THE CONCRETE STRUCTURE REMEDIAL ASSESSMENTS IN MARINE ENVIRONMENT FROM WHOLE LIFE ASSET MANAGEMENT PERSPECTIVES

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M.Sc (Eng) INTERNATIONAL CONSTRUCTION MANAGEMENT AND ENGINEERING

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Submitted in accordance with the requirements for the degree of
MASTER OF SCIENCE (ENGINEERING) INTERNATIONAL CONSTRUCTION MANAGEMENT AND ENGINEERING

The University of Leeds
SCHOOL OF CIVIL ENGINEERING

September, 2008

The candidate confirms that the work submitted is his own and that appropriate credit has been given where reference has been made to the work of others.

Acknowledgements

The author would like to show his great appreciation to those people and organisation who have contributed to the success of his dissertation topic on 'The Concrete Structure Remedial Assessment in Marine Environment from Whole Life Asset Management (WLAM) Perspectives'. The author take great pride in showing his appreciation to all administration staf in School of Civil Engineering, Faculty of Engineering, University of Leeds who facilitate him with necessary information, mainly on module coursework and the dissertation as well because without their help and assistance he might have problem in carrying out the research.

The author wish to express his deep gratitude and to acknowledge pleasant connection to the following individuals for their support all the way through the dissertation period:

- *Professor Steven Male, dissertation supervisor, University of Leeds for his guidance and remarkable supervision and endless support right the way through. He has offered precious insights to confront and inspire the thoughts of readers of this study*
- *Dr.Krisen Moodley, course leader of M.Sc (Eng) International Construction Management and Engineering (ICME) programme, who has provided motivation and attention for the period of the course.*

The research project of Masters level demands full devotion and loads of hard work in the evening, weekdays and during weekends. It cannot be successfully accomplished without incredible support and tolerant from friends, relatives and most important his own family. That is why he especially grateful to his wife Nurlailawati for her commitment to look after the kids during preparation of thesis text. The author like to express thanks to his kids, Danial and Aisyah who has been produce encouragement and inspiration all through, and finally he would be grateful to God for given him that strength, wisdom and blessing in finishing the dissertation.

MOHD REZAL MOHD SALLEH (2008)

ABSTRACT

This study makes use of a desk top review methodology to discover and understand the remedial assessment of damage concrete structures in the marine environment (sea water). Basically, the restorations of asset marine facility are done by using a correct and present repair technique to both spall concrete as well as corrode rebar and must follow the code and standards throughout construction periods. Specifically, the study undertook a comprehensive insight into the literature review of three (3) major components of research, consisting of reinforced concrete of marine structure, understanding marine environment and management of rehabilitation marine facility. The research chooses a case study of an oil refinery jetty piles terminal at Marsden Point in New Zealand. The asset facility is poorly deteriorating due to aggressive action of marine environment and need attention. The asset owners are aim to establish potential maintenance strategies in restoration of his asset facilities. The damaged marine structure will be looked at from whole life asset management perspectives; to identify various components of concrete structures that were subjected to steel corrosion and concrete deterioration. Application of whole life asset management paradigm in the case study will have significant impacts to the facilities and the owner as well. The benefits with regard to implementation of whole life asset management approaches in managing the asset marine facility correlate with risk management, accountability, service facility management and financial efficiency. The refurbishment work will make use of current repair method in assessing the restoration of damage concrete piles. This should take account of a risk management study prior selection of best procurement routes for the case studies. The case study is critically reviewed for options that suit the asset facility present condition and set up objectives to get the best approach adopted with regards to asset problem. The findings demonstrate that the adoption of the whole life asset management paradigm will promote the asset owner, to obtain best value for money concept from the investment and to gain benefits in terms of time, cost, quality and fit for purpose. It also help in promoting and prolong the asset lifespan and also to provide constant sustainable and economic service of asset facilities.

