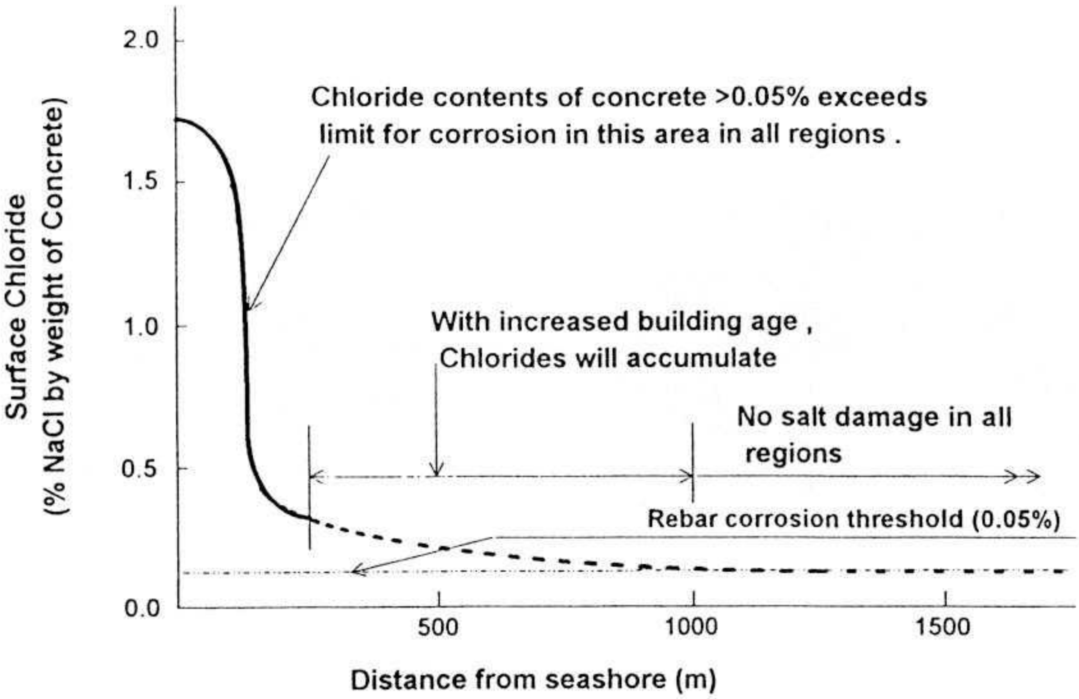


Fig. 9 Chloride levels at Concrete Surface Layer with Distance from Seashore

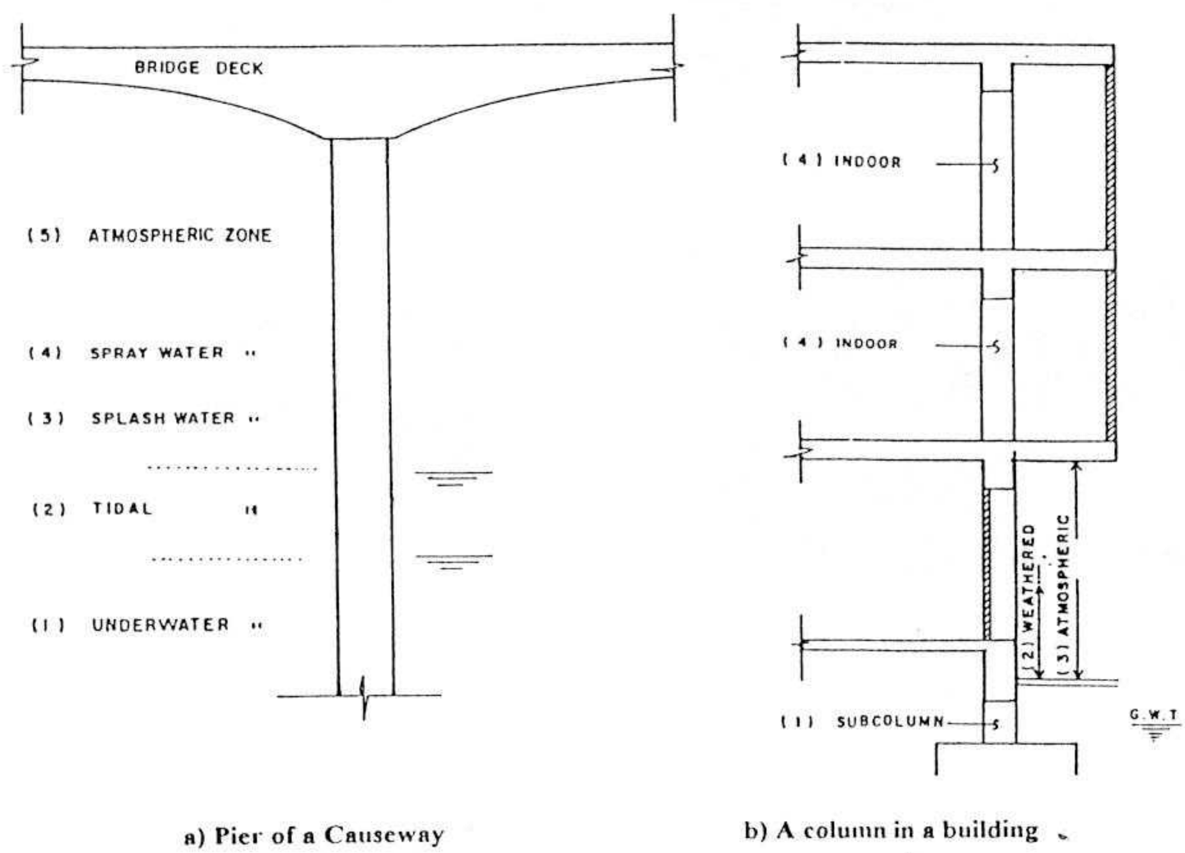
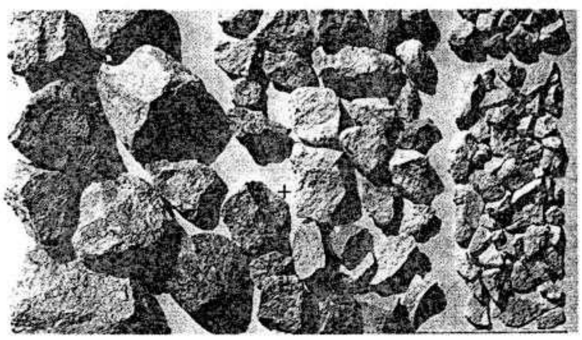


