# Structural Health Monitoring of Existing Reinforced Concrete Jetty Structure: A Review

Mohit M. Patil
P.G. Student
Department of Civil Engineering
Datta Meghe college of Engineering, Airoli, India
Email ID: mohitpatil959@gmail.com

Dr. S. A. Rasal
Assistant Professor
Department of Civil Engineering
Datta Meghe college of Engineering, Airoli, India
Email ID: sarasal@rediffmail.com

*Abstract*— **When it comes to construction and maintenance of jetties, world over similar problems are faced by the civil engineering community. A lot of researchers have studied the importance of maintenance and structural health monitoring of jetties in order to keep the structure working throughout its service life span. In this regard a literature survey has been done on the structural assessment and analysis of the jetty structures that are existed in various conditions throughout the worldwide. So in this paper an attempt is made to study the factors that cause deterioration of reinforced concrete jetties and various methods to counter these factors so that the structure remains in working condition without causing distress.**

*Keywords*-component; ***Health monitoring; Jetty; NDT***

## I.Introduction

As the jetty structure lies in sea it is susceptible to the marine water that contains chloride which is the main cause of deterioration as the chloride ions penetrate through ingress in piles, slab and beams. This chloride ingress further penetrates through concrete whether a sufficient cover is provided or not causing corrosion in the reinforcements. This is the main reason for the deterioration as the structure gets weaker thus affecting its service life. Structural health monitoring and structural assessment of these structures must be done time to time so that the authorities are aware of the condition of the jetties.

## II.Literature Review

In the field inspection carried by Odd E Gjorv (1969) of the 219 reinforced concrete wharves that were constructed in Norweigian harbours he observed that structure below low water were in sound condition but in the tidal zone deterioration was slowly occurring and above high water deck beams were severely affected by corrosion in steel and proper attention was not given for the maintenance of beams and deck slabs. Therefore he came on a conclusion that deck beam should be avoided in design and if not possible it should be as shallow as possible in all concrete structures that are exposed to marine environments.

In the inspection of concrete offshore structures that was presented by R. D. Browne et al. (1981) The planning and inspection procedures were used on Total Oil Marine Ltd.'s MCP-01 (manifold compression platform) the procedures were carried out to describe the structure's condition.

These procedures included preparation of detailed field inspection, visual, photographic and nondestructive inspection techniques and a report was designed for easy access to detailed information

On conclusion it was learnt that the structure was analysed for critical areas first , NDT plays an important role and lack of inspection methods for prestressing was observed further it was learnt that there should be more development for underwater NDTs.In the study Sixty year old concrete in marine environment by Ozaki Shinobu and Sugata Noriyuki (1987) it consisted of the study that were carried from the samples obtained from the demolition of the northern breakwater of Muroran port.

The concrete was mixed by the volcanic ash which showed improvement of the water tightness of concrete by pozzolanicaction, there was reduction in the salt content at surface by 0.1% at a depth of 8 cm which was high earlier

They concluded that concrete that was made from blast furnace slag and volcanic ash showed less deterioration even after the exposure to marine environment for sixty years.

In the paper presented by R. Ramakrishnan (1989) has a special attention given to the state of the art port Jawaharlal Nehru Port that is constructed by Government of India at Nhava Sheva. The port is first of its kind that is controlled with high tech computer controlled and equipment. For the construction of this port many operations were carried out that include Reclamation, blasting operations, use of geotextile and band drains, dredging, sand wicks, vacuum sucked concrete floorings.

Sami Rizkalla and Gamil Tadros (1991) described the uses of Carbon Fiber Reinforced Polymer, CFRP, rods and tendons for prestressing concrete highway bridges in 1991 and 1997. In the study the load test is carried on prestressed beams under static loading which later revealed that the structure had behaved linearly up to cracking and after cracking as the stiffness reduced up to the failure, after unloading and reloading, the beams showed elastic behavior and with a negligent permanent deformation also the cyclic loading tests were indicative no loss of stiffness observed due to cyclic loading.

Arie Van Der Eijk (January 1994) has described the design of wharf that has a impact of berthing vessel on the wharf structure with the selected fender system. The development of a near shore wharf with multiple berth for loading and unloading liquid cargo is very rare.It was later reached to the conclusion that the design of wharf at pulau busing is considered economical and flexible loading and unloading operation because of three loading areas.