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NOMENCLATURE

Terminology	Meaning
ACI	American Concrete Institute
AM	Asset Management
ASTM	American Society for Testing and Materials
ASR	Alkali Silica Reaction
BRE	Building Research Establishment
BS	British Standards
CIDS	Concrete Island Drilling System
DBFOT	Design-Built-Finance-Operate-Transfer
EN	European Standards
Fib	Federation international du beton
GBS	Gravity Base Structure
LNG	Liquefied Nitrogen Gas
OGC	Office of Government Commerce
PMI	Project Management Institute Standards Committee
RC	Reinforced Concrete
WLAM	Whole Life Assets Management

CHAPTER 1

INTRODUCTION

1.1 Research Background

Basically, the research topics will be focus on '**The Concrete Structures Remedial Assessment in Marine Environment from Whole Life Assets Management Perspectives'.**

In particular, the research can be divided into two (2) different areas of study with the intention to cover both engineering and management topics. At first, a deep search into technical area is conducted and will include a review with regards to reinforced concrete marine structures followed by investigation of marine environments. Additionally, research on the subject of managing asset marine facility during or after rehabilitation is also conducted.

A review will also focus on the technical and managerial perspectives in the function of:

- Structural and economic appraisal
- Value culture of the asset owner
- Asset strategies and functionality
- Maintenance and repair strategies
- Adoption of whole life asset management concept to rehabilitation of marine asset in the case study.

Case studies will act as point of reference in establishing the best strategies for repair and maintenance appraisal as well as an asset management approach. A fundamental knowledge of both engineering and management functions is very important because it will significantly affect the study outcomes.

1.2 Aims and Objective

The aim of the study is to understand the assessment of remedial work of concrete structures in marine environment (sea water) using a whole life thinking approach which will result in establishing suitable method of repair assessments and managing a rehabilitate marine assets.
The objectives of the research study as follows:

- To produce a significant literature review with regards to the dissertation title.
- To make a clear understanding of the case studies' content and draw on relevant information from the literature review with the aim of adopting the necessary information with respect to case study.
- To determine the key issues throughout the project period.
- To understand and address asset owner and stakeholders value cultures from the case studies.

- To establish a risk management plan from the case study and also identify a suitable engineering approach in exercising the rehabilitation of concrete structures subjected to marine environments (sea water) accordingly.

1.3 Research Methodology

Initially this research focused on published material dealing with the research topics. The research method focused on two different fields - engineering and management - aiming at brining these same subjects together in the asset management of marine facilities.

Research outputs deal with finding, producing and later establishing a proper method of repair assessment and adoption of the best management system to rehabilitate marine assets facilities. Equally, the output contains information on how fundamental systems apply to remedial assessments and adequately cover a management methodology. In addition, examples from the literature review also demonstrated the importance of the asset owner's plan of action in managing his assets. The asset owner's prime goal towards his asset facility remedial assessment is to obtain best value for his money by investing money for restoration projects of his asset facility including utilising inadequate resources and time allocated right through the construction period of the damage asset.
As a result, the asset facility ends up with longer life span and fitting for structural purpose. The research has critiqued and reviewed the case study and marked certain reliable solutions that suited putting the whole life asset thinking and management paradigm in place.

The case studies point out the damage to marine structures and are concerned with restoration work on a number of damaged concrete piles in an oil refinery jetty terminal in New Zealand.

The desk research derived from a series of published materials downloaded from the internet and available books from the university library.

1.4 Scope and Limitations

The scope of study is broad, especially when information gained from the literature review reveals various types of recommended repair method, thus making it impossible and uneconomic to implement all aspects of repair method. A limitation on the research study is to principally concentrate on assessing **only** the aspect of critical elements in the case study.

Primarily, the scope of study will examine to 3 (three) major key sub-topics:

(i). Reinforced concrete marine structures

- These will cover types of RC structure used in marine such as jetty, pier, pump house for power generation etc.
- Components of concrete structures poorly affected by seawater action which result to damage on pile, beams and soffit of slab.

- Highlight literature and provide an understanding of a rehabilitation methodology which was practically exercised at some of deteriorated components of structural members.
- Repair systems that are suited well to concrete and steel reinforcement.

(ii). *Marine environment*

- Looking into the natural behaviour of marine surroundings, the seawater, its properties, tidal condition, aqua marine lives, current and much more.

(iii). *Management of rehabilitation marine facility*

- Typical asset management routes for aqua marine concrete facilities.
- Clear understanding of surrounding issues and to distinguish owner and stakeholders value cultures towards rehabilitation of asset facility.
- Review two case studies and make comparison between them.
- Review the asset strategy (service delivery, capital investment, asset maintenance, asset disposal and need) and asset framework (relationship between asset and service provided, utilisation, location, capacity, functionality)

Only applicable examples in (i) are considered for developing the literature review in Chapter 2 (two). An understanding of the marine eco-system and the properties of its main constituent's behaviour in terms of physical, chemical and biological will be the key elements in (ii). The final elements in (iii) provide an asset management perspective and structural assessments in particular and seek out trends and issues which are of values in assessing appropriate management plan for deteriorate marine structures.

