Kurdistan Engineering Union

Underwater Concrete

Research

By

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Contents

CHAPTER ONE

1.0 INTRODUCTION

Almost all construction system which used above water also can be used under water with some consideration like time, cost, type of cement and the method of execution. underwater Concrete constructions such as bridge, pier, power plant..etc are a sensitive and accurate work, so an experience teams and techniques are required to carry out underwater concreting to avoid problems, commonly many of organization have a care at working concrete under water because major problems will occurs during execution of concreting under water like segregation and loss of cement.[1]

Underwater concrete technology has historically evolved primarily through a trial-and error process of constructing marine works. Many outstanding examples exist of high quality concrete placed underwater. However, failures also occurred and led to too much cost and/or agenda overruns. These failures were chiefly due to inappropriate concrete mix design or unacceptable placement. The problems may have occurred because of inadequate underwater concrete construction techniques and skills. This section focuses on methodological issues of underwater concrete mix design, concrete production and placement, and quality control. [2]
The Underwater concrete mixtures typically contain cement content in the range of 360-500 kg/m3 which is generally higher than typical concrete placed above water. [3]

In latest years, under water concrete construction have development on the way to using ternary concrete mixtures that include accurate combination of GGBF slag, fly ash, silica fume in concrete, silica fume play a significant role in under water mixture due to of high water-binding ability. [5]

Figure (1) The Palm Islands in **Dubai** [25]

Figure (2) Lake Mead Intake , Las Vegas, Nevada **[25]**

Figure (3) Dubai Creek Bridge [25]

1.1 Purpose:

- To better understanding the basic performance requirements of underwater concrete construction.
- To understanding the modern technology in underwater concrete mixtures and provide a basis for proportioning concrete mixtures.
- To provide recommendations for the underwater construction of major navigation structures.
- To provide a basis for developing specifications of underwater concrete construction.
- to understanding the significant of underwater concrete construction in the real life .

CHAPTER TWO

2.0 Underwater Concrete Materials

2.1 Water content

The workability of concrete largely depends on the ratio of water to fines content. In underwater concrete, the ratio of water to fines usually ranges from 0.9 to 1.0 by volume. When the ratio falls within this range, the concrete can be made to be very flowable by use of water reducing agents, while still maintaining adequate cohesion to prevent segregation.[1]

For a given water content, a high fines content leads to more cohesive concrete, and thus less bleeding and segregation. On the other hand, adding extra water to a concrete mixture will reduce the yield value and viscosity, thereby increasing the slump and propensity of segregation.[7]

2.2 Cement

Portland cement influences the behavior of fresh concrete in at least three fundamental ways. The first aspect is related to cement hydration. The second aspect is its influence on water demand. The third aspect is related to the cement paste Underwater concrete usually contains relatively high cementitious materials content in a range of 360 to 500 kg/m3.[1]

High-performance underwater concrete regularly needs even higher cementitious materials content to convene special performance requirements. The high cementitious materials content is necessary to enhance the cohesion and flowability of concrete, in that way reducing laitance and tendency of segregation. In massive underwater construction, the workability of concrete and the heat of hydration are the two most important concerns. In this regard, Type II Portland cement is commonly most preferable for use in underwater construction, also can use Sulphate Resisting - Portland Cement, and Low Heat - Portland Cement in underwater construction Blended cement has been recently used in some underwater construction projects. However, blended cement is generally not recommended for underwater concrete, because of the difficulties of adjusting the relative proportions and fineness of cement and mineral binders.[4]

2.3 Cement paste

Cement paste is a mixture of cement, mineral binders, fines, and water in concrete. Cement paste affects the workability of concrete in the following three ways: the volume of cement paste, the rheology of cement paste, and the interactions between cement paste and aggregates.[4]

Due to the special placement condition, underwater concrete requires different rheological parameters than those of the conventional concrete. For placements in the dry, the cement paste usually has the yield stress ranging between 10 Pa and 100 Pa and the plastic viscosity ranging between 0.01 and 0.1 Pa-sec.

Underwater concrete must be flowable and highly cohesive. The driving force that causes flow of tremie concrete is the buoyant weight of the concrete, roughly 60 percent that of concrete in air. Therefore, the workability of underwater concrete often requires that the yield stress of the cement paste be below 1.5 Pa and the plastic viscosity above 1 Pa-sec In either case, the yield stress of cement paste reaches 2 x 104 Pa and 1 x 105 Pa at the initial set and at the final set, respectively.[5]

Rheology of cement paste usually determines the cohesiveness and flow characteristics of concrete after the concrete overcomes its internal friction and starts to move. However, it does not individually determine the concrete workability. The size, angularity, gradation, and proportion of coarse aggregates play an equally important role. The effects of aggregates on the rheology of concrete mainly stem from their internal friction within the concrete. In general, the frequency of contact between aggregates decreases as the volume of cement paste increases.[7]

2.4 Mineral admixtures

The term "mineral admixture" is refers to ground granulated blast furnace (GGBF) slag and pozzolanic materials such as fly ash and silica fume. GGBF slag more or less participates in the initial hydration process, while pozzolans react only with the by-products of the cementitious reaction at a later age.[2]

For massive underwater construction, adding mineral admixtures to the concrete mixture as partial replacement of portland cement is important. At present, it is fair to say that the performance necessities of high performance mass underwater concrete cannot be reliably met without using mineral admixtures. [4]

In real meaning, proper use of mineral admixtures will improve the quality of concrete in almost all the important aspects. The general improvement to the workability and rheology of underwater concrete may be summarized as follows: [6]

- Improving workability, flowability, and pumpability.
- Improving homogeneity and uniformity of concrete mixtures.
- Enhancing the resistance to segregation and erosion.
- Extending flow time (slump retention).
- Lowering total heat of hydration.
- Slowing the rate of the hydration heat release.
- Low bleeding.
- Better control of set time.

At present, fly ash, GGBF slag, and silica fume are the three most popular mineral admixtures used in concrete mixtures. Recent research has shown that rice husk ash is promising for use in underwater concrete. Ternary or Quaternary concrete mixtures containing several types of mineral admixtures have recently found wide applications in underwater concrete construction.

In general, replacement of 10 to 25 percent cement with fly ash by weight will effectively enhance the workability and cohesion of concrete.

Unlike adding water, the increase in workability from fly ash does not correspond to a decrease in cohesion of the concrete. In general, adding fly ash at a high dosage (above 40 percent) provides little extra benefit to the concrete workability. Therefore, the dosage of fly ash in underwater concrete rarely exceeds 40 percent of total cementitious materials.

