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DURABILITY OF CONCRETE IN COASTAL AREAS OF BANGLADESH

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ABSTRACT: Good quality concrete should perform satisfactorily throughout the design life of a structure. Concrete construction along the coastal areas of Bangladesh is frequently reported to be unsatisfactory as the concrete in these areas are found to be deteriorating rapidly. Severe climatic conditions, other environmental factors, limited availability of suitable materials, absence of relevant specifications, codes of practice and proper technical know-how have adverse effect on durability of concrete and initiate premature deterioration of concrete structures in coastal areas. All these factors lead to random cracking, corrosion of embedded reinforcements and large scale spalling in the concrete members. Lack of repair and rehabilitation works accelerates the deterioration process and the durability of concrete structures is seriously affected. This paper briefly describes the results of some studies on the performance of concrete and the related construction practices in the coastal areas of Bangladesh. Based on these studies a number of recommendations have been put forward for improving the durability of concrete structures in coastal areas of Bangladesh.

KEYWORDS: Durability of concrete, corrosion of reinforcing bars, protection of concrete, coastal environment.

INTRODUCTION

Making good concrete which meet the durability requirements in coastal areas of Bangladesh is a difficult task. Premature deterioration of concrete structures in these areas is a common feature. Structures, even 10-15 years old, show alarming degree of deterioration in the form of cracking in concrete, spalling of concrete and corrosion of reinforcements. In most of the cases the cracks and spalling in concrete are due to large-scale corrosion of reinforcing bars. Environmental factors together with physical and chemical causes have adverse effect both on behaviour of fresh concrete as well as on its performance after hardening. Other constraints such as shortage of suitable materials, construction equipment, skilled labour, proper technical know-how etc. also affect the construction activities in coastal areas.

Any construction in the coastal areas, which disregard the environmental and other issues, will affect the quality, performance and durability of concrete structures. Like all other materials, concrete in coastal areas requires the employment of proper design and construction techniques if the proper durability of this material is to be realized in service. The durability of concrete construction in coastal areas needs to be considered separately from those in inland urban

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areas for various reasons. Firstly the construction shall be made taking mitigatory measures against the causes of deterioration, which may be peculiar to the region. Secondly, a method for durable construction shall have to be developed by taking into account the local materials and techniques.

This paper briefly describes the field studies carried out in the coastal areas of Bangladesh on performance of concrete and construction practices. It also describes ways to achieve greater durability of concrete constructions in the coastal areas using the experience gained from the field studies and by adoption, where appropriate, of the recommendations contained in recent research reports. Keeping in view the results of the studies and the available information, measures have been suggested for producing durable concrete in the coastal areas of Bangladesh.

EFFECTS OF COASTAL ENVIRONMENT ON CONCRETE CONSTRUCTION

Reinforced concrete structures are very common in coastal areas of Bangladesh. Many such structures are submerged, partially or completely exposed but likely to be inundated by surge water accompanied by the cyclonic storms, which quite frequently affect the coastal areas of Bangladesh. The design and construction practices for concrete works in coastal environments assume great importance with regard to their durability. Achieving long-term durability of concrete structures is considerably more difficult in coastal areas in Bangladesh than in other parts of the country. Lack of durability can be caused by external agents arising from the environment or by internal agents within the concrete. Causes can be categorized as physical, mechanical and chemical. Physical causes arise from the action of alternate wetting and drying and from differences between the thermal properties of aggregates and of the cement paste. Chemical attack takes place within the concrete mass, if the permeability of concrete is favourable for such attack. The extent of damage produced by these agents depends largely on the quality of concrete and any unprotected concrete will deteriorate.

Deterioration of concrete is rarely due to one isolated cause, especially in coastal areas where a number of environmental and other factors may contribute to damage of concrete structures. For this reason it is sometimes difficult to assign deterioration of concrete works in the coastal areas to a particular factor. Large scale deterioration and distresses in the concrete elements of the existing structures in the coastal areas of Bangladesh demand construction of durable concrete and its protection.