1.5 Dissertation Outline

Chapter 2 - Reinforced Concrete of Marine Structures

This chapter is essentially describing the subject of the reinforced concrete structures which are built up and surrounded by the marine environment. It includes the classification of marine structure based on their characteristics and some illustrations are providing in black and white photos. An example of concrete marine structure of one type or another which have been built in some parts of the world are pictured together with an explanation about the structure's functionality. They range from submerged to floating systems of a variety of shapes and sizes: cylinders, boxes, cones, rings or doughnuts and cellular construction are among those reported in this chapter which also point up a bit about buried and immersed structure. This chapter also touches on seawater exposure and its effect to structures and some example of typical causes which relate to evaluation assessment on concrete distress and deterioration causes. Finally, some basic understanding of anode and cathode processes happening in the rebar that should be a result for corrosion is covered.

Chapter 3 – The Marine Environment

This chapter considers ocean seawater in relation to reinforced concrete in marine assets and gives answers to significant question like why concrete spall and steel corrode, how long seawater can act upon structure before deterioration can develop, how chemical reactions between seawater and concrete materials take effect. It includes but is not limited to identifying the probable causes against concrete deterioration and also how steel corrosion propagates as well as influences of the damage. Because the symptoms of concrete distress and deterioration may be caused by more than one mechanism acting on the concrete, it is necessary to have an understanding of the basic underlying causes of damage and deterioration.

Chapter 4 – Rehabilitation of Concrete Structures

This chapter is essentially concerned with the methodology in assessing the rehabilitation of deteriorated asset marine facilities. However, it does take into consideration determining the primary cause or causes of the damage seen on a particular structure and to make intelligent choices concerning selection of repair materials and methods.

The objectives of structural appraisal in chapter four (4) is to know the present asset condition and discovering the cause or causes of the structural problem which may include addressing a series of question which can only define during investigation or inspection of the structures and also to mark out for possible repair option.

Chapter 5 - Management of Deteriorating Concrete Structures

The objective of this chapter is to provide a perspective on asset management and structural assessments in particular and also to seek out trends and issues which are of value in assessment of deteriorating concrete structures. This will, as a matter of course engage with some form of critical argument against input of preceding researcher that is realistic and representative and also essential to be conscious and thinking optimistically in engineering terminology.

Chapter 6 – Case Study of Deterioration Reinforced Concrete Structures Subjected to Marine Exposure.

This chapter shows one case study which briefly discuss about deterioration scenario of marine asset facility. The case study shows the asset owner efforts in establishing the best repair strategies of his asset facility. A factual critique and review on case studies will designate a reliable solution that suite the case studies scenarios. It also takes into account certain important matters that should be understood and taking necessary action to find the best solution of the problems that arise during the commencement of the project. In general, the assessments of Whole Life Asset Management (WLAM) strategy will primarily aim on four (4) **key points** as follows:

(i). The WLAM issues and analysis of the case study.
(ii). Establish the asset strategy for the case study.
(iii). Establish the maintenance strategies for the case study.
(iv). Highlight the potential risk and establish of risk management studies.

Identification of the cause or causes of the case studies issues are so important as the first move towards finding a significant solution to those issues. it might be helpful to visualised a damaged structure and relate it with the aspects behaviour of the sea. Emphasis to the relationship between structures and sea is prime concern for example; case study is about terminal oil jetty so it is important to establish the function of the jetty i.e. what it is intended to provide

Chapter 7 – Discussion

This chapter considers the impacts of whole life asset management on the asset marine facilities case studies by establishing key drivers with regards to the engineering and management fields, which should result in increased the asset life span and contribute benefits to asset owner in terms of time, cost, quality and in addition fit for purpose of asset functionality.

Exploration of the case studies and implementation of appropriate remedial work as well as embracing the whole life thinking concept should induce positive reaction in the minds of asset owners and these have to be encouraged in the future._A series of question are posed such as; Will asset function increase? And shall it behave as it intended to? Or are they sure that asset life span prolong once restoration work completed? Are we maintaining the strength properties or will it be greater than before?