Ground granulated blastfurnace slag consists primarily of calcium silicates and calcium aluminosilicates. When GGBF slag is added to concrete, both cementitious and pozzolanic reactions take place. Hydration of slag occurs immediately upon contacting water and lasts for many years. ASTM C 989 defines commercial slag in three grades according to their initial chemical reactivity in concrete: Grade 80, Grade 100, and Grade 120.

For underwater concrete, the optimum quantity of slag is frequently found to be between 60 and 80 percent of cement content by weight. In addition, the Blaine surface of the slag should be kept within 4,400 cm2/g to minimize the heat of hydration.

The Grade 80 slag retards the early hydration of C3A. Therefore, slag normally extends the flow retention and the set time of the concrete. As a rule of thumb, the set time of concrete may be delayed by 10 to 20 min for every 10 percent cement replacement with slag by weight. The Grade 100 and Grade 120 slags are normally not recommended for underwater concrete.[3,6,7]

The net effect of silica fume on concrete is high early strength gain, less bleeding, and segregation. Because silica fume can effectively improve the cohesion of concrete, it is an excellent admixture for underwater concrete. On the other hand, due to its strong propensity of flocculation, silica fume should be used together with water-reducing admixture (preferably high-range water-reducing admixture). [8]

2.5 Limestone powder

Limestone powder primarily consists of calcium carbonates that are chemically inert in concrete. In recent years, limestone powder has been used in major underwater concrete construction projects in Japan. In these applications, the objective of using limestone powder is to improve the rheological behavior of concrete. Since limestone powder has a large surface area that absorbs the mixing water, it increases the cohesion and reduces bleeding of concrete. The finer the limestone powder, the higher the water demand of the concrete mixture, which therefore requires more water-reducing admixture to obtain high flowability.[1]

In a typical underwater concrete mixture, water-reducing admixtures are normally used to adjust the water demand, while limestone powder is used to improve workability of the concrete.Long-term tests (Kanazawa, Yamada, and Sogo 1992) in Japan showed that Replacing 5 percent and 10 percent fine aggregates with limestone powder led to 50 and 85 percent reduction of bleeding, respectively. The concrete containing limestone powder had higher plasticity, faster set time, and higher compressive strength.[5]

2.6 Aggregates

Concrete may be perceived as a highly concentrated suspension in which cement paste is the continuous matrix that carries aggregates as suspended particles. As concrete flows, the aggregates will contact each other to impose friction force in resistance. The higher the friction force, the lower the slump. Thus, concrete containing large and angular aggregates tends to be less workable and often has difficulty flowing through reinforcement cages. For the same reason, crushed aggregates require higher water content than round aggregates for the same workability. [1]

The sand for the intruded grout shall be well graded, preferably of round grains and shall conform the gradation as: (Passing 1.18 mm sieve 95 - 100% , Passing 600 um sieve 60 - 85% , Passing 300 um sieve 20 - 45% ,Passing 150 um sieve 15 - 30% , Passing 75 um sieve 0 - 10%) .[5]

The relative proportion of fine aggregates to coarse aggregates also has significant effect on the workability. High content of fine aggregates tends to reduce segregation and bleeding. In 1965, Gerwick recommended 42 to 45 percent fine aggregates of total aggregates by weight, which is significantly higher than the fine/total aggregates ratio of 36 percent commonly found in concrete placed in the dry. Without effective water reducers, fine aggregate content higher than 45 percent may adversely affect the concrete flow ability. With use of high-range water reducers, modern underwater concrete usually

Contain fine aggregates in the range of 45 to 50 percent of total aggregates.

The amount of coarse aggregates in concrete is found to be a critical parameter to the workability of concrete. It is measured as the volume ratio of coarse aggregates to the total solids in concrete. A high ratio results in high yield stress and high viscosity. Since underwater concrete must be flowable and self-compacting, this ratio is usually limited within the range of 0.37 to 0.50. [6]

The coarse aggregate gradation for underwater concrete must be the Maximum Size (1.5-2 inch (100% shall pass a 75 mm sieve),and the Minimum Size - material passing a 19 mm sieve shall not exceed 5% by mass of the coarse aggregate.[11]

If the aggregates available for making underwater concrete lack the required amount of fine, it is desirable to add substitute fine materials, such as limestone powder or fly ash, as a part of the fines.[12]

Figure (4) Fine aggregates

Specific Gravity: 2.72, Fineness Modulus:2.9”,Absorption: 3.0%,Natural River Sand[10]

Figure (5) Coarse aggregates

Specific Gravity: 2.85 ,Absorption: 1.1% ,Maximum Nominal Size: 3/4-inch

Appearance: Clean and round-shaped with smooth surface texture. [10]

2.7 Chemical admixtures

Ant washout admixture (AWA) and high-range water-reducing admixture (HRWRA) are the two important chemical admixtures for high-performance underwater concrete. For many years, tremie mixture design had to be a compromise between the flow ability and the cohesion of the concrete. As a result, the slump was limited to 100 to 150 mm (4 to 6 in.). The maximum flow distance of tremie concrete was often limited to about 5 m (15 ft). Rapid placement had to be used to overcome the lack of flow ability. With the advent of HRWRA and AWA, modern concrete mixtures can achieve very high flow ability and yet retain adequate cohesion to essentially eliminate segregation and bleeding.[1]

In principle, chemical admixtures should not be used to compensate for poor mixture proportions, poor materials quality, or poor construction execution. Only when the concrete proportions are optimized can chemical admixtures effectively improve the performance of concrete.[4]

Water-reducing admixtures are primarily dispersion agents that reduce cement flocculation and release bound water in concrete. The increase in free water consequently improves the workability of concrete.

In practice, slump loss of underwater concrete has caused many problems in construction.

One way to avoid the slump loss problem is by adding a portion of the water-reducing admixture onsite prior to placing concrete under water, especially if the time between mixing and placement is extended. In large-scale projects, however, this procedure may increase complexity of the operation and lead to difficulties in quality control. It should be pointed out that there is an essential difference between adjusting slump with water reducer and retempering concrete with extra water. Adding extra water to concrete onsite will increase the propensity of segregation. Most water-reducing agents reduce the yield stress only and have little effect on the plastic viscosity.[5]

CHAPTER THREE

3.0 Proper mix Design

The essential of proportioning underwater concrete are generally the same as those appropriate to the predictable concrete. The common principles of mixture proportioning should follow the concrete industry guidelines (e.g ACI 221.1).