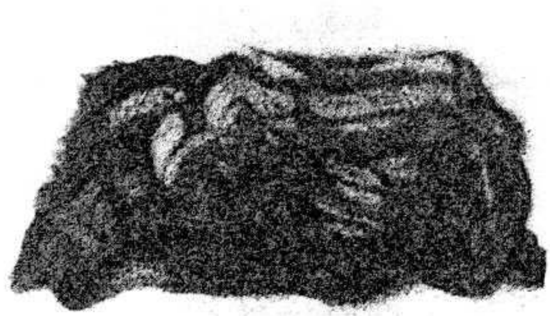
Fig. 10 Micro-Environment Practical Examples

Fig. 11 Examples of Aggregates - Western Region

Fig. 12 Examples of Aggregates - Middle Region



Coarse Aggregates



Natural Sand

Fig. 13 Aggregates from Eastern Region

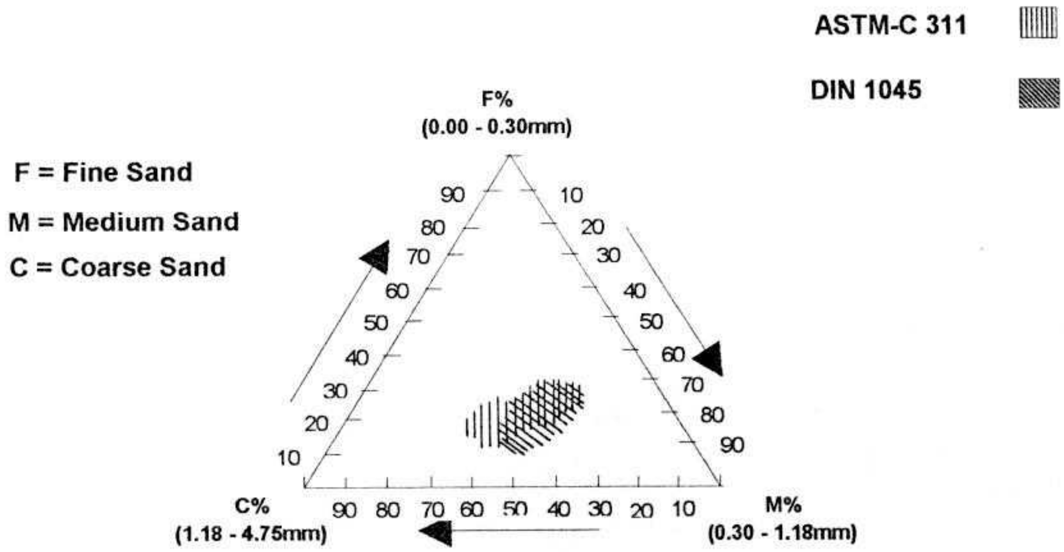


Fig 14 : Fine Aggregates Requirements, Suitability Triangle

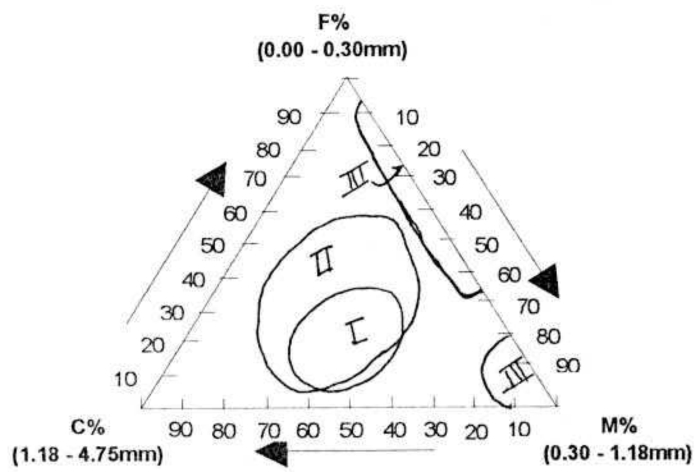


Fig.15 : Fine Aggregates from :

- **I. Western Region**
- **II. Middle Region , and**
- **III. Eastern Region**
  in Suitability Triangle