Chapter 8 - Conclusions & Recommendations

This chapter will conclude the overall research study with reference to the aims and objectives. There will be a focus on remedial work of concrete structures in marine environment (sea water) and adoption of the whole life asset management thinking approach will result in establishing a suitable repair method and management of rehabilitate marine assets.

CHAPTER 2

REINFORCED CONCRETE OF MARINE STRUCTURES

2.1 Introduction

The purpose of this chapter is to describe on reinforced concrete marine structures which build up and are surrounded by the marine environment. It will cover the following topics;

- Marine Structures Classification
- Concrete in the Marine Environment
- Concrete Exposed to Seawater
- Cause of Concrete Deterioration in Marine Environment
- Evaluation of Causes of Concrete Distress and Deterioration
- Effect of Ice Impact and Abrasion to Marine Concrete
- Structures Buried in Seawater
- Structures Immerse in Seawater

These topics are considered important topics for dissertation because it highlights the key points of the chapter and will provide basic understanding on the typical concrete structure behaviour when it's surrounded by marine ecosystem. The classification of marine structure will be based on their group and some of it is illustrated in black and white photo. Examples of concrete marine structures of one type or another which have been built in some parts of the world were pictured together with explanation about structure's functionality. They ranged from submerged to floating systems of a variety of shapes and sizes: cylinders, boxes, cones, rings or doughnuts and cellular construction are among those reported in this chapter. This chapter also touch on seawater exposure and its effect to structures and some example of typical causes which relate to evaluation assessment on concrete distress and deterioration causes. Finally, highlight a bit about buried and immersed structures which demonstrate some basic understanding of anode and cathode processes experience in rebar that result to corrosion.

2.2 Marine Structures Classification

The word, 'marine structures' as suggested by **Mehta P.K., (1991)**, typically applies to costal berthing and mooring amenities, breakwaters and tidal barriers, dry docks and jetties, container terminals, and offshore floating docks and drilling platforms. Such as report of marine structures is based on their function, and is not useful for design purposes. **Mehta P.K (1991)** has grouped the wide diversity of marine structures into five general categories: piled platforms, flexible bulkheads, gravity structures, rubble mounds, and floating structures. **Maxwell-Cook, (1973)** has notified of the FIP Symposium I which hold in USSR. Proposals described included a floating airport, LNG carriers and floating immersed tunnels. Among implemented project were immersed tunnels, bridge caisson, lighthouses, oil storage, a tidal power station and floating dry-docking.

As illustrates in Fig. **2.1** below, 5 varieties of groups containing different structural types, each group were differentiated in a way they behaved when resisting the main loads. Again, there are several fabrication options for each of these structural types, for instance, cast-in-place, precast, cellular, and prestressed concrete, which represent another level of classification. According to **Buslov (1990)**, the classified level only indentifies the primary types of a structure. Various hybrids and combinations are also possible, such as rigid anchored walls, sheet-pile cells (filled-shell gravity structures retained by flexible bulkheads), composite steel-concrete sandwich structures, etc.