Concrete placed under water is essentially subject to cement washout, laitance, segregation, cold joints, and water entrapment. Thus it must have some distinctive workability characteristics that are otherwise not required for concrete; in practice the explanation of workability is unavoidably specific to applications in each project. Unless the level of concrete workability is specifically defined and fully understood by all the parties involved in the design and construction, underwater concreting will be exposed to risks of failure. [4]

For underwater concrete workability can be normally interpreted as three essential performance requirements as follows; [7]

1- flowability

The concrete must be able to flow out easily under water and absolutely fill the placement area without trapping water inside, concrete flow is related to some factors such as rate of concrete placement, concrete pour size ,flow distance, flow impendence by obstructs like reinforcing steel.

2 – Self consolidation

The concrete must consolidate itself underwater because the consolidate concrete underwater by mechanical vibration is unworkable, the primary driving force for spreading and consolidating concrete placed underwater is its own weight, which is largely reduced by the buoyancy in water.

3 – Cohesion

The concrete is necessary to remain cohesive underwater, the primary purpose is to ensure the homogeneity and strength of underwater concrete by minimizing cement washout, segregation, laitance. The desirable degree of cohesion for concrete depends on many factors such as thickness, concrete flow distance, and exposure to flowing water during placement. The cohesion of concrete is more difficult to quantify than its flowability.

3.1 Principal Parameters in Mix Design [9]

• Particle Packing Characteristics - SandContent, Gradation, Size, and Shape
• The water-to-fine ratio - Enough Fine to Make It Flowable and Cohesive (0.85-1.0 by volume)
• Cementitious Material Content – High Volume Fly Ash plus Silica Fume
• Dispersion characteristics - Proper Use of Chemical Admixtures – HRWR and Set-retarder

Materials	**Mix No. 1 (52% F.A)**	**Mix No.2 (25%F.A)**	**Mix No. 3 (control)**
Cement Type II, lb./cy	390	580	740
Fly Ash, lb./cy	350	160	0
Micro Silica, lb./cy	40	40	40
Coarse Agg, lb./cy	1.625	1.659	1.688
Fine Agg, lb./cy	1.367	1.396	1.420
Water, lb./cy	301.8	302.5	303.3
Rheomac UW, oz/cwt	85.8	85.8	85.8
Delvo, oz/cwt	117	117	117
Glenium, oz/cy	102.6	156	189

Table (1) typical underwater mix design [13]

3.2 Concrete placement

Modern engineering practice has shown that accurate placement method is significant in achieving high quality concrete and cost-effective construction. The choice of an appropriate underwater concreting plan for a project has to be eventually determined by the site situation, engineering necessities, availability of equipment, and cost.[8] Figure (6)Placing concrete from a delivery barrage

3.3 Concrete production

Underwater concrete construction frequently entails transportation of a large amount of materials over water. Location of a concrete batch plant is an essential consideration in logistics planning and has important implications in construction cost, risks, and quality control. The batch plant can be established either onshore or offshore, depending on the placement plan and site conditions. The offshore production selection has major benefit of more reliable control of the concrete workability at the point of placement, due to the short time between concrete batching and placing. However, this alternative could entail a important investment in the equipment. An offshore concrete production facility usually consists of a floating batch plant, a concrete conveyer, materials storage/delivery barges and facilities. Purchasing or leasing such a facility is reasonable only for the largest projects. other concerns include logistics of materials supply and equipment maintenance. In common, it is hard and costly to maintain consistent concrete materials quality on barges (e.g., the moisture and temperature). As materials in storage are consumed, the floating plant will list and trim. The batch scale must be supported in such a way that gives accurate weights even though the barge list and trim. In universal, equipment breakdowns are likely and difficult to repair offshore. In order to ensure continuous placement of underwater concrete, consideration should be given to provision for redundant equipment supplies including the crucial accessory items (such as barges, tug boat, and lighting), and key standby equipment (such as pumps and tremie pipes). Alternatively, a batch plant may be set up on shore and the concrete is transported to the placement site by transit mixers or hoppers on barges. This often creates logistic problems with consider to the time fall between concrete mixing and concrete placement. In any condition, the concrete mixes must be able to maintain all the requisite properties such as flowability, cohesiveness, and selfcompacting characteristics over the work window.[8]

Underwater concrete construction of many bridge foundations normally consider delivery of concrete on barges, often with a retarding admixture in the concrete, and then re-mixing after coming at the site. The another production/delivery method is the

Use of a prepared mix plant, with delivery by trucks to the shore, and then by pump line supported over the water, This method was successfully used to place over 25,000 cy of tremie concrete during construction of the Braddock Dam. In construction of the Dame Point Bridge, however, the same proposal encountered some difficulties. The concrete mixture was pre-cooled by injection of liquid nitrogen at the mixing plant. But delays in delivery due to roadway traffic allowed the concrete warm up to near ambient temperature, resulting in extensive thermal cracks in the concrete mass. The message learned is that roadway traffic could unpredictably suspend concrete delivery. A near-shore plant should be required for this option. Once the concrete batch and mixing plant is selected, the effective mixing time is critical in defining the peak concrete production and placement rates. It is desirable to determine the mixing time in field mock-up tests taking into account the necessary field variables. The mixing time should be such that all the concrete ingredients are fully dispersed and the concrete reaches workable consistency.[13,15]

3.4 Placement Rate

The rate of concrete placement is a significant parameter to the quality of in-place concrete, the form pressure, and the construction planning in common. High quality of underwater concrete is achieved through a continuous pour at a consistent placement rate. An interruption of concrete placement for a period to the concrete set time wills consequence in a cold joint. Given the difficulties with underwater preparation of cold joints, cold joints usually degrade the quality of in-place underwater concrete. Thus, it is necessary that concrete be continuously produced and delivered to the placement point at the required placement rate. It is also important that the necessary quantities of materials can be supplied to the batch plant at the necessary rate. The logistical planning should contain provision for option or redundant supplies, provision of all the accessory items, and standby key equipment.[12]

Before chemical admixtures were broadly used in concrete construction, underwater concrete mixtures commonly had stiffer consistencies than the concretes used today. thus, concrete placed at a slow rate often had very uneven, steep surfaces and a non-homogeneous distribution of concrete mass. In practice, it was found that the rapid placement of concrete resulted in marked upgrading in the tremie concrete quality.