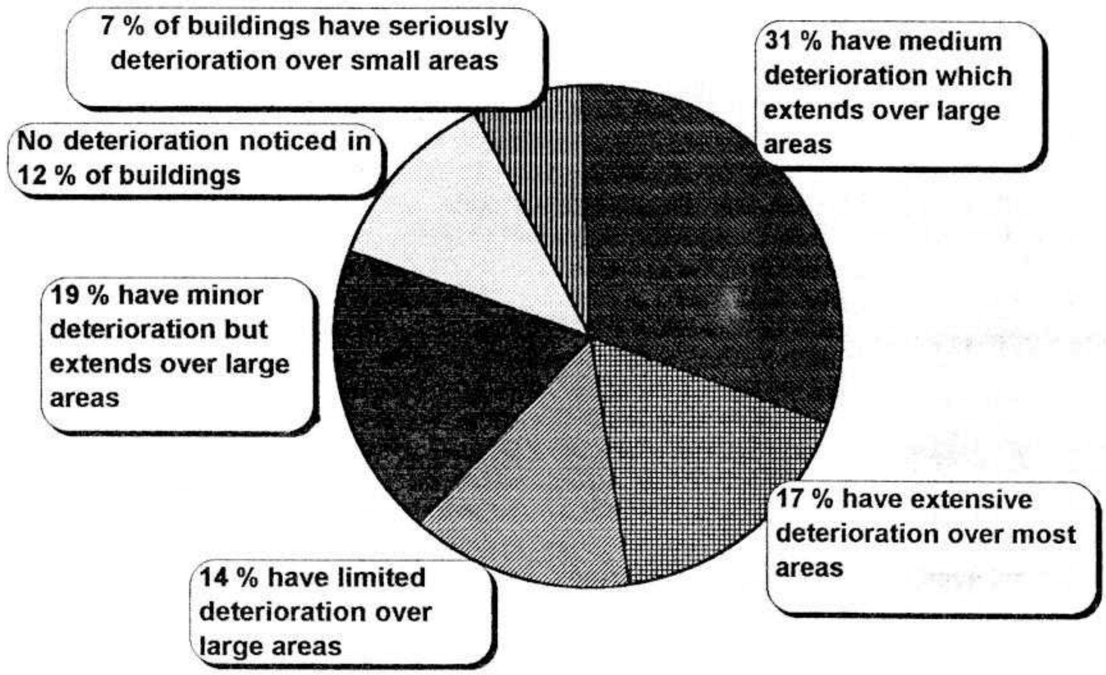


Fig. 16 a

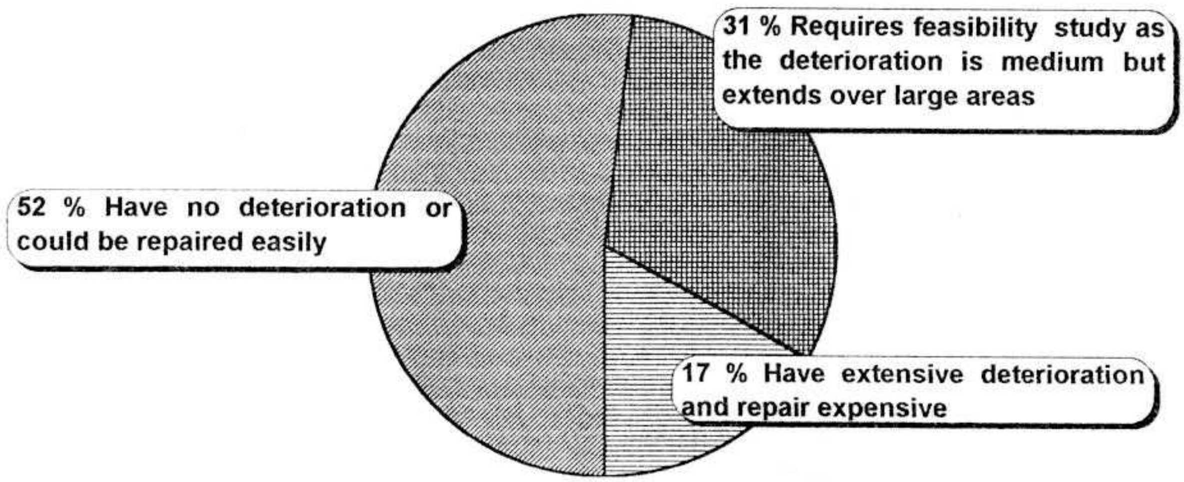


Fig. 16 b - Reduced Subdivisions lessens the Exaggeration

