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# Degradation of Waterfront Reinforced Concrete Structures at the Port of Dar es Salaam

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***Abstract***—One of the major concerns in waterfront structures, which in most cases are of reinforced concrete, is the durability. In general and discounting damage caused by physical impact , tension, compressive or fatigue cracking, degradation of waterfront structures are caused by mainly chemical attack in the form of Sulphate attack, Chloride attack and the presence of contaminants inadvertently contained within the concrete matrix that can react with cement in the presence seawater. To a smaller extent biological attack can also account for some degree of deterioration.

The integrity of the existing Dar es Salaam port structures is not well known. This study focuses on the integrity of reinforced concrete structures in the port of Dar es Salaam.

Results show that the existing reinforced concrete piled structures are in poor a condition especially those at Malindi dhow quay, which are found to need a major rehabilitation. However, carbonation test revealed that all concrete structures have not been affected by carbonation. The observed deterioration of the structures at the port is due to other environmental factors, especially corrosion of the reinforcement.

## INTRODUCTION

Durability of waterfront structures such as piers, wharves, bulkheads and other marine facilities are a major concern. The problem facing these structures and other marine facilities is their exposure to aggressive environmental phenomena. Degradation of marine waterfront structures is caused by three categories of forces namely natural environmental forces including waves, currents, winds, sunlight and in some areas earthquake; chemical environmental effects such as carbonation, sulphates, acids, salts and chlorine effects; and biological attack, which is mainly the activities of destructive marine organisms (Gaythwaite, 1990; Mpinzire, 1999; Rubaratuka and Mulungu, 1999).

The marine environment has a strong influence on the durability of marine structures. Corrosion and scouring under the foundation, result in rapid deterioration and instability of the concrete structures. Rapid deterioration of reinforced concrete is also caused by poor design, poor workmanship and the use of low quality material (Raka and Triwulan, 1992; Rubaratuka and Mulungu, 1999).

Carbonation is one of the major chemical factors that cause structure deterioration. It is a chemical reaction between atmospheric carbon dioxide and hydrated cement. It causes a reduction in the alkalinity of the concrete and destroys the passive oxide film around the steel after which corrosion happens thereby resulting in cracks to the concrete. However, carbonation has an

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advantage in non-reinforced concrete as it seems to densify the concrete surface and hence makes the carbonated paste stronger. It reduces chloride ion permeability, surface porosity and hence sorptivity in concrete (Rubaratuka and Mulungu, 1999; Ramezanianpour, *et. al.*, 2000; Arita, *et. al.*, 2001; Chi, *et. al.*, 2002; Concrete Experts International, 2002).

Corrosion of steel reinforcement contributes greatly to the deterioration of reinforced concrete structures. Corrosion products accompany the formation of the rust and occupy a larger volume than the original metal in a magnitude of 2 to 3 times. The outcome of this expansion produces internal stresses sufficient to disrupt the surrounding concrete and therefore leads to cracking and disintegration of part of the surrounding concrete (Perkins, 1976; Mpinzire, 1999).

Corrosion on concrete normally occurs when elements of cement in concrete react with seawater to produce lime. The produced lime dissolves in water, leaving pores on concrete (Mpinzire, 1999; Raka and Triwulan, 1992).

In the construction industry, it is important to have a routine maintenance programme so that damaged and deteriorated structures can be repaired as they occur. Timely repair of structures is important to avoid the risk of structural failure due to the harsh marine environmental conditions to which they are exposed. However, the responsible authorities sometime neglect marine structures to the extent that they reach a stage where a major rehabilitation is needed (Gaythwaite, 1990).

Information on the integrity of the Dar es Salaam port structures, which are known to have a long service life in sea of almost 100 years, is lacking. Since marine structures are always subjected to high risks of corrosion, damage by incoming/outgoing ships and over loading, such processes/activities may lead to the collapse of these structures (Bertlin and Partners Consulting Engineers *et al.*, 1982; SLI Consultants, 1994; Swedport Consulting AB *et al.*, 1985). The aim of this study is to provide information on the integrity of existing waterfront structures in the port of Dar es Salaam. Relevant authorities can use this information in their development plans and others.

## STUDY AREA

The study area is the port of Dar es Salaam in Tanzania. It is located on the shore of the Indian Ocean at latitude 6°50'S and longitude 39°18'E. The inner harbour is a tidal basin having a deepwater area of approximately 96 hectares with a narrow opening to the sea. The tides are semidiurnal with two high tides and two low tides daily (Mascarenhas, 1970; SLI Consultants, 1994; Shaghude, *et. al.*, 2002; Tanzania Harbours Authority, 2003). The harbour is well sheltered from strong winds and waves (Fig. 1).