The system of the rapid placement takes benefits of the dynamic energy of flowing concrete to overcome the lack of concrete flowability. With a highly flowable concrete mixture, the kinetic energy of the fast flowing concrete is not always required for placement of good quality concrete. Nevertheless, a smooth and continuous tremie placement is still important for good quality concrete. In common, a placement rate of 0.75 to 2 ft concrete rise per hour is ordinary for modern concrete mixes, depending on the concrete pour size, placement method and sequence.[17]
the experience with tremie concrete construction of numerous bell piers for bridge foundations, Gerwick (1964) provided the following rule of thumb for estimating form pressures for concrete with a slump of 6 in. (15 cm):[18]

Concrete Placement	Rate Maximum Form Pressure
1.5 m/hr	38 KPa
1.2 m/hr	29 KPa
0.6 m/hr	24 KPa
0.5 m/hr	14 KPa

Table (2) Typical placing concrete to rate pressure

3.5 Placement Sequence

Planning a tremie placement sequence must be based upon the size and geometry of the placement area, the available concrete production and delivery capabilities, and the concrete mixture properties. There are two fundamental schemes to sequence a tremie
placement. The first scheme is to feed concrete into numerous tremie pipes at about the same time. Thus, the concrete rises everywhere at approximately the same rate. In this case, the maximum concrete flow distance is approximately one half of the tremie spacing. This placement scheme is suitable for tremie placement in small areas. For relatively large concrete placement, however, this scheme demands very high, and sometimes impractical, concrete production capacity. Furthermore, cold joints can potentially form between two adjacent tremie pours as laitance accumulates at the boundaries. A practical method is to divide a large area into several smaller areas. Both walls of steel sheet piles and walls of precast concrete have been used. Within

each confined area, the simultaneous placement scheme can be applied. The second placement scheme is the advancing slope method. In the scheme, the placement starts at one location and progressively proceeds to cover the entire area. Only when the concrete at the tremie

location arises to the required elevation and an adjacent tremie has immersed in concrete by at least 0.3 m (1 ft), the tremie placement will proceed to the adjacent tremie. The tremie concrete flows out with an advancing slope. The surface slope of tremie concrete usually ranges from 1:5 to 1:40, depending on the concrete flowability and the placement rate. Thus, the tremie placement advances from one end of the placement area to the other end, following an advancing slope of the tremie concrete. The main benefit of this method is that it imposes less demand on the concrete production capacity than the first scheme. In addition, the scheme facilitates the deduction of laitance. As the placement progresses from one side to another, most of the laitance is pushed to the front edge of the advancing slope and finally collected at one end of the form. Then, the top of the hardened concrete can be jetted off and the hanging laitance be removed by air lifting or eduction. This method eliminates the potential cold joints between adjacent tremie pours. In some large-scale concrete placements, a combination of the simultaneous placement and the advancing slope scheme is the most appropriate, i.e., concrete is at the same time fed into a row of tremie pipes that proceed with an advancing slope. The purpose of this approach is to realize optimum balance between the required placement rate and the concrete production capacity.[7,10,17]

3.6 Concrete Protection

Underwater concrete has an excellent curing environment. Normally, no special post-placement operation is required. However, underwater concrete desires adequate protection before it sets and gains sufficient strength. For example, pile driving should not be performed near a concrete placement before concrete sets. Swift currents or waves can potentially erode fresh concrete. The fact that similar incidents occurred in construction of numerous bridge foundations (e.g., Tsing Ma Bridge in Hong Kong, Second Severn Bridge in England, Oresund Crossing in Denmark) shows there is a severe hazard of erosion of fresh concrete by current and waves. Therefore, protective measures need to taken to protect the concrete from current and waves. There are some effective ways to seal the gap between the bottom of in-situ forms and an existing river bed or ocean floor. In the past, sand bags and grout bags have been placed by divers to seal the gap. Steel skirts and protective mats are regularly used in offshore construction. Another technique is to attach pleated curtains of heavy canvas around the in-situ forms to seal off the gap. A more elaborate system is to use inflatable fabric grout bags. The bags are attached to the bottom of in-situ forms. Once the forms are installed under water, grout is pumped into the bag to inflate the bags.[1,19,21]

3.7 Underwater Concrete Placement Method

Underwater concreting is currently carried out by five basic placement methods: [1,7]

1- tremie method

2- pump method

3- Hydrovalve method

4- Buckets or skip method

5- Injection method

Among them the most general placement methods are the tremie method and pump method.

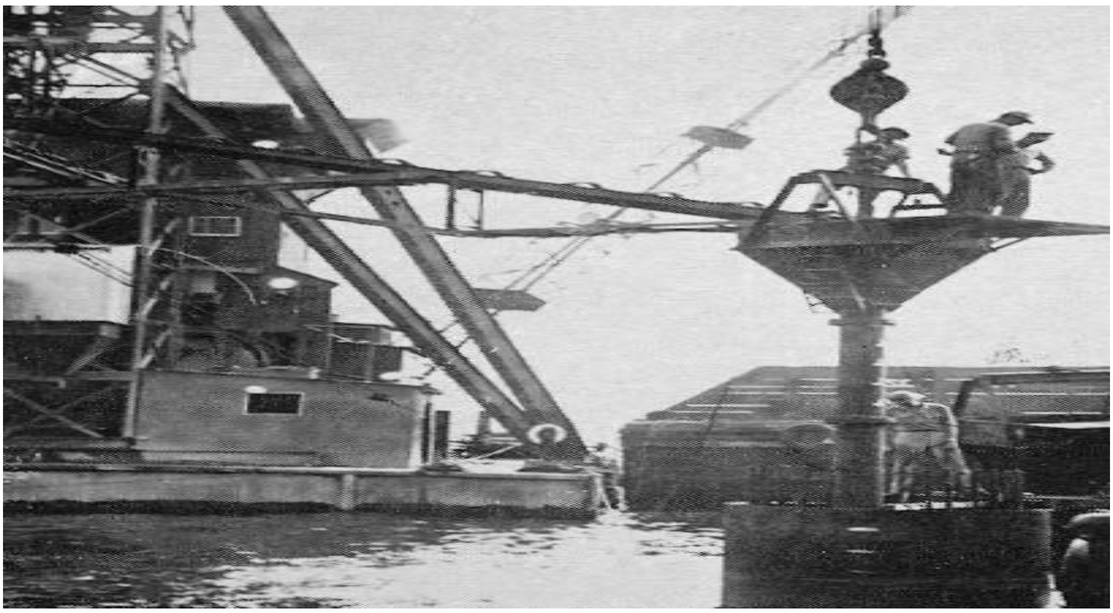
3.7.1 tremie method

The tremie method is a method which is used for placing of concrete underwater by gravity flow. The tremie system mainly consists of a rigid pipe hanging vertically through the water and hoper fixed on top of the pipe to receive concrete. In the tremie method there is a hydrostatic balance point which is the gravity force inside the tremie is in equilibrium with the resistance to flow like hydrostatic pressure, the friction between the concrete and the tremie wall, and the resistance of previously placed concrete. Any concrete add above the hydraulic balance point will cause to concrete to flow, the more concrete added above the point, the faster the concrete flow rate. thus the concrete flow rate can be constantly controlled by the speed in which is fed to the hopper.[1]