Fig. 16 : Exaggeration in Presenting Research Results

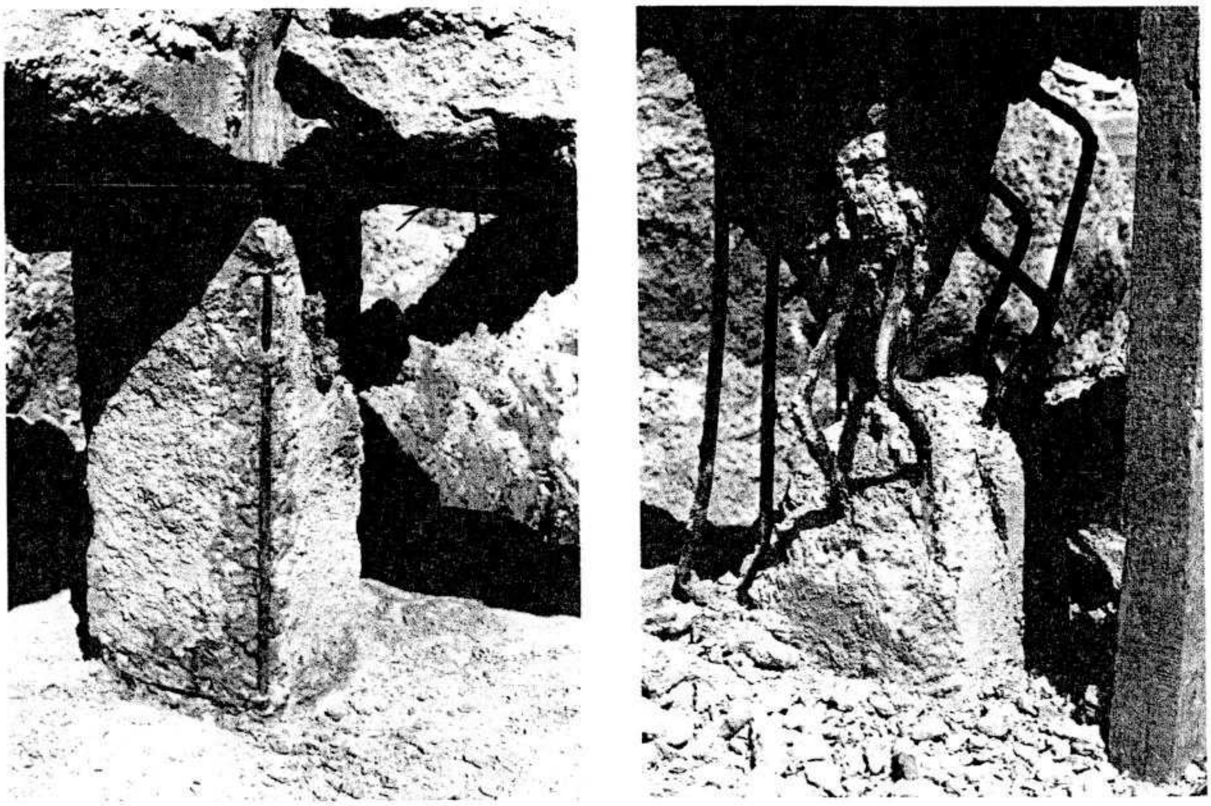


Fig. 17 Two Sub-Columns in The Same Building,One is Badly Deteriorated While The Other is Intact