The study of strengthening of existing piers and jetties was carried out by Mazurkiewicz Boleslaw (1995), the study describes the various methods strengthening existing piers and jetties. This project has three aspects viz. analysis using recalculations, deepening of harbour bottom, rehabilitation and strengthening of existing structure. The fleet of ships now in existence and being developed, built to meet the requirements of certain seaways (e.g. Panamax,Suezmax, Chinamax) impose changed demands on harbour facilities, like different types of berthing structures.

The option of constructing entirely new structure was ruled out and use of existing pier or jetty as a structural element of a new deeper berthing structure which will meet all structural and functional requirements was considered. Accordingly the jetty strengthening was done by utilizing the existing structure in various ways like part of main structure as main structural element, support for new berthing structure and as an anchor to new berthing structure.

The chloride profile interpretation for concrete exposed to the tropical marine environment is studied by P. Castro *et. al.* (2001). The chlorides from sea and marine breezes are the main source of corrosion in marine structures. The authors have identified that the structure has two zones, one under water and one intertidal zone always wetting and drying. The form of chloride concentration profiles changes with time and concrete quality and media aggressiveness so that for mathematical model few profiles with time needs to be considered, otherwise in their opinion the results obtained shall be valid for the scale of time at which it was observed.

Evaluation and the design of Wharf Berths improvement" at Morehead Port berth facility to accommodate deep draft vessels undertaken by the North Carolina State Port Authority (NCSPA). Was presented by Xavier C. Barrett *et. al.* (2002) ). It includes layer of tieback to carry additional live load. Tiebacks and king pile wall system for stabilizing existing wall during dredging and removing existing rock berm. The study examined that calculated parameters utilized in design and results can be used to remove excess conservatism in design. Effect of creep over the Tie back to be tested. . For deriving this entire system lot of engineering testing of soil and sheet pile anchor zone was carried out. The anchors need to be given double protection against corrosion. Installation of tie back under water using drilling etc. needs to be designed with re-stressable arrangements.

Antonio Costa and Julio Appleton (2002) presented study of deterioration of Reinforced concrete through various case studies of Dock, Wharves and bridges wherein the concrete is exposed to Marine conditions. They have stated that the marine is one of the most corrosive atmospheres in which chloride penetration and chloride induced reinforcement corrosion lead to reduction in service life of structures. Repair strategies to extend service life of structure are also discussed. Various zones of the corrosion were identified depending upon marine water exposure also the accessibility of atmospheric oxygen to reinforcement. This is causing rusting of steel resulting into spalling of cover concrete and deterioration of the concrete further. Various tests were conducted to assess the condition of concrete and corrosion rate was also measured.

The poor quality structure if exposed to marine environment deteriorates very fast. Principle of repair methodology was stopping anodic process, control the aggressive substances ingress by breathable surface barriers/coatings. Higher deterioration rate is observed in zones of alternate wetting and drying zones. Repair cost both financial and environmental is very high hence planning and execution must be based on sound design and good quality workmanship.

The various guidelines globally available for use of FRP in strengthening of concrete structures is studied by Rob Irwin and Amar Rahman (2002). The study also illustrates the detailing and use of FRP in the strengthening of West Gate Bridge, Melbourne, which was then the world's largest example of FRP strengthening of a major structure. G. Ramos *et. al* (2004)presented the results of an exhaustive experimental research carried out at the Technical University of Catalonia with the aim of studying the structural behavior of carbon fiber reinforced plastics when used for strengthening segmental bridges.

1. The experimental results obtained in this study demonstrate the accuracy of the bond test to predict the maximum deformation of the CFRP in segmental structures. Further, the maximum stresses obtained in the bond tests could be used in conventional design methods replacing the stresses informed by the manufacturers, and applying the partial safety factors recommended by them. It must not be forgotten that a segmental structure is similar to a conventional structure with open cracks
2. Due to the existing uncertainty regarding the design stress of the CFRP to be used, when these reinforcing systems are applied to segmental structures or monolithic structures with open cracks it is necessary to establish design methods based in experimental tests
3. Prediction of the peeling failure mechanism by means of analytical methods is very difficult and,it occurs before reaching the characteristic design strength of the CFRPs.