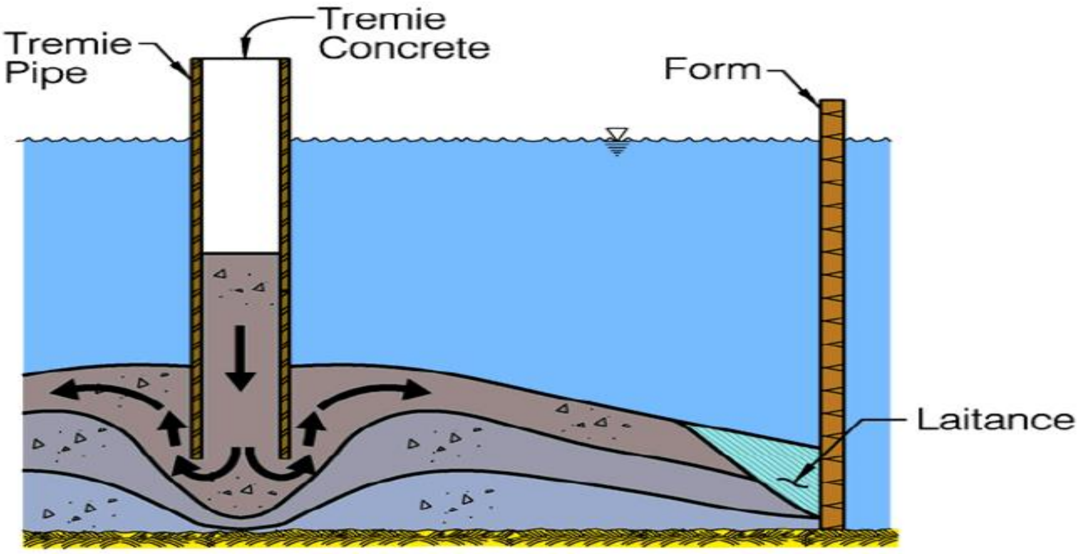
The tremie method is the most reliable way of placing high quality concrete,and the main advantage of this method is that tremie concrete can be deposited in a continuous and controlled flow speed with little turbulence. if the concrete carelessly dumped into the tremie, it defeats the purpose of the tremie method.[7]

The placement operation should cause as little disturbance to the concrete underwater as possible, In order to minimize cement washout and laitance. Most of the disturbance is occurs during starting and restarting of the placement, or due to loss of seal, or by dragging the tremie horizontally while embedded in the concrete underwater. This requires that the tremie pipe be embedded in fresh concrete to a minimum depth of 0.7 m. vertical movement of the tremie pipe should be limited to that absolutely necessary, and the horizontal movement of the embedded tremie pipe should be normally prohibited.[14]

There are two fundamental techniques to begin tremie placement which are the dry method and wet method, while the dry method utilizes an end cap to seals off a tremie pipe from the water entry, the wet method utilizes a moving plug to prevent the concrete from mixing with water, the plug fits tightly inside tremie pipe , As concrete is fed into the tremie, the plug slides down under weight of the concrete and push out water in a piston-like action.[18]



Figure(7) Placing tremie concrete for a pier at the Chesapeake Bay Bridge.[7]



Figure(8) Layered Flow -Excessive Laitance[7]

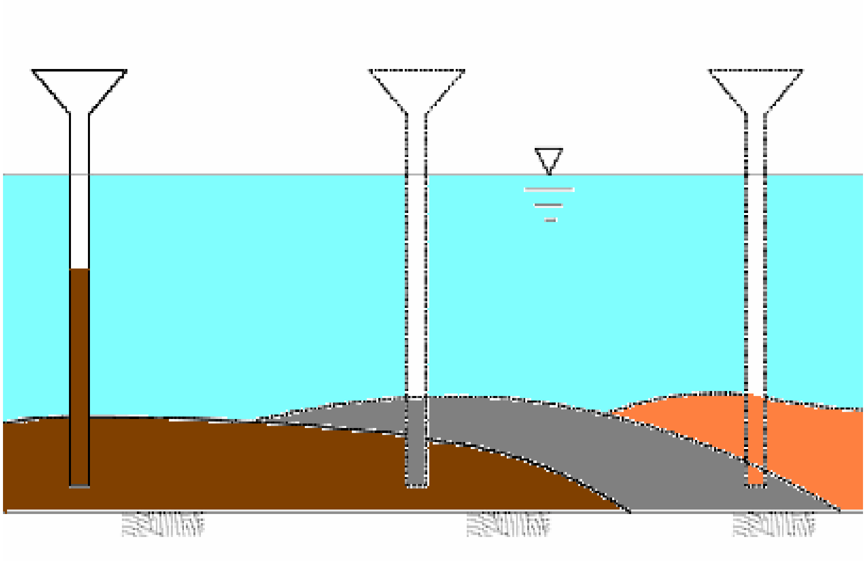


Figure (9) 3-5 Times Depth of Tremie Pours [1

3.7.1.1 Specifications of concrete to be used in Tremie method:[22]

- Coarse Aggregate: Gravel of 3/4"(20 mm) max. size. Use 50-55% of the total aggregate by weight.
- Sand, 45-50% of the total aggregate by weight.
- Cement: Type II ASTM (moderate heat of hydration), 600 Ibs./yd3.
- Water/Cement Ratio: 0.42 (0.45 maximum).
- Water-Reducing Admixture (preferably it is also plasticizer): Do not use super plasticizers.
- Air-Entrainment Admixtures: To give 6% total air.
- Retarding Admixture: To increase setting time to 4-24 hours, as required.
- Slump: 6 1/2" ±1"
- This mix will develop compressive strength in the range of 5600-7000 psi at 28 days.