DETERIORATION OF CONCRETE STRUCTURES IN COASTAL AREAS

A field survey was initiated to visit and examine the cyclone shelters along the coastal belt of Bangladesh in 1992 (BUET-BIDS, 1992). A total of 227 shelters were visited. These cyclone shelters constructed during 1974-1979 developed serious distresses and large scale deterioration over the years. These shelters are three storied reinforced concrete frame buildings, located at various places of coastal areas, constructed by Public Works Department (PWD) of People's Republic of Bangladesh and funded by International Development Association (IDA). Some typical conditions are shown in Figs. 1 through 3.

Fig 1. Cracks in column prior to spalling

Due to the serious deterioration of the different structural elements of these concrete buildings, the design criteria, use of construction materials and the construction specifications of the shelters have been reviewed. Some of the construction specifications of these shelters are as follows:

Mix ratio of concrete used: 1 : 2 : 4
Crushing (cylinder) strength of concrete,
f'_c=13.8 to 15.5 MPa(2000 to 2250 psi)
High-tensile deformed bars with allowable stress in tension,
f_s=158 MPa (23,000 psi)
Coarse aggregates: Brick chips
Clear cover for reinforcements:
Specified as for normal concrete works such as,
for slab: ¾ inch (19 mm), and
for beams and columns: 1½ inch (38 mm).

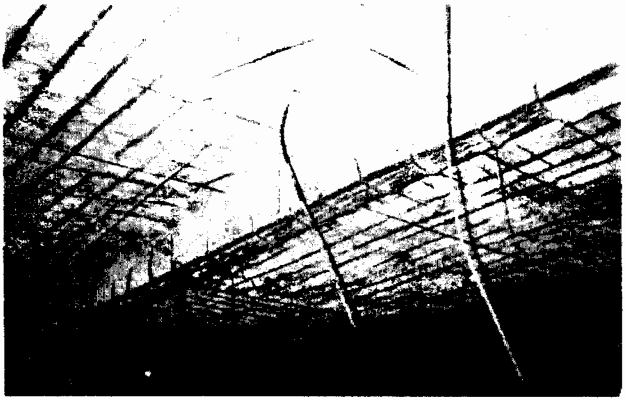

Fig 2. Slab and beam reinforcements exposed due to spalling of concrete

Fig 3. Large-scale spalling of concrete in columns

The review of the construction specifications revealed a number of deficiencies in respect of appropriate concrete construction in coastal areas. Low strength concrete is not durable and use of low strength concrete is not normally compatible with the high strength reinforcements used in the structures. The clear covers for the reinforcements in different structural elements were also not suitable for concrete construction in coastal environments and are inadequate according to codes of practice (e.g. BNBC, ACI or BS). Besides, brick chips as coarse aggregates in concrete construction in coastal environments also invite problems for the durability of the structures. Use of brick chips and the low strength concrete are likely to produce highly porous concrete.

The study of the deterioration process and the analysis of the construction specifications of these cyclone shelters reveal that the distresses in concrete elements are due to deficiencies in design and construction specifications and lack of understanding of properties of indigenous materials used. Moreover, lack of repair and timely maintenance works have accelerated the deterioration process over the years.

CONCRETE CONSTRUCTION PRACTICES AND DEFICIENCIES

Concrete construction in the coastal areas is generally carried out by using indigenous materials, labour-intensive methods and site-mixed concrete. Cast-in-place concrete construction is hardly ever carried out under ideal conditions; as a result the concrete structure may develop defects for different reasons. Allen and Edwards (1987) listed cracks in horizontal surfaces due to plastic shrinkage, cracks over reinforcing bars due to plastic settlement, surface texture defects and lack of cover to reinforcement as the common type of defects, which may occur during in-situ concrete construction. However, in the case of such construction in the coastal areas, other defects such as chemical attack will only accelerate the deterioration process.

Experience has shown that in many cases where the design has been properly carried out by using the provisions of the available codes of practice, the constructed structures developed numerous defects because of unforeseen inadequacies in construction. Some of the sources of these inadequacies in terms of materials, site practices, effect of hot weather etc. are identified and discussed below.

Materials

For good quality of concrete construction appropriate material is a prerequisite. Workability, strength and durability are three important properties of concrete, which need to be evaluated selecting the constituent materials. Type of aggregates, their maximum size, shape and grading, water-cement ratio and degree of compaction are some of the factors, which affect the above-mentioned properties of concrete.