4. The failure mechanism in segmental structures or monolithic structures with open cracks, reinforced with CFRPs is governed by the stress concentrations in the zone of the joints or cracks between elements, which originates a detachment of the concrete when it decompresses. This causes the cracking of the concrete that later propagates along the concrete–fiber interface producing the peeling effect.
5. It is further concluded that these new structural systems have revolutionized the structural engineering; however, much more research has to be carried out to completely understand its behavior.
6. The experimental results obtained in this study demonstrate the accuracy of the bond test to predict the maximum deformation of the CFRP in segmental structures. Further, the maximum stresses obtained in the bond tests could be used in conventional design methods replacing the stresses informed by the manufacturers, and applying the partial safety factors recommended by them. It must not be forgotten that a segmental structure is similar to a conventional structure with open cracks.

Haritos A. Hira (2004), reported on experimental investigations made of the performance of two separate CFRP based repair/strengthening schemes (a laminate strip scheme and a fabric system) adopted on two 40% scale model flat slab bridges. The models contained typical features of a large class of multi-span RC flat slab bridges with cantilever ends which were then 60 years old. Two CFRP based strengthening systems were applied at separate ends of two multi-span RC flat slab bridge models that had previously been severely damaged from high level loading approaching incipient collapse conditions. Both static and dynamic testing was adopted in the performance assessment of the model flat slab bridges under a number of stages/loading scenarios in the test program.Results shows that both of the CFRP based strengthening systems are viable remedial strengthening strategies in flat slab bridge deck applications. However, the performance at ultimate conditions of both the fabric sheet design and the laminate scheme were found to be somewhat brittle.Experimental model analysis can be used to calibrate FEA model of the structure and the same is valuable for condition monitoring.

B Bienen and M.J.Cassidy (2006) presented a computer programme SOS 3D, which provides an integral approach to fluid-structure-soil analysis of offshore system in three dimensions. This programme is used for pushover analysis of the jack up platform. This also can be effectively used for analysis of other marine structures composed of beam, column and foundations.The Port of Osaka has located in Japan has many berths which are over 40 years age, and the concrete superstructure of jetty has been in use under severe marine environments for a long period. It was found that the superstructure has undergone serious damage caused by Alkali-Silica Reaction (ASR) also chloride induced deterioration has taken place. The cathodic protection provided is mainly described [Takashi Habuchi*et al* (2008)]. The volume of chloride penetration into concrete in these superstructures of jetty was relatively little, because of the effect of the curtain wall hanging down at the front row of the jetty. It has confirmed that the obvious damages occurred in the pavements and top surfaces of concrete slabs as well as in the bottom surfaces of members, when the defects affected by ASR developed in the concrete of superstructures. It is further emphasized that the “record” is important to appropriately carry out the long-term maintenance of structure.

J. Paul Smith-Pardo and G. YelizFirat (2008)presented the lateral load analysis of waterfront structures supported on plumb piles in this paper. A marginal wharf was analyzed in order to investigate the implications of representing the lateral stiffness of the soil by means of constant points of fixity for the piles. Author has foundthat using such simplification may result in conservative estimates of the lateral load response of the structure. However, the overestimation of the displacement demands under low-to-moderate design spectra is minimal.

The simplified method was observed to result in slightly conservative plastic rotation demands at the pile-to-pilecap connection. This is expected because the simplified method based on points of fixity for the piles does not take into account the energy dissipation at the supporting soil through lateral displacement reversals.It observed that the extent of imprecision rendered by the simplification of the analysis method is well within the imprecision imposed by uncertainties involved with estimation of p-y curves that represent the lateral response of the soil. Hence, the simplified method presented in this manuscript is recommended as a plausible device to be used in the preliminary design of wharves under low-to-moderate seismic demands.