3.7.2 Pump method

The pump method is defined as pumping concrete directly into its final position, containing both horizontal and vertical delivery of concrete in a closed system of discharge pipes. pumping concrete has the advantage of operational efficiency with potential savings of time and labor. In recent years, the pump method has become progressively more popular for above-water structures due to the advancements of pumping apparatus and techniques. The advancements have led to increasingly high pump outputs and pressures. Concrete has been pumped up to 600 m high in one stage at a delivery rate of 24.2 m3/hr. Unfortunately, these advanced pumping technologies do not deal with the natural problems related with pumping concrete down into water. Pumping underwater concrete still faces the same technical difficulties and risk of failure as operations over 50 years ago.[1]

The pump method is an excellent method of placing underwater grout or concrete containing only pea gravels, in this case a pump line has a small diameter and the ratio of skin friction to concrete volume is high. The skin friction slows down the speed of concrete fall. It’s a good practice to install an air vent over the top bend of the pump line so that the pump method is open the atmosphere the grout flow is controlled by hydraulic equilibrium.[4]

Underwater concrete can be divided into two categories according concrete mixture design for method of placement; concrete containing NMSA greater than 9.5 mm and concrete containing NMSA smaller than 9.5 mm in. general NMSA in mass underwater concrete ranges from 25 to 37.5 mm. Pumping the mass concrete directly down to structures on the riverbed or seafloor has several technical problems that will increase the risk of construction failure or poor quality concrete:[7]

- In tremie placement by gravity feed, the concrete flow rate can be controlled by the rate at which concrete is fed into the tremie. On the other hand, the pump system fully fills the pumpline with concrete. For placement in deep water, the weight of concrete in the pumpline is much greater than the hydrostatic head from the water and concrete outside the pipe. Thus, the concrete exits the pipe at an uncontrollably high speed, causing significant disturbance of already placed concrete and segregation of the concrete being poured.

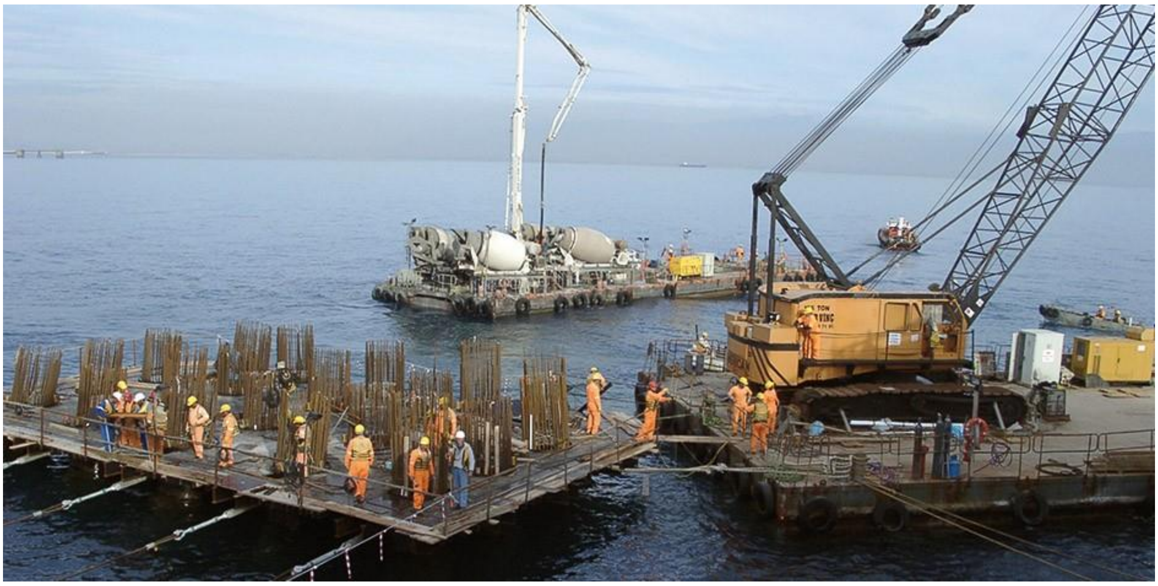
- A pump system is closed to the atmosphere. When concrete is pumped down to deep water, concrete may fall through and exit a pumpline at a rate faster than the pump output. Thus, a vacuum will be created in the line. The vacuum pressure so created will suck away the cement paste from aggregates, causing segregation and plugging of the line.

- Pressure surges from the pump can cause disruption of the concrete flow and plugging of the line.

- A concrete mixture optimized for pumping may not be the optimum concrete mixture for underwater applications.

- Pumping into a confined space can potentially result in excessive pressures.

➢ If the end of the pumpline is not adequately buried, excessive pump pressure surge can kick the pumpline out of the in-place concrete, causing mixing of the concrete with water.



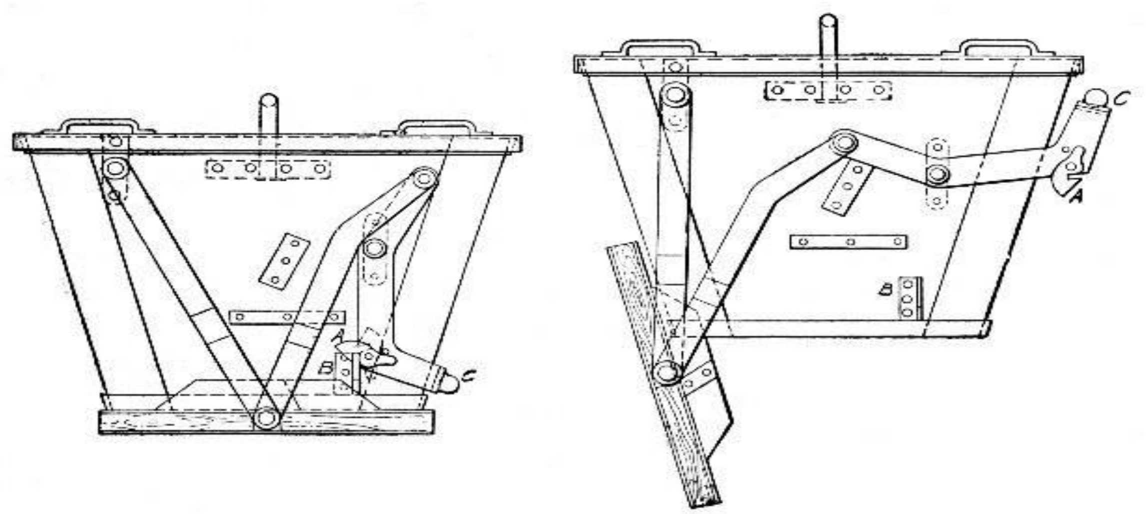
Figure(10) pum placing concrete

3.7.3 Hydrovalve method

This method is a refinement of the of the tremie pipe method or it can be said to be a cross between the skip method and the tremie pipe method. Instead of using a rigid pipe, the concrete slides down a collapsible tube, which is kept closed by water pressure until the weight of the concrete in the tube overcomes the hydrostatic pressure and the tube skin friction. The concrete plug will then slide slowly through the tube, and the tube will be sealed behind each plug by the water pressure. A valve at the bottom end of the tube controls the concrete discharge.[2,7]

3.7.4 Bucket method

The simplest way of placing underwater concrete in a formwork underwater is to lower the concrete through the water in an open bucket concreting should be only be used for very minor and temporary work. [5,7]



Figure(11) typical Bucket

3.7.5 Injection method

In this method the formwork is first filled with specially washed coarse graded aggregate. the voids in the aggregate are then filled by injection with mortar or grout consisting of cement, sand and expanding and stabilizing materials. This method can be especially useful in flowing water and in areas inaccessible to bucket, tremie, hydrovalve or pump concreting such as undercuts, for example under a foundation.[2]

7.4 Experimental underwater concrete[19]

- Slump.
- slump flow.
- unit weight.
- Temperature.
- concrete compressive strength of concrete cylinders.