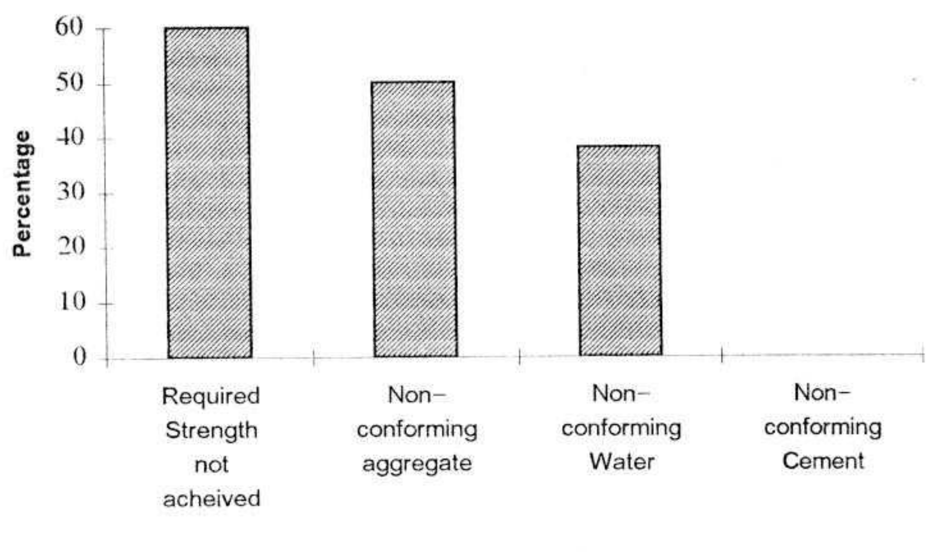
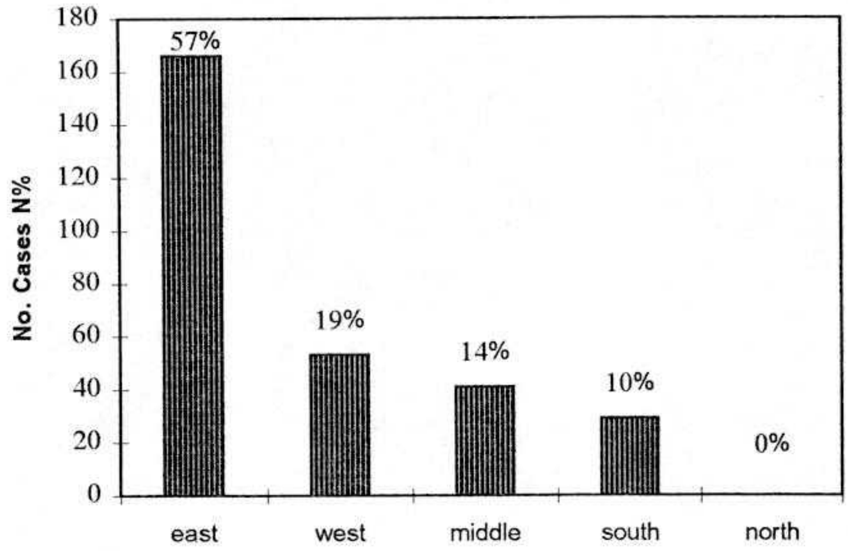
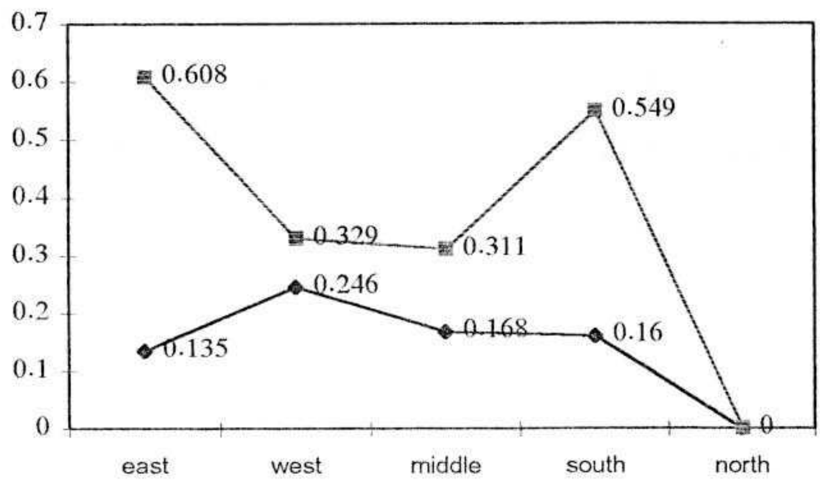