The port is uniquely situated to serve not only Tanzania, but also landlocked countries including Zambia, Malawi, Burundi, Rwanda, Democratic Republic of Congo and Uganda. The port consists of the Main quay and the Lighter Quay. The Main

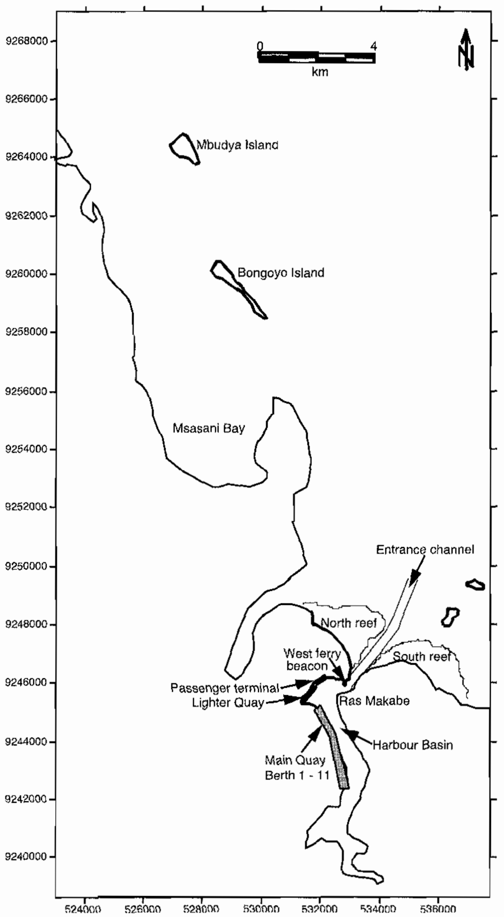


**Fig. 1. The Dar es Salaam Harbour**

Quay consists of eleven berths, which serve international vessels. Eight of the berths handle break bulk cargo and three berths handle container traffic. Lighter quay, also known as Malindi wharf, is located to the north of the Main Quay and is used to provide port services to coastal ships and dhows traffic (Fig.1).

## MATERIALS AND METHODS

A thorough check-up on physical condition of reinforced structures, materials properties and the strength of the concrete after a long-term exposure to the sea and the effect of corrosion was carried out. The first activity was to visually observe the condition of existing structures and taking photographs on affected structures. The second activity was to perform non-destructive tests with a rebound hammer on randomly selected points on piers, which appeared to be in a worse condition than the others. Results from the test provided a quick approximate compressive strength of concrete piers in different positions and on different points within the same pier. Structures were grouped into two categories according to their age and the area where the structures are found. The groups were as follows;

(a) Lighter quay: Malindi dhow quay and Malindi cargo terminal (built about 100 years ago)

(b) Main quay: Berths 4 to 11 (concrete pier aged between 25 and 35 years, constructed during independence era)

A rebound hammer was applied at the Lighter Quay and 15 points were taken on 5 piers of the dhow quay and the Malindi cargo terminal. At berths 4 to 11of the Main Quay, 81 points were tested on 30 piers. The third work was a carbonation test. This work was carried out applying phenolphthalein agent. Selected members with wider cracks were opened up using chisel in order to get inner concrete where phenolphthalein based staining agent was applied.

## RESULTS

### Observed condition

The structures at the dhow quay of the Lighter wharf are in a bad condition because the concrete has been badly damaged due to corrosion. Some of the elements of the structures have very wide cracks along the line of reinforcement bars and most of the concrete on piers and struts has been substantially spalled-off and peeled off. In some places, the reinforcement bars are exposed out (Plate 1).

**Plate 1. Concrete piers and struts severely corroded at Lighter quay**

The concrete piers at the Malindi cargo terminal are in a very good condition. No signs of cracks and rusting were found on the structures. However, one of the piers has been damaged accidentally. The fender system is in poor condition and needs immediately rehabilitation.

Berths 4 to 11 at the main quay are concrete piers. Small to wide cracks up to 20mm were observed on concrete piers of all berths and some few piers were severely corroded especially Berth 4 through Berth 8 (Plate 2). Corrosion of the reinforcement steel is very significant such that a few elements of the concrete structures have been spalled-off and peeled off, thus exposing out reinforcement steel (Plate 3). If left without repair, they may lose the designed load bearing capacity and structural strength. Concrete cover ranges between 20mm and 30mm.