There is an acute shortage of good-quality indigenous building materials in the coastal areas. Locally manufactured bricks are frequently broken to produce the coarse aggregates to be used in concrete construction. These bricks often fail to meet the requirement of standards and occasionally contain salts in them. As these bricks are highly porous, use of such brick aggregates produces porous concrete. The ingress of chemicals, chlorides or sulphates in such pores of concrete allows the crystallization of salts when the environment is dry and favourable. This process in turn exerts a very high pressure inside the pores of the aggregates resulting in volume changes, pattern cracking, spalling and other unpredictable defects within a very short period after the construction.

The rivers in the alluvial plains of the coastal areas deposit a large amount of fine sand after the monsoon period every year. This sand does not fall within the specified grading limits and its use drastically affects the workability and strength of the concrete. The use of these sands increases the water requirement in the concrete mix with consequent decrease in strength and increase in drying shrinkage (Zafar et al., 1989). Besides, these sands contain salts, which adversely affect the strength and durability of concrete. Zafar et al. (1989) reported corrosion of reinforcing steel, salt weathering and environmental cracking due to a number of factors including the use of low quality aggregates contaminated with sulphate and chloride salts.

The quality of available water is also not suitable for concrete making in the coastal areas. The water is saline in most places. In case of reinforced concrete construction saline water is believed to increase the risk of corrosion of the embedded reinforcement.

As mentioned earlier, all concrete works in the coastal areas are produced near the construction sites. Data on site mixed concrete from different sites show that, large variations occur in workability and strength of these concretes due to poor quality control procedures and supervision. Variations also occur in the properties of reinforcing steel. Data on steel reinforcing bars from different manufacturers in Bangladesh show that although the bars of different sizes fulfill the specified requirements with respect to mechanical properties, these bars frequently do not meet the requirements with respect to weight per unit length, cross-sectional area and surface deformations. The use of under-sized bars in concrete members can appreciably affect the actual capacity of the member leading to cracking and deformation under service loads, particularly when subjected to extreme dead and live loads during cyclones.

Site Practices

Volume batching of concrete mixes, with very little control of water-cement ratio is usually carried out at the construction sites all over the country. This is no exception for the concrete construction in the coastal areas also. In such cases, the quality control requirements are not implemented at the sites because of inadequate testing facilities and lack of understanding of the quality control procedures. This results in poor quality and low strength concrete.

Site practices such as, delay in placing concrete in its final position and addition of water after the concrete mix is discharged from the mixer machine are often observed. These practices produce porous, non-homogeneous and low strength concrete. Fresh concrete is usually transported in iron pans carried on head by the labourers and often dropped on forms by them from the standing position. This practice causes segregation resulting in low strength concrete. Inadequate compaction often produces honeycombed concrete; and patchwork with plastering on such surfaces is always done to hide the honeycombing. This is a very poor substitute for properly compacted concrete since it can never improve concrete, which is honeycombed right through. Such concrete does not allow necessary bond to be developed between concrete and embedded reinforcement, and over a period of time the moisture penetrates to corrode the steel causing cracking and subsequent spalling of concrete.

Hot Weather

The climatic condition in the entire coastal area is hot (with temperature very often reaching 40°C) for the most parts of the year. Concrete construction in hot weather without appropriate measures impairs the properties of fresh as well as hardened concrete. A higher temperature of fresh concrete results in a more rapid hydration and leads, therefore, to accelerated setting and to a lower strength of hardened concrete. Furthermore, rapid evaporation causes plastic shrinkage and crazing and subsequent cooling of hardened concrete introduces tensile stresses resulting cracks in concrete.

Curing Practices

Curing practices are sometimes inadequate and defective for the concrete works in coastal areas. Curing is discontinued sometimes too early and the members such as columns, beams, walls etc. are inadequately cured. Bunds often formed with locally available clay to impound water on the surface of horizontal casting allow penetration of chemicals present in clay into the larger pores of very young concrete. This results in early deterioration of concrete.