CHAPTER FOUR

4.0 Problems, Repair and Quality control Underwater concreting

4.1 Problems Underwater concreting:

4.1.1 Problems during placing of underwater concrete [3]

- Cement washout.
- Laitance.
- Segregation.
- Water entrapment.
- Cold joint.

4.1.2 Damage and Problems after placing [3,7]

- Scalling and Cracks.
- Erosion.
- Rebar corrosion.
- Spalling Concrete.
- Scour.
- Quay Wall Collapse.

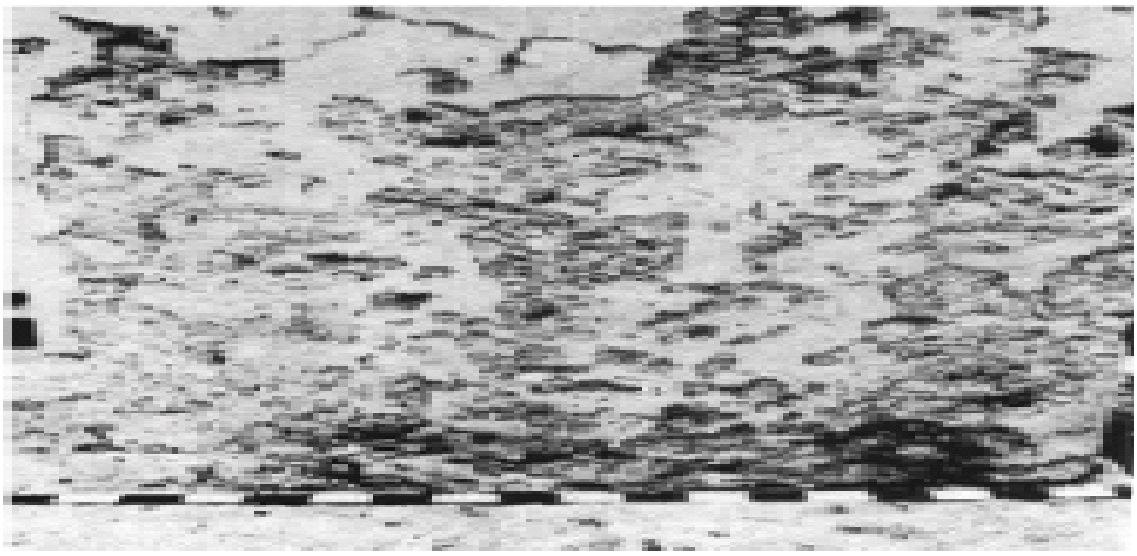


Figure (12) Scalling of concrete

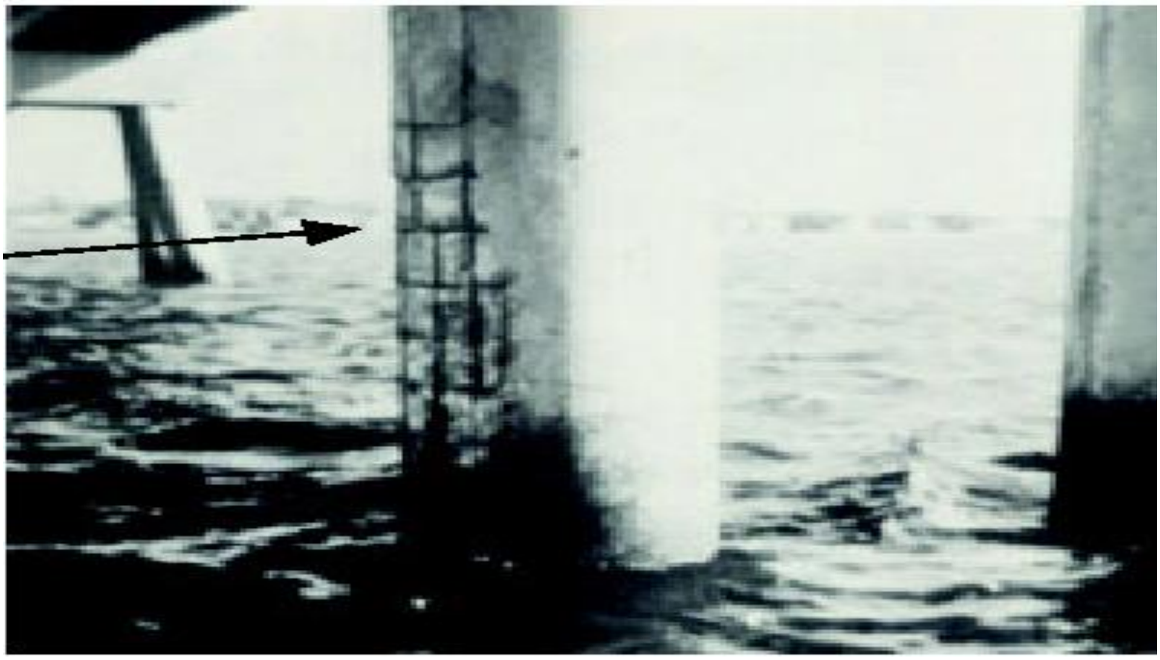


Figure (13) Spalling of Concrete

Figure (14) Rebar corrosion

Figure (15) Erosion

Figure (16) Quay Wall Collapse

4.2 Repair Underwater Concrete

In order for underwater concrete placement to be successful, the concrete must be protected from the water until it is in place so that the cement fines cannot wash away from the aggregates. This protection can be obtained through appropriate use of placing equipment, such as tremies and pumps. Also, the quality of the in-place concrete can be improved by the addition of an antiwashout admixture (AWA). An AWA increases the cohesiveness of concrete. [11]

When a repair is to be made to an existing structure, following appropriate procedures increases the likelihood that the rehabilitation effort will be successful. [15,16,23]

- The location and size of the area to be repaired should be well defined.
- The area should be thoroughly cleaned of all debris and fragmented concrete before new concrete is placed. Water jetting and air-lift techniques are effective cleaning methods. This cleaning is necessary for any momentous bond to occur between the newly placed and the existing concrete.
- In addition to cleaning, it is recommended that an appropriate number of anchors be grouted into the existing concrete to tie the new concrete to the existing concrete. The anchors are necessary to assure good bond because of the difficulty of keeping an existing surface clean until the new concrete is placed.
- All necessary equipment must be at the job site before any concrete placement is begun. There should be good organization between all parties concerned in the operation, from the concrete batch plant to the personnel truly placing the concrete.
- If the concrete is to be placed in thin lifts, in areas exposed to flowing water, or where it is to flow a significant distance, the use of an AWA is necessary. Under these circumstances a relatively small amount of concrete is exposed to a large volume of water. be washed from the aggregates. It is recommended that an AWA be used to enhance the cohesiveness of all concrete placed underwater. While not necessary in mass placements, an AWA will increase the quality of the in-place concrete.