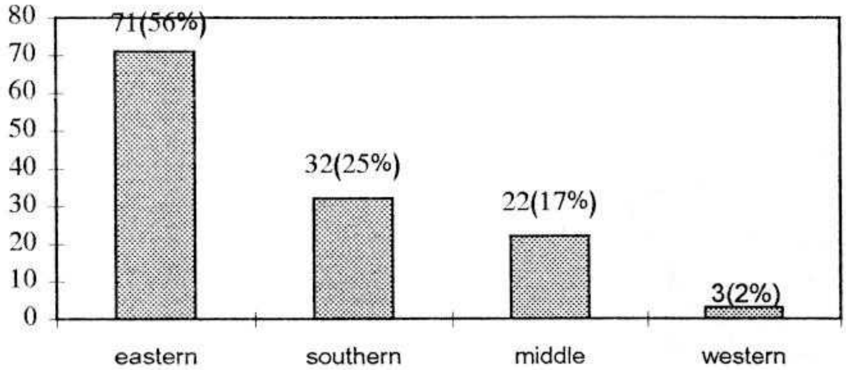
Fig. 18 Percentage of Ready-Mixed concrete Factories not Conforming to Requirments

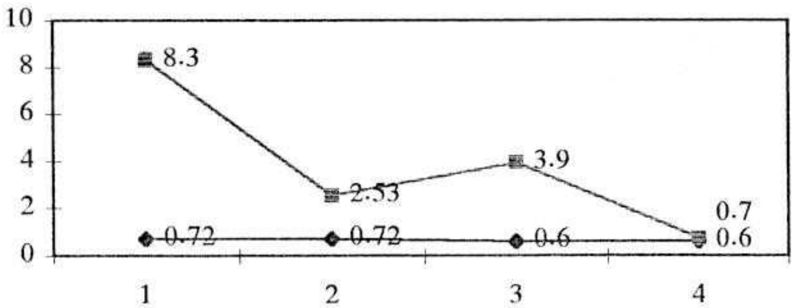




*** Note : The high Chloride Content in most of defective Concrete samples from the Middle Province may be attributed to diffusion of Chloride ions from Ceptic tanks , ground water , Soil or industrial waste water to the Concrete units especially those which are near the ground.**

Fig. 19 Distribution of defective Reinforced concrete cases in Kingdom of Saudi Arabia within the last 10





From the graph it is clear that the Eastern province has the most number of cases of contamination with sulphates and this number represents 56% of the total contaminated cases. This may be attributed to the utilization of aggregates contaminated with sulphates in making the concrete. However, it is practically known that many sources of aggregates in the Eastern province are contaminated with sulphates due to the nature of this region.

Fig. 20 Distribution of (126) concrete samples with high sulphate content between the provinces