FACTORS CONTRIBUTING TO POOR DURABILITY OF CONCRETE IN COASTAL AREAS

The major factors which are responsible for poor durability of concrete are: (1) Use of improper materials (aggregates), (2) Use of old stored cement, (3) Improper concrete mix design, (4) Poor construction control, (5) Poor concrete quality, (6) Insufficient cover to reinforcement, (7) Cracks and micro-cracks in concrete, (8) Improper placement of concrete to cause segregation and honeycombing, (9) Highly permeable concrete due to excess use of water, (10) Poor compaction of concrete, (11) Distortion or displacement of forms, (12) Disturbances during placement leading to uneven and inadequate cover, (13) Inadequate curing, (14) Lack of proper supervision.

Besides the factors mentioned above chemical causes occasionally arise within the concrete mass, the attacking agent being able to penetrate through the concrete. Concrete structures located in the islands far off from the mainland or close to estuarine rivers will usually be surrounded by chloride-laden water, which induce electrochemical corrosion of steel reinforcements. The ingress of chloride ions into the concrete will have the effect of depassivating the protective layer around reinforcing steel formed by highly alkaline cement paste matrix. Once the passivation layer is broken down, corrosion cells will be set up and formation of rust results in an increase in volume compared with the original steel so that swelling pressures will cause cracking and spalling of concrete. The principal mechanisms by which the concrete structures can be attacked, subsequently distressed and deteriorated are discussed below.

Ionic Diffusion

Chloride ions penetrate the mortar or concrete by movement through the water in the capillary pores. The rate of movement is related to their concentration gradient, the size, number and orientation of capillary pores, which may be dependent on the mix constituents of the concrete, their proportions and the curing procedures.

Wetting and Drying Effects

Wetting and drying conditions in structures are common in coastal environments since the entire coastal area is subjected to daily tides, high and low. During the wetting cycle, water will be absorbed into the outer surfaces of the concrete structures, and during drying the water will evaporate leaving behind any salts in the concrete. Concentration of salts increases with subsequent cycles of wetting and drying. As a result previously innocuous concentration of salts can be increased to levels that can attack the reinforcing steel or lead to salt crystallization damage.

Alkali Aggregate Reaction

This occurs when reactive silica in the aggregate reacts with alkalis in the cement to form an alkali silicate gel, which attracts water by absorption or osmosis and tends to increase the volume. As a result of the gel being confined by the surrounding cement paste, internal pressures develop which eventually lead to expansion, cracking and disruption of cement paste and map-cracking of the concrete.

Reinforcement Corrosion due to Carbonation

Carbon dioxide present in the atmosphere reacts, in the presence of moisture, with hydration products of cement, particularly calcium hydroxide, which then reacts to form calcium carbonate. Carbonation neutralizes the alkaline nature of the hydrated cement paste and thus the protection of steel from corrosion is vitiated. If carbonation is allowed to reach the level of reinforcement, it reduces the highly alkaline passivation layer around the reinforcement leaving it susceptible to corrosion.

Sulphate Attack of Concrete

Sulphates found in the ground water in coastal areas (sodium, calcium or magnesium sulphates) react with the calcium hydroxide and calcium aluminate hydrate. The products of the reactions, gypsum and calcium sulphoaluminate have a considerably greater volume than the compounds they replace. These reactions with the sulphates lead to expansion and subsequent disruption of concrete.

DURABILITY AND IMPROVED CONSTRUCTION PRACTICES

In order to ensure adequate performance of concrete structures, built under various environmental constraints and difficult climatic conditions of the coastal areas of Bangladesh, appropriate measures of concrete protection can be developed by considering improvements in construction practices. These measures range from selection of suitable constituent materials to moist curing for a definite period and some logical practices in concrete making for safe, economical and durable structures in the coastal areas. To produce the appropriate concrete to be used in structures in coastal areas the essential characteristics of materials and the improved construction practices are listed below.

Aggregates

Since aggregates usually occupy about 75% of the total volume of concrete, their properties have a definite influence on the behaviour of hardened concrete. The strength and the porosity of the aggregates not only affect the strength of the concrete but their properties also greatly affect durability. Natural stone aggregates conforming to ASTM C33 shall be used in the concrete construction for the coastal areas. Under no circumstances should brick chips be used in making concrete in these areas. The highly porous brick aggregates react with the salts available in the coastal environments causing an expansion of the concrete that initiates the early deterioration of the structure. Crushed, angular pieces of well-graded aggregates produce a concrete with less porosity. Such a concrete tends to be stronger and durable. Properly graded good quality sand shall be used in concrete making. If such sand is locally available it must be sufficiently washed before use in concrete making.