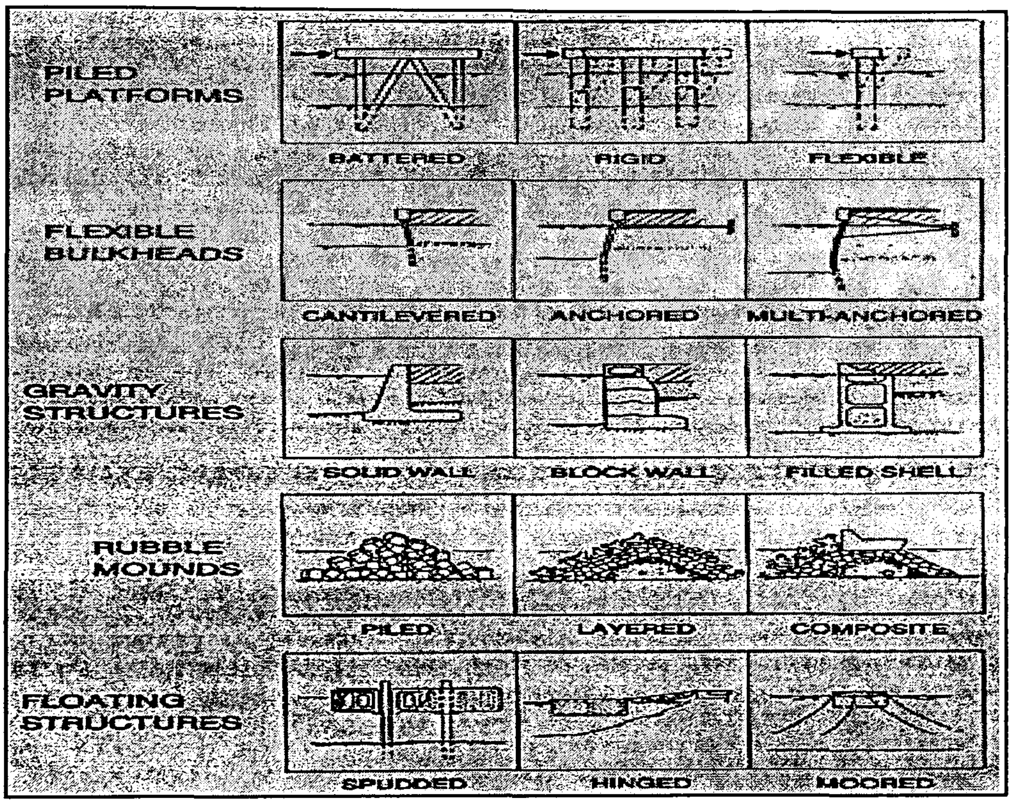

Fig. 2.1 Classification of Typical Marine Structures (after **Mehta P.K, 1991**)

2.3 Concrete in the Marine Environment

Mehta P.K (1991) had claimed that reinforced concrete has become the most frequently used material for building of marine structures whilst distinguished among three basic structural materials, specifically timber, steel, and concrete. Reinforced Portland cement concrete was invented approximately one hundred years ago, and it has become one of the most broadly used industrial materials in the world. According to **him**, there are certain number of reasons for that, such as the superb resistance of the concrete to water, the ease with which structural concrete elements can be formed into a variety of shapes and sizes, and also the low cost and easy availability of concrete-making materials that can almost find anywhere in the world. **He** compared to other building materials, concrete also happens to show better resistance to the action of salt water; the vast numbers of wharfs, docks, bridge piers and beams, breakwaters, and subsea tunnels bear a clear testimony to its general acceptance as a suitable material of construction for structures exposed to the marine environment. The use of concrete as the primary structural material in the last two decades has been extended to so many spectacular marine projects that **Gerwick (1989)** foresees the world of concrete is to be increasingly ocean-oriented and **Mehta. P.K (1991),** have suggested that the twenty-first century will be the century of concrete in the oceans.

The forecasting of the use of the concrete in both offshore and inshore sea structures are not easy to justify. A human history record in the past revealed that oceans have been used for fishing, business-related navigation and waste disposal. While world population gradually rise, approaching 6.7 billion peoples today, an equivalent grow in coastal and offshore construction were attained. The most important thing is that the rise in human expectations for a better standard of living has provided key momentum for the use of undersea energy and mineral resources. The oceans itself has cover twice as much surface as the combined area of the seven continents of the earth, which is more than 25% of the world's hydrocarbons in the form of oil and gas are being extracted from coastal and offshore deposits. The world's first offshore concrete platform named Ekofisk was constructed in 1973 in the North Sea, and nowadays there are more than 20 oil and gas production platforms containing heavily reinforced and prestressed concrete elements has been constructed **(Mehta P.K 1991)**.

Many marine construction projects concerning complex structures, such as superspan bridges, undersea tunnels, breakwaters, and man-made islands, have been built and these made known that concrete is now widely established as the preferred material of construction in the marine environment will be evident from some of the recently constructed or under-construction projects described below.