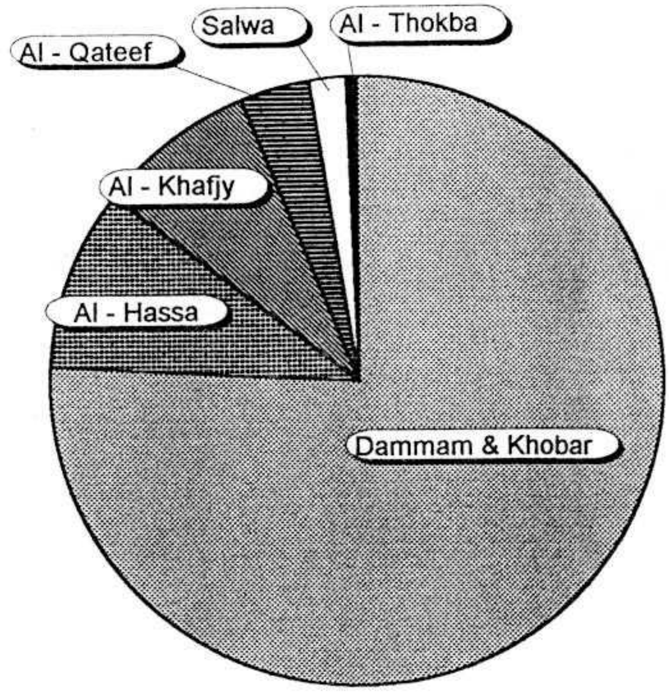


Fig. 21a Chlorides

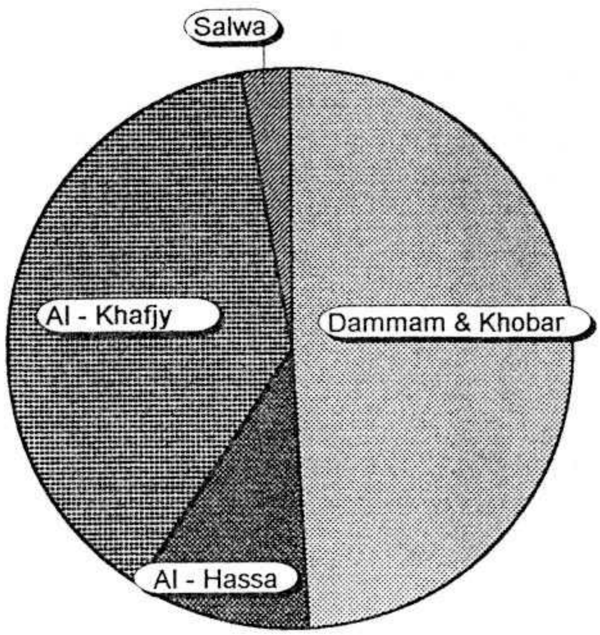


Fig. 21 b Sulphates

Fig. 21 Distribution of defective Reinforced concrete cases in EASTERN province cities.