## Compressive strength

The maximum and minimum compressive strength for concrete piers as found according to Proceq

**Plate 2. Typical cracks on concrete piers found on berth 4 through 8**

**Plate 3. Exposed reinforcement in one of the piers at main quay**

(1977) at Lighter quay was 47.97 N/mm$^2$ and 24.01 N/mm$^2$ for Malindi cargo terminal and Malindi dhow quay respectively (Fig. 2). The mean compressive strength at Malindi cargo terminal was 39.13 N/mm$^2$ while at Malindi dhow quay was 32.13 N/mm$^2$. At the Main Quay the mean compressive strength was found to be 35.38 N/mm$^2$ (Fig. 2). Fig. 3 shows the comparison of compressive strength at different terminals. Concrete piers at Malindi cargo terminal are the strongest of all with a maximum compressive strength of about 50N/mm$^2$ while a minimum compressive strength of approximately 25N/mm$^2$ was found at Malindi dhow quay.

## Carbonation

Tests performed for checking the life span of the concrete after being subjected to harsh marine condition for very long time using phenolphthalein-based staining agent on all selected piers and masonry walls have shown a very high content of calcium hydrate. The change

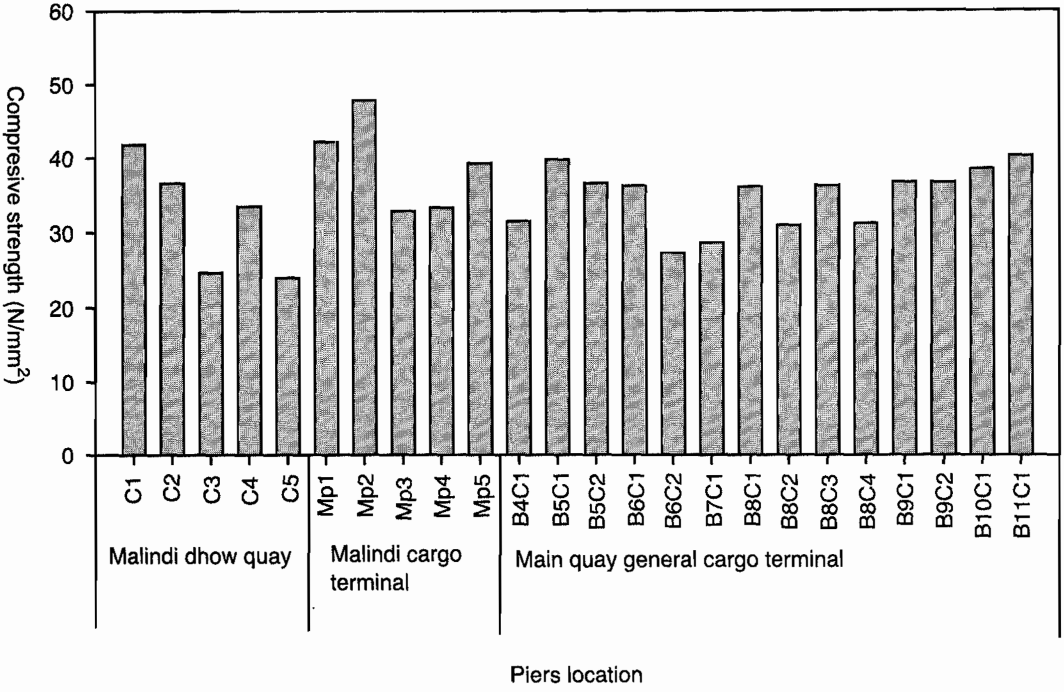


**Fig. 2. Insitu compresive strength on concrete piers at the port of Dar es Salaam**

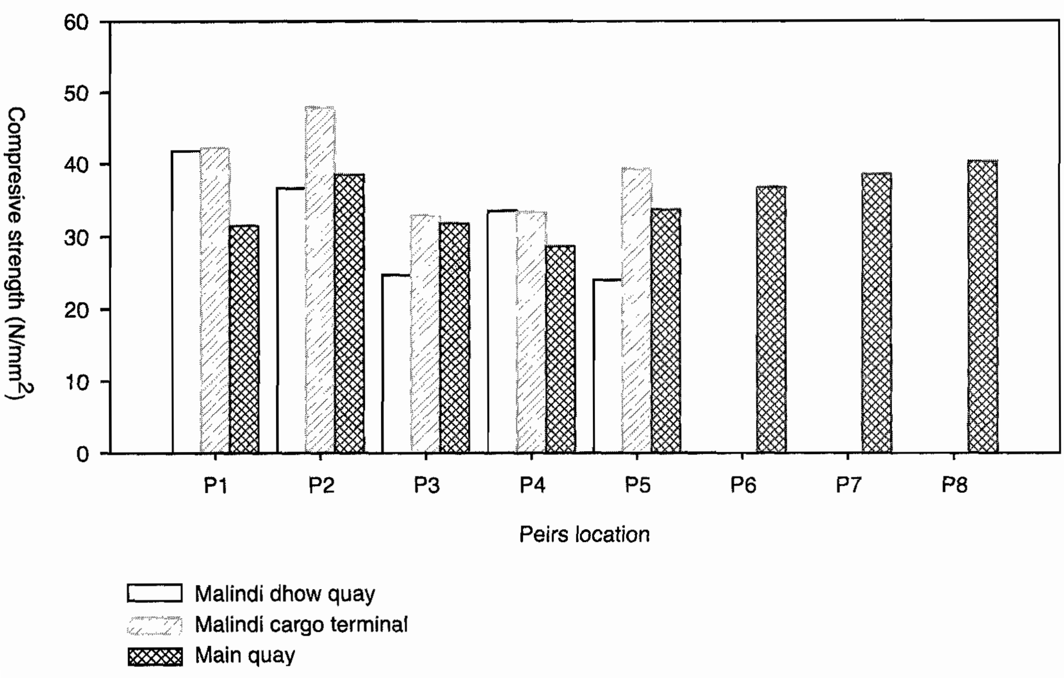


**Fig. 3. Comperative insitu compresive strength for concrete piers as measured by rebound hammer at the port of Dar es Salaam**

in colour profile on inner concrete exhibits pink colour, which is an indication that the concrete surfaces are un-carbonated.

## DISCUSSION

It was not possible to compare the obtained field results with theoretical ones because the calculations and design information used in designing the concrete structures at the port could not be found and therefore the actual water-cement ratios and cement contents of the concretes were not known. Nevertheless, according to Astill and Martin, (1982) citing the British Code of Practice, CP 110, minimum concrete grade in seawater (very severe condition of exposure) is grade 40. The results obtained at Lighter - dhow quay shows that the concrete strength of 24.1N/mm$^2$ is well below the nominal concrete grade (40N/mm$^2$). Results obtained at Malindi cargo terminal (concrete piers) shows that the concrete strength ranges between 33N/mm$^2$ and 48N/mm$^2$. Therefore the low value is slightly below the nominal concrete grade while the higher value is well above the nominal concrete grade. At the main quay (berth 4 to 11) the compressive of most of the concrete piers is lower than the nominal concrete grade except for some very few that have slightly higher strength than the nominal concrete grade as they range between 28N/mm$^2$ and 41N/mm$^2$. Therefore the rebound hammer results of relatively low values provide a preliminary indication of the poor integrity of concrete structures.