2.3.1. Offshore Concrete Platforms in North Sea

The oil industry has in the past been steel-oriented as observed by **Moksnes (1989)**. Therefore, in 1972, a daring decision was made by Phillips Petroleum Company to go for concrete as the principal structural material for the Ekofisk oilfield in the North Sea. Afterwards, a total of 20 concrete platforms containing approximately 2 million m^3 of high-quality concrete have been built in North Sea, with water depths ranging from 70 to 206m. The Condeep type platform, invented by the Norwegian Contractors, was a concrete gravity base structure (GBS) consists of several shafts supporting the upper deck as viewed in **Fig. 2.2.** The size of the caisson structure is ruled by basic need of oil storage facility. The foundation area provides structural stability during normal operation and buoyancy as floating-stability requirements during transportation and installation at the offshore location. A picture of Gullfaks C, the world's largest offshore concrete platform, is shown in **Fig. 2.3** that was fabricated in a dry dock at Hinna, near Stavanger. The concrete substructure was standing at the height of 262 m tall consist of 24 oil-storage cells and four shafts and tie in by a 50 000-tonne steel deck. In early 1989 the assembly was towed out to the installation site. The mixtures are mix up with a high-performance concrete with a range of 70-80 MPa compressive strength, a similar valued that was used for the caisson elements construction.

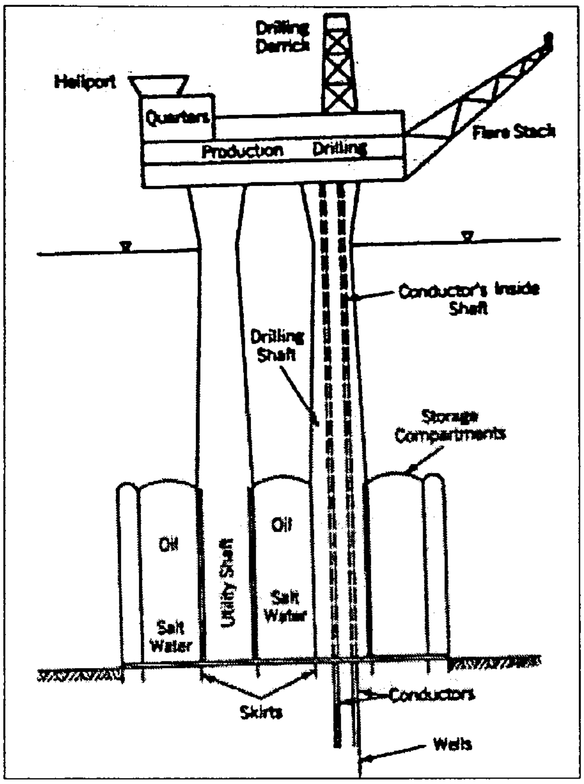

Fig 2.2. Concrete Gravity Platform – Condeep type (**B.C. Gerwick, 1988**)

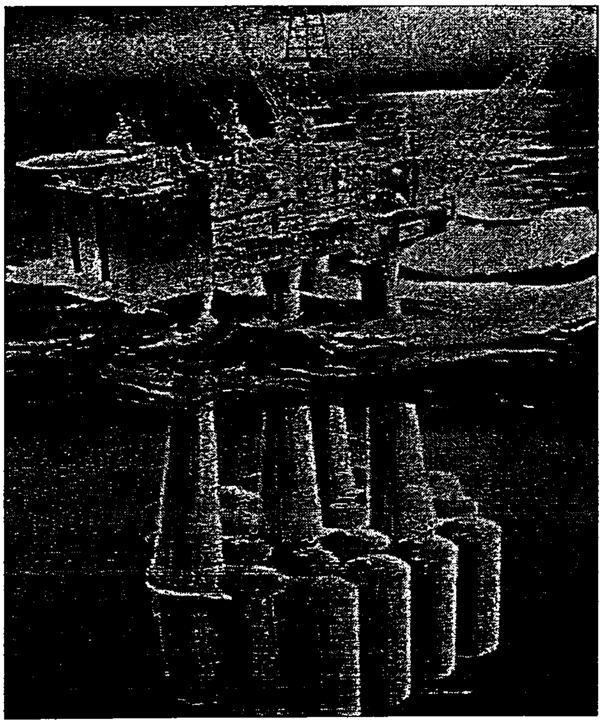

Fig 2.3. Gullfaks C – The World's Largest Offshore Concrete Platform (**J. Moksnes, Norwegian Contractors**). Key data: water depth 216 m; production capacity 245 000

bbls/day; concrete volume 240 000 m^3 (C65-70); reinforcement 70 000 tons; prestressing 3500 tons; deck weight during towing 49 500 tons.