It is recommended that all the aggregates shall be washed before use in concrete making. Experimental results reported by Zafar et al. (1989) show that by using washed aggregate in concrete the initiation of corrosion of reinforcement under aggressive environments is delayed when compared with concrete having same mix proportions, water-cement ratio and unwashed aggregates.

Water

The quality of available water is also not suitable for construction in many parts of the coastal areas. The water is saline in most places. In case of reinforced concrete construction saline water is believed to increase the risk of corrosion of the embedded reinforcement. Water from the deep tube wells shall preferably be used. The water must be free of excessive chlorides (not more than 600 ppm) and sulphates (not more than 1000 ppm). In such cases the cement content must be specially rich. Prior coating of reinforcement with a cement slurry made with fresh water shall be used. These steps help in prolonging the life of reinforced concrete exposed to the action of coastal environments. Seawater should definitely be the last resort for concrete making in the coastal areas.

Concrete Mix Proportion and Strength

Measuring the quantity of materials is an important factor for making good quality concrete. Generally a volumetric measurement by a wooden or metallic box is used. The box may be of any size as long as containers of the same size are used and filled to the same level for all materials. The minimum mix proportion of 1: 1½ : 3 (cement: sand : stones) by volume shall be used for the concrete construction. This ratio will require 1100 kg of cement per 100 cft [390 kg per m^3] of concrete. If saline water is to be used in concreting due to non-availability of fresh water the quantity of cement shall be increased to 1250 kg for 100 cft [440 kg per m^3] of concrete. The corresponding mix ratio shall be 1:1¼ :2½. To produce the dense impermeable concrete a low water-cement ratio not more than 0.45 shall be used. Low water-cement ratios diminish the bleed water that may be trapped at the paste/aggregate interface and thus initiate micro-cracking.

The minimum compressive strength of concrete at 28 days shall be 3000 psi (21 MPa) tested on standard cylinders. The 7-day crushing strength shall not be less than two third of the specified 28-day strength.

The ingredients of concrete shall be thoroughly mixed so as to produce a uniform mixture. The mixing shall be done in a mixing machine. On completion of mixing, the mix shall be discharged carefully. The green concrete should fall vertically into the centre of the receptacle to prevent segregation.

Conveying, Placing and Compaction of Concrete

When the mix is ready, the concrete shall be quickly carried and placed in final position before setting starts. Concrete that has been mixed and left standing for more than 30 minutes shall not be used. No water shall be added to concrete after it has been mixed. Placing of concrete from the pans shall be from a close distance, preferably 18 in. (500 mm). The rate of placement of concrete should not be so rapid as to impair proper compaction. Hand compaction shall preferably be avoided. Hand-held mechanical vibrators shall be used for proper compaction. The vibrator shall be inserted at fairly close intervals. It should be withdrawn slowly at each location and should be operated continuously while being withdrawn. Vibrator shall be inserted to the full depth of the top layer and into the previous layer to get good bonding of layers. For all practical purposes, the vibration can be considered to be sufficient when the air bubbles cease to appear and sufficient mortar appears to close the surface interstices and facilitate easy finishing operations. Over-vibration must be avoided as it causes bleeding and segregation.

Construction joints are a potential source of weakness and should be located and formed with care and their number shall be kept to a minimum. When fresh concrete is required to be placed on a previously placed and hardened concrete, precaution must be taken to clear the surface of all foreign matter and remove the laitance or scum before the fresh concrete is placed. For securing a good bond and watertight joint, the receiving surface shall be made rough and a rich cement slurry or grouting placed on it just before the placement of fresh concrete.

The initial temperature of concrete is an important consideration in hot weather concreting. The temperature of aggregates can be kept low during hot weather by shading the stockpiles. Shading can also provide an effective, cheap and easily manageable method to protect freshly placed concrete surfaces during the daytime. Hasanain et al. (1989) reported the results of a field study which shows that shading can reduce the rate of evaporation by 50 percent or more when compared with the rate of evaporation from freshly placed concrete surfaces without any protective measures for hot weather concreting. Before placing concrete the formwork shall be sufficiently wetted.