The various issues related to the assessment of concrete cover for concrete structures and its measurements are reported by Reuben Barnes and Tony Zheng (2008). Particularly the accurate assessment of concrete cover is vital for the marine structures as their serviceability largely depends upon adequate concrete cover and if it is lost the restoration of it is also important in order to get designed serviceability of the structure. In order to understand some common factors affecting cover measurement BCRC carried out an in-house study in 2008 which are detailed in this paper.The findings drawn by the study which are important from subject point of view are:

1. Many factors could affect cover measurement. Among them, bar diameter setting and rangesetting (low or high) in the covermeter have a greater affect than the other factors explored inthis study.
2. Setting to actual bar diameter will give more accurate results than setting to assumed bardiameter. It is desirable to obtain the information on bar diameter in the concrete before covermeasurement in order to achieve more accurate results.
3. High range settings should only be used when low range probe is not capable ofdetecting the reinforcing bars. If cover measurement is required for thick concrete coverstructural elements, a proper calibration should be carried out prior to actual covermeasurement.

The durability and corrosion protection performance of concrete cover method obtained from the exposure test carried out on HASAKI pier was studied by Yoshikazu Akira *et al* (2009). It has been built built to stick out in a direction perpendicular to the shoreline facing to the Pacific Ocean which is very severe environment compared to any ordinary port environment.Steel in submerged zone and the mud zone are protected by cathodic protection.

On the other hand, steel in tidal zone, splash zone and atmospheric zone is protected by coating.It was found that the durability of RC member in splash zone and atmosphere zone is low. On the other hand, the durability of RC member in tidal zone and under-seawater zone is high. The concrete cover methods in tidal zone have a high corrosion protection performance. Despite the chloride ion concentration at steel surface in concrete was about 20 kg/m3, steel had not been corroded. It is considered that diffusion of oxygen into the concrete was limited to the level that could not generate the steel corrosion. In future, the spalling and cracking of the concrete cover by the expansion of the corrosion products will be expected. Therefore, in order to construct the sustainable infrastructures, it is necessary to set a limit on the corrosion protection performance.

Exporting over 103 million tons per annum, the Port of Newcastle, New South Wales, Australia is one of the world’s largest single coal export ports. It has 18 operational berths, seven dedicated to the handling of coal and 11 allocated to the handling of non-coal trade. NPC also owns, operates and maintains 195 navigation aids, 16 kilometers of roads, 4.5 kilometers of rail, 51 buildings, two breakwaters and over 7 kilometers of seawalls and Heritage structures [Scott Bacon *et. al.* (2010)]Structural assessments and structural capacity checks have also typically been undertaken. Scenario analyses of remedial, maintenance and corrosion management options have been utilized. The age of the NPC wharf and berth structures varies from 32 to 63 years, some are therefore at or beyond their designed lives. However, decades of future service lives are required of the structures so Maintenance and corrosion management approaches can be engineered to achieve required future service lives and to meet budgetary constraints, maintenance funding timings and at lowest life cycle costs.

R.B. Singh (2013) presented an economical and widely used NDT tests. The paper also has discussion on combined methods, when more than one nondestructive test method is used and condition assessment is based on the data obtained from Rebound Hammer, UPV & Coretests. The aim of the study was to address the field engineers engaged in evaluation of quality of hardened concrete. The tables of std. values, photographs & comparisons have been included. Research oriented engineers who would want through treatment of the material and a more basic approach are referred to the original std. specification, NDT handbooks & original papers and literature on the subject given as reference. Although nondestructive tests are relatively simple to perform & instrument based, the analysis and interpretation of the test data are not easy, because concrete is a complex material, hence the author has cautioned engineers for interpretation of the test data which always has to be carried out by trained specialists in NDT rather than by technicians performing the tests.

Comprehensive measurements of the effective stresses developed during the installation, equalization, and load testing of displacement piles in a loose to medium dense quartz sand are presented by B.M. Lehane*et al* (2014). The results shed new light on the mechanisms that control shaft friction in sand. First, it is demonstrated directly that the stresses developed at any given soil horizon depend strongly on both the distance of that horizon from the pile tip and the soil's initial state. Second, pile loading is shown to induce radial effective stress changes associated with the soil fabric set up by installation and dilation phenomena at pile-soil interface. Thirdly, the operational angles of interface friction are found to be constant volume values that correlate well with the results from laboratory interface shear tests.Pile load tests were conducted at the London to ascertain the pile shear stress and radial stress at various levels of depths. Soil was sand.