- When AWAs are used, it is not as critical to keep the discharge end of the tremie or the pump line embedded in the concrete as it is when they are not used. However, the concrete should not be unreasonably exposed to water throughout placement. Once in place, concrete containing an AWA can flow up to 30 ft without damaging washout or segregation.
- The cohesiveness imparted by an AWA in fact improves the pumpability of concrete for moderate distances. However, if the concrete has to be pumped a long distance, the pumping distance becomes an significant parameter. If the pumping distance is 150 ft or less, there should be no problems. If the pumping distance exceeds 250 ft, pumping pressures will probable increase considerably. If the pumping pressures become too much, the concrete mixture will have to be modified by adding water or reducing the quantity of AWA, or the pump will have to be relocated to reduce the pumping distance. If the cohesiveness is reduced, the concrete is more subject to washout. Therefore, relocating the pump is the better solution.

4.3 Quality Control

there is uncertainty with the quality and integrity of underwater concrete ,Because of the poor visibility and difficult convenience of underwater work. severe enforcement of engineering requirements and quality control is required for underwater concreting. In principle, on-site monitoring and quality control of underwater concrete placement should be largely carried out above water. Under most conditions, the effectiveness of divers' inspection is very limited due to the poor visibility. Divers walking on the concrete surface will create turbulance and laitance. on the other hand, periodic inspection by divers should be made for such conditions as the seal of the precast form to the river bed. The following five critical items need continuous monitoring throughout the concrete placement:[5]

1- The rate of concrete placement.
2- The depth of concrete at various locations.
3- Volume of concrete produced vs. volume of in-place concrete measured by sounding,
4- Embedment depth of the tremie.
5- Concrete delivery system (leakage, plug or spill over).

4.4 Underwater concreting Specific recommendations on quality control :[21]

1. The human resources should have been properly trained and supervised full time by an experienced foreman or engineer who is familiar with the requirements for good workmanship.
2. Contractor should conduct frequent testing of concrete from batch-to-batch and within a batch. Important tests contain slump, slump flow, unit weight, temperature, and concrete compressive strength of concrete cylinders.
3. After the concrete hardens, cores should be taken to confirm the quality of the in-place concrete. Locations of the coring should be determined by the project engineer after examining the concrete placement log.
4. Continuous investigation at predetermined and well-marked locations over the entire placement areas. All sounding data should be recorded on data sheets and submitted to the project engineer at the end of each shift. A typical sounding device is a plate connected onto a weighted line marked for easy reading. Alternatively, sonar depth finders may be used to continuously monitor the depth of concrete at specific locations. Underwater inspection or monitoring by divers without independent soundings is not recommended.
5. The concrete placement rate and series should be carefully monitored and controlled. The concrete level within the tremie should be often checked and compared with the sounding data. The concrete placement should make sure continuous flow of concrete
6. The volume of concrete produced and fed into the tremie should be compared with the volume of concrete theoretically required to complete the placement as determined by soundings. If the in-place concrete volume measured by sounding is less than that produced and fed into the tremie, it is an underrun of concrete. If the in-place concrete volume is more than that fed into the tremie, it is an overrun of concrete. In common, underrun indicates a likelihood of loss of concrete, possibly leaking through a skirt or cut-off wall. Overrun is indicative of serious segregation of the concrete. The segregation may be caused by a leaking joint in

the tremie, or loss of the tremie seal. Overrun or underrun of 3% or less is typical. Over 5% deviation should be investigated.

7. Careful monitoring of all concreting operations including any restart and completion of concrete placement. The tremie pipe should be clearly marked to indicate the depth of the tremie tip.
8. Before using a tremie pipe, all the joints should be checked for possible leakage. Periodic checking of concrete delivery and placement equipment.
9. sufficient emergency plans should be provided in the Contractor's quality assurance program. If the sounding data indicate an detrimental distribution of tremie concrete, the foreman will determine the need to alter the placement rate or relocate the tremie according to the dependent plan.

4.5 The important properties of the structures underwater concrete include the following aspects: [2,24]

- Ability of concrete to flow around piles and reinforcing steel bars.
- self-compacting and sometimes self-leveling properties.
- Retention of workability over a reasonable work window of time.
- Adequate cohesion to avoid extreme segregation and laitance.
- Low heat of hydration.
- Low bleeding.
- restricted set times.
- Development of sufficient compressive strength and bond strength.
- Low creep and shrinkage.
- Resistance to cement dilution and washout by flowing water during concrete placement.

CHAPTER FIVE

5.0 Conclusion:

Underwater concrete construction can be accomplished with the same degree of reliability as above-water construction with some consideration like time, cost, type of cement, mixture properties and the method of execution. However, if it is not carried out appropriately, with the proper concrete mixture and placement procedure, underwater construction can result in a major overrun in construction cost and schedule. Underwater concreting is often a critical component of the marine foundation construction. It is technically demanding, usually on the critical path of the project schedule, and involves complex construction logistics. Therefore, its significance in the project goes far beyond the concreting operations themselves. This is the area where sound design and competent construction planning can achieve a meaningful reduction in risk and cost. High quality concrete can be placed underwater in drilled shafts, However, proper concrete mix and proper placement techniques are essential as well as performing effective non-destructive testing to confirm sound concrete.

The performance requirements of underwater concrete for in-the-wet construction of navigation structures have been investigated. The essential difference between underwater concrete and conventional concrete is in the workability requirements. Underwater concrete must flow laterally and compact itself under its own buoyant weight, while conventional concrete is compacted with mechanical vibration. In accordance with the requirements for concrete workability, underwater concrete mixtures can be categorized into two broad classes: the standard concrete mixture and the high performance mixture.

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