Curing

A good mix design with low water-cement ratio alone cannot ensure good concrete. Proper curing practice is one of the important steps in making good quality and durable concrete. Particularly in hot weather, moist curing plays an important role in the development of concrete strength. A study by Taryal et al. (1986) shows that for hot and dry weather, curing for 14 days by sprinkling water twice a day and keeping the concrete covered by plastic sheets is a very effective method from the view point of strength gain. Based on the experimental results on corrosion of reinforcement Zafar et al. (1989) reported that the curing period has a distinct effect on the durability of concrete. The increase in the curing period also improved the resistance against sulphate attack. The normal curing time for concrete construction in the coastal areas shall be 14 days minimum. Besides the method and duration of curing for a particular area shall be decided by considering the weather conditions, type of concrete elements and water supplies at the site. For the slabs, bunds with only cement sand mortar shall be made to allow the curing through ponding. For the beams, columns, walls etc. curing shall be made by sprinkling water at least two to three times a day depending on the weather conditions. Constant vigilant supervision must be employed so that there is no discontinuity in proper curing.

Cover to Reinforcement

In order to protect the reinforcing steel from corrosion by exposure to air, moisture and other harmful agents particularly in coastal environments and severe exposure conditions, and to develop necessary bond resistance between the steel and concrete, a minimum cover between the outside faces of steel and concrete shall be provided. For corrosion protection the minimum clear cover to reinforcing bars for any reinforced concrete construction in the coastal areas shall be as follows according to clause R7.7.5 of ACI Code (ACI 318-99): Slabs – 50 mm, Beams – 63 mm, Columns – 63 mm, and Concrete Cast Against and Permanently Exposed to Earth – 75 mm. The recommendation in BNBC clause 8.1.8 may also be adapted.

All reinforcing bars shall be held in place before and during casting of concrete so that the specified clear covers are strictly maintained. It is frequently noticed that due to labour-intensive concreting operation, the clear covers cannot be maintained which ultimately lead to corrosion of the bars and spalling of concrete. Sufficient number of mortar blocks shall be used to hold the reinforcing bars from contact with the forms and to ensure correct cover. These blocks shall be made using 1:4 proportion of cement and sand. When used to hold the vertical bars the blocks shall be cast with double wire embedded in them, so that they can be tied with the bars. Blocks must be properly cured earlier and must be wetted before the concreting operation.

QUALITY CONTROL PROGRAMME

In order to ensure that the concrete produced under various environmental constraints and difficult climatic conditions of the coastal areas of Bangladesh meets the prescribed quality norms, quality control at every stage of concreting operations is very important. Quality control must be done to ensure uniformly good concrete in respect of strength, workability, density etc. Important items of quality control include: (1) Sampling and testing of cement received in each consignment, (2) Periodical sieve analysis of aggregates to ensure uniformity in grading and shape, (3) Controlling stock piling of aggregates to avoid segregation during handling, (4) Proper adjustment of proportions of various sizes of aggregates and other constituents such as cement and water in concrete mix, (5) Sampling and testing of concrete for workability, density and strength, (6) Controlling production, transportation and placement of concrete and ensuring proper compaction, (7) Controlling construction joints, (8) Ensuring good formwork with no leakage, (9) Ensuring adequate and proper cover to reinforcement, (10) Ensuring effective curing for adequate period, and (11) Effectively controlling temperature of concrete and evaporation of the mix water.

CONCLUSIONS

Producing durable concrete meeting stringent quality requirements in the coastal areas of Bangladesh is a challenging task. Such concrete construction may be influenced by environmental and climatic condition and also by technical know-how. Adequate measures have to be taken to ensure long-term durability of structural concrete in the coastal areas of Bangladesh and for that there is a need to develop guidelines for proper construction practices, standards and specifications for these areas. For durable concrete structures in the coastal areas of Bangladesh practices and specifications have been suggested taking into account the environmental and climatic conditions in that region, the technical know-how, construction materials and the existing construction practices.

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