2.3.2. Concrete Island Drilling System

A concrete island drilling system (CIDS) lead the way in 1984 by American and Japanese consortium companies to considered drilling in shallow waters of the Beaufort Sea Alaska, United States. **Yee *et al.* (1984)** reported on three basic components of the system, based on exploitation of correct materials for altering environmental conditions; consist of a mud base, a concrete module, and a storage deck. According to him, the fully submerged mud base and the storage barges are not subjected to ice forces and thus constructed of structural steel. The 71 x 71 x 13 m reinforced and prestressed concrete module, which is located in the splashing zone, is designed to resist bending, shear, and torsional forces from ice floes. Since the platform was constructed at a dry dock in Japan and then towed to the installation site in the Beaufort Sea, structural strength and buoyancy were optimized by using two types of concrete mixtures for the module. A high-strength (55MPa) normal-weight concrete mixture was used for the interior, but in the other hand a high-strength (45MPa) lightweight concrete mixture was used for the top and bottom of the slabs and for exterior walls. Finished shale, sealed-pore type, lightweight aggregate was engaged to produce the high-strength lightweight concrete.

2.3.3. Super span Cantilever Concrete Bridges

Generally, a steel bridges span measuring between 120 to 200 m in length is an example of economical prestressed concrete beam bridges used in construction. In Norway, 16 numbers of post-tensioned box-girder bridges with 150 m or more main spans were built during 1973-83, and the number of prestressed concrete bridges, with 100 to 150 m main spans built during the same period was considerably higher. In 1987, a 230 m long main-span bridge, the Norddalsfjorden Bridge, was constructed at a cost of only 4 million US dollars. The technology to produce even longer-span bridges is readily available. For such bridges, the dead load of the superstructure represents over 85% of the total load. Considerable reduction in dead load can be achieved by make use of high-strength lightweight concrete mixtures to the above said type. Practical methods effectively use to reduce the overall dimensions, weight and cost. A first-of-its-kind superspan bridge, the Helgeland Bridge, possessing as longest main span with a 390 m long, was successfully built in 1990 **(Mehta P.K, 1991)**.

T.Y. Lin (1989) bravely expressed his belief that it may be possible for people to travel using surface transportation facilities from Alaska to Siberia across the Bering Strait by mean use of future bridges that potentially link six continents for travel, trade, and cultural exchange. Since this East-West linkage is visualized to promote commerce and understanding between the people of the United States and the Soviet Union, the proposed bridge is called the Intercontinental Peace Bridge. The design suggested by Lin is made up of 220 spans, 200 m long and approximately 23 m vertical clearance. Each of the 220 concrete gravity piers is expected to require about 20 000m normal-weight concrete; the superstructure will require 2.6 million m^3 of lightweight concrete.

2.3.4. Undersea Tunnels

An undersea tunnel was a unique example of marine structures that has been successfully built by human in 21st Century. The structure are surrounded by salt water even though sited in soils well beneath the seafloor, with an inside environment that supplies oxygen and heat are controlled by advanced system. Leakage ensures that there is a humid saline atmosphere in the interior as well as outside, with alternate wetting and drying due to ventilation and vehicle movement. However, a serious leakage has been reported from the Kanmon tunnels (between Honshu and Kyushu in Japan), the Hong Kong tunnels, the Al-Shindagha tunnel (under the estuary of the Dubai Creek), and the Suez tunnel. High-quality concrete is essential for construction of tunnel lining for the reason that structures are severely exposed to aggressive marine condition **(Mehta P.K, 1991)**.

Fig. 2.4 exhibits the cross-section and longitudinal grade of world's largest undersea tunnel measuring 54 km long. Construction of Seikan Railway Tunnel in Japan was ingeniously completed in 1988 which took 24 years for construction work to complete. The concrete-lined tunnel is approximately 100 m beneath the sea bottom at its midpoint and has both wide tracks for *Shinkansen* (Bullet) trains and narrow tracks for conventional trains. Since it provides an all-weather link between the overpopulated Honshu Island and the under populated Hokkaido Island, it is expected to play a vital role in the regional economic development of Hokkaido, wealthy island rich with natural resources.