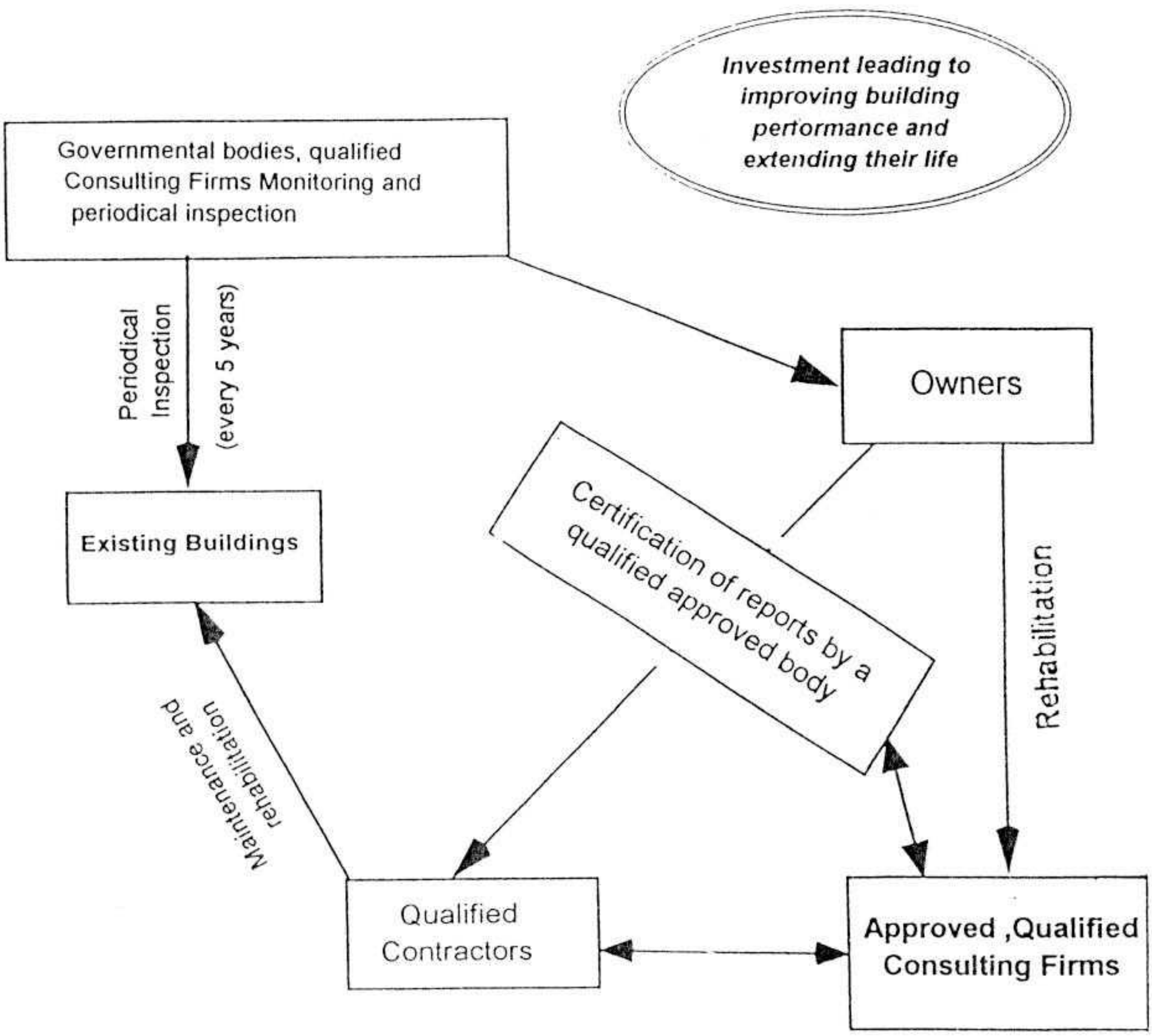


Fig. 22 Maintenance of Existing Buildings Before Deterioration

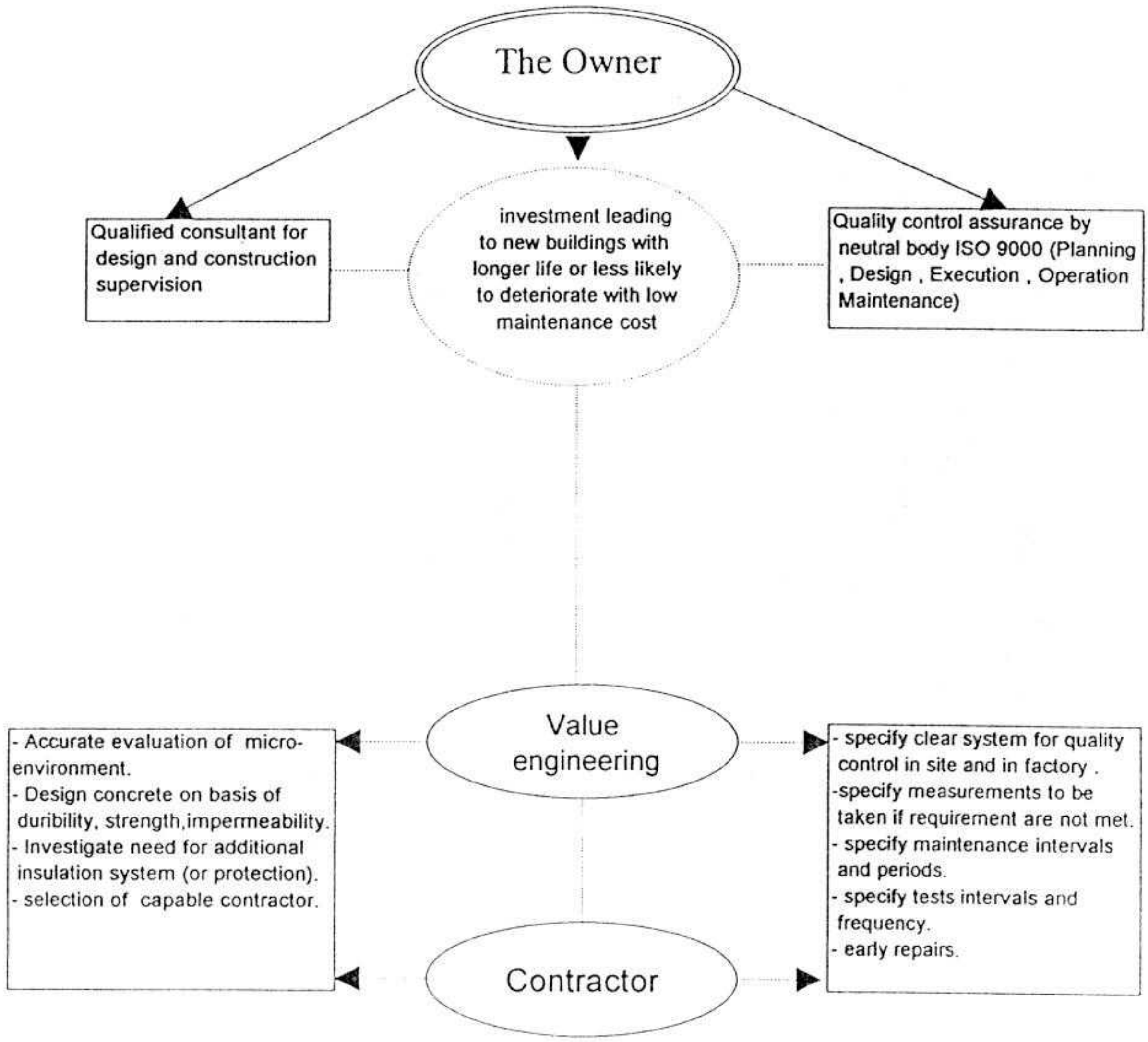


Fig. 23 Future design and construction of buildings