The performance of the nonlinear dynamic analysis of Kandla port building subjected to ground motion is reported by Chenna Rajaram and Ramchandra Pradeep Kumar (2014). Ground motions generated by Institute of Seismological Research (ISR), Gujarat at four locations on Katrol Hill Fault (KHF) and Kachchh Mainland Fault (KMF) were used in the analysis. Finally, the damage of the Kandla port building is estimated though fragility curves. The damage values obtained from fragility curve are 0.46, 0.17 and 0.88 for KHF Mandvi, NKF Jodiya and KMF Jhangi ground motions respectively. The study reported the responses of the structure for different ground motions are very less even in nonlinear analysis, because the fundamental frequency of the structure is far away from the predominant frequency range of ground motions. If the structure is fallen in predominant range, the response of the structure would be more.

The damage of the structure is easily identified from fragility curves for different ground motions. Based on the ground motions data, the maximum PGA is 0.308 g for KHF Mandvi ground motion. But the response of the structure is very less for this ground motion also because of non-predominant frequency range. If the structure’s fundamental frequency is predominant with the ground motion frequency, the damage will be around 0.2. The damage will be less than 0.4 for all other ground motions because of less PGA values. From acceleration response spectra of KMF Jhangi, more damage is observed. Based on the fragility analysis of port building the following recommendations are drawn. For the Kandla port building, the damage value is 0.2 when KHF Mandvi ground motion is applied to it. The PGA values at KHF Mandvi, NKF Jodiya and KMF Jhangi stations are 0.218g, 0.377 g and 0.396g respectively. The damage of the port building is calculated 0.46, 0.17 and0.88 for KHF Mandvi, NKF Jodiya and KMF Jhangi.

Gopal Rai (2014) discussed the new generation structural strengthening materials and techniques in this paper. Various materials and technologies for rehabilitations of the bridge structures are discussed using case studies of three bridge structures. Inspections, load testing and rehabilitation of bridge structure particularly using the CRPF and GRPF and carbon laminates are discussed in detail. The study summarized that, using these new composite materials for rehabilitation of bridge like structures are far more advantageous however need of more research is emphasized these being newer and superior material. The coastal vulnerability index (CVI) for the Peninsular Malaysia coastline was presented by MohdFauzi Mohamad *et al.*(2014). This study incorporated six variables to assess the CVI for the study area. These six variables consist of geomorphology, shoreline changerate, maximum current speed, maximum tidal range, significant wave height and sea level rise. The ranking is on a linear scale from 1 to 5 in order of increasing vulnerability; value 1 represents the lowest risk ranking assigned to the coastline whereas value 5 ranks the coastline with the highest risk. A total of 1963 km of coastline was evaluated and of this, 3.3% of the mapped shoreline is classified as being extreme vulnerability, 11% of Peninsular Malaysia shoreline is classified as very high vulnerability and 40% as high vulnerability. The implementation of the Management Plan would dependent on the co-operations of the government departments and agencies, private sector and the public.

The details of repairs that were carried on Karal Rail Over Bridge at Jawaharlal Nehru Port Trust are presented by Gopal L. Rai and A.N. Bambole (2015). An elaborate instrumentation system was installed to check the effectiveness of the repair work and both the static and dynamic load tests were carried out. The paper also presents results obtained by the tests and details of the sensors installed at the bridge before and after the repair work carried out for future monitoring of the structural health (SHM), which is believed to be an important feature of such work in India probably for the first time in India.

## III.Conclusion:

(1) On perusal of the literature it is found that rcc is used all over the globe to construct the jetties. It is further observed that, assessment of structural health of jetty mainly corresponds to corrosion of reinforcing steel embedded in the concrete.
(2) To assess the extent of the corrosion and to understand the extent of deterioration caused to the structure various tests are carried out.
(3) The Rebound hammer test, Ultrasonic pulse velocity test, Half-cell potentiometer test are carried out to obtain various structural parameters which can be used to calculate the structural strength and residual life.
(4) The paper can be used as guide to carry out study of jetties in Indian conditions.
(5) India, studies in bits and pieces are carried out for particular problem of jetty structure, but in Indian maritime conditions no such comprehensive studies are reported.

Thus Indian Civil engineering fraternity has to look into this almost unexplored area posed to attract huge financial investments through tremendous growth potential in near future .

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