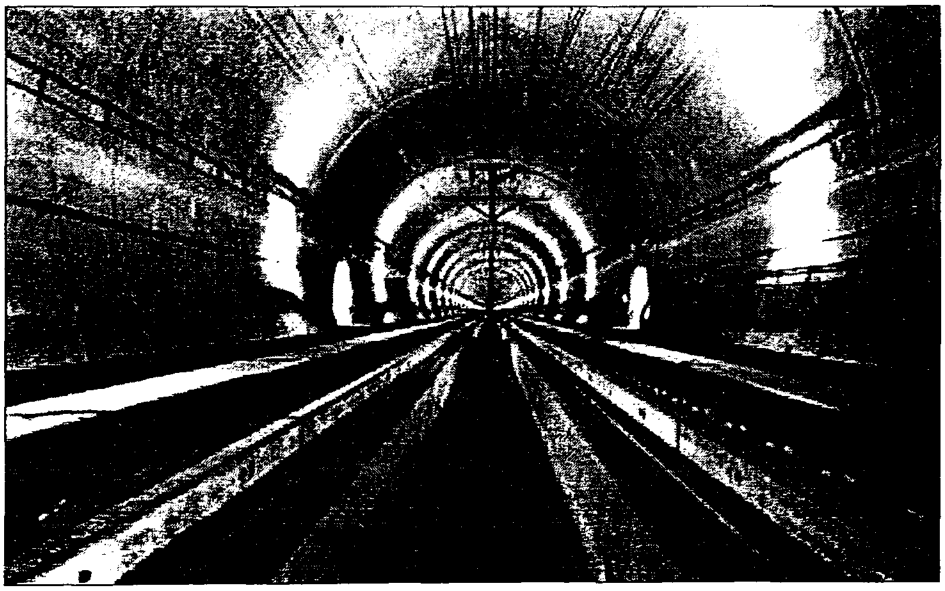

Fig 2.4. Seikan Tunnel-The World's Largest Undersea Tunnel Shows the Cross-section and Longitudinal Grade (**Japan Railway Construction Public Corp.**)

Eurotunnel, also called the Channel Tunnel, was a 50 km undersea link between France and Great Britain is reportedly the biggest infrastructure job to be privately financed in this century. The tunnel was designed for a service

life of 120 years and scheduled for completion in 1992, this 9.2 billion US dollars project contains two 7.5 m internal diameter of rail tunnels, and 4.8 m internal diameter of service tunnel, which are bored in chalk deposits 20 to 50 m below the seabed of the English Channel.
Because of the poor rock quality, prefabricated reinforced concrete liners are used to line the rail tunnels. High-quality, relatively impermeable concrete mixtures were developed for the fabrication of these concrete liners **(Mehta P.K, 1991)**.

Two subsea road tunnels, each length approximately 4 km long has been built at Aalesund on the west coast of Norway in 1987. The tunnels fall on to a depth approximately 140 m below sea level, but because of the good rock quality, extensive concrete lining was unnecessary. However, where the rock quality was poor, application of shotcreting repaired method was all set with primed wet concrete mixture containing silica fume and steel fibres put into practice. The 'wet' shotcreting techniques were also discover extensive application for repair of coastal structures. **(Mehta P.K, 1991)**

2.3.5. Storm Barriers and Breakwaters

Other example of marine structures is storm barriers and breakwaters. Breakwaters were specially designed structures purposely construct by meant of protection from aggressive waves action and usually accomplished by construction of bottom-founded vertical face breakwaters of miscellaneous constructions, rubble mound breakwaters, floating breakwaters, fixed and floating wave attenuators of miscellaneous designs **(Gregory P.T 1995)**.

Storm surge barriers and breakwaters are typical example of easily found coastal structures essentially construct to guard significant coastal and offshore structures from high ocean waves **(Leenderste and Oud, 1989)**.

Examples of the storm surge barriers highlighted by **Leenderste** are the Oostershelde Storm Surge Barrier located in the south western part of Netherlands. It was built in 1986 and strategically located at the meeting delta of three rivers, the Rhine, the Maas, and the Schelde. The barrier was part of Delta Project which includes the shutting of the main tidal estuaries and inlets in the south western part of the country. This has decreased the country's coastline by hundreds of kilometres, and keeping out of saline water from a large area and was expected to exhibit a significant improvement to freshwater management.

Leenderste and Oud (1989) also noticed the storm surge barrier which length approximately 3000 m long was built in three tidal channels. It made of 65 numbers of prefabricated concrete piers, between which 62 sliding steel gates are installed. With the gates in a raised position, the differences between the high and low tides behind the barrier are maintained at two-thirds of their original range, which sufficient to preserve the natural environment of the Osterschelde basin. When storms and dangerously high water levels are forecast, the gates can be closed in order to safeguard the population of the area from the ravages of the North Sea.