The carbonation test showed a high content of calcium hydrate, which is an index of unaffected concrete material even after long period of being in a harsh marine environment. These results could be due the facts that port structures especially piers are always subjected to high relative humidity of more than 90%. With that high humidity carbonation cannot take place (Ramezanianpour *et. al.*, 2000; Chi *et. al.*, 2002; Concrete Experts International, 2002).

Durability of concrete structures placed in the marine environment is almost directly proportional to the efficiency of cover in protecting the embedded steelwork. Concrete cover has a function to protect reinforcements from corrosion therefore it should be sufficiently thick. Usually there are several factors that do influence the thickness of the concrete cover such as grade of the concrete, conditions of the surrounding environment and fire resistance. According to Astill and Martin (1982) the nominal cover to reinforcement for structures exposed to seawater (being a very severe condition of exposure) for concrete grade 40 is 60mm and for concrete grade 50 and above is 50mm (an extract from British Code of Practice No 110 table 19). Furthermore, cement/water ratio could affect the quality of concrete significantly and therefore to the protection of reinforcement from corrosion (Raka and Triwulan 1992). At the Main Quay, the provided concrete cover range between 20mm and 30mm, this is less than what is recommended. Even if the cement-water ratio was observed during the construction (which is likely to be the case according to the results of carbonation tests and the age of the concrete in question of more than 22 years, the earlier corrosion of reinforcements from the design life span is inevitable because decreasing cover thickness increases corrosion for the simple reason that the penetration path to the reinforcement is proportionally shortened.

## CONCLUSION AND RECOMMENDATION

The results show that the examined reinforced concrete structures at the port of Dar es Salaam, especially those at lighter-dhow quay, are degraded and a major rehabilitation is required. All concrete piers at the port are not affected by carbonation even for structures built some 100 years ago. The observed deterioration of the examined structures is due to corrosion on reinforcement and is found mainly in the splash zone where dissolved oxygen levels are very high.

The piers at Lighter Quay are in desperate need of a major rehabilitation and with the present condition it is very dangerous for the quay to be in use. Piers at main quay (berths 4 - 11) need renovation to prevent the continuation of corrosion of the reinforcement. The fender system is wearing out and therefore needs an immediate repair to restore its structural capacity.

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